ABSTRACT

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

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The issue of disaster risk reduction through proper assessment of vulnerability has emerged as a pillar of disaster management, a paradigm shift from simply responding to disasters after they have occurred. The assessment of vulnerability is important for countries desiring to maintain sustainable economies, as disasters have the potential to disrupt their economic growth and the lives of thousands of people.

This study is a preliminary assessment of the hazard vulnerabilities the Norman Manley International Airport (NMIA) in Kingston Jamaica and its Access Route, as these play an important developmental role in the Jamaican society. The Research involves an analysis of the hazard history of the area along with the location and structural vulnerabilities of critical facilities. Finally, the mitigation measures in place for the identified hazards are assessed and recommendations made to increase the resilience of the facility.

The findings of the research show that the NMIA and its access route are mostly vulnerable to earthquakes, hurricanes with flooding from storm surges, wind damage and sea level rise based on their location and structure. The major mitigation measures involved the raising of the Access Route from Harbour View Roundabout to the NMIA and implementation of structural protective barriers as well as various engineering design specifications of the NMIA facility. Also, the implementation of structural mitigation measures may be of limited success, if hazard strikes exceed the magnitude which they are designed to withstand.

Keywords: Kevin Patrick Douglas, hazard vulnerability assessment, Norman Manley International Airport and Access Route, mitigation

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Glossary of Terms

a) Natural Hazards: “The elements of the physical environment that are harmful to man and are caused by forces extraneous to him. For this study, ‘natural hazards’ refers to all atmospheric, hydrologic, geologic phenomena, which because of their location, severity and frequency have the potential to cause serious damage to humans, their structures and activities” (Burton, Kates and White 1993)

b) Vulnerability: According to Ahmad (2004), Vulnerability is a “set of conditions and processes resulting from the physical, social, economic and environmental factors, which increase the susceptibility of a community or entity to the impact of hazard. The UNISDR defines vulnerability as the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.

c) Natural Hazard Vulnerability Assessments: An evaluation of the location, severity and probable occurrence of a hazardous event in a given time period and an estimate of the degree of loss or damage that could result from a particular hazardous event, including damage to structures and interruption of economic activities. (OAS 1991).

d) Mitigation: The undertaking of measures to reduce the vulnerability of the elements of risk and modifying the hazard proneness of the site by structural or non-structural means. (http://www.oas.org/dsd/publications/unit/oea66e/ch01.htm#a. disaster mitigation). Mitigation measures are of two types, structural and non-structural. The UNISDR defines both as follows:

- Structural measures are any physical construction to reduce or avoid possible impacts of hazards, or application of engineering techniques to achieve hazard-resistance and resilience in structures or systems.
- Non Structural measures are any measure not involving physical construction that uses knowledge, practice or agreement to reduce risks and impacts, in particular through policies and laws, public awareness raising, training and education

- Critical Facilities: "The primary physical structures, technical facilities and systems which are socially, economically or operationally essential to the functioning of a society or community, both in routine circumstances and in the extreme circumstances of an emergency." (UNISDR)

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List of Abbreviations used

1. NMIA- Norman Manley International Airport
2. IDNDR- International Decade for Natural Disasters Reduction
3. UNISDR – United Nations International Strategy for Disaster Reduction
4. IPCC- Intergovernmental Panel on Climate Change
5. CDEMA- Caribbean Disaster Emergency Management Agency
6. ODPEM- Office of Disaster Preparedness and Emergency Management
7. UNDP- United Nations Development Programme
8. OAS- Organization of American States

CHAPTER 1.0 INTRODUCTION

1.1 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.

1.2 CONCEPTUAL FRAMEWORK

1.0 Highlights 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.

1.1 Illustrates 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.

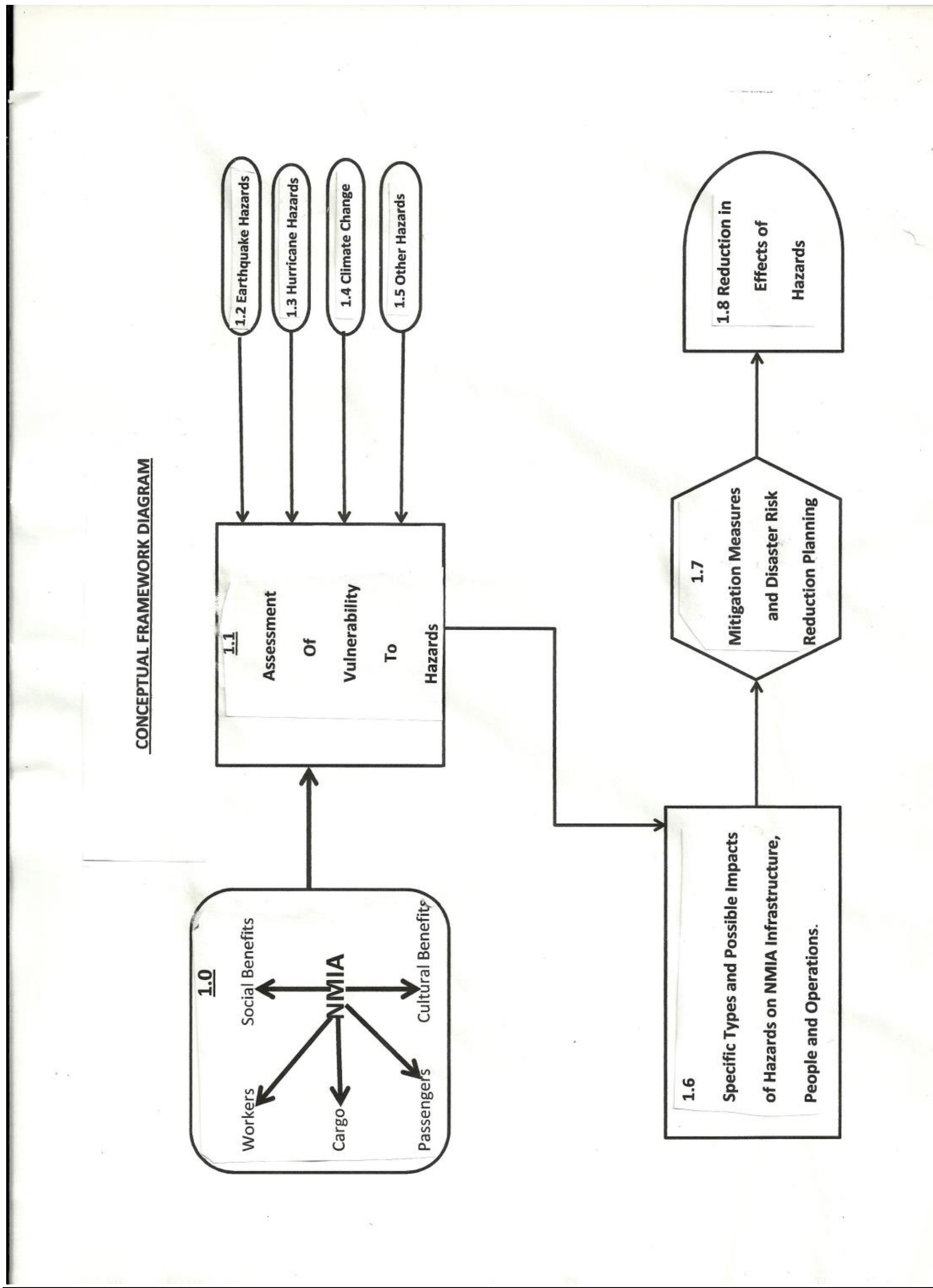
1.2- 1.5 Highlights some of the major hazards which the NMIA may be vulnerable to based on its location and other natural or anthropogenic factors.

1.6 This Data on Hazard Vulnerability 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.

1.7 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.

1.8- 1.9 This information 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.

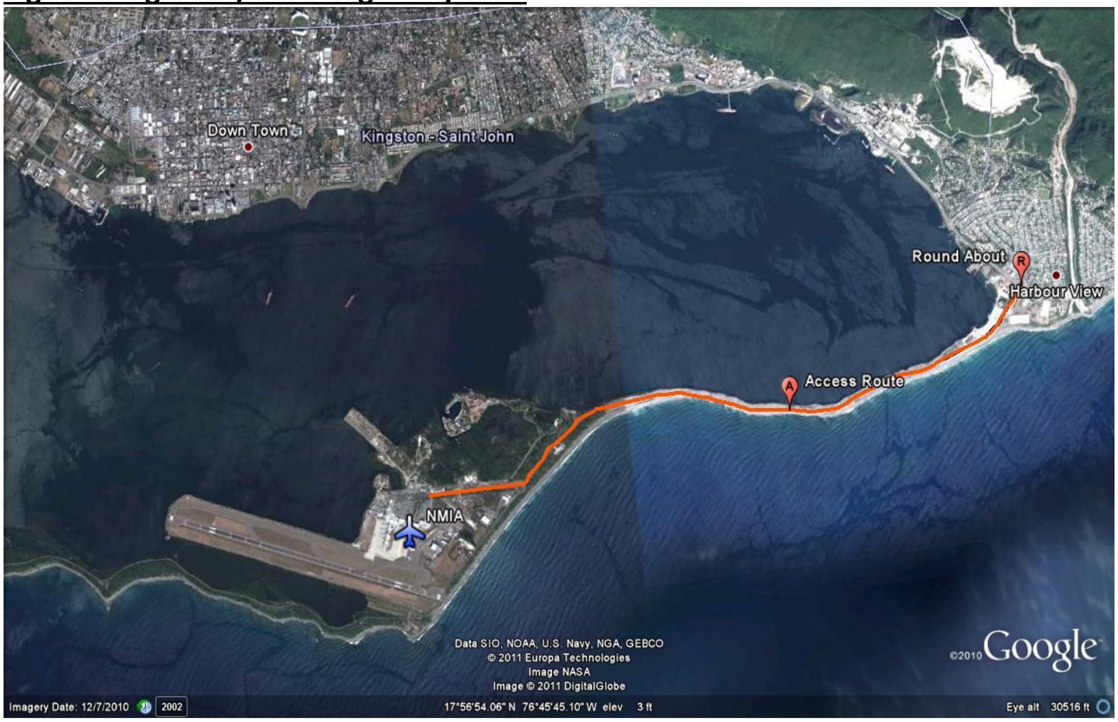
Fig. 1:- CONCEPTUAL FRAMEWORK DIAGRAM



1.3 STUDY AREA (Regional, National and Localized Setting)

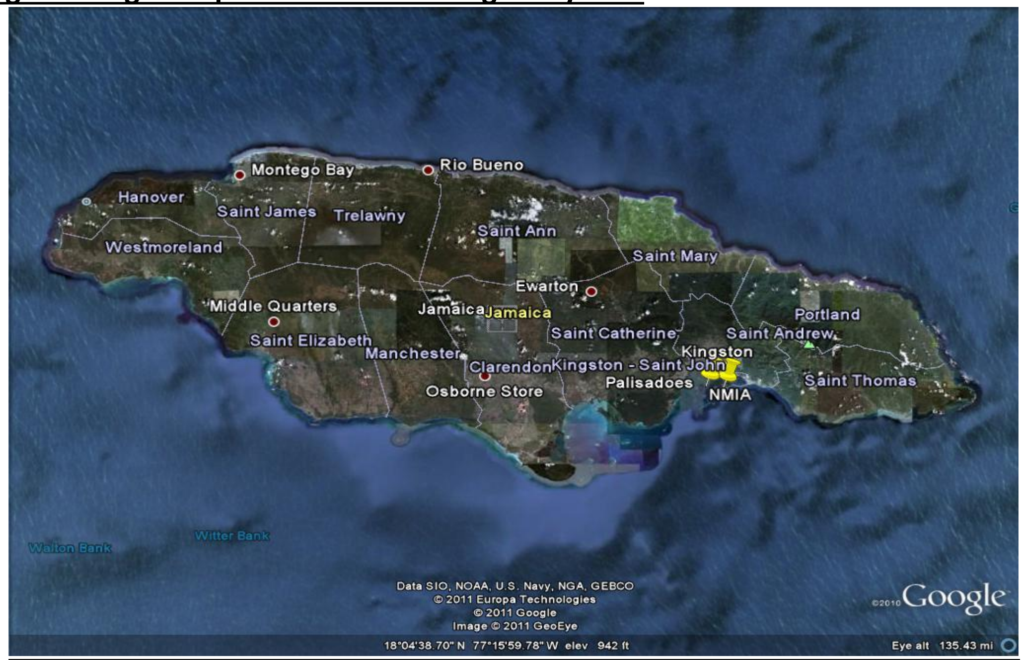
The study area encompassed a strip of approximately 3.5 km from Harbour View roundabout to the main study site, the Norman Manley International Airport.

Fig. 2- Google Map Showing Study Area



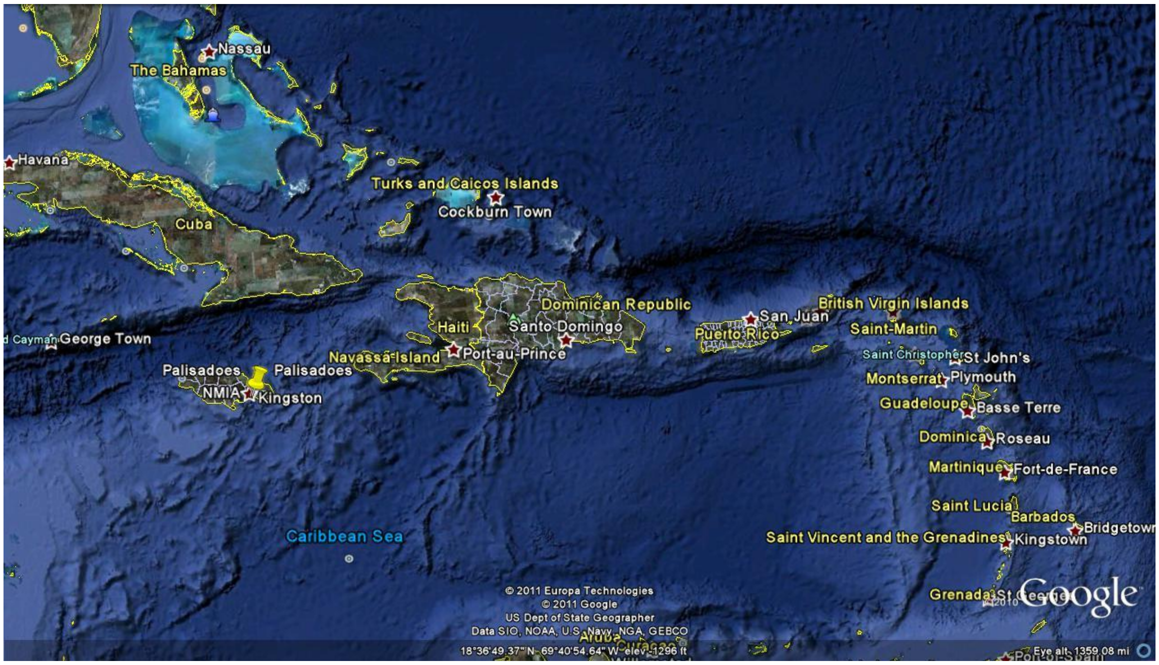
(Adopted from Google Earth)

Fig. 3- Google Map of Jamaica showing study area



Adopted from Google Earth

Fig.4- GOOGLE MAP SHOWING REGIONAL LOCATION OF JAMAICA IN THE CARIBBEAN



(Adopted from Google Earth)

1.4 RESEARCH AIM AND OBJECTIVES

AIMS AND OBJECTIVES OF STUDY

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

1.5 RESEARCH QUESTION

RESEARCH QUESTION

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

1.6Research 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.

CHAPTER 2.0 LITERATURE REVIEW

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 42nd 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 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 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 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.

CHAPTER 3- RESEARCH RATIONALE AND METHODOLOGY OF DATA COLLECTION

3.1 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

3.2 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)

3.3 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.

3.4 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

CHAPTER 4.0 :- 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 kgs/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.

<u>Socio- Cultural Significance of NMIA</u>

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.

<u>NMIA'S role in Relief and Response</u>

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.

CHAPTER 5.0- HAZARD HISTORY OF NMIA AND PALISADOES AREA

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.

5.1 Genesis/ Origin of the Palisadoes

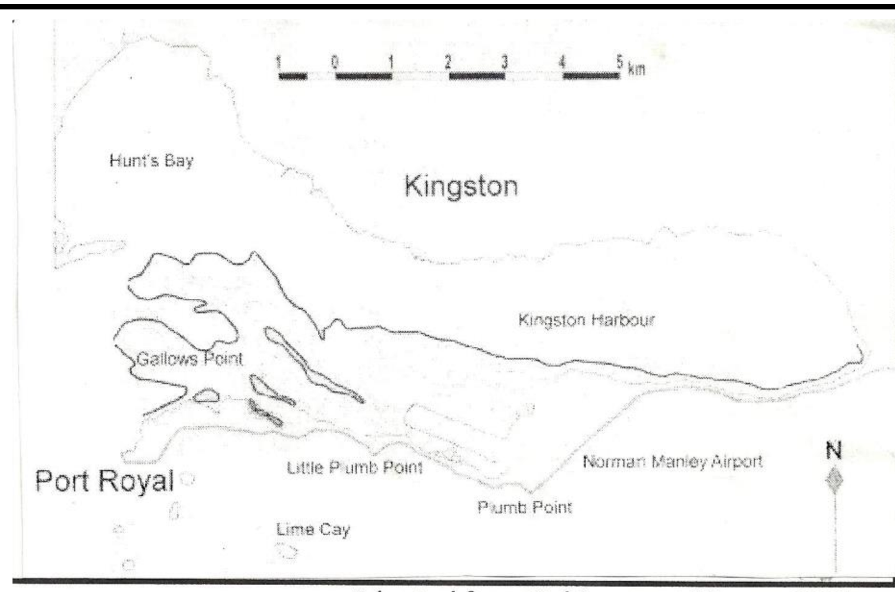
In order to arrive at an intelligent assessment of any possible future hazardous events that may occur on the Palisadoes, one need to analyze the genesis of this area. It may be said that much of the vulnerability faced by the NMIA and the Palisaodes road lies in the development and present structure 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 with one end attached to the land, while the other end lies in the open sea.” (Bowen and Pallister 2006, 73)

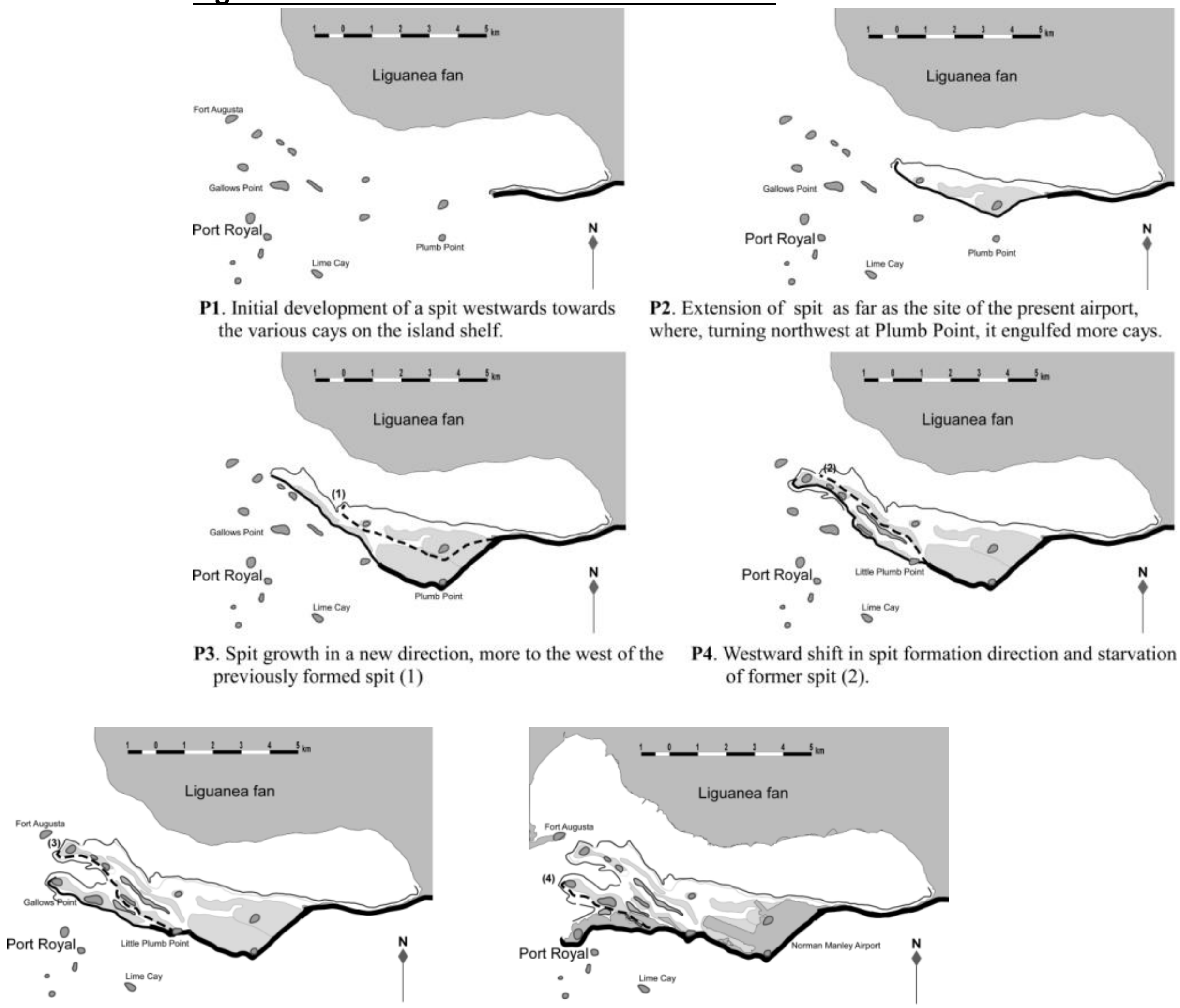
Figure. 5- Map of Palisadoes



Adopted from Robinson and Rowe, 2005

speculative and is shown in figure 6 of P1 to P6 below (Adopted from Robinson and Rowe 2005)

Figure 6: Formation Process of the Palisadoes



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).

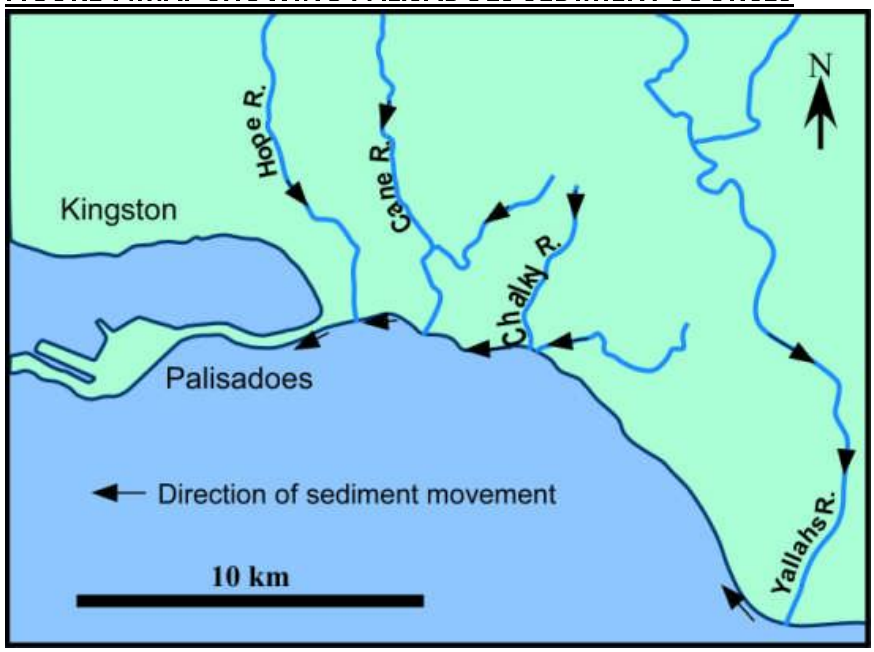
P6. Abandonment of spit (4) and extension of new spit to its present location at what was once the island of Port Royal.

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.

2) Aggregate mining which is practiced in Harbour View and other areas along river courses close to the Palisadoes (Figures 8 a and b below) , 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.

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

(a)

(b)

5.2: 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.

5.3 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.

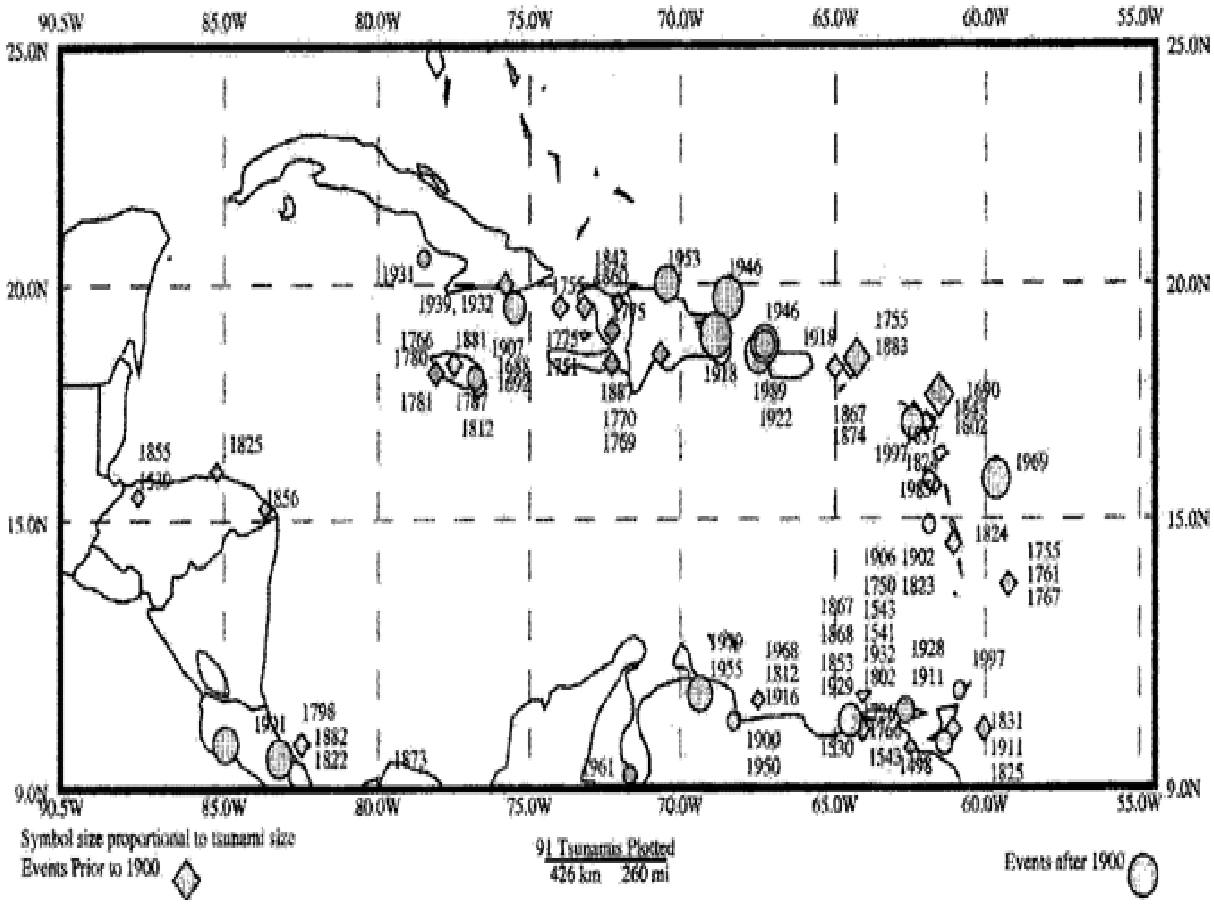
5.4 History of Hurricanes and Tropical Storm Events

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.

5.5 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 16th century.

Fig. 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.

CHAPTER 6.0 - EARTHQUAKE VULNERABILITY (SHAKING, LIQUEFACTION AND TSUNAMI)

6.1 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.

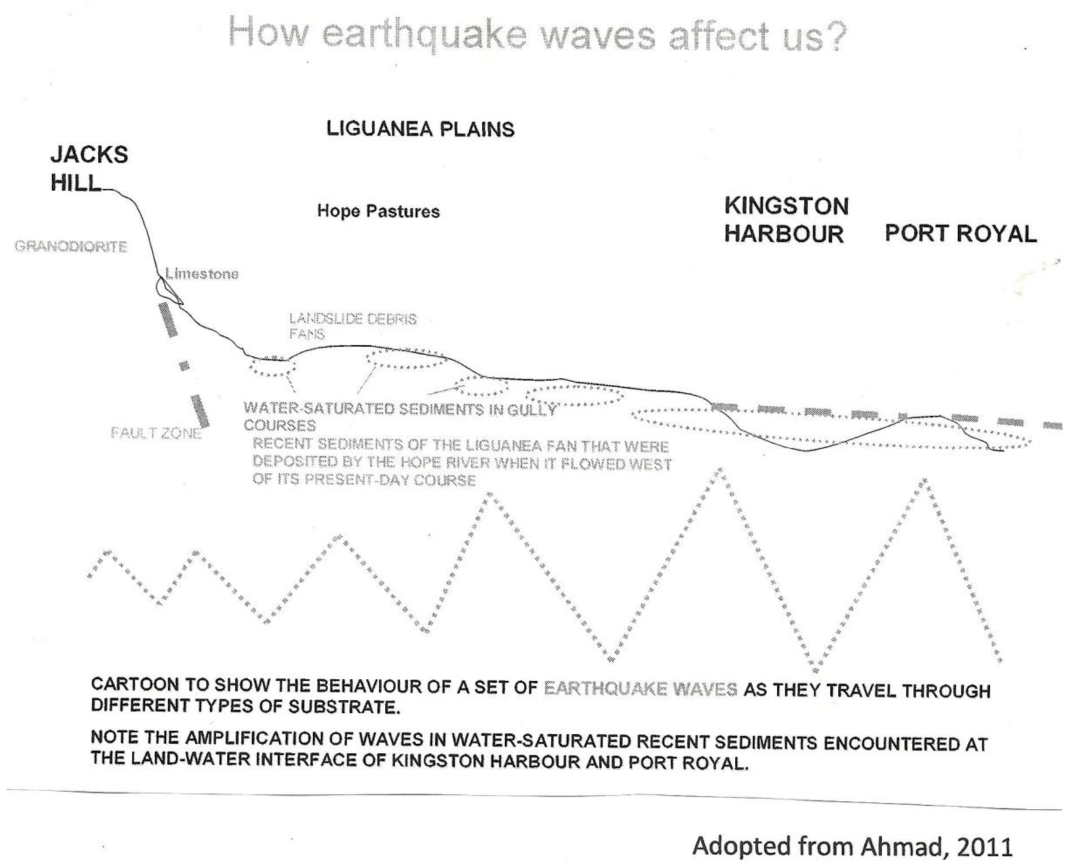
The NMIA and its access route, for a number of reasons, are highly vulnerable to seismic activities, including ground shaking, liquefaction and even the possibility of tsunami. Jamaica is located in the seismically active plate boundary zone of strike slip faulting, along the northern margin of the Caribbean 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 fig. 10.

FIG. 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.

6.2 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 tremours 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.

6.3 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.

Fig.11- 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)

Fig. 12- Old Artillery House/ Giddy house in Port Royal that suffered foundation failure in 1907 (Ahmad , 2011)

<u>Fig. 13- Illustration showing contemporary engraving of Port Royal after 1692 Earthquake (Adopted from Ahmad, 2011)</u>

Note that the buildings in the foreground have subsided.

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, as shown above and Buildings in the Niigata Earthquake in Japan on June 16, 1964 as seen in photograph # below

Fig.14- Photograph showing earthquake resistant buildings affected by Liquefaction in Niigata, Japan- June 16, 1964

Note that the building structures are hardly damaged. (www.USGS.gov.earthquakes)

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.

6.4 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.

CHAPTER 7.0 - STORM SURGES AND FLOODING VULNERABILITY

7.1 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.

7.2 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 photographs and below).

Fig. 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.

Fig 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 100km 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 (Photograph K. Douglas)

Areas of weakness which can be chemically weathered over time

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.

CHAPTER 8.0 - HURRICANES/WIND VULNERABILITY

8.1: 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:

1.0 Poor condition of building generally
1.1 Poor condition of metal roof sheeting
1.2 Roofed with common asphalt shingles or built up roofing

1.3 Roof overhangs exceeding 2 feet where there are no soffits

1.4 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.

8.2 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

Fig.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 fig. 22 below) which in comparison to wooden poles, have a reduced susceptibility to wind damage.

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

Concrete base and metal pole

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 23 below.

Fig. 20- Photograph showing large glass section of new terminal building at NMIA (Photograph by K. Douglas)

Glass panels

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.

8.3 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 eliminates 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.

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 below.

Fig. 21- Table showing Saffir Simpson Hurricane Wind Scale

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

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 reigns 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.

CHAPTER 9.0 - CLIMATE CHANGE (SEA LEVEL RISE) VULNERABILITY

9.1 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.

9.2 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."

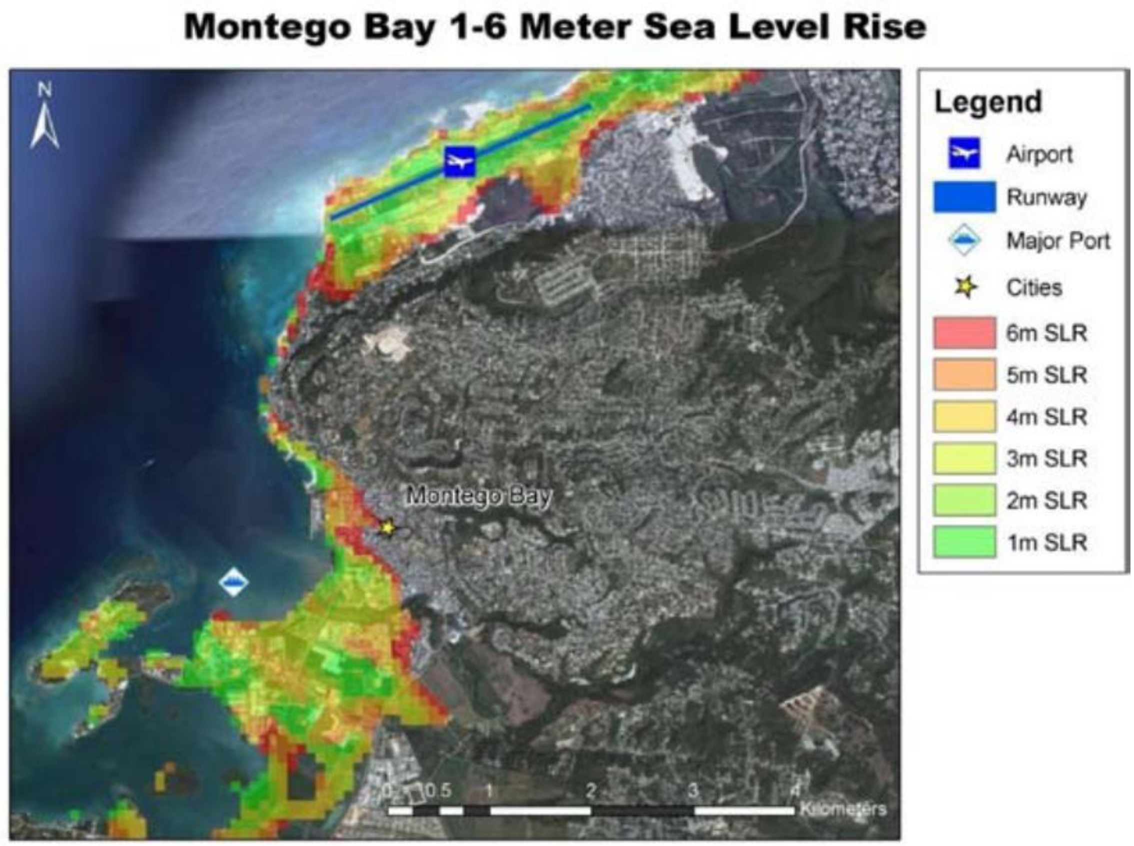
The Intergovernmental Panel on Climate Change (IPCC) in its 2007 report stated that climate change would have an even greater impact on small island development states like Jamaica because of certain characteristics, such as small land masses and the concentration of population and infrastructure along coastal zones. According to the "Caribsave's" 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.

Figure22: Model showing effects of 1-2 metres rise in sea levels in Montego Bay.



(Adopted from UNDP 2009)

Please note that that 1-2 metres 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.

Fig. 23: Table showing projected impacts of sea level rise on Jamaica

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%

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, 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.

Fig. 24 Table showing the most intense Atlantic Hurricanes and their barometric pressures

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

(Adopted from UNDP Climate Change Modelling 2009)

Fig. 25: Table showing Saffir Simpson Hurricane Scale and Accompanying Storm Surge Heights

Category	Wind Speed (mph)	Storm Sruge (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

(Adopted from US National Hurricane Centre)

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.

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CHAPTER 10. 0 Conclusion and Recommendations to reduce vulnerability

10.1 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.

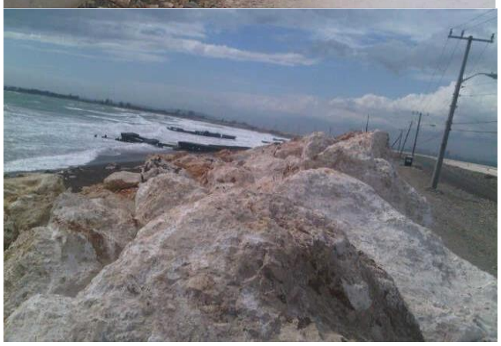
Recommendations to reduce vulnerabilities

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.

10.2 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 figures 26) as well as the raising of the roadway from 0.6 – 1.0 metre to 2.4-3.2 metres.

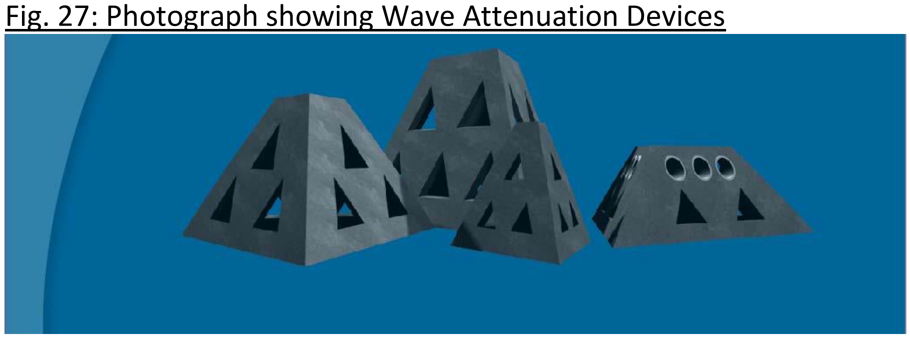
Fig. 26- Photographs showing sea wall and boulder revetments along NMIA Access Route



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.

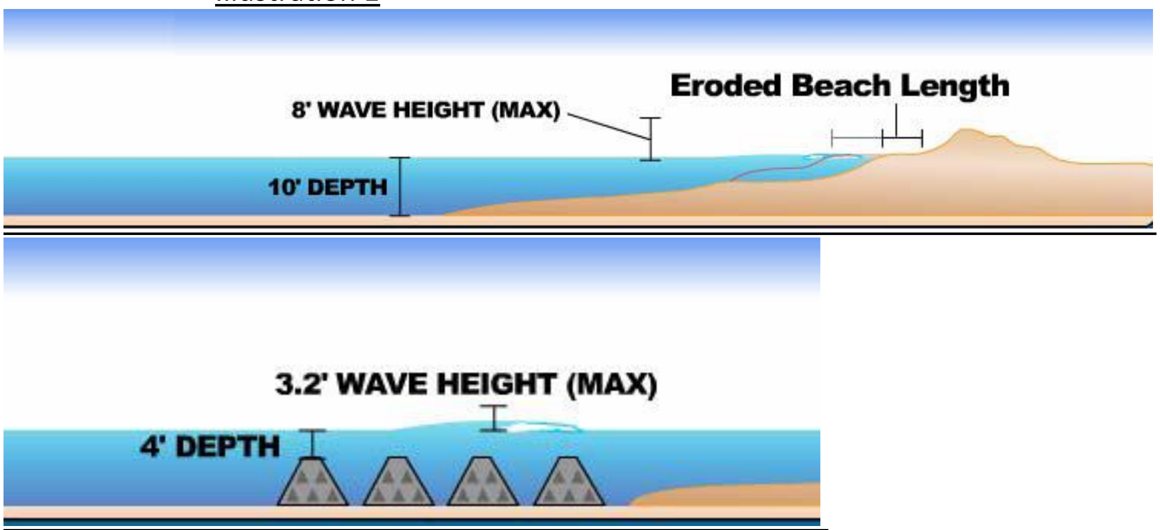
Fig. 27: Photograph showing Wave Attenuation Devices



(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 below in Figure 28.

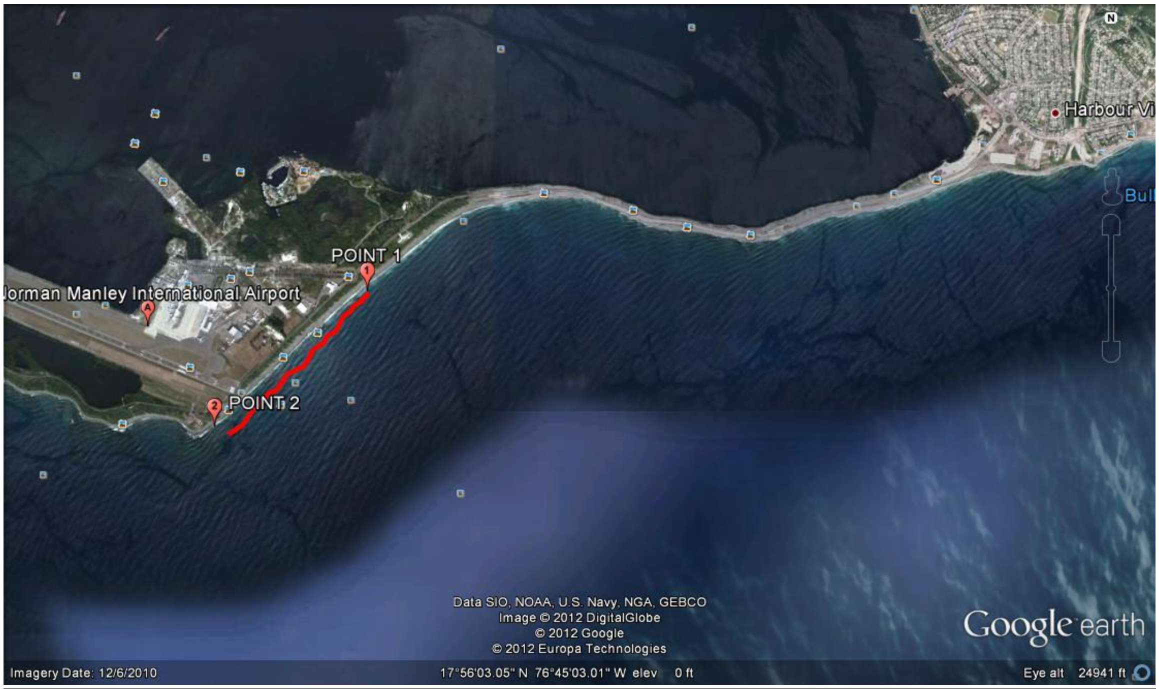
Figure 28: Illustrations showing how wave attenuation devices reduce wave height and impact on shoreline
Illustration 1



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).

Fig. 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.

10.3 <u>Reducing storm surge and flooding vulnerability at NMIA Facility</u>

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

10.4- 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.

10.5 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.

10.6 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.

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APPENDICES

Appendix 1- List of Initial Questions posed to NMIA Engineering and Emergency Response Officials

1 What are the Mitigation measures incorporated in the design and construction of the NMIA Facility to the following hazards?

A) Earthquakes:

- What magnitude earthquake was the facility designed and built to withstand?
- Has any facility on the NMIA suffered structural damage in past earthquake events? If so, which and how has it been addressed?
- List design and construction structural mitigation measures
- What are the ages of the buildings? What are dominant building materials?
- Do any of the buildings possess seismic retrofitting or strengthening measures?

- How thick are the taxiways and run ways?

2. Storm Surges and Flooding Vulnerability

- How was the NMIA designed and constructed to mitigate against flooding?
- Has there been any storm surge/ flooding damage to any facility in the past?

Strong Winds/ Hurricanes

- What kinds of materials are used for roofing across the facility?
- Are glasses all shatter proof?
- Has there been any significant damage in the past from strong winds?
- How secure are communication devices?

Sea Level Rise

- How far above sea level are the run ways and taxi ways?
- What mitigation measures are in place to guard against sea level rise?

Appendix 2- Hazard Threat Matrix of Critical Facilities

Type of Threats	Critical Facilities under greatest threat	Greatest Damage Threatened	Possible Consequences	Preventative Measures
1) Hurricanes/ Strong Winds	Meteorological Office	Breach of windows and s, damage to critical equipment	Suspension of meteorological information to the nation and airport operations curtailed.	Reduce glazing, shutter windows
	Air Traffic Control Tower	Breach of windows and s, damage to critical equipment	Airport operation suspended	Reduce glazing, shutter windows
	Fire Station	Building and equipment Damaged	inability to respond to emergencies at full strength	Shutter Building
2. Storm Surges/ Flooding	NMIA Acces Route	Inundation or complete destruction, leaving the NMIA on an island	No road access to NMIA, Operations ceased	Coastline protection mechanism, roadway, relocate NMIA
	Runways and Taxiways	Inundation	short term ceasure of NMIA operation	Raise runways and taxiways
	Power Plant	Destruction of equipment, Fuel spills	Marine pollution, death of marine life	Build protective wall
	Fire Station	Damage to building and equipment	inability to respond to emergencies at full strength	Store equipment safely and stren building
Earthquakes	All Critical Facilities, but particularly older buildings	Total Destruction of facility	Ceasure of operation	Seismic retrofitting
Sea Level Rise	NMIA Runways and Taxiways	Permanent inundation	Ceasure of operation	Raise runways and taxiways, relo inland