# VULNERABILITY AND RISK ASSESSMENT REPORT FOR NORMAN MANLEY INTERNATIONAL AIRPORT


airports authority of jamaica

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December 2017

| | **Submission to Client** | **Revision A** | |
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| Date: | July 2017 | December 2017 | |
| Comments: | Submission to client for review | Adjusted for increased exposure and revised risk analysis | |

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# 1 INTRODUCTION

## 1.1 Background

The shoreline at the southern end of the Norman Manley International Airport (NMIA) Runway is vulnerable to both long and short term coastal erosion from sea level rise and storm events. The Port Royal main road is the only road that connects the residents of the coastal community of Port Royal, commercial and institutional activities to the main land.

The width of the buffer between the edge of road and shoreline varies between 30 to 80 meters. Observations and predictions suggest that 30 to 60 meters of shoreline can be lost in a single event which renders both the road and end of runway exposed. It is therefore desirous to protect the stretch of shoreline to secure both the airport, access for the residents and the social infrastructure.

NWA designed a solution in 2013 for this stretch of shoreline. This design was deemed unsuitable as it does not meet the crest elevation criterion for not piercing the JCAA Obstacle limitation surface (OLS) obstruction envelope of approaching aircrafts. The present focus is aimed at producing designs that limit the overtopping to safe limits during the design storm event as well as to meet the JCAA requirement.

## 1.2 Project Scope

The overall project area extends approximately 9km from the Harbour View Roundabout in the east to the Palisadoes Road at the northern end of the NMIA runway. The project includes a risk assessment along the entire length of the project shoreline and shoreline protection works at the shoreline adjacent to the NMIA runway.

## 2 HAZARD, VULNERABILITY AND RISK ANALYSIS

The location of the Norman Manley International Airport (NMIA) in a low lying area with elevations ranging between 0.2 m to 4.6m above sea level renders the facility exposed to storm surge hazard. This hazard presents a potential threat not only to the infrastructural assets of the airport but also to the functioning of the facility. This analysis evaluates the levels of exposure, vulnerability and risk for current and future storm surge impact taking into consideration sea level rise owing to climate change.

### 2.1 Methodology

The study analyses risk at NMIA by assessing three important components in risk analysis: 1) hazards; 2) vulnerability; and 3) elements-at-risk (exposure). Risk analysis uses the following conceptual equation:

**RISK = HAZARD * VULNERABILITY * ELEMENTS AT RISK**

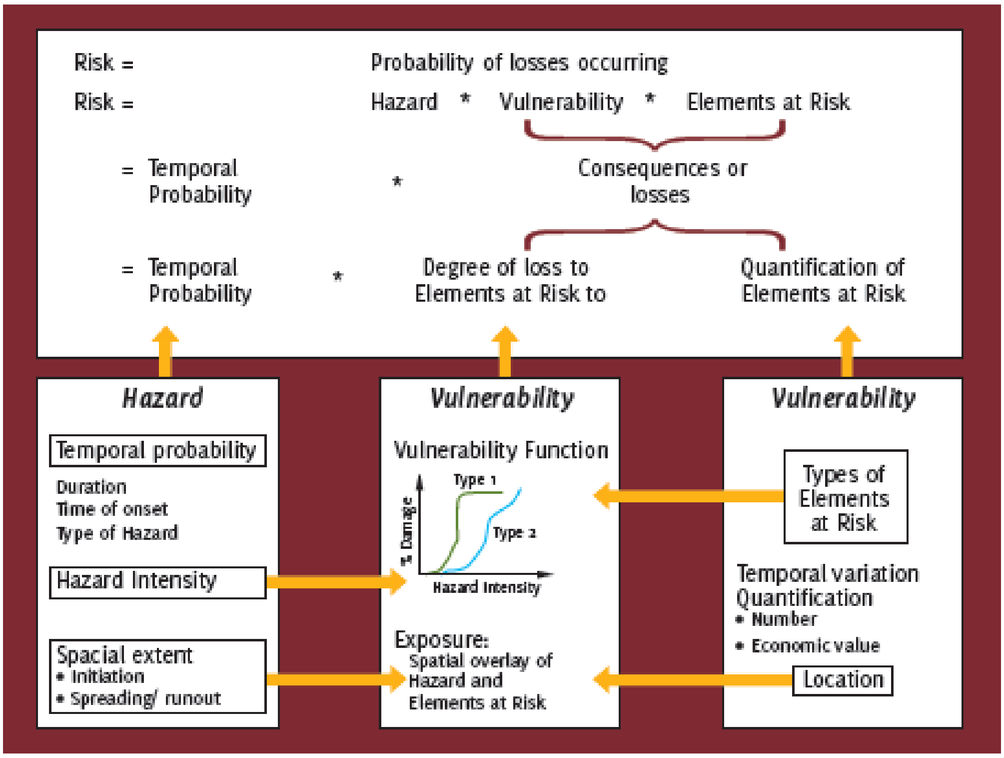



**Figure 2-1: Probabilistic Risk Assessment Methodology** Source: ITC, 2010

### 2.2 Step 1 Hazard Assessment

The hazard assessment seeks to understand the nature, frequency and magnitude of hazards as well as spatial occurrence, duration of events and their relationship. The assessment was executed as follows:

- Anecdotal Storm Surge Survey - structured questionnaires were administered to persons at NMIA and Caribbean Maritime Institute (CMI). The interviews focused primarily on collecting information on the extent and impact of major storms experienced and data includes height of storm surge etc.
- Bathymetric Survey - Storm Surge and wave heights on shore are affected by the configuration and bathymetry of the ocean bottom. Understanding the movement of currents along the seafloor aids in the prediction of wave intensity and direction on the shoreline.
- Storm surge modelling ( Numerical modelling)- The following procedure was carried out for storm surge assessment:
    - ✓ Hurricane wave track data in the Caribbean Sea was used to determine the hurricane wind and wave conditions at a deep water location offshore
    - ✓ Extraction of storm parameters that passed within 300 km radius off the coast from National Oceanic and Atmospheric Administration (NOAA) hurricane database.
    - ✓ Application of the JONSWAP2 wind-wave model. A wave model was used to determine the wave conditions generated at the site due to the rotating hurricane wind field.
    - ✓ Application of extremal statistics - to estimate different return periods for waves and surge levels
    - ✓ A bathymetric and topographic profile from deep-water to the site was then defined, respectively. This is used to calculate the wave run-up (height) based on topography of shoreline and nearshore waves.

## 2.3 Step 2 Exposure Analysis

The interaction between the elements at risk and hazard footprint defines the exposure. The analysis of exposure aims at identifying the physical as well as societal elements that are at risk. By quantifying the proportion of assets that are located in the hazardous areas, it provides an understanding of the assets that are prone to damage and losses caused by various hazard intensities. Elements at risk as defined in this study include all the assets that are found at the NMIA to include runway, buildings and so on.

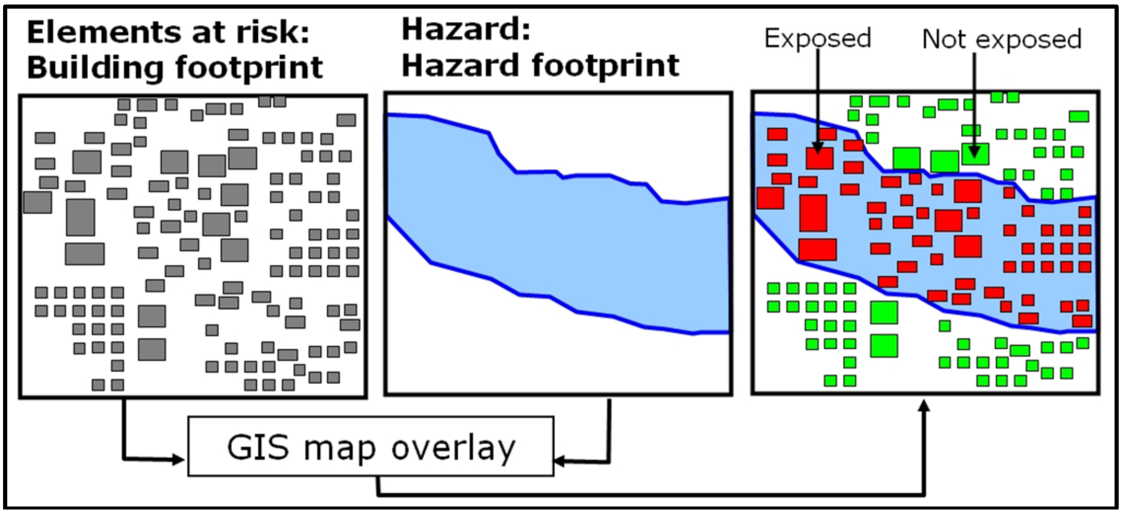



**Figure 2-2: Schematic of Exposure Analysis** Source: ITC, 2010

To facilitate the exposure analysis data collection was conducted to include the following:

- Detailed inventory mapping of buildings and facilities within the project boundary with a total of 176 positional reference points captured. The following attributes were defined:
    i. Global Positioning and Physical Attributes: size; location; floor elevations; number of stories;
    ii. Structural Information: construction type (roof; windows; wall; cladding; foundation); age; mitigation measures in place etc.
    iii. Damage History: Event; cost of and extent of damage

## 2.4 Step 3 Vulnerability Assessment

Once the exposed elements at risk are identified it is possible to assess how they would be impacted, that is, an assessment of the physical vulnerability is undertaken. Physical vulnerability is defined as the degree of loss to a given element-at-risk or set of elements-at-risk (e.g. buildings) resulting from the occurrence of a natural phenomenon of a given magnitude.

In order to assess vulnerability, existing stage damage curves developed for other coastal areas in Jamaica was used to estimate the percentage of damage for each level of hazard intensity. The curve shows the relationship between a measured parameter of the hazard intensity (e.g. water depth in case of flooding) to the likely damage level of the particular building class.

## 2.5 Step 4 Risk Analysis

This final step combines the results of the previous three analyses and determines the level of risk that occurs as a result of each hazard, and the potential losses that may be experienced.

The assessment focused both on tangible/direct losses as well as indirect losses relating to the functional downtime of the airport facility as a result of hazard impact. The replacement value of assets (cost of construction, labour, material etc.) used in the calculation of physical risk was taken from the "Valuation Report for Insurance Purposes on Buildings, Infrastructure Works & Improvements at the Norman Manley International Airport" (Allison Pitter & Co, 2016).

## 2.6 Data Used

The analysis developed in this study is based the usage of both existing local and global available data sources as well as data collected specifically for the project area.

**Table 2-1: Data Used in Analysis**

| PARAMETER | DATA | SOURCE |
|---|---|---|
| Sea Level Rise | • A2 Scenario: SLR 0.37m/yr. | IPCC (2012) |
| Storm surge | • Topographic data<br>• Bathymetric data | Consultant |
| Asset Inventory | • Field data collection | Consultant |
| Risk Analysis | • Valuation Report on assets | Allison Pitter & Co., 2016 |
| | | |

## 2.7 Limitations

It is accepted that there are inherent uncertainties with modelling such as with the probabilistic risk assessment methodology. To address this limitation, the most appropriate and current datasets available at the time of conducting this assessment were used. Assumptions and simplifications, where necessary, were applied to model coastal hazards and the validation showed a high confidence level in the results of the models.

The data used to calculate the economic contribution of activities at the NMIA is based on financial year 2008/09. With that said the economic contribution of the NMIA as 2017 could possibly be higher.

# 3 KEY FINDINGS

## 3.1 Hazard Assessment

### 3.1.1 Storm Surge

This section provides a summary of the hazard assessment taken from the Conceptual Design Brief which details the storm surge and coastal erosion assessment. The analysis considered scenarios for both baseline and future storm surges with sea level rise (SLR). The Intergovernmental Panel on Climate Change (IPCC) noted that it is virtually certain that global mean sea level rise will continue beyond 2100, with sea level rise due to thermal expansion to continue for many centuries. The amount of longer term sea level rise depends on future emissions (IPCC, 2013). Table 3-1 shows summary of the climate change considerations that were added to the baseline storm surge. For the assessment of SLR, the A2 scenario was chosen because it represents the worst case of all the emissions scenarios regarding the concentration of GHGs in the atmosphere associated with future global development patterns to the end of the century.

**Table 3-1: Climate change parameters**

| PARAMETER | CHANGE FACTOR | IMPACT |
|---|---|---|
| Sea level rise | 3.7mm/year (increase) | Storm surge |
| Storm intensity | 7% (increase) | Wind and waves |
| Number of storms per year | 5 (increase) | Waves and storm surge |

The results of the predicted storm surge models for the 5- 100 years return period is estimated to range from 0.59m to 5.19m above mean sea level (Refer to Table 3-2). The storm surge values represent the likely maximum topographic elevation storm surges will propagate inland from the coastline. Sea level rise[1] is expected to increase these values relative to current Mean Sea Level (See Table 3-2).

In the analysis of future storm surges resulting from projected sea level rise, storm surge heights will be increased from 3.7m under baseline conditions to 4.5 m for future storm surge and sea level rise combined for the 50 year return period. This represents a future increase of 18%. Higher sea level provides storm surges with a higher “launch point” for the surge, which may increase both the real extent and the depth of the surge in areas already vulnerable to coastal storms (Neumann et al, 2015). And so, as storm surges increase, they will create more damaging flood conditions as the waves propagate or move further inland.

[1] Sea level rise at a particular location is a combination of the global rise in sea levels and local trends. The primary contributors to sea level change are the expansion of the ocean as it warms (thermal expansion) and the transfer of water currently stored on land to ocean, particularly from land ice [glaciers and ice sheets] (Church et al, 2011).

**Table 3-2: Predicted Storm surge Elevations for Baseline and with Sea Level Rise**

| RETURN PERIOD | BASELINE STORM SURGE | FUTURE (2050) | FUTURE (2050) + SLR |
|---|---|---|---|
| 5 year | 0.59 | 1.14 | 1.26 |
| 10 year | 1.25 | 1.95 | 2.07 |
| 25 year | 2.48 | 3.21 | 3.3 |
| 50 year | 3.71 | 4.33 | 4.5 |
| 100 year | 5.19 | 5.55 | 5.7 |

### 3.1.2 Coastal Erosion

Two types of erosion analysis were conducted - short term erosion and long term erosion. Short term erosion refers to erosion that occurs over a period of days, rather than years as a result of extreme weather conditions such as storms. Long term erosion on the other hand usually refers to a trend of erosion extending over several years and can be caused by a deficit in the annual sediment budget or in longshore transport along the beach.

#### *3.1.2.1 Analysis of Short-term erosion*

Short term erosion was assessed using SBEACH, empirically based profile numerical model for estimating beach and dune erosion due to storm waves. The analysis for short term erosion was undertaken for the 1.0km of the Palisadoes shoreline for the 100 year return storm event. This was due to the increased number of extreme storms events over the past 28 years and anecdotal information pointing to erosion taking place on the beach during storm events.
The results of the model show that:

- The entire stretch of shoreline is vulnerable to erosion varying from 10 to 83 metres
- The area to the southwest of the runway is most vulnerable to erosion due to a 100 year storm ( Refer to Figure 3-4)
- The section of the main road immediately to the south if the runway is susceptible to failure due to erosion of the shoreline
- Erosion starts generally from 5 to 20 meters inland from the shoreline

#### *3.1.2.2 Analysis of Long-term Erosion*

The overall long-term erosion trend was estimated by observation of actual long-term shoreline positions from dated aerial photography. The Bruun Model was then used to investigate the extent to which global sea level rise was contributing to the observed erosion. The results indicate that:

- The shoreline investigate from the light house to approximately 450m east of the runway is eroding at an average rate of 0.14 to 0.21 metres per year
- The location west of the end of runway is eroding at a rate of 0.1 to 0.4metres per year
- The location to the south of the end of runway at a rate of 0.09 to 0.22 metres per year

- The location east of the end of runway is eroding at a rate of 0.057 to 0.56 metres per year
- GSLR is estimated to be responsible for approximately 57% to 100% of observed erosion.

## 3.2 Exposure Analysis

### 3.2.1 Exposure to Storm Surge Hazard

#### *3.2.1.1 NMIA*

The topography of NMIA is such that storm surges can penetrate well inland from the coastline. The analysis shows that for all return periods the land and buildings at the NMIA is highly exposed to varying degrees of flooding as a result of storm surge hazard. In fact, for both the 50 year and 100 year return periods, 100% of the airport land and facilities are inundated or within the flood hazard footprint. This can have large scale impact due to interruptions to flight schedules as well as business operations at the airport.

On the other hand, for the 10 year storm surge event the expected exposure of airport facilities is not significant as can be seen in Figure 3-1 compared to neighbouring Caribbean Maritime Institute. In fact all (100%) of the land and facilities at the institution as well as Yacht Club are inundated.

Under sea level rise conditions exposure is increased by approximately 40% and 11% for both the 10 and 25 year return periods, respectively. This increase may be attributed to the fact that higher sea level provides storm surges with a higher "launch point" for the surge, which may increase both the real extent and the depth of the surge in areas already vulnerable to coastal storms (Neumann et al, 2015). For the 50 year and 100 year scenarios, exposure remains the same for both baseline and future storm surge with sea level rise resulting in 100% of the buildings exposed to storm surge inundation as shown the Table 3-3.

**Table 3-3: Number of Buildings Exposed to Storm Surge Hazard**

| RETURN PERIOD | NUMBER OF BUILDINGS/STRUCTURES | % in HAZARD AREA |
|---|---|---|
| **Baseline storm surge** | | |
| 10 year | 88 | 50% |
| 25 year | 157 | 89% |
| 50 year | 176 | 100% |
| 100 year | 176 | 100% |
| **Storm surge with SLR** | | |
| 10 year | 147 | 84% |
| 25 year | 176 | 100% |
| 50 year | 176 | 100% |
| 100 year | 176 | 100% |

The entire length of the runway which is approximately 2,716 m including taxiways is within the 50 and 100 year storm surge scenarios (Refer to Figure 4-1). However, the greatest exposure is at the end of runway 30. This section of the shoreline is exposed to wave heights of up to 3.6 to 4.0 meters compared to wave conditions along the remainder of the Palisadoes, where wave height typically range from 2.4 to 3.2 meters.

#### *3.2.1.2 Palisadoes Road*

The Palisadoes Road is the most important roadway linking the Kingston Metropolitan Area to the Norman Manley International Airport, the coastal community of Port Royal and other important institutions such as the Caribbean Maritime Institute.

In 2004, following the passage of Hurricane Ivan, 310 metres of the shoreline was deemed to be in a critical state. The storm caused total destruction of the sand dunes, inundation and blockage of the roadway with sediment and debris which led to the "complete shutdown" of the NMIA and inability of Port Royal residents to access the mainland (Jamaica Observer, 2005). Within three (3) years of the passage of Hurricane Dean, similar impact occurred along the Palisadoes which also limited access to the airport and Port Royal resulting in shutdown of the airport.

With the construction of the rock revetment along the Caribbean Sea side of the Palisadoes, exposure from storm surge impact is expected to be reduced. It should be noted however, overtopping of the lower sections of the revetment is likely which has the potential to cause in storm surge impact. The impact therefore would not be at the same magnitude as historical experienced along the Palisadoes. Figure xxx shows that

### 3.2.2 Exposure to Coastal Erosion

Figure 3-4 below depicts the exposure of the shoreline to coastal erosion as a result of the 50 and 100 year storm event, particularly in the vicinity of runway 30. A 100 year storm event has the potential to cause erosion that result in the Caribbean Sea at the end of the road. This section of the runway is deemed exposed to hurricane waves than the remainder of the Palisadoes. The assessment found that the end of runway and sections of the dune within the project area are exposed to wave heights of up to 3.6 to 4.0 meters.

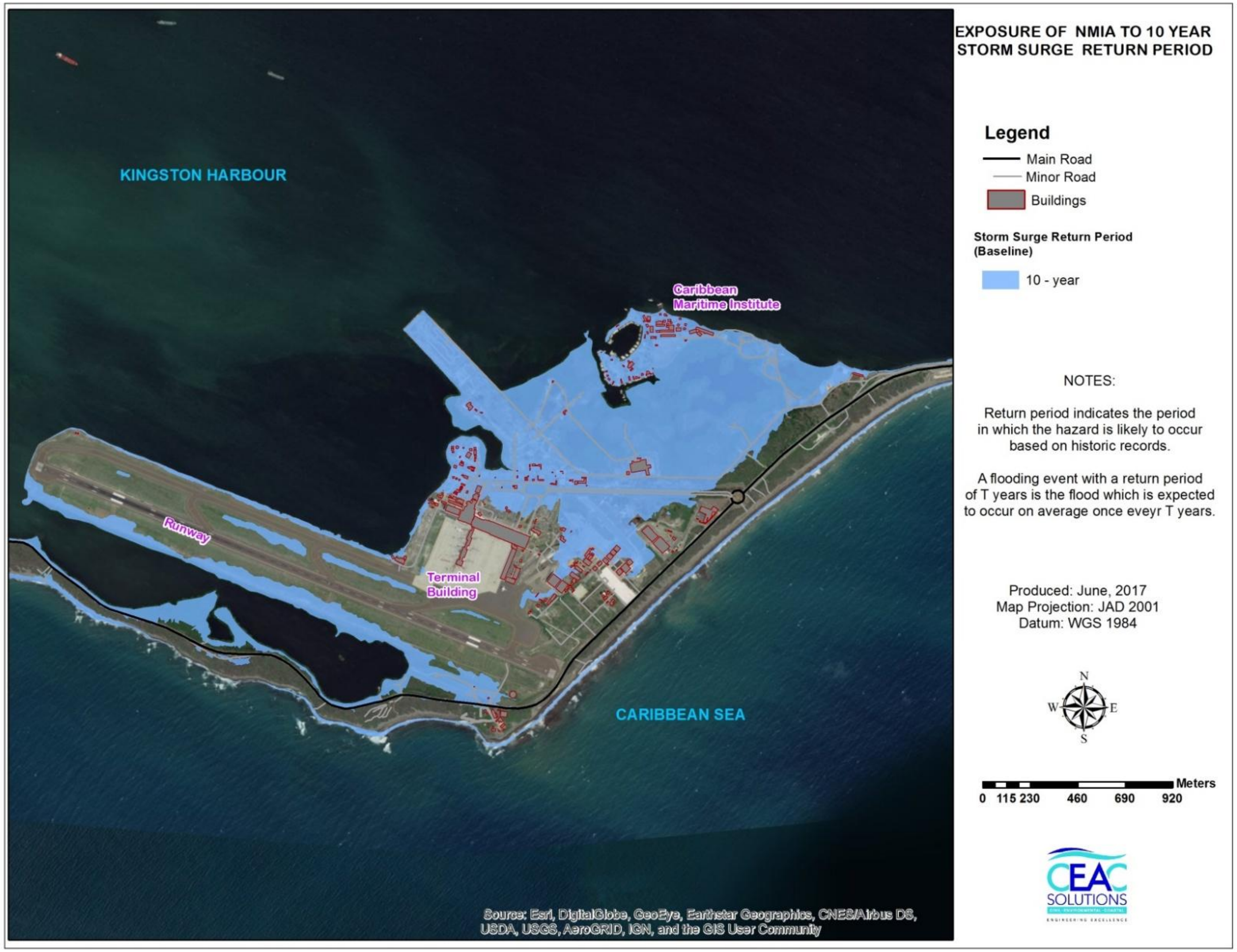



**Figure 3-1: Exposure of Airport Assets to 10 Year Storm Surge Return Period**

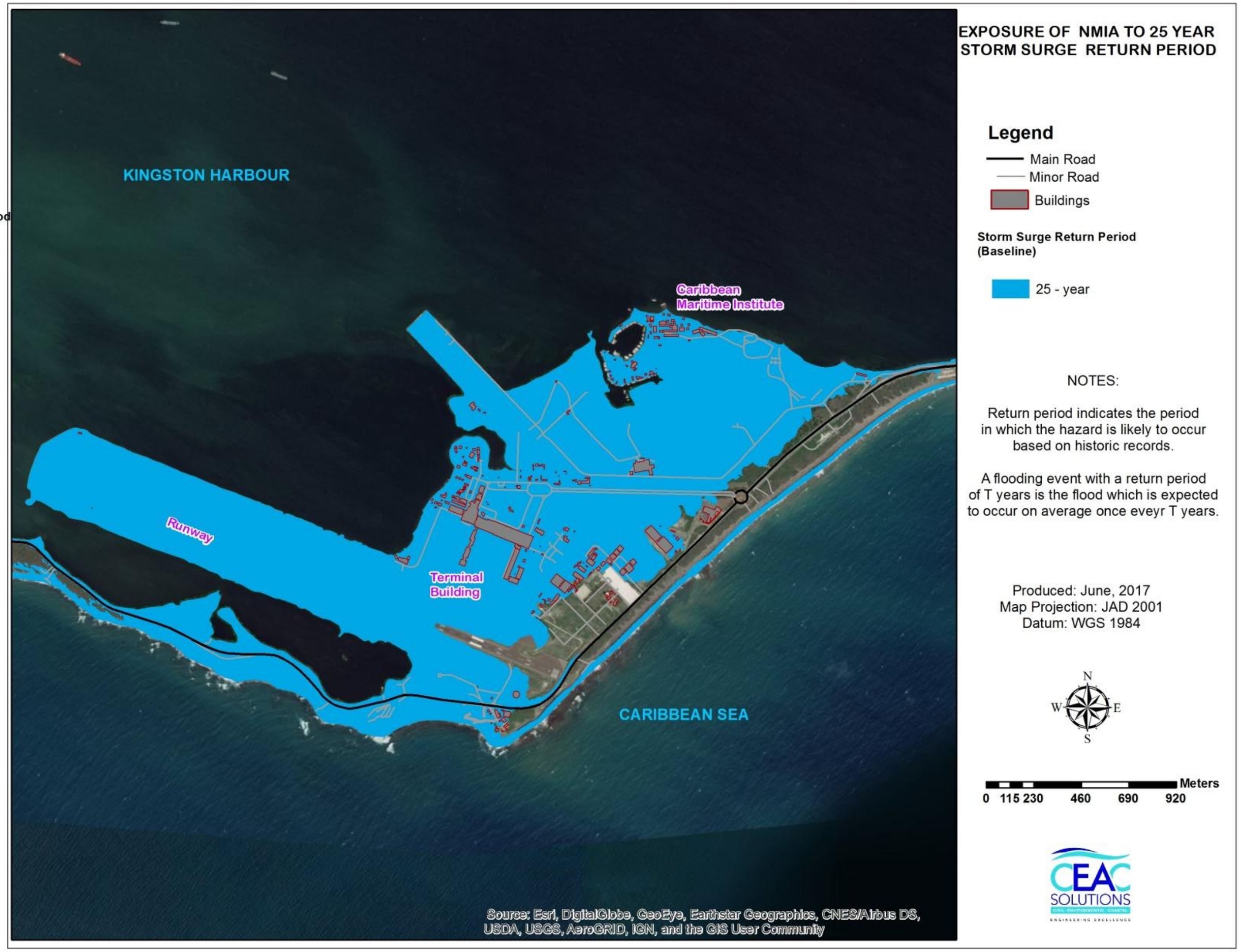



**Figure 3-2: Exposure of Airport Assets to 25 Year Storm Surge Return Period**

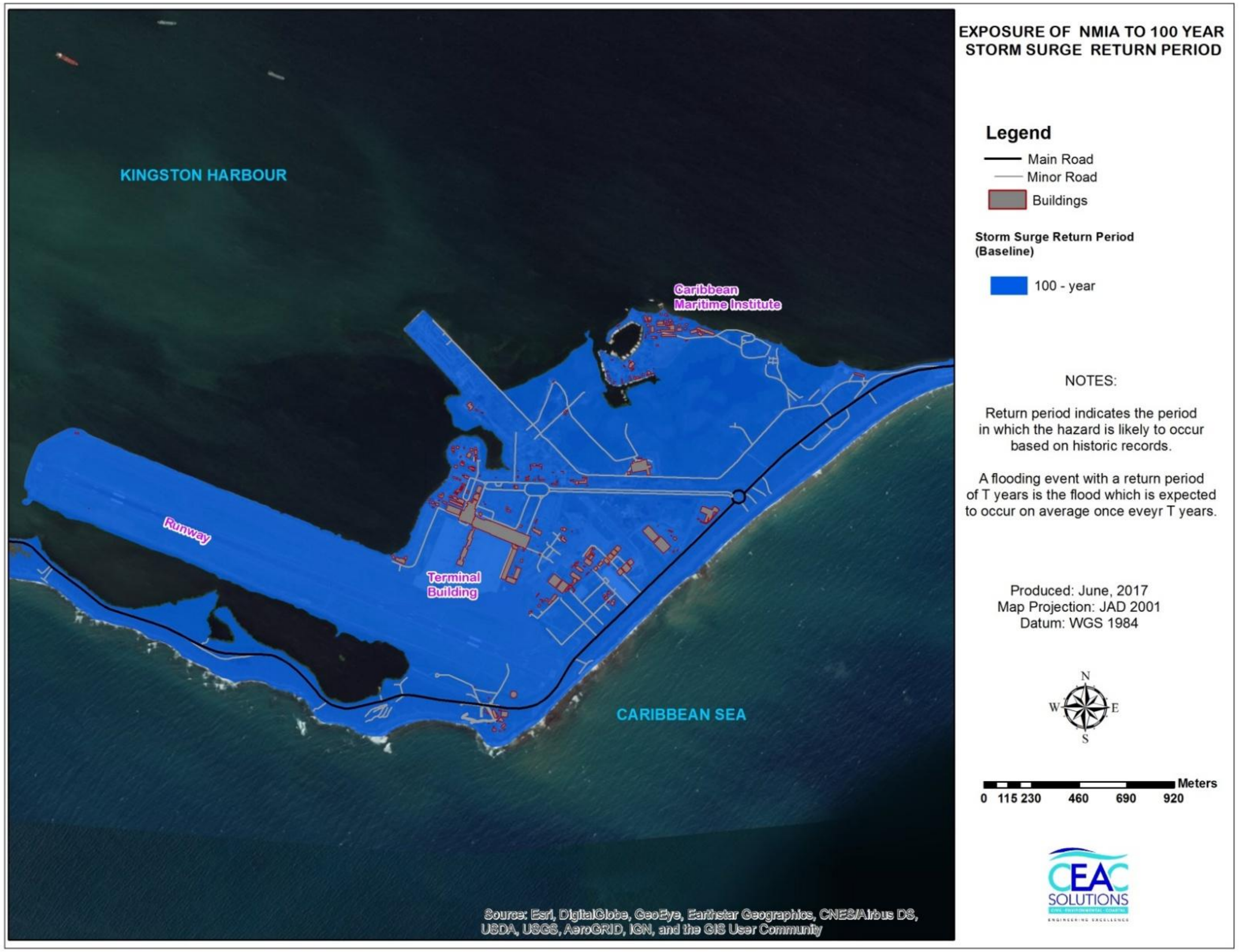



**Figure 3-3: Exposure of Airport Assets to 100 Storm Surge Return Period**


**Figure 3-4: Erosion for the 50 and 100 year storm event**

## 3.3 Risk Analysis

### 3.3.1 Direct Losses

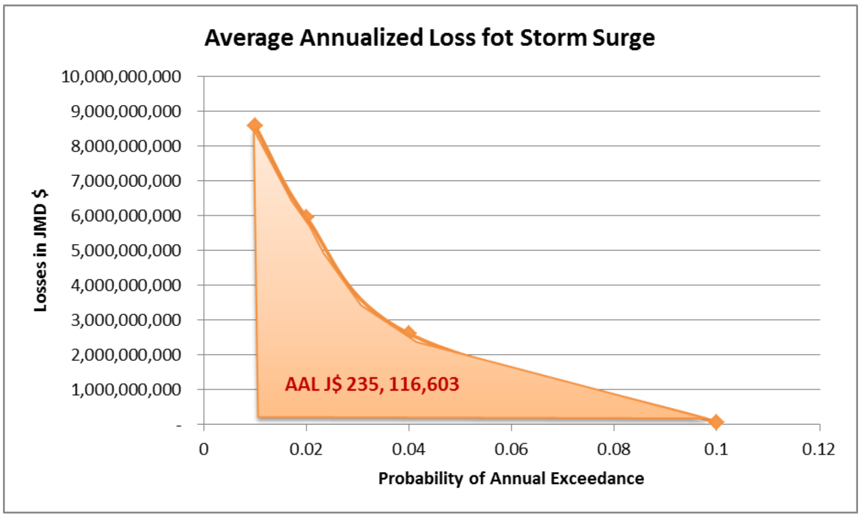
The storm surge risk is high due to the economic value of the facilities at the NMIA to include buildings, cargo, runways and taxiways and so on. It must be noted that the following estimates only considers the replacement costs of the respective component.For the 10-100 year return periods, Table 3-4 shows the average annualized loss (AAL) for storm surge at J$ 235.1 million. The maximum probable loss for 100-year storm surge is an estimated J$ 8.5 billion which would cause a serious disruption to the functioning of the airport as well as to the economy. The Probable Maximum Loss (PML) is the value of the largest loss that could result from a disaster in a defined return period.

**Table 3-4: Storm Surge Risk**

| RETURN PERIOD | PROBABILITY OF ANNUAL EXCEEDANCE | MAXIMUM PROBABLE LOSS(J$) | AVERAGE ANNUALIZED LOSS (J$) |
|---|---|---|---|
| 10 year | 0.1 | 66,840,200 | J$ $235,116,603 |
| 25 year | 0.04 | 2,609,051,400 | |
| 50 year | 0.02 | 5,946,321,000 | |
| 100 year | 0.01 | 8,579,307,160 | |

It should be noted that the risk represented in Table 3-4 above is associated with storm surge only and does not include any other hazards such as wind, earthquakes etc.

Figure 3-5 displays the estimated relationship between total losses and annual probability with the area under the curve representing expected the AAL of JM $235,116,603 million (USD $ 1,809,842)[2].




[2] BOJ rate as at May 9, 2017 of USD $1 = J$ 129.91

**Figure 3-5: Average Annualized Loss for Storm Surge (Baseline)**

The average annual loss is the expected average loss per year considering all the events that could occur over a long time frame. It represents the amount of savings that need to be set aside each year to cover the cost of long term losses from storm surge hazard (Global Assessment Report on Disaster Risk Reduction, 2015).

Another scenario was analysed looking specifically at specifically at estimating direct losses for the end of runway 30 which is highly exposed as previously discussed. The assumption is that approximately 10 m of the runway along with fence and retaining structure will sustain damage. The analysis assessed the potential risk without and with proposed mitigation works to protect runway 30. The results in Table 3-5 show that the estimated probable maximum loss is J$ 5.4 million for the 200 year storm events based on existing or AS-IS situation. The with mitigation scenario shows a potential reduction of 66 % and 80% for the 100 year and 200 year storm events, respectively.

**Table 3-5: Storm surge Risk for End of Runway 30 with and without Mitigation**

| RETURN PERIOD | PROBABILITY OF ANNUAL EXCEEDANCE | MAXIMUM PROBABLE LOSS(J$) | |
|---|---|---|---|
| | | Without Mitigation | With Mitigation |
| 25 year | 0.04 | 0 | 0 |
| 50 year | 0.02 | 541,923 | $541,923 |
| 100 year | 0.01 | 1,625,769 | $1,083,846 |
| 200 year | 0.005 | 5,419,230 | 4,335,384 |

Figure 3-6 depicts the relationship between estimated losses without and with mitigation. The solid curve shows the risk prior to mitigation while the broken curve shows the new amount of risk when risk reduction option is applied. The difference between both curves represents the expected benefits if proposed mitigation; in this case revetments are implemented to protect the end of runway 30. In other words, the blue area is the reduction in risk due to the risk reduction measure.

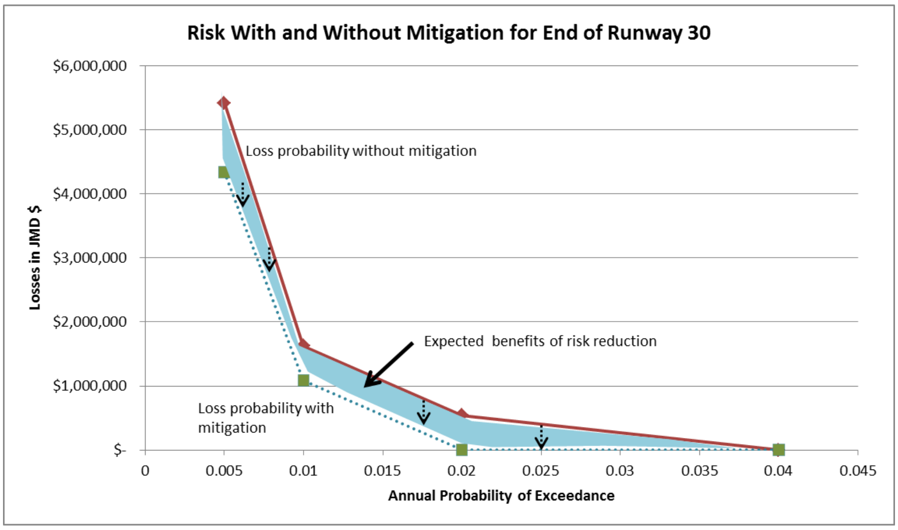



**Figure 3-6 Relationship between estimated losses without and with mitigation**

### 3.3.2 Indirect Losses

In addition to direct losses due to damage of physical infrastructure, natural disasters often result in important indirect losses also called functional loss. The interruption of the NMIA which is an essential infrastructure can cause cascading effects on the economy. Indirect economic losses are caused by the disruption or failure of physical or economic linkages (Penning- Rowsell et al., 2003; Messner et al., 2007). In other words, the indirect loss or functional downtime is the interruption in time of the operations and businesses at the airport. Temporary shutdown will affect air transport, revenue generation for the AAJ, airlines, and other small businesses at the airport with an overall net reduction of total spending in the economy, thereby having a ripple or cascading effect resulting from supply disruptions of other sectors in the economy.

To estimate the indirect losses, Federal Emergency Management Agency's (FEMA), 2001 HAZUS – MH equation was used:

***Functional Loss = (Average daily budget/sales * downtime) + (displacement cost/day* displacement time)***

To calculate the indirect losses, the lost days associated with the passage of Hurricane Dean in 2007 was used to estimate monetary losses. Research shows that the NMIA was out of operation for approximately 2 days. This took into account business interruption before Dean's effect on the island as well as time lost after the passage of the hurricane to restore access to the Palisadoes strip and clean-up operations on the airport property. Important to highlight is that the Palisadoes road is the only access road to the airport which was blocked because of the deposition of sand on the road surface (Refer to Plate 5-1). In the aftermath of Hurricane Dean, sand was piled approximately 1.5 meters high along the length of the road (PIOJ, 2007).

**Plate 3-1: Palisadoes covered with Sand** Source: JIE, 2007

The following data from the AAJ's annual report, 2015/2016 was used in the calculation:

*Actual Operating Income = **<u>USD$37,264,000 as at March, 2016</u>***

*Estimated Daily Income = USD$37,264,000/365 days = ~USD$ 102, 093*

***Functional Loss = (USD$ 102,093 * 2 downtime days) + (No displacement cost)***

***= USD $ 204,186 (J$ 24,918,896)[3]***

Under the assumption that the NMIA lost two days, the losses were estimated to be approximately J$ 24. 9 million for two days of business interruption. This figure, when added to the maximum probable loss (Refer to Table 5-1) is representative of the cumulative economic impact or loss.

Further analysis was conducted to assess the overall economic impact to the local economy with same above assumption of loss of 2 business days at the NMIA. Using the 2008/09 Economic Impact Assessment Report, the direct economic activity at the NMIA was estimated to be J$34.7 billion. This figure was used because it represents economic activities that would be disrupted at the airport itself and does not include indirect or off site activities that contribute to the overall economic impact value of the airport

**Value of Economic contribution for year 2008/09 = J$34.7 billion**

[3] BOJ rate as at March 31, 2016 of USD$1 = J$122.04 was used for conversion

**Estimated daily economic contribution = J$ 34.7 billion/365 days**

**= J$ 95,068,493 million**

**Reduction Economic contribution = J$ 95,068,493 X 2 days**

**= J $ 190,136,986 million**

Taking the above figure into consideration gives an idea of the extent of likely reduction in economic contribution if activities at the NMIA are disrupted as a result of hurricane induced storm surges and associated effects. Taking NMIA's contribution to national GDP which is estimated to be 10% in 2008/09, the reduction in economic contribution is equivalent to 0.56%.

Of note is that the scenarios did not include the coastal mitigation works (raising of road and revetment) that was recently implemented along the Palisadoes which may potentially reduce the disruptions at the airport in the future, but has not yet been tested under a powerful event.

A second scenario was analysed with 10 m of the runway being damaged along with the perimeter fencing and existing retaining structure. Communication with AAJ team indicated that operations would be halted at the airport not as a result of loss of use of runway but to conduct an assessment of the damage to inform decision-making. Table 3-6 below shows estimated indirect loss owing to the functional downtime at the NMIA for both scenarios.

**Table 3-6: Indirect Losses**

| **Scenario** | **Indirect Losses [4]** | |
|---|---|---|
| | Loss of Revenues (JMD $) | Reduction in Economic contribution (JMD $) |
| No access- Palisadoes blocked | ***24,918,896*** | **190,136,986** |
| 10 m damage to runway | **24,918,896** | **190,136,986** |

[4] Indirect losses was calculated based on 2 days of business interruption

# 4 CONCLUSION AND RECOMMENDATIONS

The data clearly shows that given the location of the Norman Manley International Airport the current risk levels posed by storm surge may be considered high and will likely increase when sea level rise and coastal erosion are factored. The projections show that the situation will continue to worsen if no mitigation measures are implemented. However, should the proposed revetment be implemented, the models show that there will be reduction in the spatial extent of inundation as well as reduction in possible risk to the end of runway 30. If unmitigated, the end of runway 30 is exposed.

Additionally, given the likely multiplier effect of a shutdown of the NMIA airport the development of a **continuity of operations plan is also important and should be considered a strategic imperative for the airport**. This is in addition to the emergency plan that exists. This plan should factor the risks posed to the facility and access to the facility by storm surge. This should extend beyond NMIA to include the airlines and other businesses that are within the airport facilities that are projected to be impacted.

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