Potential Impacts of Climate Change on the Norman Manley International Airport

Prepared for

Norman Manley International Airports Limited

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Final Report

Prepared for:
Norman Manley International Airports Ltd
Palisadoes, Port Royal
Kingston

Prepared by:
Environmental Solutions Ltd.
89 Hope Road
Kingston 6

PROPRIETARY RESTRICTION NOTICE

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EXECUTIVE SUMMARY

This Report presents a discussion about the possible impacts of climate change on the Norman Manley International Airport (NMIA). Specifically, the report focuses on potential climate change impacts that may occur within the next 25 years and determines what if any effect there may be on any capital projects already planned. The document is not intended to act as a forecasting tool for the NMIA.

The table below summarizes the most recent Climate Projections for Jamaica for the next 25 years and links it with some of projects listed under the NMIA Capital Expenditure Program.

	Climate Change Projection over the next 25 years	NMIA Capital Expenditure Program
Temperature	The mean temperature increase from the GCMs will be 0.75-1.04 °C by the 2030s, and 0.87-1.74 °C by the 2050s	Compliance and improve energy efficiency
Rainfall	The 2030s will be up to 4% drier, the 2050s up to 10% drier. The South and east of the island will have greater decreases in rainfall. Of consideration however is the increasing variability and short duration intense storms when rain does occur. This has implications for increased stormwater runoff.	Sewage treatment (2 phases) and storm water drainage upgrade, storm water management (Phase 2)
Sea Level	The range of SLR is 0.17-0.38 for 2046-2065.	RESA (Runway End Safety Areas) and Runway extension
Hurricanes	Variable conclusions provided. Over the next 25 years there may be a decrease or no change in the frequency of hurricanes but there may be a shift towards stronger storms (category 4 and 5).	RESA (Runway End Safety Areas) and Runway extension. Storm water drainage upgrade

The NMIA Master Plan (2013) indicated that the NMIA and the aerodromes are potentially vulnerable to hurricanes, precipitation increase, temperature increase and storm surge due to sea level rise. Specifically, this includes wind damage to assets, redirection of flights, flooding of airfields and roads causing delays, scour of embankments and earthworks, reduced airplane performance, increased energy use and demand, and potential closures and failures due to storm surge.

At the time, the following recommendations were made:

- strengthening and protecting structures to withstand wind loads, power outages, and flooding events
- installing redundant critical equipment

- upgrading drainage systems
- reducing energy loads where possible
- diversifying fuel supply
- elevating critical infrastructure (specifically in buildings)
- restoring natural flood defenses

Each of these recommendations would build the climate resilience of the airport.

Of all the CapEx projects identified in the NMIA Master Pan (2013) and the Jamaica Information Memorandum (2014), the RESA (Runway End Safety Areas) and Runway extension may be affected by the impacts of climate change. However, due to the existing height of the runway it is possible that it may be impacted by climate change whether or not the runway extension is carried out. The level along the runway centre line is 2.38 m above the mean sea level, and 1.95 m at the edge of the runway shoulders. The estimates for SLR vary but using any of the predicted heights, the NMIA will be affected because of its current height which is lower along the edge of the runway shoulder.

In light of this specific project and the other proposed projects which will result in building the climate resilience of the NMIA, it is essential that NMIA develop viable climate change risk management plans that incorporate a "trigger point approach" to long term climate change planning. Trigger Points refer to temperature or sea level above or below which an impact occurs or becomes significant. Thresholds/ trigger points can be determined using past experience, or from company policies, procedures or operating standards for machinery.

NMIA intends to develop a business continuity plan for the airport this year which will incorporate climate risks. Additionally, there is a climate change project also planned to start this year. Each of these can be incorporated or used along with the climate change risk management plans suggested above.

In summary, the desk based assessment indicates that like much of Jamaica's critical infrastructure located along the coastline, the NMIA is vulnerable to the impacts of climate change. However, several of the planned CapEx projects will build the airport's climate resilience thus reducing its vulnerability. Additionally, with the installation of a rock revetement on the southern/seaward side of the Palisadoes tobolo, and elevation of the access road between 2.4 and 3.2 metres above sea level, the probability of the recurrence of closure of access due to overwash from storm waves has been reduced.

1 INTRODUCTION

Environmental Solutions Ltd (ESL) was contracted to conduct a document review and prepare a report which presents a discussion about the possible impacts of climate change on the planned future CapEx projects for the Norman Manley International Airport (NMIA).

Jamaica's climate sensitivity is exacerbated by the fact that its major infrastructure, population settlements, and economic zone are primarily located on its narrow coastal plains. The location and low lying nature of the NMIA make it important to consider how the projected impacts of climate change could potentially affect the NMIA and its planned future projects.

This reports presents the contextual setting of the NMIA, the general climate projections for Jamaica and how the climate change projections may impact the NMIA and its planned projects. Specifically, the report focuses on potential climate change impacts that may occur within the next 25 years and determines what if any effect there may be on any capital projects already planned. The document is not intended to act as a forecasting tool for the NMIA.

2 CONTEXTUAL SETTING

NMIA (Figure 2.1) serving as it does the social, economic, and cultural hub of Jamaica is the primary airport for business travel and for the movement of air cargo into and out of the island. It therefore plays a critical role in the economic development of Jamaica. It caters to over 1.7 million passengers, with an approximate 4% average growth rate and handles over 70 percent (17 million kgs) of the Island's airfreight. The airport business network comprises over 70 companies and government agencies, with over 3,500 persons directly employed at the Airport (NMIA Master Plan, 2013).

The NMIA is situated within the Palisadoes and Port Royal Protected Area (PPRPA) (see Figure 2.2). This area is approximately 7,523 hectares (75.23 km^2) and encompasses both terrestrial and marine areas. The PPRPA is one of five heritage districts in the island, as designated by the Jamaica National Heritage Trust (JNHT) (NEPA, 2013).

The NMIA is also bordered by the Kingston Harbour, the seventh largest natural harbour in the world, and which accommodates the Port of Kingston and several port related facilities and industrial and commercial enterprises on the rim. These enterprises utilize the harbour for transport and processing of goods and services. Entities include, but are not limited to, the Kingston Container Terminal, Kingston Wharves Limited, Petrojam Refinery, Jamaica Flour Mills, T. Geddes Grant, Shipping Association of Jamaica, Seprod, Jamaica Livestock Association, JPS Power Barge, , Carlong Publishers, Nutramix, Willie's Trucking, Pegasus Traders, Wallenford Coffee, HEART Academy Rockfort, Rubis/Massey Gas Products and Rockfort Mineral Bath.

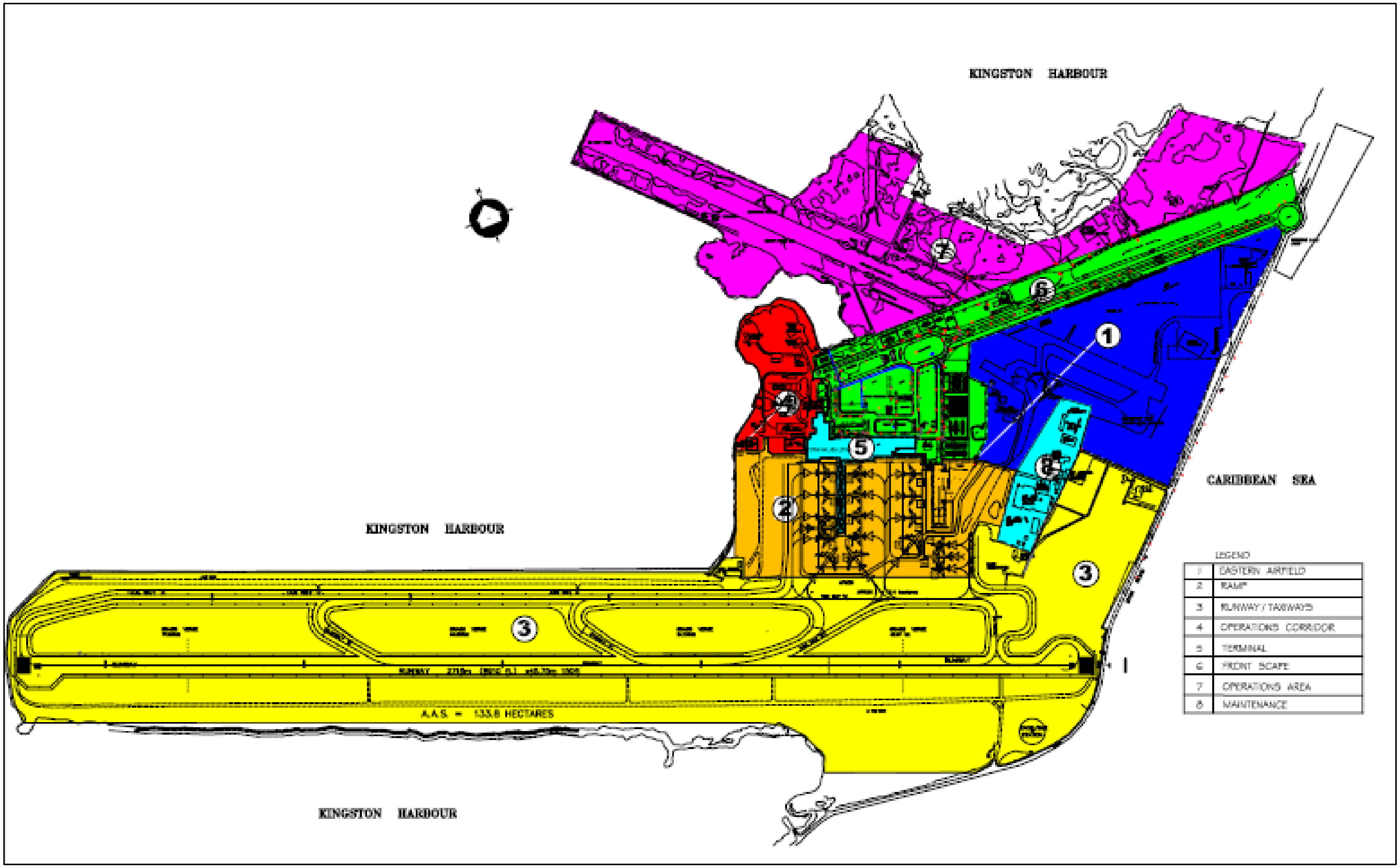


Figure 2.1: The Layout of the NMIA showing the eight 'Airport Areas' (NMIA, Master Plan 2013)

The Kingston Harbour also houses several cultural and historic entities of national significance, some dating back hundreds of years. These include Victoria Pier, Port Royal, Rockfort, and Fort Augusta.

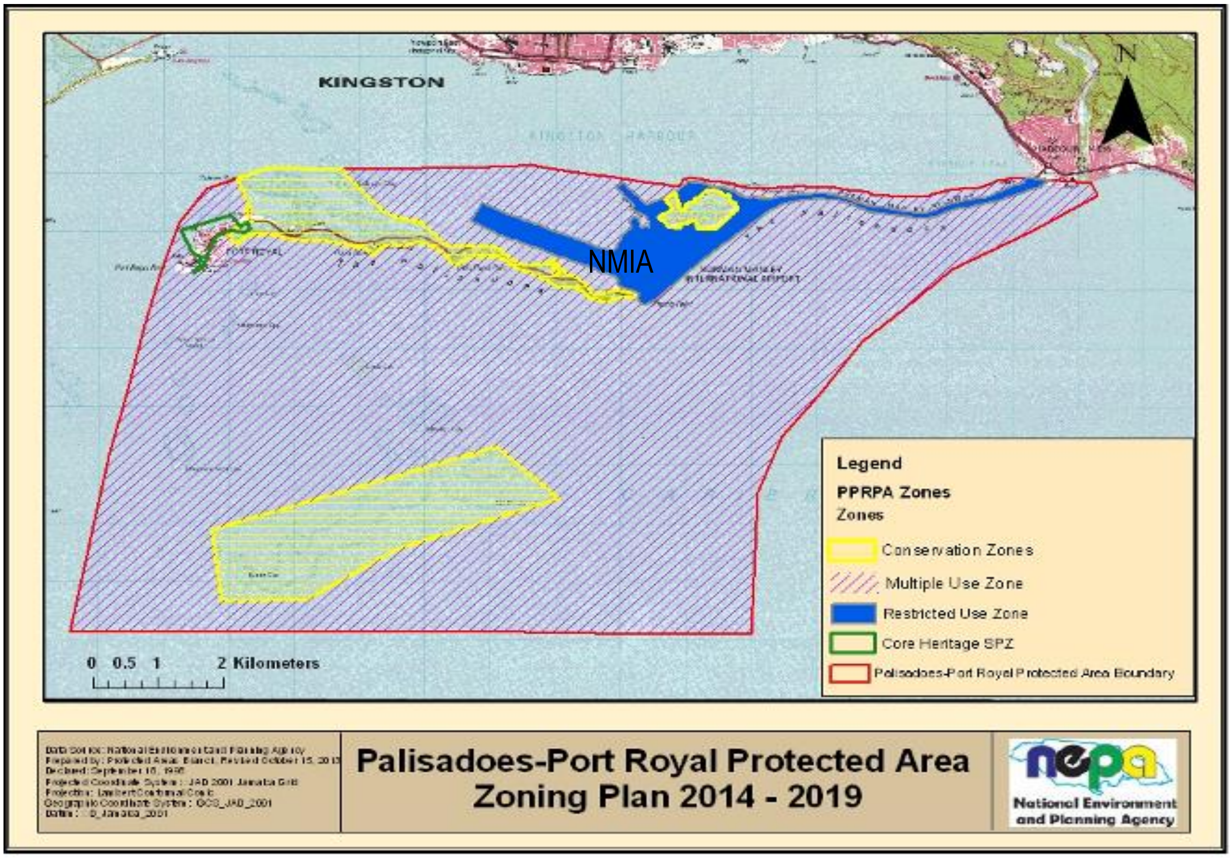


Figure 2.2: Zones of the Palisadoes-Port Royal Protected Area - 2014-2019. (NEPA, 2013)

3 THE APPROACH

The overall approach involved primarily document review, consultations with NMIA and the preparation of a final report. Several documents were reviewed to complete this project, primarily:

- The NMIA Master plan, 2013
- The Jamaica Information Memorandum, 2014
- Jamaica: Future Climate Projection, Climate Studies Group, 2016

4 CLIMATE CHANGE PROJECTIONS

4.1 Jamaica

Climate trends and projections have been prepared for Jamaica by The Climate Studies Group, UWI Mona, Jamaica. This section presents a summary of the main results. The climate data is presented for: temperatures (Maximum, minimum, mean), rainfall, sea level rise and hurricanes. With respect to the future, absolute change is presented for the temperature variables while percentage change is presented for rainfall. Future data is presented for four time slices –the 2020s, 2030s, 2050s and for the end of the century (2075-2098). For temperature and rainfall, the data are averaged for over three month seasons: November-January (NDJ), February-April (FMA), May-July (MJJ) and August–October (ASO), roughly consistent with the Caribbean dry season (November –April) and wet season (May –October) (Taylor et al.,2002). The mean annual change is also given.

Projections for Jamaica using data from an ensemble of global climate models (GCMs) were provided on a whole and were further downscaled using ensemble data from a regional climate model (RCM) to provide sub-island projections. Figure 4 .1 shows the 26 grid boxes covering Jamaica.

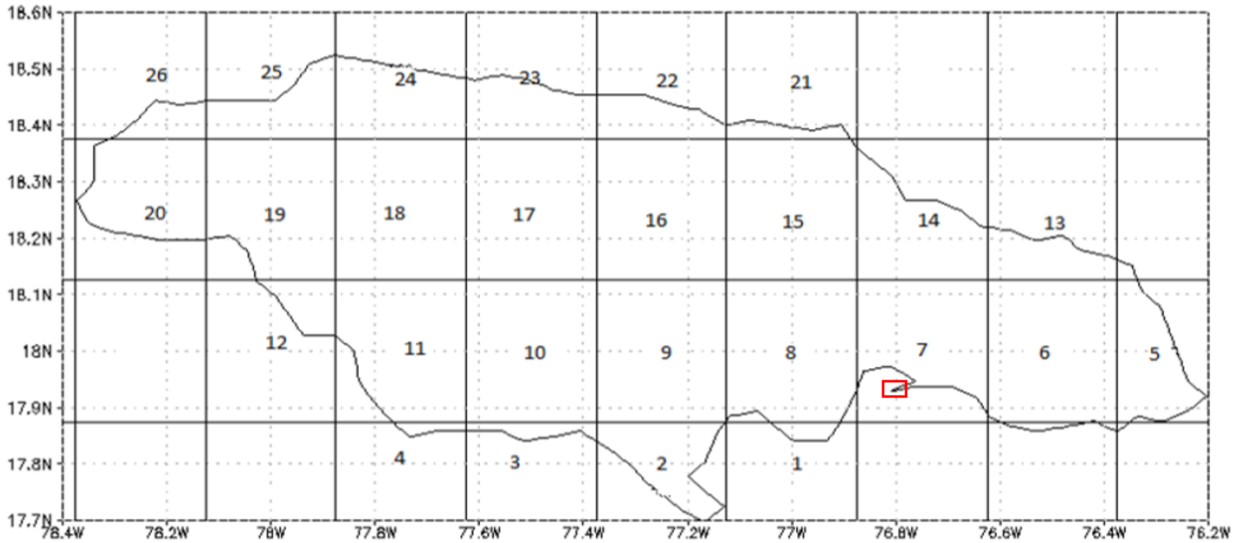


Figure 4.1: PRECI 25-km grid box representation over the island of Jamaica (Climate Studies Group, 2016). NMIA oultined with a red box.

The table below presents a summary of the historical trends and future projections for Jamaica.

Table 4.1: Summary of the historical trends and future projections for Jamaica

Historical Trend	Projection
Temperatures	
• Maximum, mean, and minimum temperatures show upward (linear) trend. • Minimum temperatures are increasing faster (~0.27 °C/decade) than maximum temperatures (~0.06 °C/decade). Mean temperatures increasing at a rate of 0.16 °C/decade. • Increases consistent with global rates. • Daily temperature range has decreased.	• Min, max and mean temperatures increase irrespective of scenario through the end of the century. • The mean temperature increase (in °C) from the GCMs will be 0.42-0.46 °C by the 2020s; 0.75-1.04 °C by the 2030s, 0.87-1.74 °C by the 2050s and 0.82-3.09 °C for 2081-2100 over all four RCPs. • RCMs suggest higher magnitude increases for the downscaled grid boxes – up to 4 °C by end of century. • Temperature increases across all seasons of the year. • Coastal regions show slightly smaller increases than interior regions. • Mean daily maximum temperature each month at the Norman Manley International Airport station is expected to increase by 0.8-1.3°C (1-2-2.0°C) across all RCPs by early (mid) century. • The annual frequency of warm days in any given month at the Norman Manley International Airport station may increase by 2-12 (4-19) days across all RCPs by early (mid) century.
Rainfall	
• Significant year-to-year variability due to the influence of phenomenon like the El Nino Southern Oscillation (ENSO). • Insignificant upward trend • Strong decadal signal. With wet anomalies in the 1960s, early 1980s, late 1990s and mid to late 2000s. Dry anomalies in the late 1970s, mid and late 1980s and post 2010. • Four rainfall zones. • Interior (1), West (3) and Coasts (4) co-vary on decadal time scale. East least well correlated. • Intensity and occurrence of extreme rainfall events increasing between 1940-2010.	• GCMs suggest that mid 2020s will see 0 to 2 % less rainfall in the annual mean. The 2030s will be up to 4% drier, the 2050s up to 10% drier, while by the end of the century the country as a whole may be up to 21% drier for the most severe RCP scenario (RCP8.5). • The GCMs suggest that change in summer rainfall is the primary driver of the drying trend. • Dry season rainfall generally shows small increases or no change • RCM projections reflect the onset of a drying trend from the mid-2030s which continues through to the end of the century. • There is some spatial variation (across the country and even within Blocks) with the south and east showing greater decreases than the north and west. • The decreases are higher for the grid boxes in the RCM than for the GCM projections for the entire country.
Sea Levels	
• A regional rate of increase of 0.18 ± 0.01 mm/year between 1950 and 2010. • Higher rate of increase in later years: up to 3.2 mm/year between 1993 and 2010. • Caribbean Sea level changes are near the global mean. • SLR at Port Royal, Jamaica ~ 1.66 mm/year.	• For the Caribbean, the combined range for projected SLR spans 0.26-0.82 m by 2100 relative to 1986-2005 levels. The range is 0.17-0.38 for 2046 – 2065. Other recent studies suggest an upper limit for the Caribbean of up to 1.5 m under RCP8.5 • For Jamaica, projected SLR over all RCPs for the north coast is 0.43 - 0.67m by the end of the century. Maximum rise is 1.05 m. SLR rates are similar for the south coast.
Hurricanes	
• Dramatic increase in frequency and duration of Atlantic hurricanes since 1995. • Increase in category 4 and 5 hurricanes; rainfall intensity, associated peak wind intensities, mean rainfall for same period. • South more susceptible to hurricane influence.	• No change or slight decrease in frequency of hurricanes. • Shift toward stronger storms by the end of the century as measured by maximum wind speed increases of +2 to +11%. • +20% to +30% increase in rainfall rates for the model hurricane's inner core. Smaller increase (~10%) at radii of 200 km or larger. • An 80% increase in the frequency of Saffir-Simpson category 4 and 5 Atlantic hurricanes over the next 80 years using the A1B scenario.

(Climate Studies Group, 2016)

4.2 Temperature and Precipitation

4.2.1 Grid box 7

The NMIA is located in grid box 7. This section presents the mean projected absolute change in minimum, maximum, and mean temperature and mean projected percentage change in precipitation for the 2020s and 2030's, and the 2050s and end-of-century (2075-2098) relative to the 1960-1990 baseline for each 25 km grid box (Table 4.2). Data presented for mean value of the six-member ensemble.

Table 4.2: Projected Temperature and Precipitation Change for Grid box 7

	Mean Temp(∘C)	Min Temp (∘C)	Max Temp (∘C)	Precip (%)	Mean Temp (∘C)	Min Temp (∘C)	Max Temp (∘C)	Precip (%)
	2020's				2030's			
NDJ	1.33	1.25	1.15	4.33	2.07	1.93	1.91	2.69
FMA	1.26	1.36	1.06	23.79	1.94	2.09	1.74	16.68
MJJ	1.22	1.33	1.42	3.39	2.05	2.15	2.34	-10.41
ASO	1.38	1.45	1.59	-16.96	2.25	2.19	2.62	-30.93
Annual	1.30	1.35	1.30	-1.20	2.07	2.09	2.15	-11.13
	Mean Temp (∘C)	Min Temp (∘C)	Max Temp (∘C)	Precip (%)	Mean Temp(∘C)	Min Temp(∘C)	Max Temp (∘C)	Precip (%)
	2050s				2100			
NDJ	2.79	2.60	2.64	-4.65	3.46	3.47	3.49	-10.34
FMA	2.68	2.84	2.28	24.64	3.55	3.66	3.29	22.19
MJJ	2.96	2.88	3.44	-18.53	3.81	3.77	4.59	-39.80
ASO	3.11	3.00	3.73	-37.74	3.85	3.83	4.76	-46.90
Annual	2.88	2.83	3.02	-17.62	3.67	3.68	4.03	-28.52

(Climate Studies Group, 2016)

4.3 Sea Level

Using a number of scenarios, a range of estimates for end-of-century sea level rise (SLR) globally and in the Caribbean Sea have been calculated. The combined range over all scenarios for the Caribbean spans 0.13-0.56 m by 2100 relative to 1980-1999 levels. Diagrams from Perrette et al. (2013) suggest a higher upper bound of up to 1.5 m by the end of the century.

Projections for SLR for the north coast versus the south coast of Jamaica are extracted from the ensemble of models available in SIMCLIM (Table 4.3). Generally, the difference between north and south coast is approximately 0.01 m (1 cm). By mid-century the projection in the mean is 0.33 m rise and by the end of the century 0.69 m.

Table 4.3: Projected increases in mean sea level rise (m) for the north and south coasts of Jamaica. Range is the lowest projection under low sensitivity conditions to the highest annual projection under high sensitivity during the period. Projections relative to 1986-2005.

	Sea Level Rise (m) North Coast (-77.076W, 18.8605N)							
Centered on	**2025**		**2035**		**2055**		**End of century**	
Averaged over	**2016-2035**		**2026-2045**		**2046-2065**		**2081-2100**	
	Mean	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**
RCP2.6	0.11	0.05 - 0.20	0.16	0.09 – 0.27	0.26	0.15 – 0.41	0.43	0.26 – 0.65
RCP4.5	0.11	0.05 - 0.20	0.16	0.09 – 0.27	0.28	0.25 – 0.43	0.51	0.31 – 0.76
RCP6.0	0.11	0.05 – 0.19	0.16	0.08 – 0.26	0.26	0.15 – 0.42	0.51	0.31 – 0.78
RCP8.5	0.12	0.05 – 0.21	0.17	0.09 – 0.30	0.32	0.18 – 0.51	0.67	0.41 – 1.05
	Sea Level Rise (m) South Coast (-77.157W, 17.142N)							
Centered on	**2025**		**2035**		**2055**		**End of century**	
Averaged over	**2016-2035**		**2026-2045**		**2046-2065**		**2081-2100**	
	Mean	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**
RCP2.6	0.12	0.05 - 0.17	0.16	0.09 – 0.28	0.27	0.15 – 0.42	0.44	0.26 – 0.67
RCP4.5	0.12	0.06 - 0.21	0.17	0.09 – 0.28	0.29	0.17 – 0.44	0.52	0.32 – 0.78
RCP6.0	0.11	0.06 – 0.20	0.16	0.09 – 0.26	0.27	0.15 – 0.43	0.52	0.32 – 0.80
RCP8.5	0.12	0.06 – 0.22	0.18	0.09 – 0.31	0.33	0.19 – 0.53	0.69	0.42 – 1.08

(Climate Studies Group, 2016)

**NB.- The NMIA is located on the South Coast.*

4.4 Hurricanes

A review of the historical paths associated with all hurricanes, tropical depressions and tropical storms in the tropical Atlantic between 1950 and 2014 and those passing within 200km of Jamaica show that the preferred path of hurricanes that impact Jamaica is from the southeast to northwest, with the majority approaching from the south of the island. Therefore, the south coast is more susceptible to highest wind, rain and surge events associated with hurricane passage.

The IPCC Special Report on Extremes (IPCC 2012) offers five summary statements with respect to projections of future hurricane under global warming which are of relevance to Jamaica. They are:

- No change or slight decrease in frequency of hurricanes.
- Shift toward stronger storms by the end of the century as measured by maximum wind speed increases of +2 to +11%.

- +20% to +30% increase in rainfall rates for the model hurricane's inner core. Smaller increase (~10%) at radii of 200 km or larger.
- An 80% increase in the frequency of Saffir-Simpson category 4 and 5 Atlantic hurricanes over the next 80 years using the A1B scenario.

5 CAPITAL EXPENDITURES PROGRAM

5.1 NMIA Master Plan, 2013

Since 2004, NMIAL has invested approximately US$136m in its Capital Development Program:

1. Phase 1A (2004 to 2011) - significant infrastructure improvements including the terminal and apron expansion and upgrading, the new Cargo and Logistics Centre (CLC), and improvements to landside facilities and site services.
2. Phase 1B (2012-2017) - NMIA is now implementing the Phase 1B program worth $26m. This phase includes additional upgrading of mechanical, electrical and IT systems, expansion of the CLC, Phase 1 East Airfield development, equipment acquisition and major maintenance. Due to the GOJ's funding agreement with the World Bank, NMIAL must work within the $26 million budget. Therefore as other priorities arise, this budget must be updated and some CapEx may have to be deferred beyond 2017 (NMIA Master Plan, 2013).

The Master Plan (2013) identifies two main categories of investments:

1. **Minimum**- investments that are needed to maintain the airport's safety and operations, and to extend the life of the assets
2. **Discretionary**- additional investments that may be desired to improve operations, level of service, and/or to accommodate additional demand in the later years of the concession term.

The projects included under each category are listed in the table below.

CATEGORY	PROJECTS
Minimum	• Runway rehabilitation • Modest renovations to existing terminal areas including improvements to duty • Free store and replacement of existing baggage claim devices • Upgrades to life safety, mechanical and electrical systems to ensure code • Compliance and improve energy efficiency • Access road and parking improvements • Upgrade sewage treatment and storm water drainage • General maintenance for airfield, terminal, and ancillary facilities • RESA (Runway End Safety Areas) and Runway extension

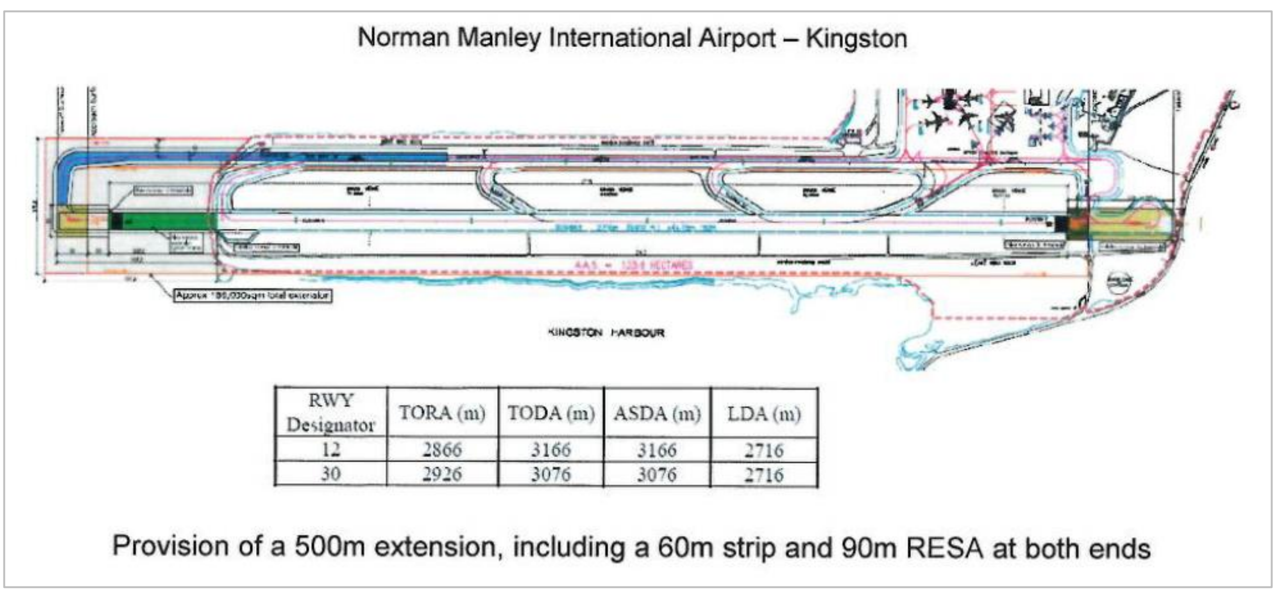
CATEGORY	PROJECTS
Discretionary	• Expansion of facilities to accommodate Code F aircraft • Incremental costs of baggage carousels compared to replacement of racetrack devices • Fixed power and air conditioning services at the gates to improve apron operations and reduce emissions • Other initiatives related to providing operational resiliency and protection for potential implications of climate change

Total projected Minimum Base Case CapEx for the period 2014 to 2039 is anticipated at approximately US$54m, excluding RESA and runway extension CapEx which is considered separately as three scenarios. By contrast, total Discretionary Base Case CapEx for the same period is anticipated at approximately US$21m. It is noted that reference to interventions for climate change resilience is included under "Discretionary" expenditure.

5.2 Jamaica Information Memorandum

Subsequent to the creation of the NMIA Master Plan (2013), an additional, more recent document was created for new Concessionaires- Jamaica Information Memorandum (2014). It indicates that the Master Plan is an indicative plan and is not a recommendation or requirement for the new Concessionaire, except for CapEx elements designed as mandatory. These mandatory capital improvements include:

- Airfield- RESA and Runway extension (no less than 500 metres). To be completed by 2020 (Figure 4.1)
- Terminal- Replace complete baggage claim system, replace tenants' offices A/C units with chilled water system and review/upgrade fire detection system.
- Ancillary Services- relocate electrical west substations. Upgrade incinerator system and relocate cargo road.



RWY Designator	TORA (m)	TODA (m)	ASDA (m)	LDA (m)
12	2866	3166	3166	2716
30	2926	3076	3076	2716

Figure 5.1: Proposed Runway Extension (Jamaica Information Memorandum, 2014)

The Capital Investment Plan (CIP) is expected to take place over the proposed 25-year concession period and has a total expenditure of US$134,126,000. Table 5.1 presents a summary of the costs. Majority of the works will be required to take place within the first 10 years.

Table 5.1: Capital Investment Plan Summary- NMIA, Kingston

Projects	Cost
AIRSIDE	**$76,280,000**
Runway repairs	1,000,000
Remediation of Existing Cargo Apron	430,000
Interim RESA	1,200,000
Runway Rehabilitation	15,000,000
General Airside Maintenance CapEx	1,650,000
Loading Bridge Refurbishment	1,000,000
Taxiway A Modifications	4,000,000
RESA-Runway Extension (500m)	52,000,000
TERMINAL	**$46,130,000**
Renovations to Customs Area	320,000
Revisions to Security Area	250,000
Retail Area Modifications	1,300,000
Replacement of Passenger & Baggage Screening	2,700,000
IT Upgrades	1,545,000
Upgrade Fire Suppression Systems	1,800,000
Terminal AC Upgrades	1,870,000
Baggage Handling System Upgrades	5,500,000
Baggage Claim Area Expansion	6,000,000
General Terminal Maintenance CapEx	24,045,000
Access Road, Parking & Landscaping	800,000
ANCILLARY FACILITIES	**$11,716,000**
Incinerator Upgrades	650,000
Cargo Road Relocation	1,000,000
Floodlight Upgrades	516,000
Environmental Management	600,000
Phase 1B Upgrade storm water and sewage mains	600,000
Phase 2 Upgrade storm water management	250,000
Replace Electrical Substations	5,000,000
Water upgrades	600,000
Fire Station Upgrades	200,000
New RFF Station	2,000,000
Upgrade Sewage Treatment	300,000

Source: Consultants/IFC.

Most of the improvements identified as mandatory capital improvements in the Jamaica Information Memorandum (2014) were previously listed as minimum investment projects in the NMIA Master Plan 2013.

There a relatively few requirements related to capacity enhancements at the airport over the proposed 25 year concession period. In the Master Plan the proposed requirements relate primarily to ensuring ICAO compliance and improving operational efficiencies. In that context, the notable requirements over that concession period include:

- Passenger Terminal Aircraft Parking- 1 new Code F contact stand and one additional loading bridge to serve the Code F stand.
- Passenger Terminal Complex- Three additional security lanes and additional baggage claim area and baggage carousels
- Additional Vehicle Parking
- Replacement of Aviation Support services

Most the projects identified above were previously identified as Discretionary Investments in the Master Plan. Notably excluded now are the initiatives related to the protection for potential implications of climate change.

6 CLIMATE CHANGE AND THE NMIA

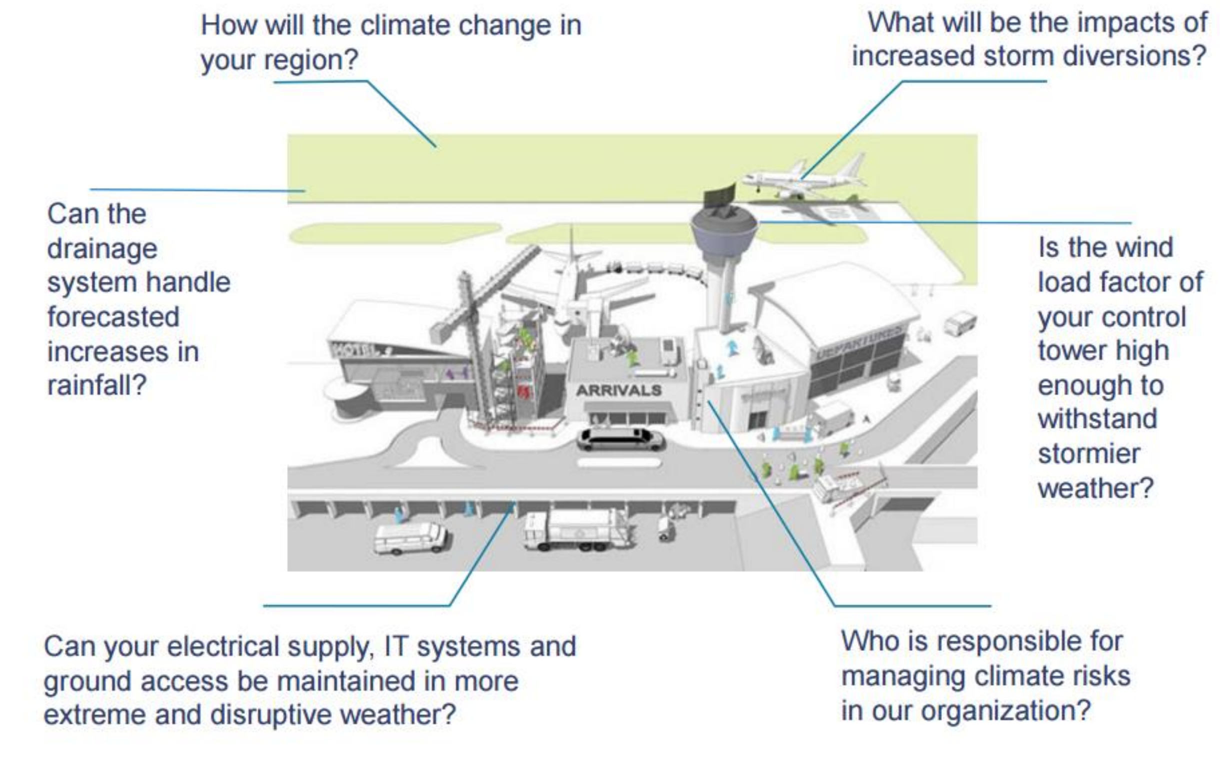
6.1 Climate Change Risks Faced by Airports

The table below outlines the impact to airports as a result of the climate risks identified. These risks can be grouped into physical and business risks.

Table 6.1: Climate Risks and Impacts on Airports

CLIMATE RISK	IMPACT
Precipitation change	• Inundation of critical infrastructure, utilities, and ground access system. • Drought and water availability
Temperature change	• Damage to runways, taxiways and stands. • Increased heating and cooling requirements. • Changes in aircraft performance.
Extreme weather	• Disruption to flight operations. • Disruption of utilities, ground access.
Wind changes	• Convective weather- operations and route extensions. • Jet Stream- turbulence and routing. • Local wind- operations and noise impact.
Sea level rise	• Flooding/Loss of critical infrastructure, airport capacity, utilities, and ground access.

In assessing airport climate resilience several questions have to be asked (See Figure 6.1).



Source: planetillustration.co.uk

Figure 6.1: Assessing airport climate resilience

Several of the planned projects for NMIA will answer these questions, thereby building the climate resilience of the airport. The following subsection expounds further on this.

6.2 NMIA

The NMIA Master Plan (2013) indicated that the NMIA and the aerodromes are potentially vulnerable to hurricanes, precipitation increase, temperature increase and storm surge due to sea level rise. Specifically, this includes wind damage to assets, redirection of flights, flooding of airfields and roads causing delays, scour of embankments and earthworks, reduced airplane performance, increased energy use and demand, and potential closures and failures due to storm surge.

At the time, the following recommendations were made:

- strengthening and protecting structures to withstand wind loads, power outages, and flooding events
- installing redundant critical equipment
- upgrading drainage systems

- reducing energy loads where possible
- diversifying fuel supply
- elevating critical infrastructure (specifically in buildings)
- restoring natural flood defenses

Each of these recommendations would build the climate resilience of the airport. As seen in Section 5, several of these recommendations would be addressed.

The table below summarizes the most recent Climate Projections for Jamaica (discussed in Section 4 above) for the next 25 years and links it with some of projects listed under the NMIA Capital Expenditure Program that may be affected by climate change impacts.

	Climate Change Projection over the next 25 years	NMIA Capital Expenditure Program
Temperature	The mean temperature increase from the GCMs will be 0.75-1.04 °C by the 2030s, and 0.87-1.74 °C by the 2050s	Compliance and improve energy efficiency
Rainfall	The 2030s will be up to 4% drier, the 2050s up to 10% drier. The South and east of the island will have greater decreases in rainfall.	Sewage treatment (2 phases) and storm water drainage upgrade, storm water management (Phase 2)
Sea Level	The range of SLR is 0.17-0.38m for 2046-2065.	RESA (Runway End Safety Areas) and Runway extension
Hurricanes	Variable conclusions provided. Over the next 25 years there may be a decrease or no change in the frequency of hurricanes but there may be a shift towards stronger storms (category 4 and 5).	RESA (Runway End Safety Areas) and Runway extension. Storm water drainage upgrade

Several projects in the Minimum category of investment/ Mandatory Capital Improvements will address the possible impacts of climate change i.e. temperature increase and rainfall variability. There are also several interventions for climate change resilience included under "Discretionary" expenditure. However, in the Jamaica Information Memorandum these are not listed explicitly.

However, there is one major project considered as a Minimum investment project/ Mandatory Capital Improvement that may be impacted by climate change whether or not it is undertaken. This is the RESA and runway extension. The levels along the runway centre line is 2.38 m above the mean sea level, and 1.95 m at the edge of the runway shoulders. The estimates for SLR vary but using any of the projected heights, the NMIA may be impacted because of its current height which is lower along the edge of the runway shoulder.

The threats from rising sea level rise may be:

- the gradual breach in the coastal defenses surrounding the airport (damage to the mangrove ecosystem)
- a slower rate of run-off during intense rainfall events resulting in exacerbated flooding

Rising sea levels may also exacerbate the impact of storm surge. However, The NMIA is in the Kingston Harbour and is therefore more protected from the direct impacts of storm surge.

In the past, access to the airport via the Palisadoes has been affected by storm "over wash" due to tropical storms and hurricanes. However, with the reinforcement of the coastal side of the Palisadoes strip, and the raising of the road, the probability of recurrence has been reduced. The road has been elevated by and the rock revetment on the Caribbean side of the peninsula is intended for coastal protection.

7 MANAGEMENT PLAN

A review of the projected impacts of climate change in Jamaica and the proposed CapEx projects for the NMIA suggest that within the next 25 years the only major project that may be impacted by climate change is the RESA (Runway End Safety Areas) and Runway extension. It is important to note however, that whether or not the extension takes place the current height of the runway makes it vulnerable.

In light of this specific project and the other proposed projects which will result in building the climate resilience of the NMIA, suggested measures are discussed below.

In addition to undertaking the recommendations made in the Master Plan (2013), some of which are already included in proposed CapEx projects, it is essential that NMIA develop viable climate change risk management plans that incorporate a "trigger point approach" to long term climate change planning. Determining when to implement adaptation measures depends on future estimations of climate change impacts. Trigger points state "at what level" action should be taken rather than time specific actions to adequately plan for critical risks.

NMIA will need to consider risks and action trigger points (thresholds) associated with critical infrastructure assets, including runways, taxiways/aprons, terminal buildings and coastal infrastructure such as sea walls, on a case by case basis. Trigger Points refer to temperature or sea level above or below which an impact occurs or becomes significant. Thresholds/ trigger points can be determined using past experience, or from company policies, procedures or operating standards for machinery.

Adopting a trigger point approach will enable NMIA to adopt an adaptive design and management approach for new works, meaning works can be built to a current standard, but with sufficient capacity to be "upgraded" to a higher standard sometime in the future when the relevant trigger point threshold is exceeded. This allows NMIA to effectively prioritise and plan for:

- infrastructure reinforcement, active maintenance, decreasing investment in asset maintenance or initiating a managed retreat;

- stormwater improvements including drainage upgrades, pumping and storage;
- response frameworks for disruptions caused by unexpected and/or extreme weather; and
- refined emergency management plans.

By identifying, prioritising and planning for a broad and multi-faceted range of climate change induced risks, NMIA will be able to develop and implement thorough and adaptable climate adaptation plans and adaptive design approaches that are focused on improving the airport's resilience. These plans should include prioritised proactive and targeted actions to address the broad range of potential climate induced effects that will be required to mitigate future impacts on costly infrastructure and business operations.

The proposed infrastructure projects for the NMIA (such as the sewage treatment and storm water drainage upgrade) should be done in the light of climate change. Climate change risk will demand higher standards of flood immunity. To protect NMIA's infrastructure assets, it is vital to design the right infrastructure that will allow storm flows to be conveyed through the airport site and achieve the required flood immunity now and into the future. It is also critical that whilst flood immunity is achieved, airport infrastructure is designed to not have an adverse impact on the surrounding environment.

To ensure that appropriate response measures are developed for future climate change challenges, NMIA should consider implementing base case and diligent monitoring tools, which include being aware of mean sea level changes and monitoring groundwater and salinity levels, to identify action trigger points. No two infrastructure assets share the same lifespan, particularly when climate change is factored in. NMIA should consider risks and action trigger points associated with critical infrastructure assets, including runways, taxiways/aprons, terminal buildings and coastal infrastructure such as sea walls, on a case by case basis.

NMIA intends to develop a business continuity plan for the airport this year which will incorporate climate risks. Additionally, there is a climate change project also planned to start this year. Each of these can be incorporated or used along with the climate change risk management plans suggested above.

Climate change will comprehensively impact airport operations. All areas of airport operations will be challenged by increasingly unpredictable extreme weather and climate events, despite how well prepared an airport is. For NMIA to operate efficiently in increasingly adverse climate conditions, it is vital that all departments and operations of airport activity have a broad, holistic understanding of how a fully integrated airport functions and the risks associated with all areas of operations.

Areas/ departments of NMIA will need to work with each other to develop a more resilient system capable of reducing infrastructure vulnerabilities both airside and landside. The system must cope with disruptions of normal services, and manage the implementation of an efficient emergency response framework.

8 SUMMARY

This desk based assessment indicates that Jamaica, like all other Caribbean islands is vulnerable to the impacts of climate change. Climate projections indicate that by the 2040's there are likely to be increases in temperature and decreases in precipitation. Sea level is likely to rise and hurricane frequency may decrease but intensity is likely to increase.

Like much of Jamaica's critical infrastructure located along the coastline, the NMIA is vulnerable to the impacts of climate change. However, several of the planned CapEx projects will build the airport's climate resilience thus reducing its vulnerability. Additionally, with the installation of a rock revetment on the southern/seaward side of the Palisadoes tombolo and elevation of the access road between 2.4 and 3.2 metres above sea level, the probability of closure of the road due to overwash from storm waves has been reduced.

Further climate studies, specific to the airport, like those planned for later this year, will be more useful in guiding NMIA in building their climate resiliency.

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