ANALYSIS OF CURRENT SITUATION REPORT (D3)

VARIOUS ENVIRONMENTAL, ZONING & OTHER BASELINE STUDIES FOR THE NORMAN MANLEY INTERNATIONAL AIRPORT

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airports authority of jamaica

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Executive Summary

In October 2018, the Government of Jamaica (GOJ), through the Ministry of Transport and Mining, entered into a Public Private Partnership (PPP) with PAC Kingston Airport Limited (PACKAL). As part of the PPP, Airport Authority of Jamaica (AAJ) is required to conduct due diligence through a series of studies focused on the Norman Manley International Airport (NMIA). These studies are to provide a diagnosis of the current situation of the airport and future obligations regarding the PPP. As such, AAJ developed the project "Various Environmental, Zoning and other Baseline Studies". This project is a combination of five (5) sub-projects, namely: i) GIS/GPS Asset Mapping; ii) Noise Exposure; iii) Airport Zoning; iv) Obstacle Limit Surface; and v) Climate Change Adaptation.

GIS Database Design & Data Dictionary

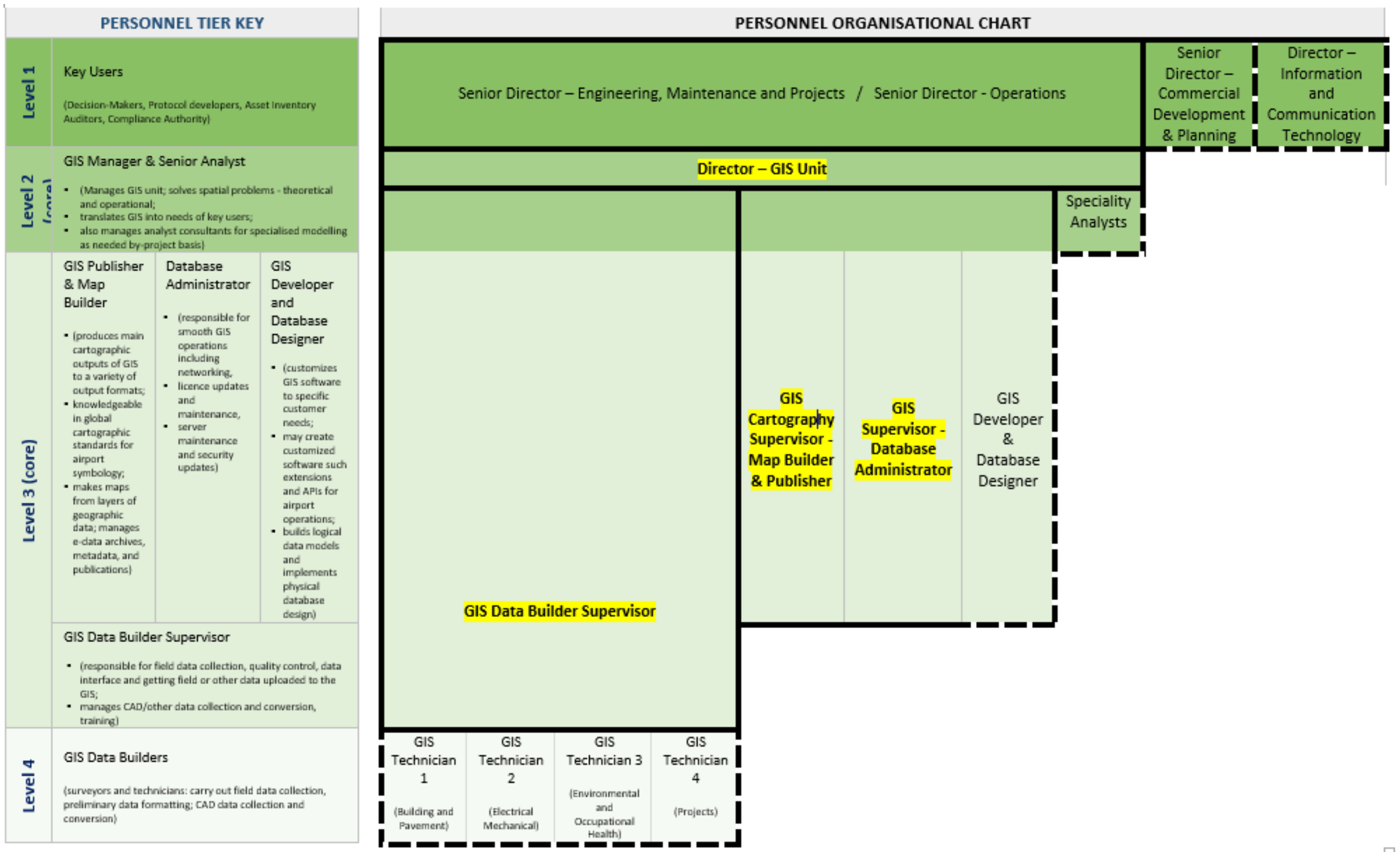
Gap Analysis of existing GIS datasets: The AAJ sought to update the current drawing file database by mapping the various assets (electrical, mechanical, environmental, civil structures, airside facilities, and natural features) while developing a database management system, which would allow for the continual updating of the assets as the development of the airport continues. This phase of the project was carried out in a four-step logical process: (i) Data Conversion; (ii) Data Summarization; (iii) Data Verification; and (iv) Data Gathering.

In executing the **Gap Analysis Assessment**, there were several hindrances to the implementation of the assignment which would affect the accuracy of the findings. The original data received (drawings/shapefiles) had multiple themes or categories of assets and in most cases contained significant overlaps with other data layers. Secondly, data was mislabeled in many cases which made it difficult to discern what the feature layer was referring to. Furthermore, in many cases, the received drawings contained illegible elements at fine scale which could not accurately be converted to shapefiles.

GIS Database Requirements: The minimum requirements for technical infrastructure such as hardware, software, networking, and data needed for the seamless integration of the proposed Geographic Information Database System into the airport's business procedures were established. For field data collection and desktop studies, **recommended hardware and software requirements** where itemized and presented. For data collection, components such as a capable GPS unit, external antennas and data cable are recommended with the use of Terra-Sync Software, ArcGIS Enterprise and Esri – Collector for ArcGIS can be utilized. Desktop studies would require the use of a keyboard, mouse, motherboard, graphics card and data storage are required. Moreover, it should be noted that the proposed GIS System will make use of variety of software applications including ArcMap for Desktops, ArcGIS Dashboards, Microsoft Office and GPS Pathfinder Office.

In regards to **networking requirements**, in order to access the service of ArcGIS Online, the ArcGIS Server must communicate on specific ports. As such, HTTPS Ports - 6443 & 6080, and internally used ports - 1098 or 1099, 6006 & 6099 need to be open for machines on the internet and intranet: Likewise, the organization's domain name service (DNS) must include an entry of the fully qualified domain name (FQDN) of the machine hosting Portal for ArcGIS.

The roles and personnel for a GIS implementation are considered the most crucial component. The GIS roles and responsibilities may be incorporated within the AAJ's **organizational structure**. It is proposed that this proposed GIS management falls under 'Engineering, Maintenance and Projects' with four (4) core personnel – Level 1 (Key End User); Level 2 (GIS unit manager and analysts; Level 3 (GIS Operations Supervisors); and Level 4 (GIS DATA Builders).



Noise Exposure

<u>Ambient Noise Monitoring:</u> Seven (7) noise meters with outdoor monitoring kits were set up at each monitoring location to collect data every second for twelve (12) days (March 13 – 24, 2020). The monitoring locations were as follows: Runway 12; Runway 30; Caribbean Maritime University (CMU); Port Authority Harbour Department; Harbour View - Martello Drive; Port Henderson - Royal View Hotel; Grand Port Royal Harbour Hotel.

Runways 12 and 30 had the highest average daytime and night-time noise levels of all the stations surveyed. **The CMU had the lowest daytime and night-time noise levels of all the stations surveyed** but were still non-compliant with NRCA Guidelines for Educational Institutions. All other stations had daytime and night-time noise values compliant with their respective NRCA Guideline values.

The FAA has established a DNL noise guideline (< 65 dBA) for land-use compatibility (residential, commercial, educational land-use zones). These are areas where people spend widely varying amounts of time in which quiet is a basis for use. All survey locations (residential, commercial and educational stations) were compliant with the 65 dBA FAA DNL guideline. **Both airport runways (industrial stations) had noise values compliant with the 75 dBA DNL guideline.**

Some of the maximum noise levels for each sampling day (during March 13-24 survey) were extracted and evaluated to determine if the noise was attributed to an aircraft. This was done by comparing date and time of aircraft arrival/departure and date/time of noise spike, in addition to listening to the recorded noise signature. The table below gives an indication of the percentages of aircraft and non-aircraft noise sources which exceeded the respective NRCA Land Use Noise Guidelines at each monitoring location.

Location	% of Noise from Aircraft	% of Noise from Non-Aircraft Sources
Airport Runway 12	100%	0%
Airport Runway 30	100%	0%
CMU - Petro Caribe Development Fund Building	42%	58%
Port Authority Harbour Dept	0%	100%
Harbour View - Martello Drive	0%	100%
Port Henderson - Royal View Hotel	44%	56%
Grand Port Royal Harbour Hotel	30%	70%

The data showed that **three out of the five non-runway monitoring stations had noise levels attributed to aircrafts, which exceeded the respective NRCA guidelines**. These three stations were: Grand Port Royal Harbour Hotel, Port Henderson Royal View Hotel and the Caribbean Maritime University (CMU). The CMU and Grand Port Royal Harbour Hotel are the two closest receptors to the airport runways. **A trend was noticed whereby departures from Runway 12 were the most frequent occurrence resulting in elevated noise levels at these two locations**, which is expected since they are the closest. When an aircraft is departing and ascending it employs roughly 70% thrust power (depending on the weight/load of the aircraft), therefore noise levels would be at their highest during ascent. Grand Port Royal Harbour Hotel is in the direct departure flight path after an aircraft departs from Runway 12 and makes the right turn to loop around and head in a north north-westerly direction. Although CMU is not in the direct departure flight path from Runway 12 or 30, it is still in close enough proximity to the airport to detect elevated noise levels during departure, regardless of which runway the aircrafts depart from. CMU is also zoned as an educational institution, therefore the NRCA Noise Guidelines are much lower compared to the other residential and commercial locations and noise impact would be higher during class time. However, Friday March 13th was the final day of regular school activities before a lockdown of the entire campus due to Covid-19.

Airport Zoning

Land use decisions that conflict with aviation activity and airport facilities can result in undue constraints being placed on an airport. Zoning is a preventive technique of land use planning that ensures land use compatibility around airport is achieved to eliminate the costly corrective measures required to keep an airport viable.

<u>NMIA Airport Locality Boundary:</u> The airport's runway is closely tied to the delineation of the **airport's locality boundary**, since the runway's size/rating will dictate the required space for both take-off and landing. **NMIA operates a Precision Approach Category 4 Runway that can accommodate Code C aircrafts**. Based on ICAO guidelines, the approach and take off horizontal surface should extend a radius of 15,000m (Hunter, 2007) from the airport. This is established through a series of obstacle limitation surfaces (OLS) that define the limits to which objects may project into the airspace.

The OLS is divided into three (3) sections. The first section extends to a horizontal distance of 3,000m with divergence of 15 % on each side and has a 60m height from the runway threshold with a 2 % slope. The second section starts directly after the first section at a slope of 2.5 % and extends horizontally 3,600m. The horizontal section then extends to 8,400m and has a 90m height from the runway threshold - for a total approach length [and radius] of 15,000m.

<u>Runway Protection Zone:</u> NMIA has a 2,716m long runway, which however, does not meet ICAO Annex 14 standards for **Runway End Safety Areas (RESAs)**. These are graded areas of at least 90m in length beyond the runway end strips at each end of the runway to provide a measure of safety for stopping on landing or take-off. **NMIA is currently non-compliant** in

this area and JCAA has advised NMIAL that this is a mandatory requirement (P54) or risk downgrading the airport from a 4E to a 4C certification, which would mean that aircraft larger than Code C would be restricted from operating (International Finance Corporation, 2013).

For the Interim RESA project, NMIAL will be submitting the plan for the full **500m extension** to JCAA in order to establish the **Obstacle Limitation Surfaces (OLS) chart.** The purpose of the OLS chart is to clearly define the zoning height limitations of the proposed cranes at the Kingston Container Terminal (KCT) Fort Augusta expansion which lies directly west of NMIA. It is important that the planning of NMIA and the Kingston Container Terminal (KCT) Fort Augusta Expansion be carefully coordinated to ensure that vertical clearances are protected for the safe operation of the runway in its existing and proposed extended configuration. It has been determined that the proposed Super Post Panamax cranes that form part of the KCT Fort Augusta Expansion plans, if operated in traditional procedures with a vertical hurricane stowage position, would exceed the Vertical Operating Distance (VOD) available within the Obstacle Limitation Surfaces (OLS), at NMIA for both the existing runway condition and for the 500m western extension.

The NMIA is located within an environmentally sensitive area with endangered as well as threatened species. There are special declarations in respect of the Palisadoes and Kingston Harbour. These declarations are significant due to potential activity restrictions, approvals required, airport land use planning implications and mitigation activities. The entire NMIA is located within the **Palisadoes & Port Royal Protected Area (PPRA)** and the **Ramsar site** is within 3km of the western edge of the current Runway.

Flight Hazards are those that may interfere with aircraft operations such as electrical interference, glare and smoke. The Caribbean Maritime Institute conducts fire drills where open flames and explosions are used for simulation in training. This is within 3 km of the airport. The smoke stacks at the Caribbean Cement Company should also be assessed, if not for height obstruction, then for visual obstruction.

Obstacle Limit Surface Model Analysis and Lidar Calibration Report

<u>LiDar Ground Control Points Survey:</u> The purpose of these control points was to aid in geo-referencing aerial photographs and LiDar data. The absolute accuracy of these twenty-two (22) GCPs are critical for controlling the accuracy of the LiDar data collected. The observations were done over a period of three (3) days using GNSS Static survey method which given the extent of the survey area may have been the most practical method used. The survey yielded favourable accuracy results which met the national standards of positional accuracy of 0.1m.

Summary on GNSS Accuracy		
Parameter	Horizontal Positions	Vertical Positions
Approximate GNSS Accuracy	±0.050m	±0.030m
Achieved GNSS Accuracy	±0.030m	±0.025m

There were two (2) OLS models created based on two (2) scenarios for the Norman Manley International Airport (N.M.I.A.). The two (2) scenarios entail an existing scenario for the runway in its present state and a proposed 300m runway extension to the northwestern section of the runway. The **OLS model created for the existing scenario** was done for a runway in its present state, where the runway length was 2703m in length and 45m wide. The code number and code letter used were 4 and E respectively and the classification and category were precision approach and i respectively. The **OLS model created for the proposed extension scenario** was executed, where the runway length simulated was 3003m in length and 45m wide. The code number and code letter used were 4 and E respectively and the classification and category were precision approach and i respectively.

The **major terrain obstacles identified** based on the OLS model for the existing runway scenario shows the possible terrain obstacles (natural & man-made features) mostly in the Blue Mountain, Mona, Liguanea, Long Mountain and Portmore hills. Obstacles were also found in the Downtown Kingston, Kingston Wharves and NMIA property. These obstacles were mostly buildings and in the case of the NMIA property was the property fence along the southern edge of the runway.

Declination shows the variation between True North and Magnetic North and changes over time at different rates depending on location and magnetic pull. This survey seeks to determine the declination value as it relates to NMIA runway centerline which may ensure the safe alignment of approaching aircraft while using onboard instrumentation. Based on the observed compass readings and the geographic coordinates of the runway ends, **the calculated declination for the runway alignment (30-12) is 7° 57' 48" West.**

A manned aerial LiDar survey was executed, covering designated Area 2C (11026 hectares) surrounding NIMA in support of obstacle and navigational aid identification and analysis work. Flight and operational settings/parameters within the following ranges were used to maintain 5-10 ppsm LiDar return capture density throughout Area 2C:

Parameter	Value	Unit
Flight altitude	1200-2000	m AGL
Aircraft speed	150	knots
Scan FOV	11 - 40	degrees
Scan Rate	52-71	Hz
Pulse Rate	422-582	KHz
Sidelap/line spacing	30-60% / 900-1100	m
Swath width	365-1000	m
Raw point spacing	0.3 m / 5-10	ppsm

The captured LiDar return was calibrated, georeferenced and classified using TerraSolid and GeoCue LiDar processing software. The georeferenced return was processed/classified to yield Class 2 ground and Class 1 non-ground return, and first return.

Parameter	Value	Unit
Average dz	+0.004	m
Minimum dz	-0.041	m
Maximum dz	+0.056	m
Average magnitude	0.027	m
Root mean square	0.031	m
Std deviation	0.031	m

Climate Change Scenarios and Vulnerability Report

As apart a part of the NMIA Various Environmental, Zoning and other Baseline Studies, an assessment was undertaken to analyze the current and future climate change situation at NMIA. Preliminary research indicated that the study area has been vulnerable to hurricane waves, short-term storm events and erosion.

The extremal analysis results indicate that for the climate change scenario RCP 8.5(worse case), the 10, 25, 50 and 100-year return period event for current climate scenario are predicted to produce deep water wave height of up to 7.4 m, 9.4 m, 10.8 and 12.2 m respectively. The results for the storm surge suggest elevations of 1.41, 2.22, 2.94, 3.79m for the 10-, 25-, 50- and 100-year return period (RP) respectively.

Storm Surge: The future climate scenario was extended to investigate harbour-generated **storm surges**. The results of this analysis indicate that waves coming from the north-western direction towards the study area within the harbour are the worst-case scenario. For the 50 yr. and 100 yr. return period storm event wave heights were predicted to be up to 0.43 – 1.86 m under the all future climate scenario (RCP 2.6, 6, 8.5). In regards to the Caribbean Sea Side, storm surge (present climate) the surface elevation is approximately 2.3 m at the shoreline. While for the 100yr RP (future climate) the storm surge elevation varied from 2.29, 2.64 and 3.68 m for the all the scenarios (RCP2.6, 6 and 8.5). This is due to the existence **of sand dunes that currently situated along the shoreline that act as protection barrier** for such surges.

Wave Climate: After analyzing **nearshore wave heights** for current and future storms on the Caribbean Sea shoreline, it was displayed that the significant wave height ranges up to approximately 2.4 m at the shoreline whereas the future climate wave model showed that the wave heights ranged up to approximately 3.14 m. In relation to the Harbour-associated shoreline, it was identified that wave heights for current and future storms are approximately 1.36 m at the shoreline whereas the future climate wave model showed that the wave heights were approximately 1.49 m.

Under current climate scenario, results indicate that the shoreline is the most vulnerable to **short-term erosion** when waves and wind speeds are attenuated along the northern profile. The north-western profile was however observed to experience the least amount of erosion. Along the northern profile the shoreline is expected to experience a maximum vertical erosion of 0.8 m with an inland reach of up to 78 m for the 100-yr. return period. It was also observed that the eroded sediments were displaced seaward resulting in accretion of up to 0.7 m. Under the future climate, the shoreline is expected to experience a maximum vertical erosion of 0.9 m with an inland reach of up to 79 m for the 100-yr. return period along the northern profile. It was also observed that the eroded sediments were displaced seaward resulting in accretion of up to 0.5 m.

In terms of **long-term erosion**, a maximum around of 0.86 meters of erosion and 0.96 meters of accretion has occurred along the various sections of the bounded shoreline based on the observation of historical areal and satellite images of the area (years 2002 – 2020). Both accretion and erosion trends occurred along the harbour side of the project area, with maximum accretion and erosion rates of 0.86 m/yr and 0.96 m/yr respectively. In the period from 2002 to 2020, the shoreline accreted at a maximum rate of 0.7 m/yr and eroded at a maximum rate of 0.4 m/yr. With focus on the project area, it is estimated that sea level rise accounts for approximately 1.2- 28.7 m of erosion along the Harbour side. In regards to the Caribbean Seaside, sea level rise would account for 1.2- 12.5 m of erosion along the harbour side. The most vulnerable area is along the north-eastern section of the shoreline.

A **condition assessment** of the NMIA shoreline (8100m) was conducted along the project shoreline to gain an appreciation of the effects of the existing climate conditions on the site. The shoreline appears to be relatively unstable illustrated by the north-western corner of runway 12 which displays rapid deterioration of the existing armoured revetment. Furthermore, the south-eastern area of the beach adjacent to the airport where major blow outs and rills were observed. The results showed that 36% of the revetment needs rehabilitation, 49% is in need of repairs, and 15% has recorded minor damages. From the risk assessment carried out, it revealed that **64% of the revetment is at moderate risk while the remaining 36% is exposed to major risk.** The results showed that 32% of the revetment which have less than 40 metres width of vegetation and blowouts needs rehabilitation, while 50% is in need of repairs, while 18% has minor damages. The risk assessment also reflected that **46% of the revetment is at moderate risk, 46% is exposed to major risk and the remaining 8% is exposed to minor risk.** Currently, 9% of the mangroves needs rehabilitation, 43% is in need of repairs, while 48% has experienced minor damages, see Figure 6.61 below. The risk assessment carried out depicted that **46% of the mangroves is at minor risk, 46% of the mangroves is at moderate risk and the remaining 8% is exposed to major risk.**

From the data it was deduced that the location of the Norman Manley International Airport causes the level of vulnerability posed by storm surge to be moderate and will increase when sea level rise is factored in. More than 80% of the airport will be affected by storm surge with exception of the area south of the Old Air Jamaica Hanger, which has an elevation of 5m. Therefore, mitigation plan should be put in place in order to reduce the vulnerability of the project to hazards. As, the disruption of operations at NMIA would have a multiplier effect on other businesses, a continuity of operations plan should be considered a strategic imperative for the airport.

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1 Introduction

1.1 Background

The Norman Manley International Airport (NMIA), located in Palisadoes, Kingston, is the main airport in Jamaica for business travel and the movement of air cargo. In October 2018 the Government of Jamaica (GOJ), through the Ministry of Transport and Mining, entered into a Public Private Partnership (PPP) with PAC Kingston Airport Limited (PACKAL). As part of the PPP, Airport Authority of Jamaica (AAJ) is required to conduct due diligence through a series of studies. These studies are to provide a diagnosis of the current situation of the airport and future obligations regarding the PPP. As such, AAJ developed the project "Various Environmental, Zoning and other Baseline Studies". This project is a combination of five (5) sub-projects, namely:

1. Noise Exposure
2. GIS/GPS Asset Mapping
3. Airport Zoning
4. Obstacle Limit Surface
5. Climate Change Adaptation

Noise Exposure from aviation noise can be a constraint on airport expansion and development as it is the responsibility of AAJ to protect the general public and airport users from aviation noise impacts. The previous noise exposure study conducted in 2011 saw the development of Noise Contour/Exposure Map prior to the 2013 Master Plan Future Development. The noise exposure study needs to be repeated, taking into consideration the 2013 Master Plan and to review the compatibility issues in regards to the airport operations.

GIS/GPS Asset Mapping is required of assets, as the NMIA does not have accurate (georeferenced) as-built drawings of the location of underground and above-ground facilities and assets. AAJ is seeking to map the assets and develop a database management system, which would allow for the continual updating of the assets as development of the airport continues.

Currently, the zoning plans and regulations for the lands surrounding the airport are outdated and ineffective in dealing with the growth in urban areas. These outdated regulations restrict the development and expansion of the airport. As such, AAJ is seeking the development of an Airport Zoning Plan to assist in the preservation, continued development and expansion of the airport, consistent with international and local regulations, policies and the 2013 Master Plan.

Obstacle Limit Surface (OLS) is an airport specific three-dimensional polygon that surrounds the airport and extends outward and defines a region of space where no obstacles may penetrate for aviation safety. NMIA does not have a well-defined OLS, this is currently needed to identify obstacles to warn airport users. The runway at the airport is to be extended and there is no information about the OLS obstacles after the completion of the project. Therefore, NMIA is seeking a well-defined OLS in keeping with the International Civil Aviation Organization (ICAO) Annex 15 regulations.

The effects of Climate Change are currently being experienced throughout the Caribbean region with increased extreme weather events (hurricanes, flooding droughts etc.). Due to the location of the NMIA on the Palisadoes Peninsula, the airport is considered to be highly vulnerable to such extreme weather events. Therefore, AAJ is seeking a Climate Change vulnerability assessment, adaptation assessment and implementation plan for the future environmental impacts on the airport.

1.2 TORS requirements: Analysis of the Current Situation (Phase 2)

The terms of Reference for this deliverable calls for and analysis of the current situation. The scope of this phase is to analyze the current situation in the airport and its environment with the data obtained in the previous phase. The available data will be complemented with stakeholders' meetings in order to draw a realistic picture of the current conditions, problems and opportunities.

1.2.1 Activity 2.1: GIS Database design & Data dictionary

In this activity the contractor will create a conceptual system design for both GIS & GPS capabilities which will provide a general framework for structuring both technologies within the organization. The conceptual system design should address software recommendations, physical system configuration (computers, network, requirements, etc.), infrastructural layout and configuration, as well as a conceptual database design based on the applications identified and master data list generated during the previous phase.

The contractor will also create an Airport GIS Database and Data Dictionary describing the attributes of the assets to be captured. For example, the attribute data set for electrical poles may comprise the following:

- Pole number,
- Section number,
- Type of pole,
- Earthing,
- Type of foundation,
- Substation number

Once the data dictionary is completed, it will be uploaded to the GPS receivers for the field data collection and mapping. The receivers will be running the compatible adequate software.

Finally, the contractor will develop and Standard Operating Procedures for the continuous updating of the data dictionary by NMIA staff. These Procedures will be consistent with the long-term infrastructure improvements at the airport.

1.2.2 Activity 2.2: GIS applications & models' assessment

In this activity, the contractor will review and analyze NMIA's business processes along with associated data and recommend appropriate GIS applications and model for improving airport operations.

The issues to be analyzed will be, at least, the following:

- Determine NMIA Resiliency in order to provide better coordination and collaboration through connectivity of departments and entities. The analysis will include the design centralization of critical operations and the provision of a schematic for greater efficiency and profitability.

- Identify important visualization capabilities that give a common operational picture of all airport facilities.

- Visualize online capabilities that help NMIA keep in touch with the public through the Internet, such as the delivery of real-time information of benefit to airport's customers.

- Set out how would NMIA benefit from:

- Linking all digitized documents to features and areas on the airport's main map viewer so that by clicking on specific property, airport staff can quickly pull up documents such as lease agreements, construction bids, architectural drawings, proposals, building footprints, bid acceptance, and repair orders.
- Using this application to track correspondence between the airport, its consultants, and the local government

- Airport information map, marketing map, construction status map.

1.2.3 Activity 2.3: Obstacle Limit Surface Model Analysis and LIDAR calibration

The tasks to be developed in this activity will be focused on the preliminary tasks to LIDAR survey.

Visual Inspection of the OLS and GPS data

The first task will be the performing a visual inspection of the Obstacle Limitation Surfaces, including:

- Review all aeronautical geographical coordinates for accuracy in accordance with the WGS-84 geodesic reference datum.
- Review the Aerodrome Reference Point (ARP) for accuracy in accordance with WGS-84 standards,
- Review and confirm Runway Direction and Magnetic Declination.
- Establish location, coordinates and height of air navigation aids.

This task can be developed with the support of data obtained in GPS mapping activity.

Control point surveys are to be conducted for the development of a LiDAR point cloud and ortho-imagery data bases. Identification of markers, GPS survey, and validation of existing or the establishment of PACS and SACS within the airport property. PACS and SACS are primary and secondary control stations, respectively, established near an airport and tied directly to the National Spatial Reference System (NSRS).

Collect 1"=100' scale aerial photography with a maximum pixel ground sample distance of six inches for the purpose of identifying obstructions for the vertically guided approach surfaces for Runways 12 and 30. Airborne LiDAR is also to be collected for the airport property with the purpose of generating one-foot contours and creating an accurate DTM.

GPS field collection of coordinates and elevations is to be performed for runway ends and thresholds, displaced thresholds, runway centerlines, runway lengths and widths, crossing runway centerline intersections, crossing runway/taxiway centerline intersections, runway true azimuths, NAVAIDS (electronic and visual), lighting and signs.

Digital OLS calculation

The second task of this activity will be calculation of the OLS (Obstacle Limitation Surface) for NMIA in a digital model.

OLS will be done in relation to International Civil Aviation Organization (ICAO) Annex 14 – Obstacle Limitation Surface and Airport Services Manual (Doc 9137), Part 6.

Work involves the application of relevant principles, regulations, protocols and procedures when inspecting and reporting on the Obstacle Limitation Surfaces as part of commercial airport activities across a variety of operational contexts within the Jamaican aviation industry.

The OLS estimation should be done under different scenarios:

- The current airport configuration (current runway, operation and design aircraft)
- A future scenario, that it could include the optional extension of 500 metres westward, 1000 metres westward and options which could include combinations of east & west extensions to achieve an overall increase in runway length by 1000 metres.

LIDAR Survey parameters and requirements

The lasts task of this activity will be the definition of requirements for LIDAR Survey.

LIDAR is an active technology utilizing its own source of electromagnetic radiation (a laser), rather than relying on the sun as the source of illumination, as is the case with more traditional aerial photography. As with its predecessor technology radar, LIDAR has proven to be an effective tool for a variety of survey and mapping applications. Airborne LIDAR in particular has emerged in recent years as a competitive alternative for topographic surveys and terrain mapping projects, especially for the survey of large areas.

LIDAR Survey will cover the airport property and continuous areas necessaries for OLS estimation with sufficient accuracy and quality. The size of the airport property is approximately 230.6 hectares, but additional is required for OLS estimation as they are defined in ICAO Annex 14 or Doc 9137.

LiDAR and imagery acquisition of sufficient accuracy are also required to describe the physical infrastructure and topography of the airfield and glide path in order to enable airport engineers to determine the need for compliance modifications in accordance with ICAO & Federal Aviation Administration (FAA) Standards.

This will include the design of the aerial photography and the design of the technical plan, specifying all equipment to be used.

The Contractor is expected to provide technical guidance and instructions pertaining to the following areas:

- Calibration tests: Radiometric qualification tests for obstruction detection and system calibration (factory calibration, field calibration by flying over a building site of known topography, and in-flight calibration).
- Survey planning calculations: Grid and point spacing (along and perpendicular to the flight path), field of view, scanner angle and frequency, ground speed of the aircraft, swath width, number of flight lines, and line coverage perpendicular to the flight line.
- Flight mission planning parameters: Coverage parameters (to ensure complete coverage of the required obstruction identification surface), swath overlap, flight line directions, flying height (as low as possible within the applicable eye-safety limits), and flight clearance.

The contractor must ensure the airborne LIDAR equipment fully conforms to the guidelines below to ensure that the highest possible data quality is achieved during the survey.

- Multiple Look Angles. To achieve a high probability of detection and to assist in distinguishing between real objects and noise in the point cloud data, it is important to scan each section of the survey area from multiple look angles (i.e., different viewing geometries).
- Horizontal Point Spacing. The density of laser points on the ground is a key factor in the ability to detect obstructions.
- Vertical Point Spacing (if found to be applicable). Because many obstructions are tall, small-diameter objects, such as poles, the vertical point spacing is also a key consideration.

- Mission Planning. The mission parameters to be chosen must will meet the required horizontal and vertical point spacing, radiometric considerations (i.e., those related to the received signal strength) must be taken into account. Additionally, swath overlap, cross-lines, and other mission planning parameters must be carefully planned based on the unique considerations involved in airport obstruction surveying, including precautions taken to avoid missed objects.
- Radiometric Performance. The consultant shall design and execute an onsite radiometric qualifications test in obstruction surveying must pass the international standards.
- Processing. Processing must emphasize high probability of detection, PD, on vertical objects in any vertical object detection algorithm.
- Imagery. High definition, aerial photography (digital or film) to be used.

1.2.4 Activity 2.4: Airport Zoning Analysis

The objective of this activity is to develop a policy framework to support land-use designations and implementation strategy

For this, the Contractor will:

1. Identify the area of land to be designated the 'airport zone':
   - Compile and review all regulations/Acts related to Airport Zoning
   - Establish the process by which local governments draft the aviation element of their local plans.
   - Map area to be defined in the 'airport zone'
2. Review and assess the existing airfield analysis (2013 Master Plan of other potential studies)
   - Review all documents associated with airfield, including any recent study
   - Map airfield parameters
   - Airfield capacity
   - Assess if airfield fits in with community/city development plans
   - Need for expansion or installation of additional runway
3. Review and assess intermodal transport guidelines, taking into consideration the City's overall Transportation Master Plan.
   - Review and assess the internal transportation network, including roads, transit and pedestrian walkways
   - Identify potential external transportation corridors, such as a more efficient transportation link between the Airport and the major City business centers, Downtown Kingston and New Kingston.
4. Review and assess the most important environmental constraints:
   - Storm water management
   - Protected spaces and natural resources
   - Wildlife
   - Soils

1.2.5 Activity 2.5: Develop Noise Exposure Maps and Land-Use Compatibility Analysis

In this activity the Contractor will undertake a noise survey to measure current noise events at NMIA in order to ascertain ambient noise levels, distinguish single level events and cumulative noise levels. This will be the noise exposure map current scenario.

To analyze noise conditions at NMIA it will be considered operational and other appropriate factors, including but not be limited to the following:

- Daily operations i.e. aircraft take-offs and landings.
- Aircraft fleet Mix i.e. the various types of aircraft using the airport.
- Runway use i.e. directional flow of aircraft at the airport.
- Flight corridor and corridor use i.e. paths that aircraft follow when approaching or departing the airport.
- Seasonal use factors such as Day/Night, High/Low season, etc.

The noise exposure maps will be a graphical noise contour map.

Additionally, the Contractor will prepare an updated baseline and five (5) year Noise Exposure Map using an appropriate and designated noise modeling system taking into consideration current and forecasted information. This will be the noise exposure map future scenario.

On the other hand, it will be necessary the following for land use compatibility analysis.

- Analyze the current regulatory framework and its effect on compatibility. Evaluate existing planning tools currently in practice to determine how compatibility issues are to being or to be addressed.
- Analyze forecasted plans for NMIA operations and its effects on noise and noise compatibility issues (e.g. NMIA Master Plan, Runway End Safety Area Development Project).

Finally, it will be assessed and quantified, where applicable, any reductions in noise needed and that could plausibly be achieved by various measures, including but not limited to:

- Airport access restrictions based on any or all of the following:
  - time of day,
  - day of the week,
  - season,
  - numbers of airport operations,
  - types of operations,
  - classes and types of aircraft;
- Route and altitude controls; and
- Physical changes at the airport and/or alternative facilities.

1.2.6 Activity 2.6: Climate Change Scenarios and Vulnerability Report

The scope of this phase is to analyze the current situation in the airport and its environment with the data obtained in the previous phase. It is focused in the climate change scenarios and vulnerability report.

The location of NMIA makes it particularly susceptible to storm surge and sea level rise as major hazard factors especially in the context of shoreline erosion. Modeling of these factors in particular should assist to guide adaptation planning under the project. Contractor will:

- Review existing databases on hurricanes, storm surge and sea level rise, and identify gaps in data in data quality, suitability and relevance including:
  - Existing topographic data, sediment sampling.

- Existing bathymetric surveys and if necessary to determine whether the collection of new or additional near-shore bathymetric data is required to supplement existing data
- Anecdotal information regarding historical storm surge levels.

- Produce and/or prepare digital raster images of elevation/bathymetry from newly acquired and existing topographic surveys to common geo-referencing for NMIA location.
- Utilize established scientific models to simulate, calibrate and analyze storm surge inundation levels for NMIA location. The model should include coastal erosion modeling for typical annual swell 10, 25, 50 and 100 year hurricane events.
- Produce GIS data layers depicting storm surge hazard footprint 10, 25, 50 and 100-year storm surge scenarios.
- Conduct a qualitative analysis of the correlation between storm surge inundation levels and hurricane category as well as coastal erosion.
- Use appropriate and designated global and/or regional models to forecast sea level rise projections and the intensity of hurricanes in future.

The contractor will develop a minimum of three climate change scenarios representing storm surge and sea level in regards to status quo, master planning and significant projects/ programs at NMIA.

With the results of these scenarios, the contractor will create a prioritized list of vulnerable facilities in order of criticality.

To assess the vulnerability it will be necessary to design the criteria for an evaluation matrix. The application of this matrix will turn out to be results for rating the criticality of assets vulnerable to impacts of climate change and extreme weather.

Finally, the assets and specific vulnerable locations/ facilities will be included in a GIS based map of NMIA. This map should include impact type, asset type and level of criticality.

2 GIS Database design & Data Dictionary

2.1 Background

2.1.1 Project

Figure 2.1: Image showing various GIS datasets of NMIA in Jamaica

The main objective of this project is to protect the future development of the airport and quantify any likely impacts on the environment. To achieve this main goal, AAJ sought to map the various assets (electrical, mechanical, environmental, civil structures, airside facilities, and natural features) and develop a database management system, which would allow for the continual updating of the assets as the development of the airport continues. Consequently, CEAC Solutions Co. Limited was commissioned to undertake the Collection and Conversion of the Geospatial Datasets to support the Preparation of the various Environmental, Zoning and Baseline Studies. The project was estimated to last a total of seven (7) months.

2.2 Gap Assessment

2.2.1 Data Collection Process

This phase of the project was carried out in a four-step logical process as detailed below. Where possible, screenshot examples from significant process stages have been included to assist in the understanding of the methodology.

2.2.2 Step 1: Data Conversion

Various files in a variety of formats (.pdf, .dwg) were received from the AAJ. All files received contained geospatial information on airport assets, whether they be electrical, civil, natural features or other categories. These files were converted using AutoCAD software to shapefiles (.shp) comprised of geospatial elements (points, lines and polygons) which enabled the data to be entered and evaluated by GIS processing software such as ESRI ArcMap. This conversion allowed for the identification and assessment of specific layer properties to accurately determine what features were present within the drawings received from AAJ.

Figure 2.2 Drawing file (.dwg) showing the various NMIA buildings and components (AutoCAD, 2020)

2.2.3 Step 2: Data Summarization

For each layer presented within the converted shapefiles, a 'summary' table was created from isolating a specific feature within the complete attribute table of the shapefile. The 'Layer' feature of the shapefile attribute table in addition to the relative count numbers was used to isolate individual layers within the shapefile. This process allowed for the 'cleaning' of the data presented, as many layers included in the shapefile were not relevant to the data being represented.

2.2.4 Step 3: Data Verification

These "cleaned" shapefiles were uploaded to mobile GIS devices and their accuracy checked via infield observation. This verification phase consisted of two main components namely:

1. ***Basic data crosschecking*** – Features within each shapefile were compared with their respective infield counterparts to assess their spatial (location) accuracy, availability of attribute data as well as the coverage provided by the digitized layer.

Figure 2.3 Samples of the pictures collected for the supporting buildings, substations and variety of pipes found across the airport property.

2. ***Consultations*** – Field members were accompanied by skilled personnel with a wealth of experience and knowledge, having worked with the various features. These individuals were able to provide valuable information as to whether gaps existed in the dataset or why a digitized feature had not been observed in the field.

Moreover, where discrepancies were identified, the respective features were tagged with a note detailing the specific type of gap identified. In the end, these observations and notes were compiled and used to generate the GIS/GPS Asset Gap Report.

2.2.5 Step 4: Data Gathering

Using the GIS/GPS Asset Gap Report and the created data dictionary (see Fig 42 and the Appendix), the process of infilling the identified attribute and spatial gaps is now underway. In this process – using handheld GPS and RTk units, data relating to the previously identified attribute gaps for each feature is captured and added to the respective shapefile's attribute table. Moreover, new features – or features that are otherwise absent, are digitized and the available attribute data captured for each feature. Lastly, once all the available data has been collected, the shapefiles under post-processing. Here, all misalignments are corrected using infield reference points and/ Lidar imagery, and all the attribute data cleaned to ensure that the provided data is grammatically correct.

2.3 Baseline Data

Baseline data represent to the collection of digitized assets that provide the background detail necessary to orient the location of the map. In other words, this subset of assets usually provide references for features that are characterized by seemingly static locations such as property boundaries, building outlines, roads, and highways.

2.3.1 Airside features

These assets refer to the collection of features used by aircrafts and in extension airport personnel in the processes of loading, takeoffs, and landings.

2.3.1.1 *Airside Areas*

(a)

Runways

	X1	Y1	Z1	Dimen	Condition	Specificat
	773757.853338	642357.107535	0		Good - small cracks along sides	Asphalt

(b)

Taxiways

X1	Y1	Z1	Dimen	Condition	Specificat
773928.92501	643184.362905	0		Good	Asphalt
772627.704194	642967.84012	0		Good	Asphalt

Figure 2.4: The Attribute Tables for the Runway (a) and Taxiways (b) Datasets

Of the four (4) specified airside areas, coordinate, condition, and general specification data have only been provided for the runway and taxiway features. Resultantly, as seen in the tables provided, the identified attribute gaps for these two features coincides mainly with the lack of dimensions data. Moreover, spatially, the ramp and aircraft stands features are found to be completely absent. As these features were not digitized, the attribute tables of these features are completely empty – signifying gaps in attribute data such as coordinates, dimensions, condition, and specifications.

2.3.2 Civil category

2.3.2.1 *Buildings*

One of the main subcategories of the Civil Category is the Buildings subcategory. Using the imagery and CAD files provided, various buildings across the airport were digitized and placed into three subgroups namely: Air Traffic Control Buildings, Support Buildings and Terminal Buildings. Additionally, using the drawing files provided by AAJ, the internal layout or plan of several of these buildings were digitized. Whilst these "building plan shapefiles" were not found to have any attribute gaps, it was found to possess an "AB" spatial gap. This is as a few building plans were found to be completely absent.

Figure 2.5 Small metal hangar found over by the Airport's East Airfield

2.3.2.2 *Air Traffic Control Buildings*

Air_Traffic_Control_Buildings

X1	Y1	Z1	Descript	Condition	Material	Ownership	Dimen
773441.829704	643096.510243	0	Older grey-blue tower w/ circular layout & windows	Good	glass, metal and concrete	AAJ	
773447.996634	643111.281267	0	Older grey-blue tower w/ circular layout & windows	Good	glass, metal and concrete	AAJ	
773180.985291	643218.852511	-213.837	Grey tower w/ circular layout and several windows	Excellent	glass, metal and concrete	AAJ	

Figure 2.6: The Air Traffic Control Buildings Attribute Table

No spatial gaps were identified for the features within this dataset. Moreover, of the six required attribute data, only data related to coordinates, photographs, description, construction material(s) and condition, were provided for both air traffic control buildings. As a result, gaps exist in the attribute table with the absence of mainly dimensions data.

2.3.2.3 *Support Buildings*

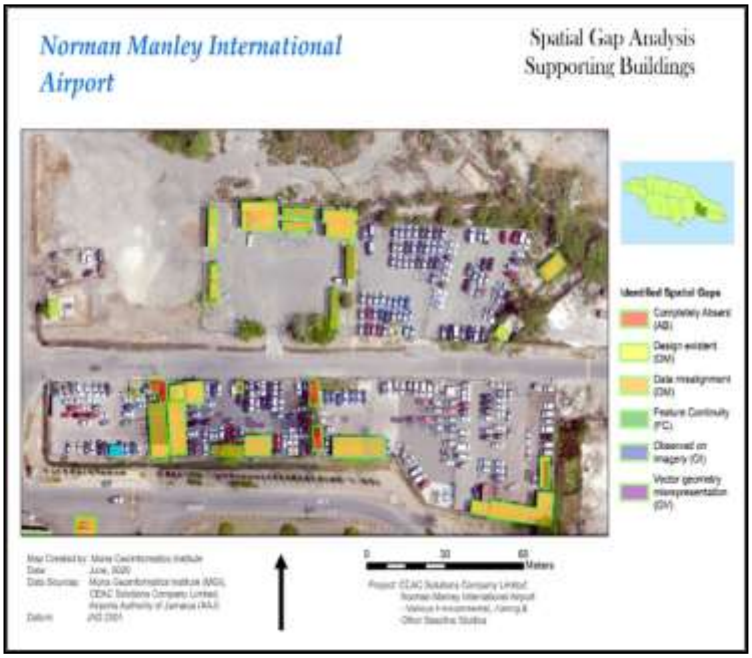


Figure 2.7: A Map of the general spatial gaps identified within the vicinity of "Container Village"

Coordinates, photographs, description, construction material and condition data were recorded for the support buildings found both airside and landside. As such, the attribute gaps in this dataset is marked mainly by the absence of dimensions data. Moreover, generally, the features of this dataset are found to be slightly misaligned. As a result, the polygon features do not fully represent the extent/area covered by each supporting building. Moreover, it should be noted that several support buildings are missing from the dataset.

Figure 2.8: Photograph of the new AAJ Sports Club

Consequently, a spatial gap arises with the complete absence of buildings such as the large hangar found in East Airside, the makeshift JDF container restroom, the security posts of the various car rental facilities near "Container village" and AAJ Sports Club pictured above. Another spatial gap has been identified - particularly with the feature representative of the gas station. Here, the geometry of the created vector was smaller than the building, and as such did not adequately/ fully represent the building.

2.3.2.4 *Terminal Buildings*

Terminal_Buildings

X1	Y1	Z1	Descript	Condition	Material	Ownership	Dimen
773458.093689	643062.753606	0	Rectangular building with a protruding finger	Good	Concrete, sheet metal	AAJ	

Figure 2.9: The Attribute Table of the Terminal Building

Coordinates, photographs, description, construction material and condition data were recorded for the terminal buildings. As a result, major gaps exist in the attribute table with the absence of dimensions data. Moreover, seeing as these building features were found to be spatially correct, no spatial gaps were identified within this dataset.

2.3.2.5 *Light Masts- Airside*

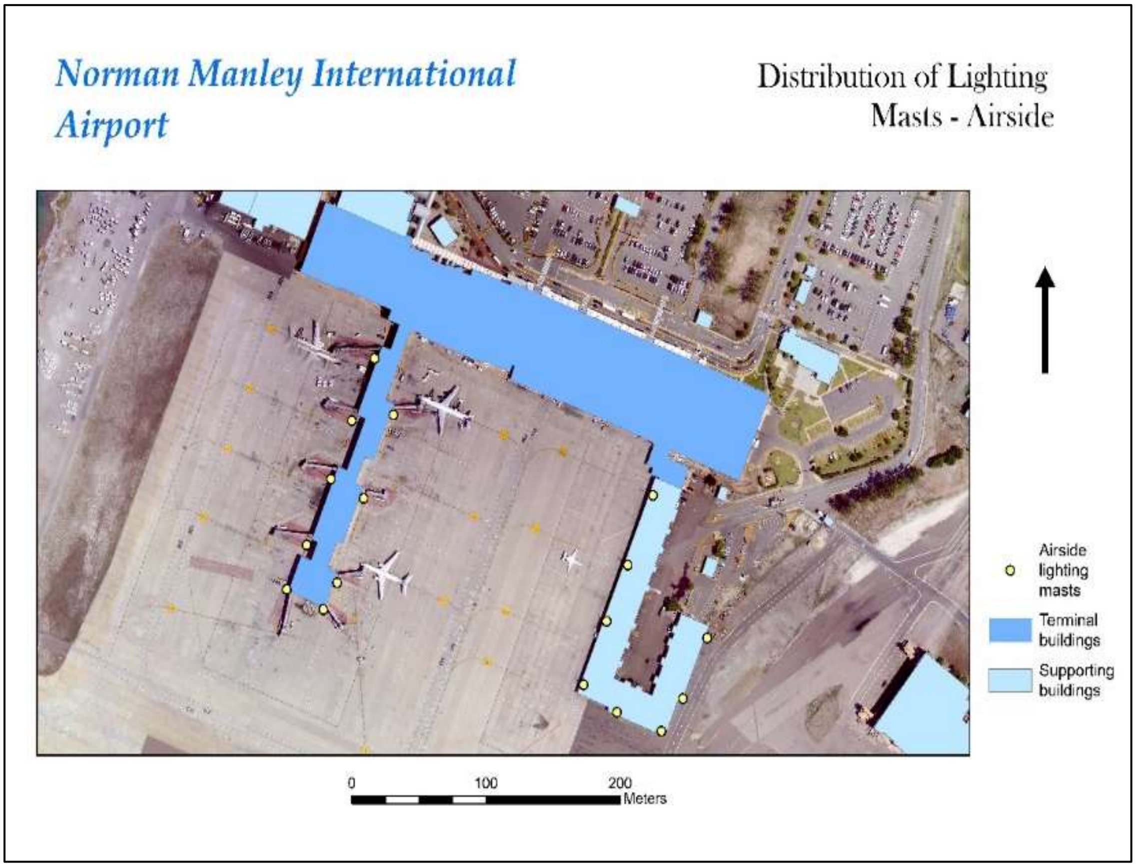


Figure 2.10 The distribution of lighting masks airside

The coordinates, description, condition, and construction material fields have been populated for the light masts identified via the CAD files. As a result, the only identified gaps within this feature's attribute table are the lack of dimension data and pictures. Conversely, as all the features were correctly and/ accurately digitized, no spatial gap was identified for the features within this dataset.

lighting_masts_airside

FID	Shape *	POINT_X	POINT_Y	Descript	Dimen	Condition	Material
0	Multipoint	773361.321973	643042.933293	A metal pole adorned with 4 lights, the number zero inscribed and a camera		Good	Metal
1	Multipoint	773330.262914	643039.100054	A metal pole adorned with 4 lights and camera on pole (Gate 2)		Good	Metal
2	Multipoint	773314.635095	642999.981365	A metal pole adorned with 4 lights and no camera (Gate 3)		Good	Metal
3	Multipoint	773347.168478	643080.774236	A metal pole adorned with 4 lights and camera		Good	metal
4	Multipoint	773339.01056	642987.007327	A metal pole adorned with 4 lights and the number 44 inscribed		Good	Metal
5	Multipoint	773296.550073	642955.849979	A metal pole adorned with 4 lights and camera on pole		Good	Metal
6	Multipoint	773319.202461	642930.444309	A metal pole adorned with 4 lights , the letter X inscribed and a visibly removed camera		Good	Metal
7	Multipoint	773309.07878	642912.457575	A metal pole adorned with 4 lights		Good	Metal
8	Multipoint	773281.754671	642926.021342	A metal pole adorned with 4 lights and the letter X inscribed		Good	Metal
9	Multipoint	773502.804752	642862.134035	Square post adorned with two lights (Gate 14 - Customs Warehouse)		Good	Concrete
10	Multipoint	773520.005181	642904.594522	Square post adorned with two lights		Good	Concrete
11	Multipoint	773560.893058	642830.976687	Square post adorned with two lights		Good	Concrete
12	Multipoint	773527.769946	642843.65586	Square post adorned with two lights		Good	Concrete
13	Multipoint	773535.829576	642942.238889	Square post adorned with two lights (Gate 11)		Good	Concrete
14	Multipoint	773554.602615	642989.122343	Square post adorned with two lights and a satellite system (Gate 10)		Good	Concrete
15	Multipoint	773576.864024	642852.848151	Square post adorned with two lights		Good	Concrete
16	Multipoint	773594.960133	642893.442067	Square post adorned with two lights		Good - paint chipping	Concrete

Figure 2.11 The Attribute table for the airside subset of lighting masts

2.3.2.6 *Light Masts- Landside*

lighting_masts_landside

FID	Shape	POINT_X	POINT_Y	Descript	Dimen	Condition	Material
0	Multipoint	773546.871333	643231.447129	High Mask Lighting Tower 3		Good	Steel
1	Multipoint	773543.627824	643161.072804	High Mask Lighting Tower 4		Good	Steel
2	Multipoint	773483.475467	643251.596203	High Mask Lighting Tower 2		Good	Steel
3	Multipoint	773470.386078	643196.058783	High Mask Lighting Tower 1		Good	Steel

Figure 2.12 The attribute table for the landside subset of lighting masts

The coordinates, description, condition, and construction material fields have been populated for the four (4) light masts identified via the CAD files. Consequently, the only gaps identified within this feature's attribute table are the lack of dimension data and pictures. In using the CAD files provided, it should be noted that shapefiles were only created for the taller/larger lighting masts – thereby providing no representation for the smaller surrounding masts. As such, one of the main spatial gaps identified within this dataset is the complete absence of corresponding point features for the smaller landside light masts that are indeed present.

Figure 2.13 Spatial Gaps within the landside subset of lighting masts

2.3.2.7 *Roadways*

Only coordinate data has been supplied for the roadways' dataset. This leaves major gaps within the attribute table as the remaining five attribute fields – description, dimension, condition, construction material and pictures, were not populated.

2.3.2.8 *Perimeter Fencing and gates*

Only coordinate data has been supplied for the perimeter fencing and gates dataset. Like the attribute gaps of the Roadways dataset, the absence of data related to description, dimension, condition, construction material and pictures within this feature's attribute table denotes the major attribute gaps identified. Moreover, it should be noted that the perimeter fencing and gates found within the vicinity of GCG catering are completely absent from the dataset. Likewise, there is also the absence of features observed on the drawing/design plan that have been verified in the field such as the concertina wires found directly facing the sea (near the approach lights) as well as the chain-linked and picket fences found on either side of the runway.

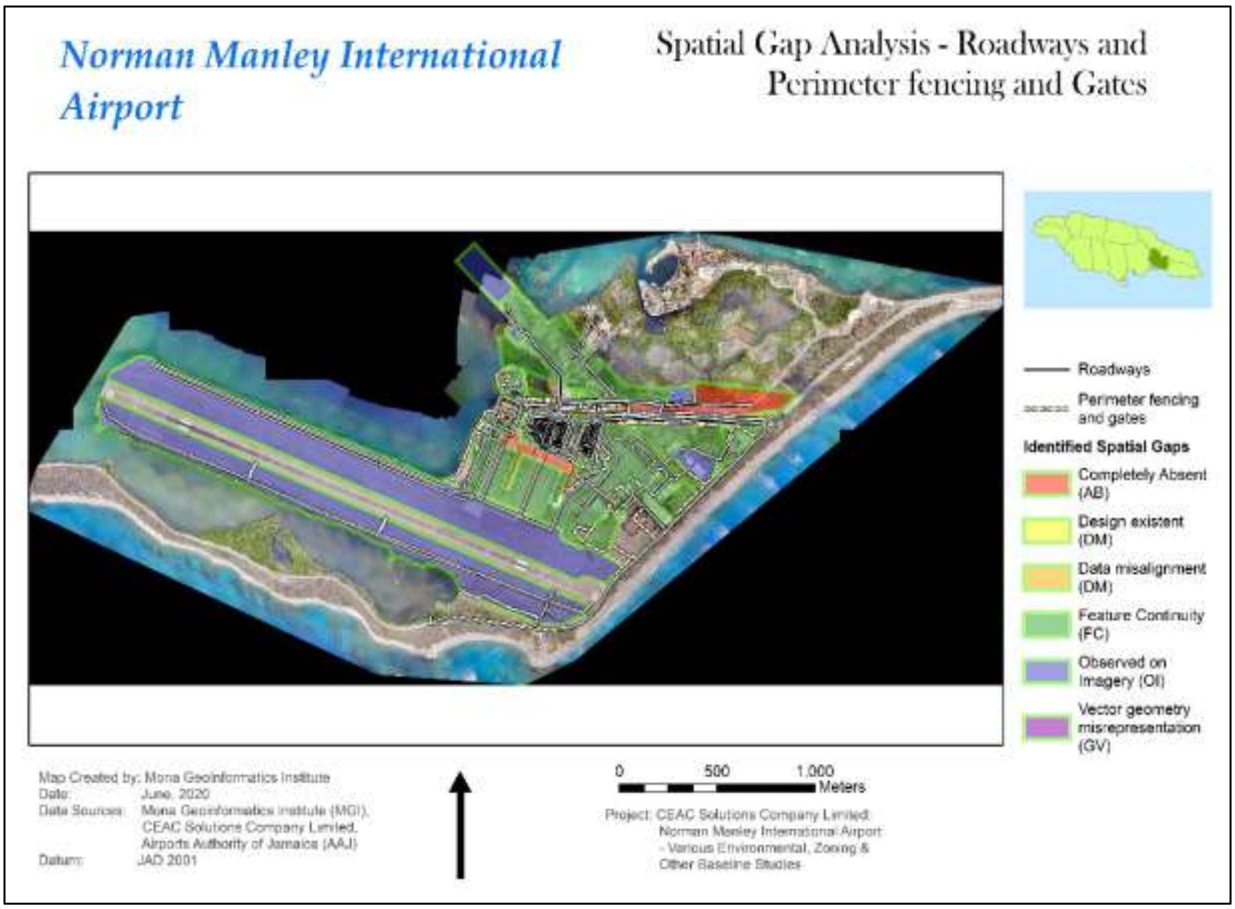


Figure 2.14 Spatial gaps identified within the roadways and perimeter fencing and gates datasets

2.3.3 Natural Features

2.3.3.1 *Vegetation*

Vegetation_points

FID	Shape *	X1	Y1	Z1	Condition	Descript
1	Point ZM	773861.937736	643337.251929	0	Healthy	TREE
2	Point ZM	773877.219865	643338.072066	0	Healthy	TREE
3	Point ZM	773937.732993	643323.309616	0	Healthy	TREE
4	Point ZM	774567.570108	643181.191493	0	Healthy	TREE
5	Point ZM	774577.387399	643185.759349	0	Healthy	TREE
6	Point ZM	774581.936156	643190.305994	0	Healthy	TREE
7	Point ZM	774591.033669	643199.046525	0	Healthy	TREE
8	Point ZM	774595.072652	643203.240412	0	Healthy	TREE
9	Point ZM	774600.404887	643208.273152	0	Healthy	TREE
10	Point ZM	774603.893356	643213.055118	0	Healthy	TREE
11	Point ZM	774606.484791	643218.43483	0	Healthy	TREE
12	Point ZM	774591.091115	643242.933225	0	Healthy	TREE
13	Point ZM	774584.535022	643243.242332	0	Healthy	TREE
14	Point ZM	774578.226324	643243.67508	0	Healthy	TREE
15	Point ZM	774571.855779	643243.365975	0	Healthy	TREE
16	Point ZM	774565.700811	643243.86313	0	Healthy	TREE
17	Point ZM	774558.835464	643244.295878	0	Healthy	TREE
18	Point ZM	774552.588621	643243.98677	0	Healthy	TREE
19	Point ZM	774546.279927	643244.3577	0	Healthy	TREE
20	Point ZM	774539.785681	643244.481343	0	Healthy	TREE
21	Point ZM	774533.600689	643244.666805	0	Healthy	TREE
22	Point ZM	774526.982741	643244.852269	0	Healthy	TREE
23	Point ZM	774520.612196	643244.852269	0	Healthy	TREE
24	Point ZM	774514.179805	643245.099553	0	Healthy	TREE

Figure 2.15 A subsection of the Vegetation points attribute table

The digitized point features for the vegetation dataset are representative of the trees, flowers and shrubs observed across the airport. As can be seen in figure 30, coordinate, condition (health), and general description data have been provided for these point features. As a result, the only gap observed with this dataset is the lack of associated pictures. Conversely, the digitized polyline features are representative of the mangroves seen in and around the airport property. For these polyline features, only broad description and coordinate data have been provided. Consequently, attribute gaps can be identified within this dataset with the absence of conditions data and pictures.

Moreover, four main types of spatial gaps have been identified within the polyline vegetation dataset. The first spatial gap identified is that of feature discontinuity. Here, the polylines do not connect to form full enclosures representative of the area covered by the mangroves. Likewise, because of this same feature discontinuity, there is also the issue of vector misrepresentation as the vectors provided do not adequately represent the various mangrove features. Additionally, as seen in the figure below, another spatial gap arises where features have been observed on the drawing/design plan but not on the imagery (DE). The final spatial gap identified is that of the complete absence of the polyline features – particularly the mangroves found to border the runway.

Figure 2.16 Spatial Gaps Identified within the Vegetation polyline dataset

2.3.3.2 *Water Features*

Infield verification of this dataset has revealed that only four (4) of the seven digitized features are actual found to exist in nature. However, all four water features were found to be dry and abandoned. Nevertheless, coordinate and conditions data have been supplied of the four existing hydrological or water features. The remaining three (3) points are representative of a spatial gap. This is as these features have only been found to exist on the drawing files and not infield or on the imagery.

2.4 Operational Data

Operational data represent to the group of digitized assets that are essential to execution of daily business operations across the airport property. In other words, this subset of assets or features are directly linked to the success of the airport's core business activities and the generation of revenue.

2.4.1 Airside Features

2.4.1.1 Navigational Aids

All the navigational aids found airside have been digitized and have been verified to be spatially correct. More particularly, coordinate, conditions, material, and general specifications data have been provided for four of the five navigational aids. As such, the main attribute gaps identified for the AWOS, ILS, Windsocks, and DVOR/DNE features correlate with the lack of dimensions and detailed specifications data as well as pictures. Conversely, for the PAPI navigational features, only coordinate and conditions data have been provided. Resultantly, the attribute gaps identified in this feature layer coincides with the empty dimensions, specifications and construction material fields seen in Figure 2.17

PAPI

FID	Shape	X1	Y1	Z1	Dimen	Condition	Specificat	Material
0	Point ZM	773347.047461	642625.483245	0		Good		
1	Point ZM	773343.746202	642617.322421	0		Good		
2	Point ZM	773340.292344	642608.827552	0		Good		
3	Point ZM	773337.029407	642600.476116	0		Good		
4	Point ZM	773308.864165	642530.184972	0		Good		
5	Point ZM	773305.37456	642521.77644	0		Good		
6	Point ZM	773302.071901	642513.617051	0		Good		
7	Point ZM	773298.51998	642505.270804	0		Good		
8	Point ZM	771677.724178	643298.376975	0		Good		
9	Point ZM	771674.265174	643289.974696	0		Good		
10	Point ZM	771670.888613	643281.612822	0		Good		
11	Point ZM	771667.347166	643273.250546	0		Good		
12	Point ZM	771639.081047	643202.918785	0		Good		
13	Point ZM	771635.73074	643194.567087	0		Good		
14	Point ZM	771632.380438	643186.336426	0		Good		
15	Point ZM	771629.024771	643177.884273	0		Good		

Figure 2.17 The attribute table of the PAPI Dataset

2.4.2 Civil Category

2.4.2.1 Substations

No features have been digitized for the ICT Substations. Here, the identified gaps coincide with the absence of a spatial representation of these features alongside the lack of attribute data such as description, dimensions, conditions, pictures, and construction material.

2.4.2.2 Cell Towers

Cell_Towers

Descript	Dimen	Condition	Material	POINT_X	POINT_Y
Cell Towers		Fair - rusting	Metal	773357.389212	643254.279695
Cell Towers		Fair - rusting	Metal	773792.135929	643632.55881
Cell Towers		Fair - rusting	Metal	773670.812993	643601.897977
Cell Towers		Fair - rusting	Metal	773774.818859	643723.785008

Figure 2.18: The Attribute Table for the Cell Towers

The cell tower dataset has been found to be spatially accurate. However, in relation to the attributes, only data pertaining to the coordinates, description, condition, and construction material(s) have been provided for the four (4) cell towers. As such, the attribute gaps identified can be correlated with the lack of dimensions and pictures.

2.4.3 Electrical Category

2.4.3.1 *Runway Lights*

The coordinate, condition and specifications data have been provided for all runway light features. Infield verification has confirmed that these features are spatially correct, thus no spatial gaps were identified. As only data pertaining to the color of the lights were provided for the specifications data, the major attribute gaps identified coincide with the lack of detailed specifications data as well as manufacturer data.

2.4.3.2 *Taxiway Lights*

The coordinate, condition and specifications data have been provided for all taxiway light features. Infield verification has confirmed that these features are spatially correct, thus no spatial gaps were identified. However, as only data pertaining to the color of the lights were provided for the specifications data, the major attribute gaps identified for this feature layer coincide with the lack of detailed specifications data as well as manufacturer data.

2.4.3.3 *Approach Lights*

The coordinate, condition and specifications data have been provided for all approach light features. Infield verification has confirmed that these features are spatially correct, thus no spatial gaps were identified. However, seeing as only data pertaining to the color of the lights were provided for the specifications data, the major attribute gaps identified for this dataset coincide with the lack of detailed specifications and manufacturer data.

Figure 2.19 The Distribution of Airfield Lights Airside

2.4.3.4 *Airfield Directional Signs*

Airfield_Directional_Signs

	FID	Shape *	POINT_X	POINT_Y	Dimen	Condition	Specificat
	0	Point	773626.020626	642781.81272		Good	Yellow rectangular signs with black writing
	1	Point	773623.35888	642673.784837		Good	Yellow rectangular signs with black writing
	2	Point	773526.173343	642623.780513		Good	Yellow rectangular signs with black writing
	3	Point	773463.168773	642547.202395		Good	Yellow rectangular signs with black writing
	4	Point	773351.81507	642697.651622		Good	Yellow rectangular signs with black writing
	5	Point	773113.458683	642790.819041		Good	Yellow rectangular signs with black writing
	6	Point	772811.681498	642820.512749		Good	Yellow rectangular signs with black writing
	7	Point	772899.498826	642784.629301		Good	Yellow rectangular signs with black writing
	8	Point	772710.392583	642956.845504		Good	Yellow rectangular signs with black writing
	9	Point	772110.881021	643198.254482		Good	Yellow rectangular signs with black writing
	10	Point	773672.483784	642521.547409		Good	Rectangular designator sign with 30 -12 E inscribed in black
	11	Point	773544.135758	642574.906147		Good	Rectangular designator sign with 30 -12 E inscribed in black
	12	Point	773208.591308	642693.851167		Good	Rectangular designator sign with 30 -12 D inscribed in black
	13	Point	773140.183007	642763.875834		Good	Rectangular designator sign with 30 -12 D inscribed in black
	14	Point	772636.38544	642974.420283		Good	Rectangular designator sign with 30 -12 C inscribed in black
	15	Point	772566.774491	642957.224002		Good	Rectangular designator sign with 30 -12 C inscribed in black
	16	Point	771331.831429	643455.47004		Good	Rectangular designator sign with 12 A inscribed in black
	17	Point	771295.774605	643512.949011		Good	Rectangular designator sign with 12 A inscribed in black
	18	Point	771969.905276	643200.441617		Good	Rectangular designator sign with 30 -12 B inscribed in black
▸	19	Point	772033.544522	643219.224761		Good	Rectangular designator sign with 30 -12 B inscribed in black

Figure 2.20 The attribute table of the airfield directional signs

Within this dataset, two main categories of directional signs were digitized. These include the runway directional signs and the taxiway designator signs. In accordance with the *"Terms of Reference"*, coordinate, conditions, and specifications data were provided for both classes of Airfield Directional Signs. In this case, the attribute gaps identified for these sign features coincide with the lack of more detailed specifications and manufacturer data as well as photographs.

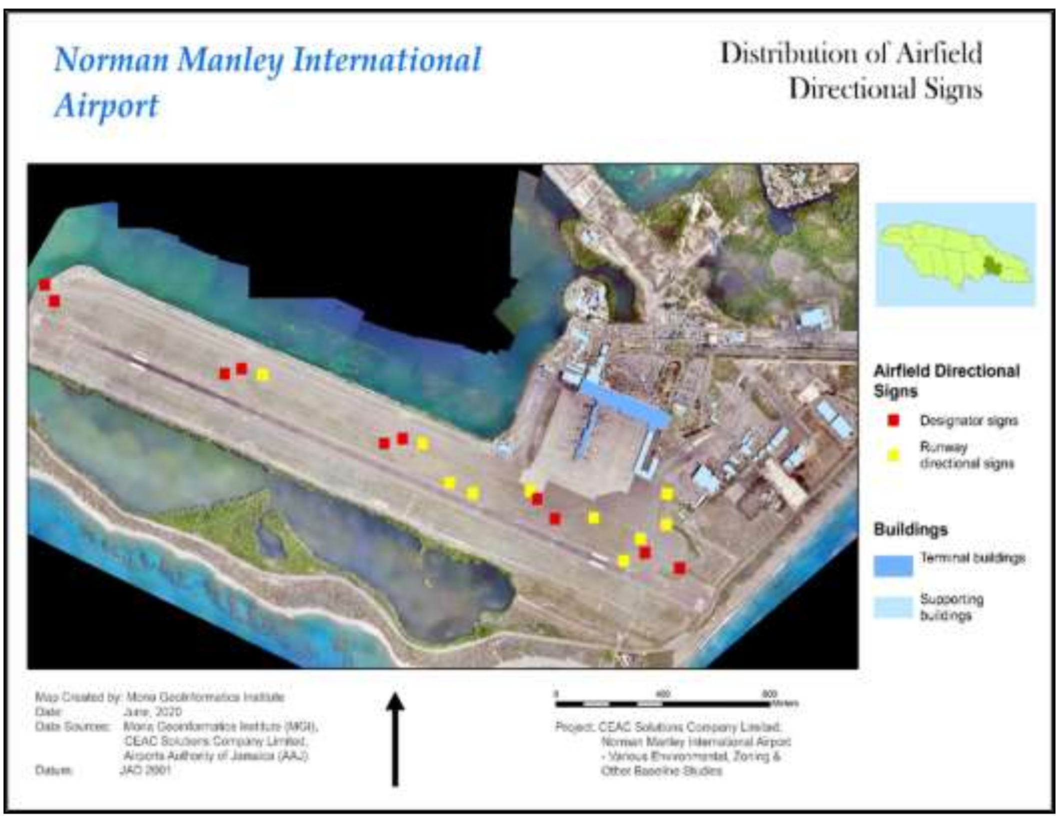


Figure 2.21: The distribution of Airfield Directional Signs

2.4.3.5 *Ramp Markings*

The ramp markings dataset is marked spatially by the complete absence of the required features. As no ramp markings were digitized. The attribute gaps coincide with the lack of coordinate, dimensions, condition, specifications, and manufacturer data.

Figure 2.22: The Spatial Gaps identified within the various Airfield Markings Datasets

2.4.3.6 *Runway Markings*

Though the various runway markings can be observed on the provided imagery, no taxiway markings have been digitized – thereby signifying an "OI" spatial gap. Resultantly, the identified attribute gaps coincide with the lack of coordinate, dimensions, condition, specifications, and manufacturer data.

2.4.3.7 *Taxiway Markings*

Similar to the runway markings dataset, none of the taxiway markings observed on the imagery have been digitized – thus, an "OI" spatial gap exists. Consequently, the attribute gaps coincide with the lack of coordinate, dimensions, condition, specifications, and manufacturer data.

2.4.3.8 *Electrical Manholes*

Only coordinate data has been supplied for the electrical manholes. As result, there are major gaps in the attribute table with the absence of dimensions, condition, depth, and photographs data. Moreover, the dataset has been found to have a general offset or slight misalignment. Likewise, it should be noted that spatially, gaps exist in the dataset with the absence of representative point features for the electrical manholes to the east of the Colonial Concourse as well as the presence of visible breaks in the continuity of the features even though assets that require electrical input have been observed.

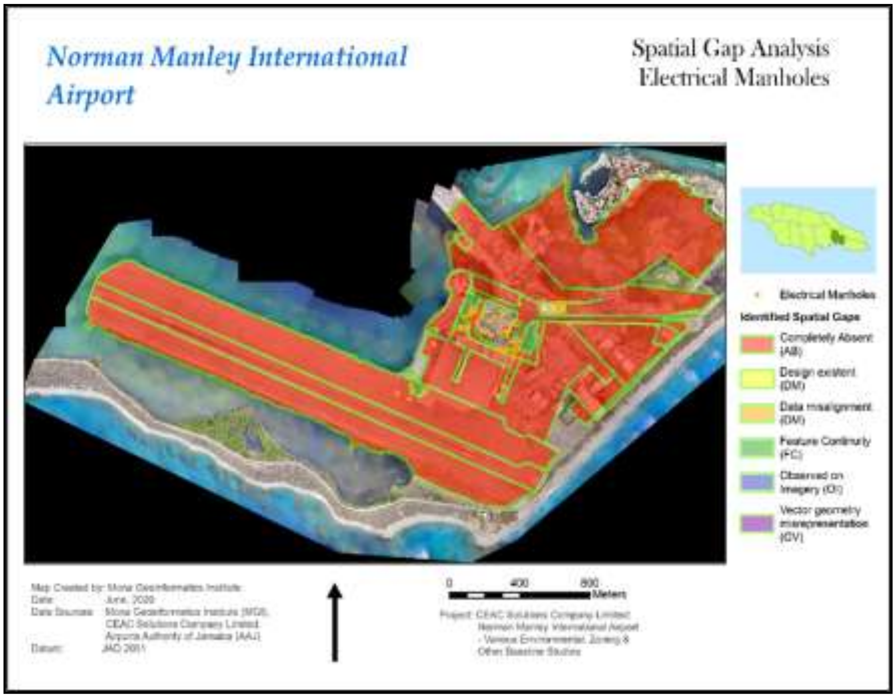


Figure 2.23: The Spatial Gaps identified within the Electrical Manholes Dataset

2.4.3.9 *Overhead Electrical Cables*

Figure 2.24: The Spatial Gaps identified within the Overhead Electrical Cables Dataset

Only coordinate data has been supplied for the overhead electrical cables. Resultantly, existing gaps within this dataset coincide with the lack of information on the type of conductor, number of conductors, cross-sectional area, condition, route, impedance, manufacturer, operating voltage, single or three phases as well as the type of phase connection. It must also be noted that spatial gaps exist within this dataset as some of the overhead electrical cables have not been digitized and as such, are completely absent. Likewise, another spatial gap identified is the observation of features on the CAD / design file that are found to be nonexistent on the imagery.

2.4.3.10 *Electrical Poles*

Generally, for this dataset, only coordinate data has been provided. As it relates to the electrical poles that exist landside, attribute data on the type, condition, and serial number (where available) as well as pictures have been supplied. It must be noted -however, that serial numbers were largely absent from quite a few of the verified landside poles. As result, the major gaps in the attribute table of the landside subset of this dataset coincide with the absence of serial numbers and height data. Conversely, for the airside subset of this dataset, the identified gaps coincide with the absence of type, condition, height and serial number data as well as pictures. Similarly, gaps existed spatially with the complete absence of several poles that have been observed in the field.

2.4.3.11 *Electrical Poles with Lights*

No differentiation was provided in the CAD files between this dataset and the Electrical poles dataset. However, during the verification process, a few of the landside features that had been identified as largely "Electrical Poles" have been tagged to represent this dataset. For these landside features, attribute gaps existed mainly in the absence of serial numbers and height data. Like the airside subset of the Electrical Poles, the identified gaps for the airside "Electrical Poles with Lights" coincide with the absence of type, condition, height, and serial number data as well as pictures.

2.4.3.12 *4,000 V West Substation Runway Distribution System*

T4000V_West_Substation_Runway_Distribution_System

X1	Y1	Z1	Condition	kVa_Rating	Pri_Voltag	Sec_Voltag	Sing_3Phas	Phase_Con
771442.393954	643562.694922	0	Good					

Figure 2.25 The Attribute Table of the 4,000 V Runway Distribution System Substations

As is typical of most buildings dataset, the major spatial gap identified within the West Substation Runway Distribution System dataset is data misalignment. Moreover, this dataset is found to have a general lack electrical data – with only coordinate and conditions data being provided. As a result, as seen in the figure below, the attribute gaps identified coincide with the lack of kVa rating, primary voltage, and secondary voltage data.

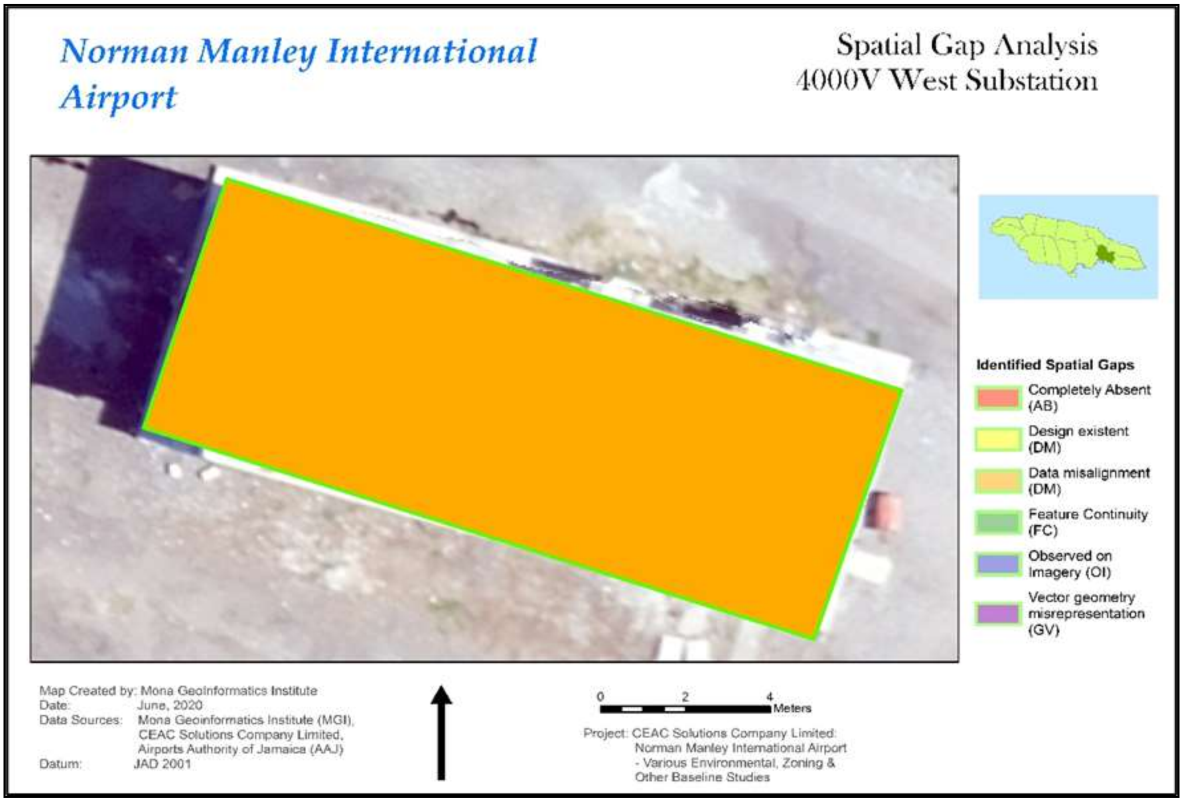


Figure 2.26: The Spatial Gaps identified within the 4000V West Substation Dataset

2.4.3.13 *24,000 V Main Distribution System Substation*

For the five (5) distribution system substations verified, coordinate and conditions data as well as tagged pictures have been provided. It should be noted that no electrical data was collected for the various features within this dataset. As a result, the identified attribute gaps coincide with the lack of kVa rating, primary voltage, secondary voltage, single or three phase, and phase connection data within the attribute table. On the other hand, though the features within this dataset are found to accurately represent the observed geometry of the substations, much like the various buildings' shapefiles, the features are found to be slightly misaligned.

T24KV_Main_Distribution_System_Substations

X1	Y1	NAME	Condition	kVa_Rating	Pri_Voltag	Sec_Voltag	Sing_3Phas	Phase_Con
773638.223617	642689.944965	East Substation	Good					
773606.810291	642989.903356	T-059	Good					
773593.067556	643106.829252	T-050	Good					
773338.051126	643209.146132	Old Energy Building	Good					
773887.637523	643322.510662	Energy Building	Good					

Figure 2.27: The Attribute Table of the 24,000 V Main Distribution System Substations

2.4.3.14 *Distribution Transformers*

No features were digitized for the distribution transformers – i.e., this dataset is completely absent. As a result, the identified attribute gaps coincide with the lack of coordinates, condition, kVa rating, primary voltage, secondary voltage, single or three phase, phase connection, impedance, manufacturer, PCB content, serial number, and the date manufactured data within the attribute table.

Figure 2.28: The Spatial Gaps identified within the Distribution Transformers Dataset

2.4.4 Mechanical Category

2.4.4.1 *Storm Water Drains (Open)*

Only three (3) open storm water drains have been digitized. As a result, the major spatial gap identified for this dataset is the complete absence of features that are otherwise present within the field. Moreover, the attribute gaps for this feature coincides with the lack of depth and dimensions data.

2.4.4.2 *Sewage Manholes*

Figure 2.29: The Spatial Gaps identified within the Sewage Manhole Dataset

Table 2.1 Percentage of attribute gaps found in each subcategory

Category	*Subcategory*	*Percentage of Attribute Gaps*
AIRSIDE FEATURES	Aircraft Stands	100%
	Ramp Stands	100%
	Runways	20%
	Taxiways	20%
	Navigational Aids	20%
CIVIL	Air Traffic Control Buildings	17%
	Support Buildings	17%
	Terminal Buildings	17%
	Roadways	83%
	Perimeter fencing and gates	83%
	Cell Towers	33%
	ICT Substations	100%
ELECTRICAL	Electrical Manholes	80%
	Light Masts – Airside	33%
	Light Masts – Landside	33%

	Runway Lights	40%
	Taxiway Lights	40%
	Approach Lights	40%
	Airfield Directional Signs	40%
	Runway Markings	100%
	Taxiway Markings	100%
	Ramp Markings	100%
	Electrical Poles	50%
	Distribution Transformers	100%
	4,000 V West Substation Runway Distribution System	63%
	24,000 V Main Distribution System Substation	63%
	Overhead Electrical Cables	91%
	Underground Electrical Cables	89%
MECHANICAL	Sewage Manholes	83%
	Underground Wastewater and Potable Water Pipes	86%
	Potable Water Valves	33%
	HVAC Chilled Water Valves	33%
	Storm Water Manholes	100%
	Underground Storm Water Pipelines	80%
	Storm Water Pump Stations	100%
	Wastewater Lift Station	90%
	Storm Water Drains (open)	50%
NATURAL FEATURES	Vegetation (points)	25%
	Vegetation (polylines)	50%
	Water Features	50%

2.4.4.3 *Challenges*

In executing the Gap Analysis Assessment, there were several hindrances to the implementation of the assignment which would affect the accuracy of the findings. These challenges, while unavoidable at the present, can be reduced if specific interventions are made throughout the next steps of the project. Proposed recommendations on how to reduce the severity of the impacts of the challenges are further detailed as follows.

1. Data received (drawings/shapefiles) had multiple themes or categories of assets and in most cases contained significant overlaps with other data layers.
2. Data was in many cases mislabeled which made it difficult to discern what the feature layer was referring to. In many cases there were several layers with layer attributes which had numerical layer tags. For example, a layer would be labeled "0" within the attribute table, however on closer inspection; the layer represented a road or tree. This level of detailed investigation was unable to be completed at this stage of the project and so in many cases it has been left up to onsite inspection to confirm these cases.
3. Data conversion was not as smooth a process as intended based on resolution specifications of the input data/drawings. In many cases, the input drawing contained illegible elements at fine scale which could not accurately be converted. This indiscernible data had to be removed from consideration as it was unclear what was being illustrated.

2.4.5 Summary of the *Asset Gap Analysis*

The gap assessment process saw the use of a two-tiered approach for the purpose of identifying potential gaps or inadequacies within the Airport's existing datasets. Here, each dataset was first assessed at a location or geospatial level to get an idea of its spatial coverage and accuracy, followed by a more in-depth analysis at the subcategory level to ascertain the presence (or lack thereof) of attribute gaps. The preliminary findings of our Gap Analysis has suggested that the highest percentage of spatial gaps can be found within the vicinity of the Apron zone, whilst the Fuel Farm/Maintenance/Sewage Plant area recorded the least. Conversely, majority of the attribute gaps identified throughout the datasets coincided with the lack of available electrical data and product/ dimensions details. Consequently, the categories found to possess the most attribute gaps were the Electrical and Mechanical categories.

2.5 Needs Identified

This section details the minimum requirements for technical infrastructure such as hardware, software, networking, and data, needed for the seamless integration of the proposed Geographic Information Database System, into the airport's business procedures.

2.5.1 Hardware Needs

Detailed below is proposed list of minimum hardware components required for the implementation of the proposed GIS System. For ease of understanding, the hardware requirements have been divided into two categories namely: field and desktop.

2.5.1.1 *Field*

One key component involved in the integration of a Geographic Information System in business practices is fieldwork. Through the advancements in technology, many devices have been produced to aid in the data collection process. The following is a list of recommended hardware to be mainly utilized by the field users in the data capture or collection process. These devices work in tandem with the created data dictionary to automate and expedite the data collection process.

1) Trimble Handheld GPS units – preferably, Trimble Geo7x devices
2) Trimble Battery Pack
3) AC power adapter
4) USB data cable
5) External antennas such as Tornado tempest and Zephyr, to improve the accuracy of the readings and/ coordinates produced.
6) Range pole bracket and 2m carbon fiber range pole, for use with an external antenna.

Figure 2.30 Trimble Geox7x handheld GPS device

Similarly, through the creation of several mobile data collection apps such as Locus GIS and ESRI's Collector for ArcGIS, companies and field collectors are also able to utilize smartphones and tablets – particularly android devices, to aid in the data collection process.

Figure 2.31 Example of a field officer using a tablet in the process of data collection

2.5.1.2 *Desktop*

This section outlines the minimum hardware requirements for deploying the proposed GIS Database System. The umbrella term – Computer Hardware, refers to the physical collection of elements and/ external tools used by users to operate a computer. These include components such as the keyboard, mouse, motherboard, graphics card and data storage. Moreover, it should be noted that the proposed GIS System will make use of variety of software applications including ArcMap for Desktops, ArcGIS Dashboards, Microsoft Office, and GPS Pathfinder Office. For these proposed software applications to function efficiently, it is recommended that the desktop machines within the various departments be fitted with the following specifications:

1) CPU speed: 2.2 GHz or higher; Hyper-Threading Technology (HTT) or multicore recommended.
2) Processor: Intel Pentium 4, Intel Core Duo, or Xeon Processors; SSE2 minimum.
3) Disk space: 50 MB is needed for the app, and more is needed for cache and swap.
4) Memory/RAM: 2 GB or higher.
5) Display: 24-bit color depth.
6) Screen resolution: 1024x768 or higher recommended at normal size (96 dpi).
7) Swap space: Determined by the operating system; 500 MB minimum. ArcGIS Runtime will create cache files when used; additional disk space may be required.
8) Video/graphics adapter: 256 MB RAM minimum, 1 GB RAM recommended; NVIDIA, ATI, and Intel chipsets supported.

2.5.2 Software needs

Detailed below is a list of the proposed minimum software components required for the integration of Geographic Information Systems into the airport's business procedures. Similar to the hardware components, the suggested software have been divided into two categories namely: field and desktop.

2.5.2.1 *Field*

For optimal use of the suggested Trimble handheld units, the following software have been recommended:

1. Terra-Sync Software – This software acts as the interface between the GNSS receiver and the field officer, allowing for the collection of GNSS positions, as well as the collection and updating of (existing) GIS data.

Figure 2.32 Trimble devices fitted Terra-Sync software

Likewise, for the process of data collection, using the ArcGIS Enterprise license, in addition to the handheld devices, field officers may utilize their mobile devices as well. To facilitate this, the ***Esri – Collector for ArcGIS*** application software would be useful for real-time updating of the remote database.

Figure 2.33 Examples of mobile devices fitted with Esri's Collector for ArGIS

2.5.2.2 *Desktop*

In hindsight, desktop software or applications can be referred to as a local version of a service or web application that facilitate the interaction between the application processing and user without having to directly connect with the web service. More specifically, Geographic Information System (GIS) Software are applications that are designed for the creation, manipulation, visualization, and analysis of all types of geographic and spatial data. In both instances, the proposed GIS System utilizes three main software applications namely:

1. ***ArcGIS Desktop*** – This software will mainly be used by Cartographers and in some instances, data builders (see section 3.1.5.1) in the process of editing and updating the central GIS database with the newly collected and/ updated spatial information (data integration). Fitted with a variety of extensions and add-ins as the ones depicted in Figure 2.34, this application allow users to create, manipulate and manage geographic data, whilst also facilitating the use of powerful analytical tools and workflows to identify spatial patterns, trends, and non-obvious relationships – thus aiding in the decision-making process.

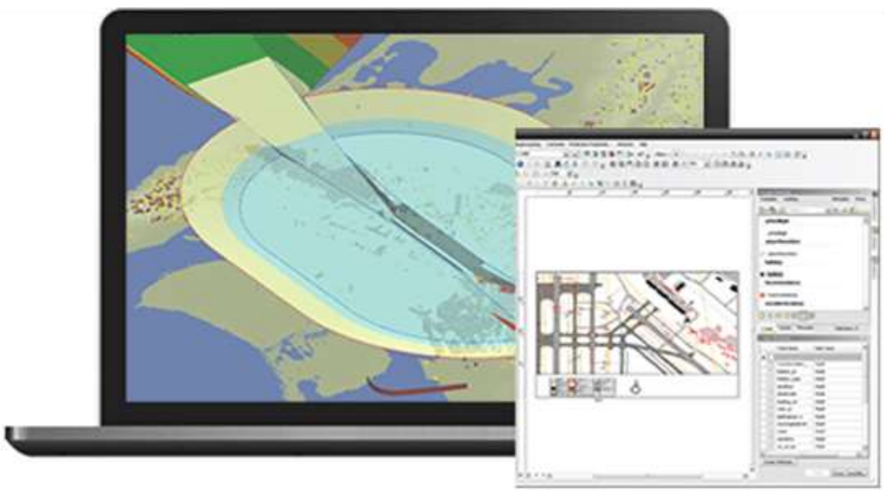


Figure 2.34 Example pf the ArcGIS for Desktop software application with the Airport and aviation enabled

2. ***Database Management System software*** – This software will mainly be used in the data entry or collection phase. For the proposed GIS Database System, two separate database management systems were considered namely: Microsoft Access and Microsoft excel. Using user-friendly forms, both options allow users – more particularly database administrators, to. Moreover, both software applications also facilitate the execution of queries and the generation of reports, charts, and graphs to assist with the processes of decision-making and data analysis. The Excel option however, working in tandem with the ArcGIS Maps for Office add-in, provides the added function for users to generate interactive geospatial maps as well as export data directly to ArcGIS without leaving the confines of the Excel application.

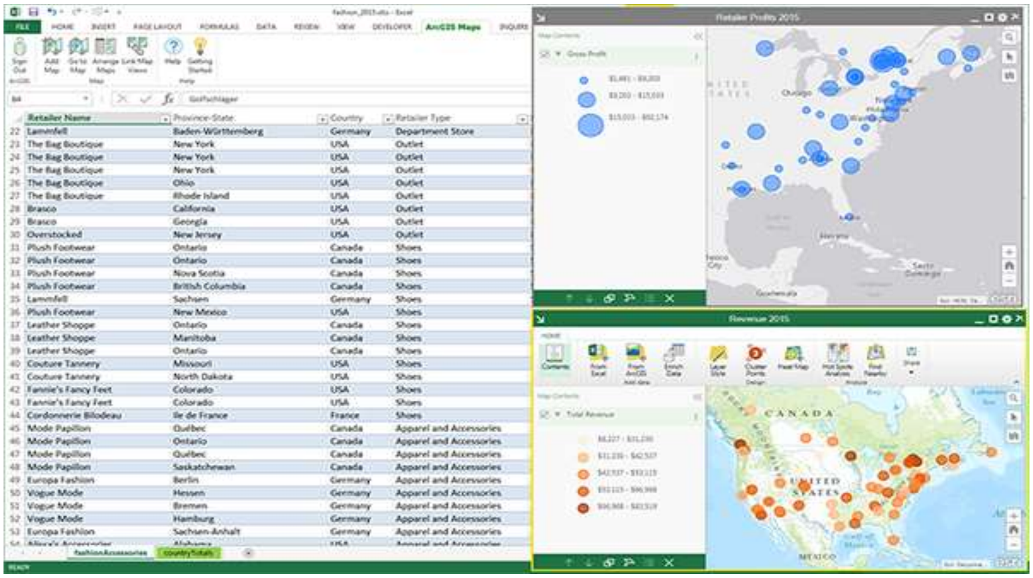


Figure 2.35 Interactive geospatial maps created in Microsoft Excel using the ArcGIS Maps for Office Add-in

3. *GPS Pathfinder Office software* – This software will mainly be used in the data processing stage. Once back in office, field officers may process or correct the collected spatial data to ensure that it is at the required standard (quality control) before exporting same to the geodatabase. However, it also provides the added function of data dictionary creation (Figure 2.36) as detailed in the Standard Operating Procedures (SOP) document.

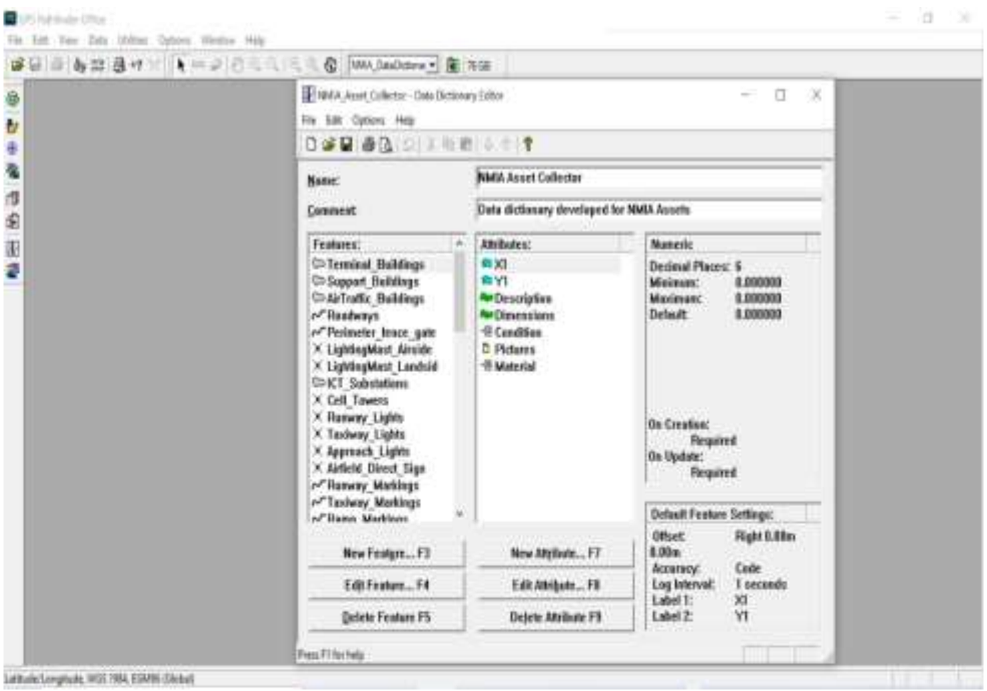


Figure 2.36 A snapshot of the data dictionary created for GPS/GIS Asset Mapping using the Trimble GPS Pathfinder Office software

2.5.3 Networking Needs

As the central system or core of the proposed GIS Database Systems, the airport must ensure that all the networking needs of the ArcGIS software are met. Detailed below are all the networking components necessary for the efficient use and functioning of ArcGIS services. To be able to access the service of ArcGIS Online, the ArcGIS Server must communicate on specific ports. As such, HTTPS Ports - 6443 & 6080, and internally used ports - 1098 or 1099, 6006 & 6099 need to be open for machines on the internet and intranet: Likewise, the organization's domain name service (DNS) must include an entry of the fully qualified domain name (FQDN) of the machine hosting Portal for ArcGIS. Moreover, for the best performance in the portal website, use the latest versions of the browsers listed below:

1. Google Chrome
2. Microsoft Edge
3. Microsoft Internet Explorer 11* (Active scripting must be enabled for the portal website to function correctly.)
4. Mozilla Firefox
5. Safari
6. Android Browser
7. Chrome for Android

2.5.4 Data Needs

The GIS/GPS Asset Gap Analysis Process has revealed that much of the required attribute data is not readily available. More particularly, in-field observations have exposed a large need for data pertaining to the functionality of the electrical assets – such as the kVa rating, phase connections and voltage. Likewise, there is also a great need for the dimensions data– especially, for the underground features whose dimensions cannot be extracted from high quality LiDAR imagery. Lastly, access to a procurement registry or database would be ideal to ascertain the required product details. This procurement documentation would provide a detailed listing of all the assets that have been purchased over the years at the Norman Manley International Airport – thus allowing for the infilling of gaps related to product specifications, manufacturers, manufactured date, and serial numbers.

2.5.5 GIS Processes

Processes are recommended here for characterising the data life cycle to ensure its preservation, relevance, and longevity. Data collections are carried out in lifecycles[1]. The Data Lifecycle describes the complete process of interrelated activities performed on a dataset during its lifetime. It can be separated into:

1. planning and production of data (by an observing system or data collection project),
2. data management (processing, verifying, documenting, advertising, distributing and preserving the data), and
3. data usage activities (performed by the consumer of the data).

[1] Maxam, A., D. Oswald, T. Baur & W Hollingsworth, 2019. *Data Management Protocol for Managing Climate and Hydrometeorological Data in the Eastern and Southern Caribbean (ESC).* Submitted to Caribbean Community Climate Change Centre (CCCCC), April 1st, 2019. pp88.

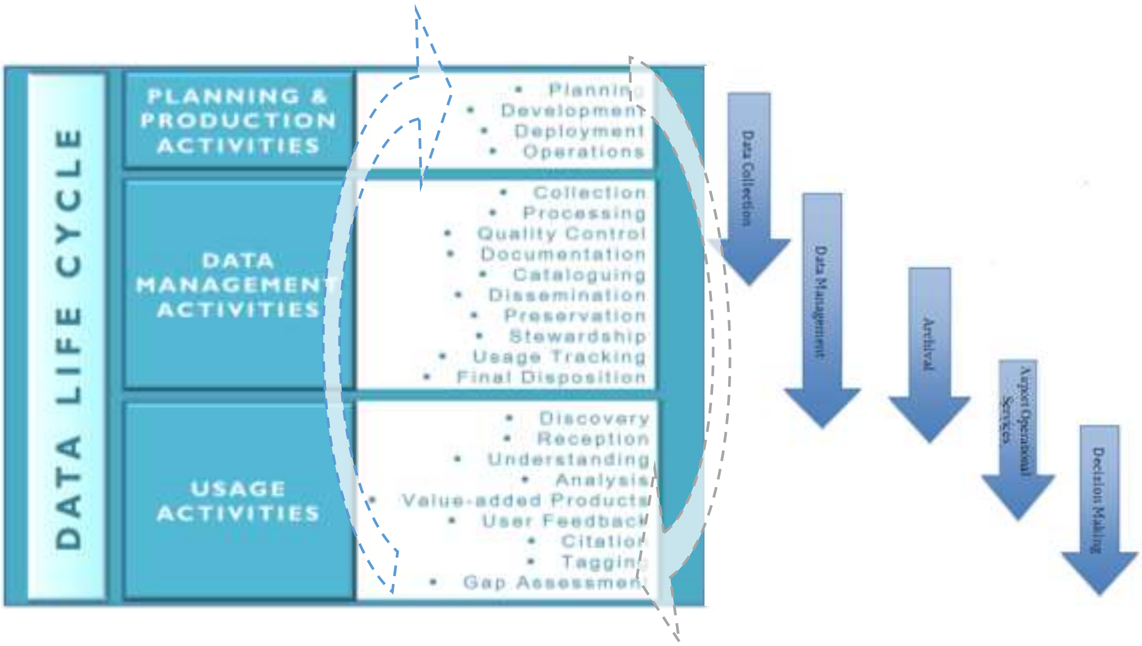


Figure 2.37 Inter-related activities to be performed on a dataset are shown on the left. On the right is shown the alignment of key initiatives with different parts of the data life cycle.

For Geographic Information System to be adequately incorporated in the airport, three main processes must be completed. These include:

1. ***Data Collation*** refers to the process by which the information on various map attributes, facilities, assets, and organizational data are digitized and organized into their appropriate layers. For this project, it is suggested that the spatial datasets be grouped in two main layers namely:
    - Baseline – This layer would include features such as the basic outline of the airport, terrain, taxiways, and runways.
    - Thematic – This layer would include features belonging to the categories of electrical, mechanical, environmental, civil structures, airside facilities, and natural features.

2. ***Data Formatting*** refers to the process by which all the digitized data is standardized. This phase may include the use of techniques such as:
    - Conversion to spatial formats: vector, raster, images
    - Error corrections, data clean-up and quality checks
    - Checking attribute consistency
    - Checking geometry consistency

3. ***Data Transformation*** refers to the process by which various forms of data may be changed from one format to another. This process may involve the use of techniques such as:
    - Georeferencing - The process of spatially characterizing images and plans
    - Re-projections – Adjusting the coordinate system of the layer. E.g. changing from the GCS_WGS_1984 projection system to JAD_2001.
    - Conversion of tabular data (.csv or .xsl) to vector format.

- Conversion between various formats – for example, from raster to vector formats
- Data reclassifications.

2.5.5.1 *Database Maintenance*

Through the use of ArcGIS "Checkout replicas" – otherwise known as the checkout replication feature, the GIS database will run a daily check of the local versions of the geodatabase found on the individual desktops – making notes of any updates or changes and synchronizing same to the shared or remote database. More particularly, it is recommended that maintenance checks and or conditions data for the various features be collected as follows:

Table 2.2 Proposed frequency of maintenance for the various assets

Category	*Subcategory*	*Recommended Frequency of Maintenance*
CIVIL	Air Traffic Control Buildings	Annually
	Support Buildings	annually
	Terminal Buildings	annually
	Roadways	annually
	Perimeter fencing and gates	annually
	Cell Towers	quarterly
	ICT Substations	quarterly
ELECTRICAL	Electrical Manholes	monthly
	Light Masts – Airside	quarterly
	Light Masts – Landside	quarterly
	Runway Lights	monthly
	Taxiway Lights	monthly
	Approach Lights	monthly
	Airfield Directional Signs	monthly
	Runway Markings	annually
	Taxiway Markings	annually
	Ramp Markings	annually
	Electrical Poles	quarterly
	Distribution Transformers	monthly
	4,000 V West Substation Runway Distribution System	monthly
	24,000 V Main Distribution System Substation	monthly
	Overhead Electrical Cables	quarterly
	Underground Electrical Cables	quarterly
MECHANICAL	Sewage Manholes	monthly
	Underground Wastewater and Potable Water Pipes	quarterly
	Potable Water Valves	monthly
	HVAC Chilled Water Valves	monthly
	Storm Water Manholes	monthly
	Underground Storm Water Pipelines	quarterly
	Storm Water Pump Stations	quarterly
	Wastewater Lift Station	quarterly
	Storm Water Drains (open)	monthly
NATURAL FEATURES	Vegetation (points)	bi-annually
	Vegetation (polylines)	bi-annually
	Water Features	bi-annually

2.5.6 Personal Needs

The roles and personnel for a GIS implementation are considered the most crucial component. The best of data, hardware, software, and protocols could be in place for running a GIS but without competent and well-positioned personnel to update, analyse, manage and maintain things, any GIS quickly falls apart. Good data management must become a part of core business practices and explicitly covered in the organisational structure[2]. Personnel considerations include:

1. **Clear roles and responsibilities:** Employees responsible for any aspect of data management should have that role and responsibility clearly stated in their job descriptions, with the authority and means to carry out that role.
2. **Capacity-building and knowledge retention:** Roles for training and knowledge retention are crucial for sustainability of the platforms.
3. **Enabling and encouraging existing technical capacity:** Technical personnel with expertise in the particular type of data being managed, and the motivation to do so, should be enabled and encouraged to take part in data management activities and in the governance of the protocol, for example, the Coordination Committee and assessments.
4. **Collaboration:** Personnel are more effective when they can exchange knowledge and work together and collaborate with experts from other departments and organisations.

The success of NMIA's GIS begins and ends with the right personnel: from efficiently understanding and meeting key user needs, to getting in place a good work force for carrying out maintenance, keeping the database relevant and ensuring sustainability. Within the AAJ's organisational structure, the GIS roles and responsibilities may be incorporated. All of this will have to fit into an existing organizational structure within NMIA. It is proposed that, while GIS may typically fall within an ICT department, in the case of NMIA, this would fall under *Engineering, Maintenance and Projects*, with a broken line relationship with the ICT department, given the technological components and requirements of the unit.

Many of the GIS processes and tasks undertaken for this project, especially as they relate to data, are under the auspices of *Engineering, Maintenance and Projects*, and many of the projects forecast by NMIA would benefit from the contributions of a GIS Unit. There will also be roles for the unit with the *Operations* and *Commercial Development* and *Planning* Departments. Because of these cross-disciplinary functions, and that GIS activities are inherently different than ICT administration and management, which is largely purposed for ICT governance within an organization, and implements systems by which other operational units in that organization function, the GIS Unit belongs in an operating department.

[2] *NOAA Environmental Data Management Framework*'. Silver Spring, MD : US National Oceanic and Atmospheric Administration, 2013, https://nosc.noaa.gov/EDMC/framework.php

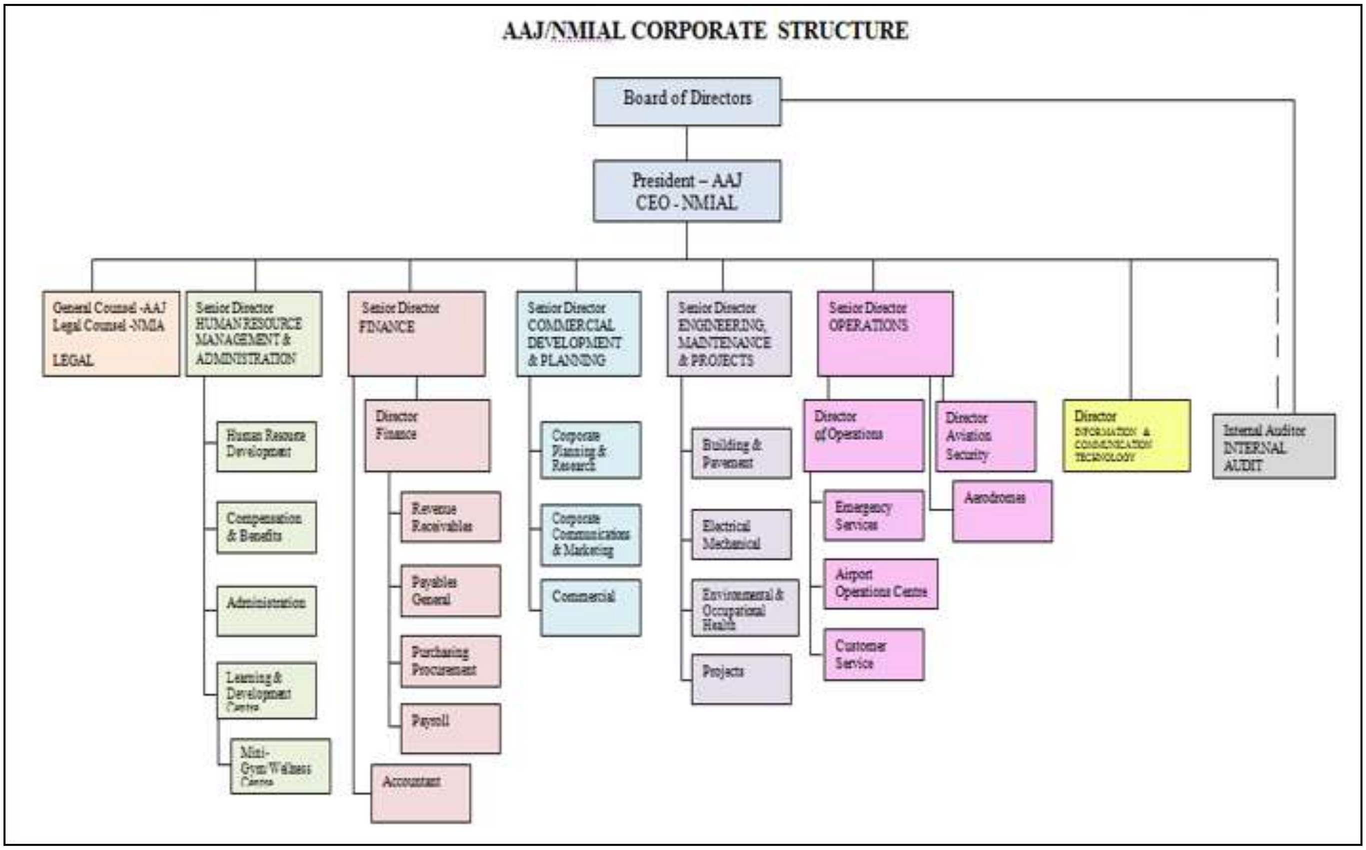


Figure 2.38 The current organisational structure of the Airports Authority of Jamaica (AAJ) Please note that red dashed line indicates the main divisions under which the GIS unit may be incorporated.

2.5.6.1 *Proposed NMIA GIS Organisation*

Whether the GIS Unit falls under the current Engineering, Maintenance and Projects Department or the Operations Department, the GIS Unit structure proposed is meant to be cross-cutting in serving all departments. The GIS Unit itself would have a minimum size of four (4) core personnel, one for each role.

2.5.6.2 *Level 1- Key End User*

Key end-users of the GIS will be the decision-makers, that is, Senior Directors or higher needing to inform decisions on operations. They are the primary consumers of the GIS outputs. Demand for the GIS from the very top strengthens its relevance. GIS can support decisions not only on data collection but as a more comprehensive, powerful spatial decision support system (SDSS). The knowledge and processes managed by Senior Directors are combined with spatial databases, reporting, visualisation, and analytics. Senior Directors are supported in this way to make optimal decisions to solve a problem, as well as determining the consequences of implementing a selected decision (modelling scenarios).

2.5.6.3 *Level 2- GIS unit manager and analysts*

The manager of the GIS Unit is responsible for solving spatial problems – theoretical and operational – for the airport needs. This is the most senior person in the unit and reports to the Senior Director of Engineering, Maintenance and Projects. This role could be equivalent to Directors in other divisions within the organizational structure.

The GIS Director is essentially a senior analyst and must be capable of thinking well beyond day-to-day operations, monitoring and troubleshooting. They carry out decision analysis, implement plans and execute spatial evaluation, monitoring and feedback. Their primary mandate is to translate and dynamically apply GIS to answer the needs of decision-makers across the board. This means being able to recognise issues that can be solved using spatial applications, determining the right spatial solution, and then implementing the answer. This role should be prepared to use GIS for not only managing the physical assets of the NMIA but also for assisting in compliance, auditing, and sustainability for business support. This role will also identify and procure Specialist Analysts from time-to-time to assist with solving particular problems (e.g. remote sensing, LiDAR collection). The GIS Unit Manager is responsible for the rest of personnel in Level 3 and Level 4 that make up the GIS unit. The GIS Unit Manager / Senior Analyst is a core role that should be a permanent member of the unit.

2.5.6.4 *Level 3- GID Operations Superviors*

The GIS Supervisors oversee key spatial operational components and report directly to the GIS Unit Manager. A supervisor should be in place to manage each of the main spatial operations: GIS map building and publishing, database administration, and data building being the three (3) permanent core roles while the software development and database design role is filled temporarily.

2.5.6.5 *Level 4- GIS Data Builders*

This may be the most dynamic level where roles are filled by demand and may contract and expand in numbers depending on needs. GIS Data Builders are surveyors and technicians that report to the GIS Data Builder Supervisor and may be temporarily or permanently contracted. At the very least, there should be one technician per physical asset category: building and pavement; electrical and mechanical; environmental and occupational health; and projects.

Technicians should be able to capture detailed data in the field and from existing files, working closely with airport electrical, sewerage, mechanical experts, *et cetera*, to constantly map, convert and update infrastructure information. The detail required in capturing electrical data, for example, goes beyond what can be seen directly in the field. Often, more time and investigation are required to consult with existing and past airport electrical engineers in order to build a more comprehensive database of legacy and existing electrical information.
As larger datasets need to be captured, the number and types of technicians may be expanded. During emergency management, for example with hurricane season, additional technicians may be called in for environment and safety assessment before, during and following an event. Where there is a fall-off in data needed to be captured, the GIS Data Builder Supervisor can easily carry out data collection on their own.

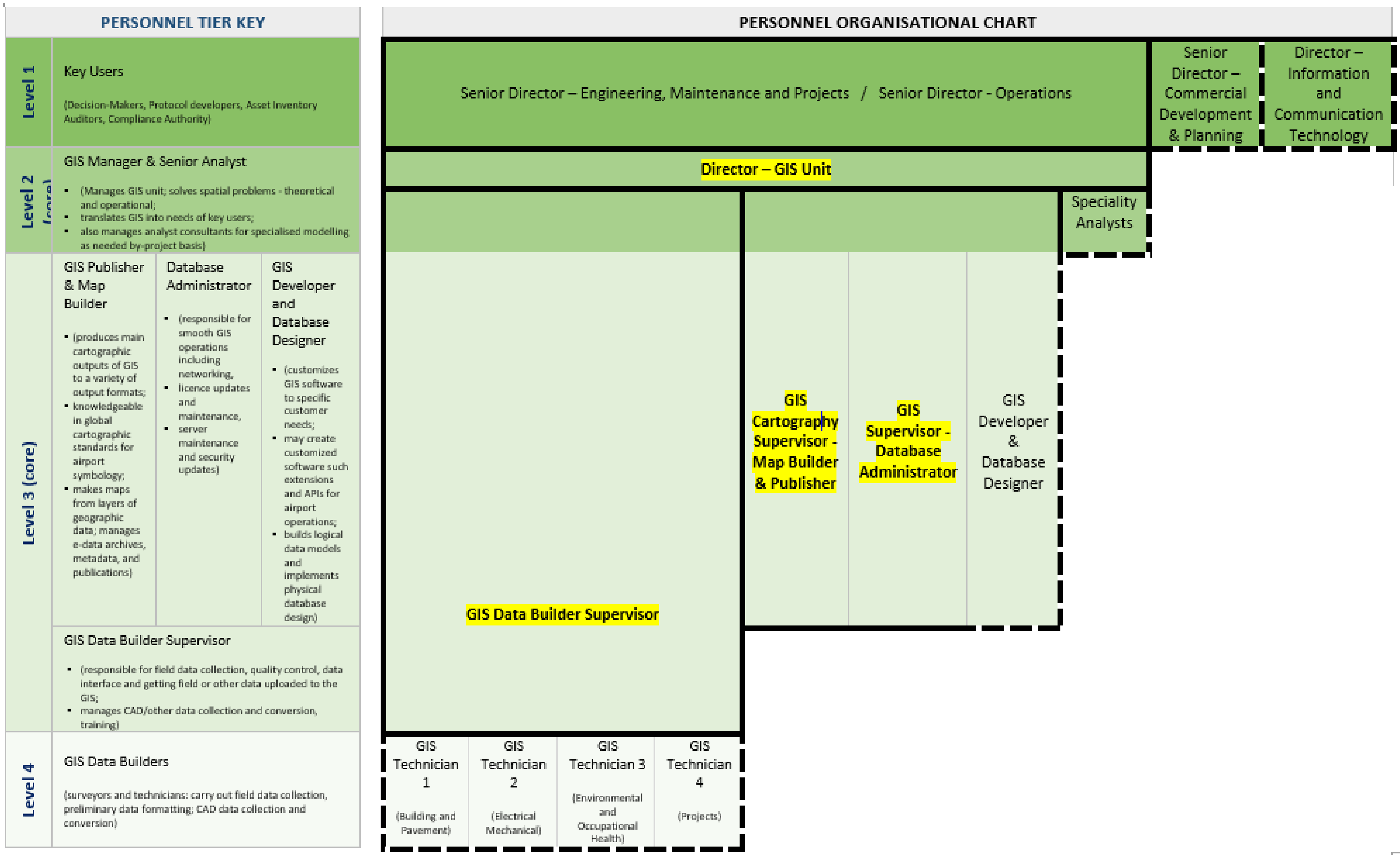


Figure 2.39 The hierarchy is proposed for NMIA's GIS team

2.5.6.6 *Skills Levels and Requirements*

Requirements for the roles of the GIS Unit personnel are detailed in

	Position	Role	Required Skills	Status
1	**Director - GIS**	GIS management / senior analyst	▪ Post-graduate degree in GIS, Geography, Land Surveying, Urban Planning, or related field. ▪ At least 3 years' applied use of GIS for planning urban infrastructure. ▪ At least 3 years' experience managing a GIS unit for a large asset inventory. ▪ Experience with airport asset management an asset.	core
2	**GIS Specialty Analyst**	Expert analyses	▪ Post-graduate degree in speciality field. ▪ At least 3 years' applied use of speciality field in GIS. ▪ Demonstrated experience applying GIS in non-GIS arenas	as needed
3	**GIS Supervisor – Data Building**	GIS data builder management	▪ First degree in Geography, GIS, land surveying, Urban Planning, or related field. ▪ At least 3 years' experience in using GIS for data management (proprietary and open source systems); ▪ Demonstrated experience supervising field personnel. ▪ Demonstrated experience in data collection, metadata building and quality control techniques.	core
4	**GIS Supervisor - Cartography**	GIS map building & publishing management	▪ First degree in Geography, Cartography, GIS, land surveying, urban planning, or related field. ▪ At least 3 years' experience in publishing and hosting GIS maps for urban planning off- and online. ▪ Demonstrated experience in various cartographic techniques, standards and publication standards (electronic and hardcopy). ▪ Knowledge of projection systems, datums and transformation parameters. ▪ Experience in graphic design standards, applications and systems. ▪ Experience with airport data standards and symbology an asset	core
5	**GIS Supervisor – Database Administrator**	GIS database administrator management	▪ First degree in Geography, GIS, Computing, IT, Networking, or related field. ▪ At least 5 years' experience in database administration of a GIS unit within a large organization. ▪ Experience with network configuration and administration. ▪ At least 3 years' experience maintaining software and server environments and protocols for both proprietary and open source systems. ▪ able to manage GIS operations, including software and data licenses, server and hardware specifications.	core
6	**GIS Supervisor – Database Developer and Designer**	GIS database development and database design	▪ First degree in Geography, GIS, Computing, IT, Networking, or related field. ▪ At least 3 years' experience in software development. ▪ Demonstrated experience developing applications and designing databases for GIS.	as needed
7	**GIS Technician / Surveyor**	Data collection and building	▪ Diploma in Geography, GIS, land surveying, Urban Planning, or related field. ▪ Experience in at least 1 year collecting data using GNSS. ▪ Experience in terrain and aquatic environment field collection.	as needed

2.5.6.7 *Training*

Building capacity development improves GIS sustainability and relevance. Training should be carried out at relevant intervals on airport protocols and standards. This can be a mixture of training on current airport systems as well as a few will need to be developed targeting GIS data maintenance.

Manuals for standard operating procedures (under usual and emergency scenarios) should cover:

1. Refresher database maintenance (at least once per year)
2. Refresher data standardisation (…once per year)
3. Maintaining security protocols (…once per quarter)

4. Maintaining software and server environments (…twice per year).

Training objectives will be measured for their success by pre-determined indicators.

2.5.6.8 *Analytical Needs*

GIS analyses are different from routine GIS work, requiring a greater level of skill and ability to integrate GIS data and tools with the wider operations and objectives of NMIA. The GIS analysts will have to interface with the other departments within the AAJ organizational structure, nominally operating within the GIS unit, but serving these other departments as well. The GIS analysts will need to translate the GIS needs and requirements of these other units, operationalize these within the GIS unit, then present these back to the other departments. They will have to assess both incoming and existing information for GIS conversion and integration. Critically, they will have to answer questions being asked for operational management, not just create maps. As such, they will have to be very agile in their approach and execution of GIS tasks.

2.5.6.9 *Sustainability*

For the Unit to be sustainable, it will need to fulfill those tasks mentioned above to the degree that it becomes valuable to the NMIA operations. This will have to be a long-term proposition and will require continued budgetary support for all the GIS components (data, hardware, software, personnel). Personnel costs will be recurring. Software components may have annual licenses depending on the selection and options therein; open-source software have different, usually reduced, running costs.

Start-up costs can be expected to be high. These will involve the procurement of hardware (networked computers, servers, GPS units, etc), software (core GIS software and extensions; possible specialized and customized open-source tools), data (acquiring and converting base data; building a proper database), and personnel recruitment and on-boarding. The latter part will also involve integrating a new unit in the wider NMIA organization chart and incorporating into the overall human resources system, including employee benefits consideration and any collective bargaining agreements the NMIA may already have in place. Additional start-up costs may be the identification and conversion of a dedicated work area for the operations of the GIS Unit.

Non-fiscal elements of sustainability are more crucial and can include buy-in from management and stakeholders to use the system as-advertised, and to not allow the investment to sit idle. This will necessitate the incorporation of the GIS Unit in decision-making exercises, especially in planning and procurements involving any of the different zones within the airport. Seemingly non-GIS tasks (that is, not involving map output) can yield valuable information for such exercises, such as counts, densities and distribution of certain assets when conducting scoping or site definitions. Assessments of histories, such as changes in land use, can also be important when looking at expansion or regulatory reporting.

As such, the buy in from department heads outside the GIS Unit, as well as from senior management, will become important. The unit needs to be seen as a strategic tool, not a data repository. The GIS Unit itself needs to be proactive in its engagement with other departments, operating less like an extension of an IT department, with largely an inward-facing operational and administrative mandate, and more towards outward-facing corporate services, connecting different NMIA internal and external stakeholders.

Once the department has been established, it can be expected that reports and other GIS output can be generated immediately and routinely. Special and one-off requests may be common depending on the operational schedules and activities of the other departments. The usefulness of the unit can be reviewed quarterly in the first year, then routinely annually. Internal audit reviews can also be conducted to review operations (procurements, adherence to departmental and organizational procedures, etc), while management reviews can be conducted as necessary to determine the unit's strategic value to the organization.

2.5.7 Summary of GIS Applications and Models Assessment

A close examination of the airport's business practices has revealed that though the airport operators have employed the use of a database management system – particularly the SQL Database, in the monitoring and maintenance of the airport assets and/ infrastructure, this system lacks the necessary spatial or visualization component. Consequently, following the completion of the Assets Gap Assessment Report and an assessment of the airport or client's technical infrastructure, this assessment details the necessary data, hardware, software, personnel, networking and analytical needs needed to address the gaps and inefficiencies identified with the current business practices/ system. Likewise, using the ArcGIS Enterprise Suite, the consultants have recommended the implementation of a three-component GIS Database Management System that not only would allow for the easy collection, monitoring/updating and spatial visualization of airport assets by various airport personnel – whether it be the maintenance/ field collectors, management, but also would provide the functionality of a remote map viewer for the general public to utilize.

2.6 Recommendation

Increasingly, airports worldwide are implementing GIS solutions to combat the wide range of challenges they are faced with, including Compliance Management, Maintenance, Infrastructure Management, Noise control and Emergency Management. The Norman Manley International Airport is no exception and will find GIS a useful tool to support these, as well as many other activities. The NMIA can expect significant benefits because of implementing an Airport Geographic Information Systems Database. This proposed GIS database will provide the Norman Manley International Airport staff community with a central access to all airport related information via the internet using ArcGIS.

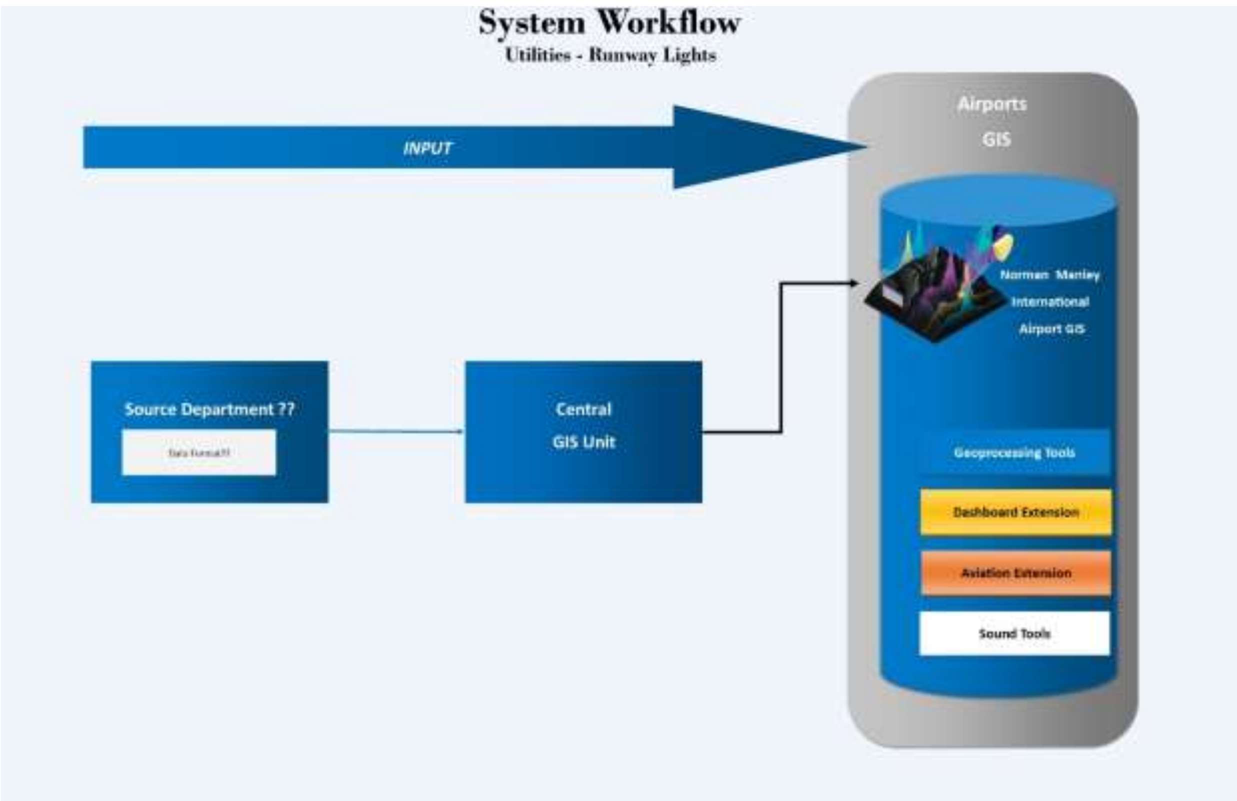


Figure 2.40 Proposed GIS Systems Workflow for Data Entry.

However, to meet NMIA's business objectives, bringing any existing data into operational use is a key first step. Existing datasets are required to have sufficient coverage and accuracy across the different operational areas (civil, electrical, etc.) to have a comprehensive overview of airport operations. It is for this reason we have begun the process of converting and verifying all available existing data. These spatial datasets (shapefiles, geospatial images, CAD drawings, reports, etc.) will then be uploaded to central geodatabase. Once the geodatabase has been published, various users across the airport may utilize the system to aid in the completion of their various tasks. Detailed methodologies have been provided below with how our GIS database will help to fulfill the following NMIA's business objectives.

- Air side and land side facilities.
  - Using the Standard ArcGIS Desktop software alongside proposed handheld GPS/ mobile devices, GIS can be used to identify and manage the various facilities found within each of these two (defined) zones. Here, each asset will be digitized and added to a central database. However, for the proper management of the facilities, one must first have access to the respective photographs, CAD drawings, compliance reports and maintenance surveys for each facility. Once populated, this central geodatabase can be shared as both a Map and Geodatabase service via ArcOnline – thus allowing it to be accessible to a wider audience. Once all the necessary data has been provided, this remote GIS database will allow users to update, store and access a variety of data related to each facility through simply clicking the asset.
- Capacity planning
  - Capacity planning can be facilitated for different scenarios, and for the different airport zones. Using the geodatabase, capacity information related to traffic, power consumption, and water availability may be populated and accessed for the various assets (buildings, roadways, etc) across the airport. This will then aid in the planning process through the provision of a visual representation of the maximum as well as daily distribution of personnel in the various areas across the airport. This then allows for assessment of the proper allocations of manpower and resources to these areas for both normal and extra-normal conditions. Capacity expansion can be simulated, and actual expansion information can be incorporated into the overall management GIS. These can inform training exercises, as well as orientations and operations resourcing, scheduling, and maintenance.

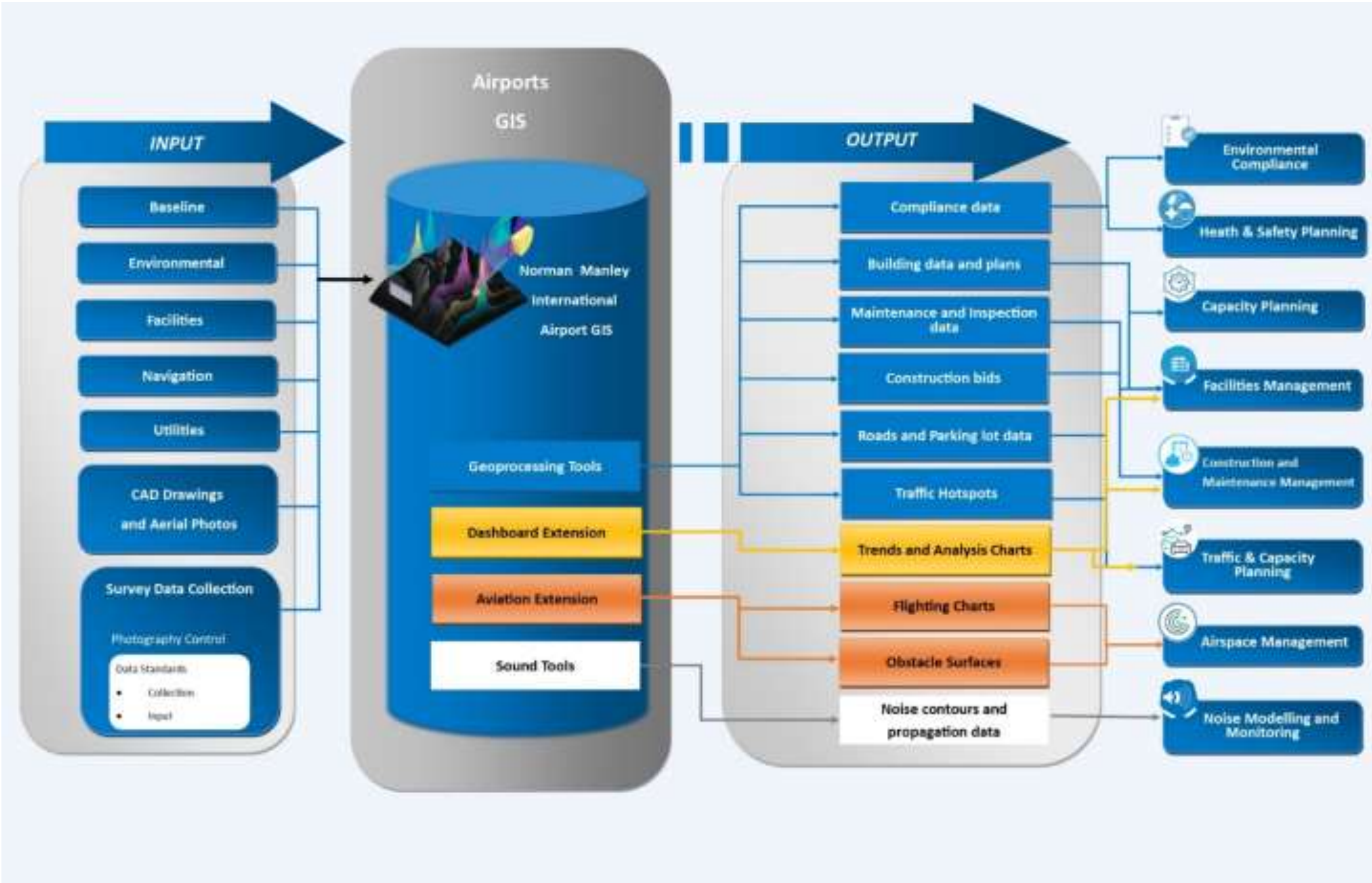


Figure 2.41 Conceptual overview of the proposed GIS Database System

- Model and monitor noise.
  - Utilizing the ArcMap Sound Tools, real-time sensors would feed information into the system as coordinates, which can then be incorporated and modelled as noise contours, either in isolation or in conjunction with other variables such as building dimensions and layout, atmospheric conditions and terrain data, Overtime, these generated contours alongside provided noise compliant reports can be used by the airport staff to monitor the propagation of the noise in the area as well as minimize the exposure of neighboring community residents to excessive noise.
- Track environmental compliance.
  - Environmental data such as air quality, water quality, runoff, solid waste, wind, rainfall and other hydro-meteorological data are all routinely measured by the airport and the Meteorological Office of Jamaica, and can be integrated with each other spatially and over time. Here, the locations of sensors as well as point- and network-based locations for the collection of environmental data (such as garbage bins, storm-water drains etc) across the airport can be incorporated in the geodatabase – thus providing users with on-demand or historical information, as well as the ability to create baselines for comparisons, for example, for peak usage or for any unusual activities. This will then allow the airport personnel to better manage its operations and provide an independent record when dealing with regulators.

- Manage construction and maintenance.
    - With construction and maintenance as routine parts of airport operations, ranging from major projects such as runway or terminal expansions, to the development of concession stands or changes to traffic flows, GIS allow for many operational uses. These include the management of building and property records, the integration of site plans with existing layouts, and the possible 3D model development which allows for easy visualization of plans with stakeholders. This proposed geodatabase system allows for the integration of CAD drawings with GPS surveys, along with satellite imagery, and spreadsheet records, all in a common and accessible platform.
- Plan traffic and capacity.
    - Through a similar process to the one outlined for the airside and landside facilities, the geodatabase provides the added functionality of integrating the digitized road layouts with traffic surveys. There, the provided data may be used to generate visual representation of flow volumes and peak traffic periods, as well as aid in the decision making process as it relates to infrastructural plans such as additional road lanes, parking areas, or signage, or for the realignment of existing flows and tasking of security personnel and other administrators. Moreover, the provided data can also be used in evacuation and emergency planning including the determination of staging areas and evacuation assembly areas.
- Have better command of airspace.
    - Using the ArcGIS Aviation extension, daily enroute and departure charts may be generated and uploaded to the geodatabase to aid the proper management of the airspace. This is as it provides a general idea of the expected air traffic and/ a complete listing or chart of all flights moving In and out of the Norman Manley International Airport on a day to day basis. Likewise, it also provides a means of integrating other airspace information such as local visibility measures, including low visibility coverage. Terrain and building elevations can also be factored in to determine visibilities from the airport, particularly from the air traffic control tower. Together, these datasets or layers can all be integrated in the creation of an Obstacle Limitation Surfaces model, thereby defining any obstruction to air navigation. Moreover, existing OLS models can be compared to the new model.
- Airspace management and permitting.
    - Similar to the process outlined above, the geodatabase provides users with the ability to access and generate reports of the daily planned enroute and departure charts as well as the hydro-meteorological information. Here, the hydro-meteorological information can be accessed in the form of satellite imagery with GPS data as well as ground survey data. In the end, these reports and visual charts will provide a means for better tracking and management of the airspace as well as aid in the decision – making process as it relates to the permitting of aircrafts in and out of our local airspace.
- Environmental compliance assessments.
    - Assessments, both internal and external (whether independent or regulators) can be facilitated in the geodatabase, since they will all involve access to common data and environments.
    - Even independent equipment should capture similar data to the airport's own sensors if the latter have been properly calibrated. If these are off, historical baselines and proper monitoring should detect deficiencies and allow for proper alerting and addressing of the problems.
- Weather routing and contingency planning.

- Using the Standard ArcMap Desktop or ArcMap Pro software, the future and existing weather and hydro-meteorological information, already being collected on-site at the airport, can be integrated into the airport GIS system. Systems already in place can use forecast information to predict potential impacts from weather systems and pre-position or re-position assets accordingly. Moreover, emergency protocols can also be activated based on an integrated situational assessment. This would facilitate operations management in the event of emergency diversions of aircraft outside of normal routine operations. Existing zones within the airport can be defined or redefined to allow for the parking of aircraft, as well as access planning for supplies, emergency vehicles and personnel.

2.7 Standard Operating Procedures

2.7.1 Purpose

This Standard Operating Procedure (SOP) provides technical guidance and procedures that will be employed to add a new data structure or asset to the NMIA Assets Data Dictionary.

2.7.2 Scope

These procedures apply to all personnel submitting data re: the creation of a data structure to represent new infrastructural developments and/ previously unrecorded infrastructure(s) at the Norman Manley International Airport. This will aid in the automation of the data collection process as well as the provision a general template of all recorded assets and their respective attributes. It is imperative that the duplication of data structures and data elements be avoided.

2.7.3 Responsibilities and Qualifications

The Consultant (GIS/GPS Asset Mapping Supervisor) will have the overall responsibility for implementing this SOP. He/ She will be responsible for ensuring that the procedures are followed accurately. All personnel performing these procedures are required to have a complete understanding of the procedures described within this SOP and to receive specific training regarding these procedures.

2.8 Equipment and Software List

For update to and use of the data dictionary, the entity MUST have in-house:

1. A valid Trimble GPS Pathfinder Office Software
2. Access to a computer with one of the following Operating Systems (OS): Microsoft Windows 2000 Professional or later, Microsoft Windows XP Home Edition, Microsoft Windows XP Professional Edition, Microsoft Windows Vista Business, Microsoft Windows Vista Home Basic, Microsoft Windows Vista Home Premium, Microsoft Windows Vista Ultimate
3. Trimble GPS units/ receivers

2.8.1 Procedure

This section provides a general summary of the procedures for incorporating new infrastructural features observed at the Norman Manley International Airport into the created NMIA Assets Data Dictionary. These procedures will be supplemented by training sessions with the AAJ/NMIA staff - providing recommendations and generally accepted conventions/practices.

1. Prior to the process of updating of the data dictionary, it is recommended that a small data gathering phase be completed. Here, the personnel will gain a general understanding of the features to be mapped as well as formulate a comprehensive list of the requited attribute data for the feature.
2. Once infield observations have been completed, using GPS Pathfinder Office, navigate to the Utilities tab and select the Data Dictionary Editor option. This will launch the data dictionary editor. Once the data dictionary editor window has opened, go to file > open. Navigate to the location of the original data dictionary file (NMIA_Asset_Collector.ddf), select it and click open. This should open the original NMIA Asset Data Dictionary.
3. To record or create a new feature to the data dictionary, click the “New Feature” button. In the associated pop-up window, input a name, and select the best feature (point, line, or area) to represent the new asset or infrastructure. A description can be provided for each feature via the comment field. Once all the necessary fields for the feature been populated for the feature, select ‘OK’.
4. The next step is to add the associated attributes. Attributes are the information about the feature that need to be recorded. To add each desired attribute, select the newly created feature and navigate to the “New Attribute”

button in the center pane. A prompt will be generated for the selection of the desired data type or format. The Pathfinder Office provides seven main attribute types namely:

a. Menu – creates picklists or checklists for a defined set of options.
b. Numeric– allows entry of numeric values. Minimum and maximum values help prevent incorrect entries.
c. Text– allows for letter and numbers to be added. It is limited by number of characters that can be entered.
d. Date– automatically populates the attribute with the current data.
e. Time– automatically populates the attribute with the current time.
f. File Name– associates a file with the feature such as a photo.
g. Separator– separates attributes and be used to group related attributes

5. Once the data type has been selected, a name and description should be provided via the "Attribute Name" and "Comment" fields, respectively. Likewise, regardless of the data type chosen, it is recommended that the default specifications (format or length) be updated to adequately for represent the data that will be entered each attribute. For example:
   - For an attribute such as description (text data type), it is best to set the length to 100 to ensure that there are enough characters available to properly document what might be observed in the field.
   - Similarly, a mandatory attribute for all created features would be the Latitude/Longitude coordinates. As a standard for this project, all coordinate data is recorded using the JAD2001 projection system. Thereby, this attribute would be best captured using the numeric data type with the decimal places option set to 6.
6. The final step is deciding whether data entry of the created attribute is mandatory infield or if can be supplied in the post-processing or update stage.
7. Once steps 4-6 have been completed, select 'OK". Subsequent new attributes can be created by repeating steps 4-7.
8. Should any personnel desire to update the data dictionary with numerous new assets or infrastructural features in one setting, once all the desired attributes have been added for the first created feature or asset, subsequent new features can be added by following steps 3-7.
9. At any point, should any adjustments be required to a particular feature, simply select the desired feature and click the "Edit Feature" button. Similarly, should any adjustments be required to a specific attribute, this can be achieved by selecting the desired feature, navigating to the desired attribute and clicking the "Edit Attribute" button.
10. Finally, once all updates to the data dictionary has been completed, navigate to file, select "Save as", provide a file name and press save.

2.8.2 Limitations in Using the Data Dictionary

The following are a few limitations to keep in mind when working with the GPS Pathfinder - Data Dictionary Editor:

1. There is a 20-character maximum length for the feature name, attribute name and menu attribute
2. There is a 255-character maximum length for a character string
3. There is a 6-character maximum length for a user code
4. There is a 40-character maximum length for comments.

2.8.3 Version Control System

It is recommended that a form of version control system be implemented to keep track of all updates to the data dictionary.

2.8.4 *Summary* of the *Standard Operating Procedure (SOP)*

In the automation of the data collection phase, a data dictionary dubbed the ***NMIA Assets Data Dictionary*** was created. This data dictionary provides the definitions and associated attribute fields of approximately forty (40) airport assets as stipulated in the ***Terms of Reference (TOR***). As the client seeks to properly monitor and document the future development of the Norman Manley International Airport, this ***Standard Operating Procedure (SOP)*** has been developed to provide the necessary personnel with the technical guidance and procedures needed for the updating and addition of new data structures to represent new infrastructural developments and/ previously unrecorded infrastructure(s) to the ***NMIA Assets Data Dictionary***.

3 Noise Exposure Maps and Land Use Compatibility Analysis

3.1 Background

The Norman Manley International Airport (NMIA) is the major gateway linking Jamaica's capital city to destinations worldwide (NMIA, 2008). The primary airport for business travel to and from Jamaica and for the movement of air cargo, NMIA 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.

The airport property covers 228 hectares and is located on the Palisadoes Peninsula between the communities of Harbour View and Port Royal (NMIAAL, 2008). It consists of the existing runway areas, public terminal and aircraft apron facilities, public access road and car parks, airside commercial development lands and areas used for airport and airline support functions. In addition, the property includes approximately 3 hectares, to the east, opposite the roundabout at the main entrance road.

The NMIA, which is bordered by the Kingston Harbour (7th largest natural harbour in the world), is located on a gently sloping to flat terrain. The topography of the site ranges from sea level at the Harbour's shoreline to approximately 10 feet midway the peninsula. The site's geomorphic and geological characteristic indicates a younger sediment formation (quaternary), consisting of coarse stipple and sand.

The NMIA is situated within the Palisadoes and Port Royal Protected Area (P-PRPA) which was declared a protected area under the Natural Resources Conservation Authority (NRCA) Act on 18 September 1998. The area is approximately 13,000 ha (130 km^2) in size and comprises the tombolo (Palisadoes), offshore cays, reefs and mangroves. The area was given protected status owing to its historic and archaeological sites of educational and cultural significance; spiritual values; natural resources as a basis for the livelihood for residents and other communities; unique ecosystems (sand/ dune, coral reef, lagoon, seagrass beds); nesting sites for sea turtles, birds and fish; protection and shelter prospects for small vessels/ boats during storms and hurricanes; and ability to act as a major local and international gateway i.e. by sea (seaports) and air (airports).

3.2 Literature Review

This review focuses on the noise impact from the operations of airports generally and more specific from the Norman Manley International Airport. It examines the possible impacts from noise pollution such as changes in the noise climate (environmental noise), nuisance factor and communication impacts.

3.2.1 Sound

Brüel & Kjær, a world leader in sound and vibration measurement and analysis states: Sound is such a common part of everyday life that we rarely appreciate all of its functions. It provides enjoyable experiences such as listening to music or to the singing of birds. It enables spoken communication with family and friends. It can alert or warn us; for example, with the ringing of a telephone or a wailing siren.

Sound also permits us to make quality evaluations and diagnoses — the chattering valves of a car, a squeaking wheel, or a heart murmur (Brüel & Kjær, 1984). Singal (2005) defines sound as an oscillation in pressure in an elastic medium, which is capable of evoking the sensation of hearing. Simply put it is any pressure variation in (air, water or other medium) that the human ear can detect.

3.2.1.1 *The Physics of and Propagation of Sound*

Sound propagation in air can be compared to ripples on a pond. The ripples spread out uniformly in all directions, decreasing in amplitude as they move further from the source.

Human audio frequency range (hearing range) from approximately 16 Hz up to 20,000 Hz (or 20 kHz) while the range from the lowest to highest note of a piano is 27.5 Hz to 4186 Hz. Sounds in the frequency range of 0.1 to 20 Hz are known as infra sounds, whilst frequency ranges above 20 kHz are known as ultrasound. The highest frequency of mechanical vibrations is found in atoms in the range of 10k million Hz. This is known as hypersonics. All three are inaudible to the human ear (Campbell, 2014).

Some persons will probably already have some idea of the speed of sound. There is a familiar rule for determining how far away a thunderstorm is from an observer. The observer would record the time period between seeing the lightning until hearing the thunder; and then assume 3 seconds per kilometre to determine the distance. This time interval corresponds to a speed of sound in air of 1,238 km h^{-1}. For acoustic and sound measurement purposes, this speed is expressed as ≈ 344 meters per second at 20°C. It is however higher in liquids and very high in solids (Campbell, 2014).

Chambers and Jensen (2004) suggested that in a free field, sound propagates with the velocity c (ms^{-1}) defined by: $c = 20.05\sqrt{T_k}$ *(m s^{-1})* (Chambers and Jensen 2004, 454). where T_k is temperature in Kelvin. A simpler formula for the velocity of sound in air sufficiently accurate at normal temperatures, 0 – 30°C is $c = 331 + 0.6T_c$. Where T_c is the temperature in centigrade. An example of the application of these formulas is given as follows: Determine the speed of sound at 20 °C. The Kelvin temperature (T_k) = 273.2 +20 = 293.2 K. Therefore, the speed of sound $c = 20.05\sqrt{293.2} = 343\ ms^{-1}$ or $c = 331 + 0.6(20) = 343\ ms^{-1}$

With Jamaica being a tropical country, air temperature rarely reaches 20 °C or below but typically averages 27 °C. Historically the temperature at the Norman Manley International Airport, averages 27.2 °C and range from a low of 23.9 °C to a high of 30.0 °C. Therefore, the speed of sound within the study area is typically 347.3 ms^{-1} but ranges between 345.3 – 349 ms^{-1} depending on the time of day, month of the year or weather conditions.

3.2.1.2 *Sound Pressure Levels and Loudness*

Chambers (2004) indicated that sound waves produce changes in the density of air which in turn produces pressure changes. The parameter lending itself to quantification is sound pressure, the incremental variation in pressure above and below atmospheric pressure. The human ear can detect sound pressures ranging from as low as 2 x 10^{-5} N/m^2 the threshold of hearing, to over 200 N/m^2, the threshold of pain (Chambers, 2004). To give you an indication, one atmosphere pressure is equivalent to 101,325 N/m^2 or Pascals. Therefore, the human ear can detect much less than 1 atmosphere change in pressure that is approximately one billionth of atmospheric pressure.

To represent this wide pressure range, a logarithmic scale is used to report sound pressures. This is stated as decibels (dB), which is a dimensionless unit used to report sound pressure level (SPL or L_p). It is called a level because it is an expression of a logarithm of a ratio which is defined by the following equation (Chambers 2004):

$$SPL = 20 \log (p / p_{ref}) \text{ decibels (dB)}$$

Where p is the measured root mean square sound pressure (N/m^2) and p_{ref} is the reference sound pressure, as 2 x 10^{-5} N/m^2.

Another reason for using dB is that the human ear tends to respond roughly in a logarithmic way to changes in stimulus intensity.

Loudness is a physical response of the human ear to sound pressure and intensity. It is a subjective evaluation of the intensity of the sound but is not dependent on the sound level alone but also on its frequency. Over the years numerous studies have been conducted on human perception of loudness of pure sounds and other sounds. Several authors developed various sets of equal loudness level contours commonly called envelopes of hearing (Kryter & Pearson, 1963); Robinson & Dadson, 1956; (Stevens 1957, 1961).

3.2.1.3 *Weightings*

The human ear does not respond to loudness non-subjectively. Instead the human ear and brain combine to have a subjective assessment of loudness using a complex relationship. It has been seen that the ear is not equally sensitive at all frequencies and is most sensitive between the 200 -300 Hz – 10 kHz range (Moller & Pedersen, 2004) and least sensitive at low frequencies (infra sound) and high frequencies (ultra sound and hypersonics) (Campbell, 2014).

To represent the subjectiveness of the human ear, weighting systems were developed for electronic circuits used to measure sound to vary with frequencies in the same manner as the ear. Three internationally standardized characteristics (IEC:651-1979), termed ‘A’, ‘B’ and ‘C’ weighting networks were developed. The ‘A’ network approximates the equal loudness curve at low SPL (40 Phon), the ‘B’ network corresponds to medium SPLs (70 Phon) and the ‘C’ network, which is more or less a linear behaviour, to high levels (100 Phon). (Singal, 2005, p. 44).

When sound pressure levels are weighted, they are expressed as dBA, dBB or dBC so as to distinguish them from one another. The dBA weighting is the most widely used for environmental measurements since the A weightings best approximates the human response. The dBB weighting is not used much, however the dBC is used for high amplitude tests for example in military test ranges.

3.2.2 Noise

Noise is an unwanted sound without agreeable musical quality. It is only when the effects of sound are undesirable that it may be termed as noise (Agarwal, 2009). It can be defined as unwanted /undesired sound or sound in the wrong place at the wrong time. It is considered a pollutant and can be measured. The definition of noise as unwanted sound implies that it has adverse effect on human beings and their environment, including land, structures and domestic animals. It can disturb natural wildlife and ecological systems (Agarwal, 2009).

However, the level of annoyance does not depend solely on the quality of the sound, but also our attitude towards it. The sound of his new jet aircraft taking off may be music to the ears of the design engineer but will be ear-splitting agony for the people living near the end of the runway. Sound does not need to be loud to annoy. A creaking floor, a scratch on a record, or a dripping tap can be just as annoying as loud thunder. Worst of all, sound can damage and destroy. A sonic boom can shatter windows, shake plaster off walls and cause furniture and crockery to rattle. But the most unfortunate case is when sound damages the delicate mechanism designed to receive it, the human ear.

The noise problems of the past are incomparable with those plaguing modern society; the roar of aircraft, the thunder of heavily laden lorries and the thumps and whines of industry provide a noisy background to our lives. But such noise can be not only annoying but also damaging to the health and is increasing with economic development (World Health Organization, 2009). Noise pollution has been described as the 'modern unseen plague' (Hume, 2010). It is generally accepted that the developed and developing countries are becoming noisier places (Hume, 2010). This is true of Jamaica, a developing country.

Typical Noise levels are listed in Table 3.1 below:

Table 3.1Typical Noise Levels

SOUND SOURCE	SOUND PRESSURE LEVEL (dBA)
12 Gauge Shotgun Blast	165
Jet engine at 100'	140
Air Raid Siren at 50 feet	120
Maximum Levels at Rock Concerts (Rear Seats)	110
On Platform by Passing Subway Train	100
On Sidewalk by Passing Heavy Truck or Bus	90
On Sidewalk by Typical Highway	80
On Sidewalk by Passing Automobiles with Mufflers	70
Typical Urban Area	60-70
Typical Suburban Area	50-60
Quiet Suburban Area at Night	40-50
Typical Rural Area at Night	30-40
Isolated Broadcast Studio	20
Audiometric (Hearing Testing) Booth	10
Threshold of Hearing	0

Source: (NYC Mayor's Office of Environmental Coordination, January 2012 edition (REV. 6/5/13))

3.2.2.1 *Descriptors Used in Noise Assessments*

3.2.2.1.1 General Measurement Descriptors

There are a number of descriptors used in noise assessments. These include Equivalent Sound Levels (Leq), L_{max} and L_{min}. Very rarely noises are constant, noise levels generally fluctuate and the unit of sound pressure level (dBA) normally reflects the sound pressure level at one instant in time. To describe fluctuating sound levels, the L_{eq} was developed. This represents the fluctuating noise heard over a specific time period as if it was a steady unchanging noise. The L_{eq} represents the constant sound level in a specific situation and time period (e.g. 1hour ($L_{eq\,(1)}$) or 24 hours ($L_{eq\,(24)}$ conveys the same sound energy as time varying sound.

L_{min} is the lowest instantaneous noise level during a specific period of time. The L_{max} may also be referred to as the "peak (noise) level." L_{max} is the highest SPL measured over a time interval. It may also be referred to as the "peak (noise) level." L_{max} (maximum A-weighted RMS sound level) is the greatest RMS (root-mean square) sound level, in dBA, measured during the defined measurement period. It can also be described as the maximum instantaneous sound pressure level generated by a piece of equipment (Campbell, 2014).

3.2.2.1.2 Community Noise Level Descriptors

The following sound level descriptors are commonly used in community noise measurements:

1. Day - Night Average Sound Levels (L_{dn} or DNL) is a 24-hour equivalent continuous level in dBA where 10 dB is added to night-time noise levels from the hours of 10:00 p.m. to 7:00 a.m. before being averaged. It accounts for the moment to moment fluctuations in a weighted noise levels over a 24-hour period due to all noise sources. The L_{dn} represents the averaging of the Leq (1) over the 24-hour period with the penalty added.

2. Community Noise Equivalent Levels (CNEL) is a 24-hour equivalent continuous level in dBA where 5 dBA is added to evening noise levels from 7:00 p.m. to 10:00 p.m. and 10 dBA is added to night-time noise levels from 10:00 p.m. to 7:00 a.m.

Persons expect quiet environment at nights so that their bodies can get rest, recuperate and rejuvenate so that they can function at optimum the next day. It is the importance of this rest why the descriptors Ldn and CNEL place a penalty on the evening and night-time noise levels.

3.2.3 Effects of Noise

3.2.3.1 *Biological*

A review of studies conducted on environmental and industrial noise between the years 1993 – 1998 by Stansfeld et al. (2000) found that the question of whether environmental noise exposure causes mental ill-health is still largely unanswered. It found that recent community-based studies suggested that high levels of environmental noise were associated with mental health symptoms such as depression and anxiety but not with impaired psychological functioning.

Noise and mental health studies before 1993 showed inconsistencies as it related to environmental noise and mental health outcomes. There were consistent results for less severe outcomes, namely psychological symptoms.

Three studies indicated that high levels of aircraft noise resulted in reports of `headaches', 'restless nights', 'irritability' and being 'tense and edgy' (Finke et al. 1974; Kokokusha 1973; OPCS 1971). However, Grandjean et al. (1973) conducted a study around three Swiss airports but made no explicit links between aircraft noise and health. They did not find any association between noise and symptoms. On the other hand The West London Survey found depression, irritability, waking at night and difficulty getting to sleep was more common as acute symptoms (within the last two weeks) in high aircraft noise exposed areas, but as chronic symptoms in low noise areas. Tarnopolsky, Watkins, and Hand (1980) postulated that the apparent contradiction may be explained by poorer pre-existing ill-health, probably related to high levels of social disadvantage rather than specifically to noise, in the low noise areas, leading to more chronic symptoms.

The frequency of noise determines its potential impact on humans:

Low frequency noise causes extreme distress to a number of people who are sensitive to its effects. Such sensitivity may be a result of heightened sensory response within the whole or part of the auditory range or may be acquired (Leventhall, 2003).

Early work (late 1950s to 1960s) on low frequency noise was started by the American Space programme as astronauts were experienced to these sounds in their launch vehicles (spaceships). These vehicles produced their maximum noise energies in the low frequency range. This occurred approximately two minutes after lift-off as the crew compartment experience boundary layer turbulence noise. Therefore, studies were conducted to determine what if any were the impact(s) on such an exposure. From these experiments two conclusions were drawn. The first was that short term exposure to noise of 140 to 150 dB in the frequency range of up to 100Hz was tolerable once the subject is experienced in noise exposure and was wearing ear protection. The second was that they could tolerate both broadband and discrete frequency noise in the range 1Hz to 100Hz at sound pressure levels up to 150dB.

Later work suggests that, for 24 hour exposure, levels of 120-130dB are tolerable below 20Hz. These limits were set to prevent direct physiological damage (Gierke and Nixon 1976; Mohr et al. 1965; Westin, 1975). It is important to note that these levels are below what would be experienced in a home from environmental, traffic, industrial and other noise sources.

After the mid-1960s there was a misconception that low frequency noise known as infrasound or the 'silent sound' was responsible for many misfortunes. An alternative explanation had not yet been found for example brain tumours, cot deaths and road accidents. This misconception was further fuelled by some press headlines during that:

1. The Silent Sound Menaces Drivers, *Daily Mirror*, October 19, 1969
2. Does Infrasound Make Drivers Drunk, *New Scientist*, March 16, 1972
3. Brain Tumours 'caused by noise', *The Times*, September 29, 1973
4. Crowd Control by Light and Sound, *The Guardian*, October 3, 1973
5. Danger in Unheard Car Sounds, *The Observer*, April 21, 1974
6. The Silent Killer All Around Us, *Evening News*, May 25 1974
7. Noise is the Invisible Danger - *Care on the Road (ROSPA)* August 1974 (Leventhall, 2003)

The WHO recognises low frequency noise as an environmental problem. In their publication on Community Noise; Berglund et al. (1999), made several references to this.

Low frequency noise occurs between 10 – 200Hz, while infrasound is noise from 20 Hz and below. It is widely thought that infrasound cannot be heard, however, it has been shown that frequencies below 20 Hz are audible. Tonality is lost below 16-18 Hz resulting in the loss of a key element on perception. Both low frequency noise and infrasound are produced by machinery (rotational and reciprocating), all forms of transportation and turbulence (Leventhall, 2003). Typical sources might be pumps, compressors, diesel engines, aircraft, shipping, combustion, air turbulence, wind and fans.

Attenuation of sound in air is very low at low frequencies. Other attenuating factors, such as absorption by the ground and shielding by barriers, are also low at these frequencies. The net result is that the very low frequencies of infrasound are not attenuated during propagation as much as higher frequencies, although the reduction in intensity due to spreading out from the source still applies. This is a reduction of 6dB for each doubling of distance. Wind and temperature also affect the propagation of sound.

Attenuation of low frequency noise in air or other medium is greater than that of infrasound because of the higher frequencies. As with infrasound, there is reduction of 6dB per doubling of distance due to spreading out of the wave and any other reduction which might occur due to absorption over the ground or by shielding. At low frequencies, air attenuations are a small contributor to losses, as a result, noise which has travelled over long distances is normally biased towards the low frequencies.

3.2.3.2 *Annoyance*

A central effect of noise is annoyance. Annoyance is defined as a feeling of discomfort which is related to adverse influencing of an individual or a group by any substances or circumstances. Annoyance expresses itself e.g., by malaise, fear, threat, trouble, uncertainty restricted liberty experience, excitability or defencelessness. With chronically strong annoyance, a causal chain may exist between the three steps: health - annoyance - disease (Niemann & Maschke, 2004). Noise annoyance encompasses broad psychological feelings which include irritation, discomfort, distress, frustration, and offence (among others) when it interrupts a person's psychological state or ongoing activities and interferes with an individual's quality of life (Seabi, 2013).

In the European Member States, noise from transportation is by far the most widespread source of noise exposure, causing most annoyance and public health concerns (Wolfgang, 2011). Over the years research has shown that environmental noise may have serious adverse effects on cognition and health (e.g., Stansfeld, et al., 2005). An important index of these effects is annoyance (e.g., Ouis, 2001).

The effect of annoyance on age is described by inverted U-shaped curves. The relatively young, as well as relatively old individuals, report less annoyance than people of intermediate ages do. The largest number of highly annoyed individuals was found in the middle-aged segment of the sample peaking around 45 years (van Gerven et al. 2009).

3.2.3.3 *Cardiovascular Disease*

The cardiovascular effects of noise have been the source of growing interest in recent years. This is because on the one hand evidence has increased that noise affects cardiovascular health. On the other hand, high blood pressure and ischemic heart diseases (including myocardial infarction) have a high prevalence in industrialized countries and are a major cause of death (Lopez, Mathers, Ezzati, Jamison, & Murray, 2006). The question at present is no longer whether noise causes cardiovascular effects, it is rather: what is the magnitude of the effect in terms of the exposure-response relationship (slope) and the onset or possible threshold (intercept) of the increase in risk (Wolfgang, 2011).

Most environmental epidemiological noise studies been carried out in The Netherlands, Sweden, the United Kingdom, Serbia and Germany. It is well understood that noise levels below the hearing damaging criterion cause annoyance, sleep disturbance, cognitive impairment, physiological stress reactions, endocrine imbalance, and cardiovascular disorders (Wolfgang, 2011). The general stress theory is the rationale for the hypothesis that noise affects the autonomic nervous system and the endocrine system, which in turn affects the homeostasis of the human organism.

In Sweden, traffic noise is an important environmental health issue. Almost two million persons in Sweden are exposed to average noise levels exceeding the outdoor national guideline of 55 ($L_{Aeq,24h}$). Despite efforts to reduce the noise burden, noise-related health effects, such as annoyance and sleep disturbances, are increasing (Bluhm & Eriksson, 2011). The majority of the studies in Sweden on cardiovascular outcomes have been on noise related to road or aircraft traffic with only a few studies on railway noise. Swedish studies on road traffic noise support the hypothesis of an association between long-term noise exposure and cardiovascular disease. However, the magnitude of effect varies between the studies and has been shown to depend on factors such as sex, number of years at residence, and noise annoyance. No association has been found between railway noise and cardiovascular diseases (Bluhm & Eriksson, 2011).

One proposed biological mechanism for the possible causative relation between noise and cardiovascular diseases is that noise causes the release of stress hormones, which in turn affect the cardiovascular risk factor pattern (Babisch, 2003; Bigert, Bluhm, & Theorell, 2005). Glucocorticoid hormone cortisol is the main secretory product of the neuroendocrine cascade and a good indicator of stress (Bluhm & Eriksson, 2011).

The Hypertension and Exposure to Noise near Airports (HYENA) project conducted by Jarup, et al., 2005 aimed at assessing the cardiovascular health effects of noise related to aircraft and road traffic. One of its aims was to investigate the use of saliva cortisol as a possible marker for noise induced stress. A subsample of 439 subjects of this project indicated that:

A significant elevation in morning saliva cortisol level was observed in women exposed to aircraft noise levels above 60 dB (LAeq,24h), in comparison to women exposed to noise levels lower than 50 dB (L Aeq,24h). No association between noise exposure and saliva cortisol levels was found in men (Selander , et al., 2009).

The study also found that employment status appeared to have a modifying effect on the response. Employed women had higher morning saliva Cortisol levels than did retired women, particularly among those with high exposure to aircraft noise (Selander , et al., 2009). This effect could be a result of disrupted sleep during the night and lack of recovery during the day due to employment. It could also be a result of stressful activities related to employment.

A subset of the HYENA study that looked at the Swedish portion found:

The Swedish part of this saliva cortisol study comprised of 85 study participants, who were selected to ensure a satisfying contrast in aircraft noise exposure. Among women, there was an increase of 1.09 nmol/l (95% CI - 0.12, 2.31) in the morning saliva cortisol level per 5 dB(A) increase in noise exposure. No association between noise exposure and saliva cortisol levels was found in men (Bluhm & Eriksson, 2011)

Two studies, one in Stockholm County and the other from the west of Sweden, saw no indication of an increased prevalence of hypertension related to railway noise exposure (Barregard et al. 2009). There was a clear association between self-reported annoyance and sleep disturbances and the estimated noise exposure levels with increased railway traffic. However, there were no differences in annoyance due to age or gender.

As it relates to road noise, there was an association between road traffic noise and hypertension in the HYENA project. A significant relationship between average road traffic noise exposure and risk of hypertension was found in men, but not in women (Bluhm & Eriksson, 2011). In the Swedish part of this investigation, a country-specific odds ratio (OR) of 1.3 (95% CI 1.0, 1.7) per 10 dB increase in road traffic noise exposure ($L_{Aeq\ 24h}$) was found for hypertension (Bluhm & Eriksson, 2011). A statistically significant association was found between a road traffic noise exposure above 55 dB(A) and self-reported treatment for hypertension (Barregard, Bonde, & Öhrström, 2009).

Experimental studies on humans and epidemiological studies conducted on the adult and children population of Belgrade and Pancevo, Serbia started in 2002. The studies found that experimental exposure to noise [Leq = 89 dB (A)] had a hypodynamic effect, significantly lowering the cardiac index, cardiac work, and pump performance (P <0.01). The vasoconstrictive effect of noise was shown through the significant elevation of after-load (P <0.01). In a cross-sectional population study that was carried out on 2874 residents [1243 males and 1631 females] in Pancevo City, a significant odds ratio (adjusted for age, body mass index (BMI), and smoking habits) was found for self-reported hypertension (OR = 1.8, 95% CI = 1.0 - 2.4, P <0.01) in men with a high level of noise annoyance compared to those with a low level of noise annoyance. In another study on 2503 residents (995 men and 1508 women) residents of Belgrade, the proportions of men with hypertension in the noisy [(L night , 8h >45 dB (A)] and quiet areas [(L night , 8h <45 dB (A)] were 23.6% and 17.5%, respectively. The adjusted odds ratio (OR) for hypertension of the exposed group was 1.58 (95% CI = 1.03 - 2.42, P = 0.038), where men living in quiet streets were taken as a reference category.

Associations between road traffic noise and blood pressure were also investigated in 328 preschool children in Belgrade. The systolic blood pressure was significantly higher among children from noisy residences and kindergartens, compared to children from both quiet environments (97.30 +- 8.15 and 92.33 +- 8.64 mmHg, respectively, P <0.01). As a continuation of the study on preschool children, investigations were also carried out on 856 school children, aged between seven and eleven years, in Belgrade. It found that systolic pressure was significantly higher among children from noisy schools and quiet residences, compared to children from both quiet environments (102.1 +- 9.3 and 100.4 +- 10.4 mmHg, respectively, P <0.01) (Belojevic, et al., 2011).

Men living in the noisy areas had a higher risk of hypertension compared to men from quiet areas, after adjustment for the relevant factors. The proportions of men with hypertension in the noisy and quiet areas were 23.6 and 17.5%, respectively. The adjusted odds ratio (OR) for hypertension of the exposed group was 1.58 (95% CI = 1.03 - 2.42, P = 0.038) when men living in quiet streets were taken as a reference category. This relation was statistically insignificant for women (Belojevic, et al., 2011).

Since 1970, 14 Dutch studies were published which investigated the possible impact of road traffic (6 studies), aircraft noise (6 studies) and both aircraft and road noise (2 studies) exposure on the cardiovascular system. Within these studies a large variety of outcomes were investigated, ranging from blood pressure changes to cardiovascular mortality. The effect of road traffic noise exposure on hypertension was inconsistent and rather small with relative risk (RR) 5dB ranging from 0.96 to 1.02 (van Kempen, 2011). A wide range of effects were investigated. These were blood pressure, hypertension, use of anti-hypertensives and / or cardiovascular medicines, angina pectoris, myocardial infarction, consultation of GP / specialist, coronary heart disease, and cardiovascular mortality. The estimated RR 5dB ranged from 0.87 to 1.29. A positive association between aircraft noise exposure during the day-evening-night period and the prevalence of the use of cardiovascular medicines was found with an estimated RR 5dB ranged from 0.95 to 1.26. Three studies also investigated the effect of night-time exposure, where an RR 5dB ranging from 1.05 - 1.17 was found (van Kempen, 2011).

Other studies in the United Kingdom and Austria showed weak association with hypertension and road traffic noise in men and no such association in women, but positive associations with aircraft noise (Lercher, Botteldooren, Widmann, & Kammeringer, 2011; (Stansfeld & Crombie, 2011). The Dutch studies found a positive association between aircraft noise exposure during the day-evening-night period and the prevalence of the use of cardiovascular medicines.

Children are often considered a vulnerable risk group because they have less control over the environment than adults. The studies showed (primarily systolic) blood pressure increases in children exposed to aircraft and road traffic noise. The studies, however, were not always consistent (Wolfgang, 2011).

3.2.3.4 *Sleep*

During sleep the auditory system remains fully functional. Incoming sounds are processed and evaluated and although physiological changes continue to take place (World Health Organization, 2009), sleep itself is protected because awakening is a relatively rare occurrence. Sleep is an essential need for living creatures. It is needed for the restorative function where the body gets to repair and rejuvenate itself. Sleep deprivation can lead to a myriad of physical, psychological, emotional and mental problems. It also affects learning and memory functions. A sleep deprive individual may exhibit the following symptoms: irritability, cognitive impairment, memory lapse or loss, impaired moral judgement, severe yawning, hallucinations and impaired immune system.

While social surveys have found that annoyance is the most frequent effect of noise, noise induced sleep disturbances are regarded as the most deleterious (Griefahn & Spreng, 2004). The sleep-wake cycle is the most significant sign of the circadian rhythm, which develops during the first months of life in humans. Total sleep time alters dramatically during lifetime. A new-born baby sleeps up to 16 hours a day but as they grow older daily sleep time decreases rapidly. Young children exhibit 11 to 12 hours of sleep, school children approximately 10 hours, adults between 7 and 8 hours, whereas aged people sleep no more than 5 to 6 hours. The inter-individual variability is, however, huge, where sleep time ranges between 2 and 12 hours whereas the intra-individual sleep duration is rather stable (Griefahn & Spreng, 2004). Sleep can be broken down into two main portions: REM-sleep (paradoxical sleep, dream sleep) and non-REMsleep (NREM). REM and non-REM sleep alternate periodically, thus structuring sleep into 4 to 6 cycles of 90 to 100 minutes each (Griefahn & Spreng, 2004).

Sleep disturbances may be divided into:

1. Those related to underlying diseases thus requiring causal therapy; and
2. Sleep disturbances that are caused by environmental influences thus allowing prevention by an adequate design of the environment (Griefahn & Spreng, 2004).

Noise induced sleep disturbances are determined by the acoustic characteristics of the impinging noises as well as by individual and situational factors. The informational content, acoustic parameters and individual, biorhythmic, and situational characteristics all play a role in determining the impact of noise on an individual(s). The informational content of the noise is determined by the person(s) experience with the particular noise, and also the physical parameters of the noise. Over a period of time the informational content may change and become either less or more significant to an individual. This may result in habituation (a decrease in response to a stimulus after repeated presentations) as well as sensitization (Campbell, 2014).

The reaction to noise pollution is dependent on individuals' differences and traits. Persons who are sensitive to noise or have neurotic tendencies tend to have stronger reactions. The type of noise (Continuous/Steady, Intermittent or Impulse) and the age of persons determine the influence/reactions:

The temporal distribution of noises has a considerable influence on the reaction. Noise emissions from aircraft, rail and road traffic are same equivalent noise level, however, the intermittent noise form air and rail traffic disturbs much more than the noise from continuous caused by high- density road traffic. Stronger effects are also registered in aged people whose overall time awake is scarcely longer in noisy than in quiet nights but who attribute the time awake more often to noise intrusion. Contrary to a common belief, children are much (about 10 dBA) less sensitive than adults, whereas gender has no influence on the susceptibility to noise (Griefahn & Spreng, 2004).

Sleep disturbance, especially with regard to time to fall asleep and tiredness in the morning are commonly reported by persons exposed to low frequency noise (20 -200Hz). Owing to the low attenuation, low frequencies may propagate for long distances, with little attenuation apart from distance. Low frequencies will also pass with little attenuation through walls and windows. Low frequency noise causes structure borne vibrations which causes glass and plates to rattle which is in turn heard. This is also called the "plate and rattle effect" (Campbell, 2014).

Numerous studies have shown the low frequency at comparatively low sound pressure levels, disturbs sleep.

In 1999 Verzini et al. found that the energy content of 20 to 160 Hz was significantly related to sleep disturbance, concentration difficulties, irritability, anxiety and tiredness (quoted in Waye, 2004).

Ising and Ising (2002) found in children a significant correlation was found between the maximum levels of low frequencies in the noise, measured as L_{Cmax} , and urine cortisol levels sampled in the first half of the night, while no correlation was found between noise exposure and the excretion of urine cortisol in the second half of the night. The increase of cortisol during the first half of the night was furthermore significantly related to impaired sleep, memory and ability to concentrate (Ising & Ising, 2002).

Different indices have been used to describe various types of community noise exposure, and there is no general agreement on which should be preferred among the various integrated energy indices (LAeq, LDN, LDEN, and Lnight), statistical indices (L10, L50,...), or event indices (LAmax, Sound Exposure Level: SEL, Number of Noise Events: NNE,...) (Finegold, 2010).

The WHO Regional Office for Europe published Night Noise Guidelines for Europe (NNGL) in October 2009 (WHO 2009). They recommended a night time noise guideline ($L_{night, outside}$) of 40 dBA where lowest observed adverse effect level (LOAEL) for night noise is seen to prevent any adverse health effects from night time noise. An interim level of 55 dBA is recommended if the $L_{night, outside}$ cannot be immediately met. They also observed that below a level of 30 dB $L_{night,outside}$, no effects on sleep were observed except for a slight increase in the frequency of body movements during sleep due to night noise (World Health Organization, 2009).

There is no sufficient evidence that the biological effects observed at the level below 40 dB L night are harmful to health. However, adverse health effects are observed at the level above 40 dB L night, such as self-reported sleep disturbance, environmental insomnia and increased use of sleeping pills and sedatives (Rokho & Martin van den, 2010).

There are few studies on noise effect on sleep from non-traffic related sources. A review of these studies has indicated noise such as sounds made by neighbours, conversations, laughter, music, slamming doors, structural equipment, ventilation, heat pumps, animals, outdoor events, etc., had some definite effects while some were more inconclusive with others. More studies of all types of these selected ambient noise sources of appropriate quality for quantitative analysis are consequently needed (Omlin, Bauer, & Brink, 2011). Currently there are no studies conducted in Jamaica on the effect of night-time noise on sleep disturbance.

3.2.3.5 *Cognitive Skills*

A review of the literature on noise and health in vulnerable groups by van Kamp and Davies (2013) found that among 10-year-old schoolchildren in France, school noise exposure was associated with fatigue, headaches and higher cortisol level indicative of a stress reaction. These findings were also supported by a Swedish study (Wålinder , Gunnarsson , Runeson R, & Smedje , 2007), which found increased prevalence of fatigue, headache and reduced diurnal cortisol variability in relation with classroom Leq during school day levels between 59 and 87 dBA.

A cross-sectional study in Nigeria found at least some annoyance and concentration disturbance in 70% of the children frequenting a school near a major road (noise range: 68-85 dBA) (Ana , Shendell , Brown, & Sridhar, 2009). Fatigue and lack of concentration were the most prevalent noise-related health problems.

Parra et al. (2010) reported that in people over 60 years of age living in Bogota, road traffic noise was negatively related to both the physical and the mental dimension of health-related (HR) quality of life.

Based on the Road Traffic and Aircraft Noise Exposure and Children's Cognition and Health study (RANCH), research of exposures around three major European airports, found that exposure at home was highly correlated with aircraft noise exposure at school and demonstrated a similar linear association with impaired reading comprehension after adjustment for a range of confounders (Clark, et al., 2006). Kaltenbach , Maschke , & Rainer , (2008) found exposure to aircraft daytime noise of 50 dBA and over to be associated with learning difficulties in school children. Road traffic noise exposure at school was not associated with reading comprehension in the RANCH study (Clark, et al., 2006). Ljung, Sörqvist, & Hygge, (2009) concluded that road traffic noise impaired reading speed and basic mathematics but had no effect on reading comprehension or on mathematical reasoning. Klatte , Meis , Sukowsk, & Schick, (2007) found that serial recall of visually presented digits was severely disrupted by background irrelevant speech. Train noise exposure did not show comparable effects. Shield & Dockrell, (2008) related in and outside noise exposure at school with standard test scores for literacy, mathematics and science in children aged 7-11 years in London.

3.2.3.6 *Learning*

One of the main objectives of children is to learn. Most of this learning takes place through attending verbal auditory information. When there is high noise level either from external or internal sources, there is a reduction in the signal/noise ratio (the sound level of what is being communicated relative to the sound level of the background) which makes it more strenuous and difficult to grasp what is being communicated. The result is that the students cannot hear clearly what the teacher is saying because he/she is not speaking loud enough. Reverberation (reflected sound from ceiling and walls) can obscure the auditory sound information. The noise emitted from a power plant has the potential to affect (reduce) the signal/noise ratio in classrooms and as such may affect learning in schools.

WHO recommended a 35 dBA noise levels for community learning (school) environments (Ana , Shendell , Brown, & Sridhar, 2009). This is based on signal- to-noise ratio of +15 dB. That is the speech should be at least 15 dB above the background noise level to make it intelligible (95% speech intelligibility or better) (Bradley & Sato, 2008). This assumes that the normal conversation/speech level of 55 dBA.

The comprehension of a verbal communication depends on the linguistic and cognitive abilities of the person receiving the message. Adults and children with a good grasp of the language have the ability to fill in the gaps of an incomplete message and deduce its content. Younger children have greater difficulty understanding speech in even modest levels of ambient noise (Campbell, 2014).

Several authors have reported results showing that the ability to recognize speech in noise improves systematically with age. It is clear that children need quieter conditions and corresponding larger signal-to-noise ratios than adults to achieve high speech recognition scores and that the younger the children, the quieter the conditions should be (Bradley & Sato, 2008).

The inability of younger children to understand many of the words a teacher speaks must make it more difficult for children to learn new concepts. There is a growing literature of results indicating that increased noise levels are associated with a number of educational factors such as delayed reading ability, effects on memory and student behaviour (Bradley and Sato 2008). For children with hearing problems, learning difficulties, with a different native language etc., the problem of comprehending a verbal message is exacerbated.

Emerging evidence suggests that meaningful irrelevant speech does produce disruption in tasks in which meaning is used as the basis for retrieval. Evidence has suggested that noise in learning environments has considerable effect on the learning abilities and the general productivity of children in terms of their academic performance as compared to children in serene learning environments (Ana et al. 2009).

There are no studies conducted in Jamaica on the effect of noise on health. There are also no studies on noise emissions from various sources, noise annoyance, signal to noise ratios, the effects on children (cognitive skills, etc.).

3.2.4 Noise Guidelines and Standards

3.2.4.1 *International*

3.2.4.1.1 World Health Organization (WHO)

The WHO prepared the Guidelines for Community Noise in a response to the realization that an increasing number of persons are being exposed to noise levels that are considered detrimental to health as a result of urbanization and industrialization. The guidelines outlined in Table 3.2 are arranged according to specific environments and critical health effects and the need to protect health.

Table 3.2 Guideline values for community noise in specific environments

SPECIFIC ENVIRONMENT	CRITICAL HEALTH EFFECT(S)	L Aeq [dB(A)]	Time base [hours]	L Amax fast [dB]
Outdoor living area	Serious annoyance, daytime and evening Moderate annoyance, daytime and evening	55 50	16 16	- -
Dwelling, indoors Inside bedrooms	Speech intelligibility & moderate annoyance, daytime & evening Sleep disturbance, night-time	35 30	16 8	45
Outside bedrooms	Sleep disturbance, window open (outdoor values)	45	8	60

School classrooms & pre-schools, indoors	Speech intelligibility, disturbance of information extraction, message communication	35	during class	-
Pre-school bedrooms, indoor	Sleep disturbance	30	Sleeping time	45
School, playground outdoor	Annoyance (external source)	55	during play	-
Hospital, ward rooms, indoors	Sleep disturbance, night-time Sleep disturbance, daytime and evenings	30 30	8 16	40 -
Hospitals, treatment rooms, indoors	Interference with rest and recovery	#1		
Industrial, commercial shopping and traffic areas, indoors and outdoors	Hearing impairment	70	24	110
Ceremonies, festivals and entertainment events	Hearing impairment (patrons:<5 times/year)	100	4	110
Public addresses, indoors and outdoors	Hearing impairment	85	1	110
Music and other sounds through headphones/ earphones	Hearing impairment (free-field value)	85 #4	1	110
Impulse sounds from toys, fireworks and firearms	Hearing impairment (adults) Hearing impairment (children)	-- --	-- --	140 #2 120 #2
Outdoors in parkland and conservations areas	Disruption of tranquillity	#3		

- #1: As low as possible.
- #2: Peak sound pressure (not LAF, max) measured 100 mm from the ear.
- #3: Existing quiet outdoor areas should be preserved and the ratio of intruding noise to natural background sound should be kept low.
- #4: Under headphones, adapted to free-field values.

Source: (Berglund, Thomas, & Dietrich, 1999)

3.2.4.1.2 International Finance Corporation (IFC)/World Bank (WB)

The IFC is a member of the World Bank Group, has developed Environmental Health, and Safety (EHS) Guidelines to guide new developments in which there are investing in. These EHS guidelines are technical reference documents with general and industry-specific examples of Good International Industry Practice (GIIP).

In addition to the guidelines, the IFC has a 3 dBA rule; which states that noise impacts should not exceed the levels presented in Table 3.3, or result in a maximum increase in background levels of 3 dB at the nearest receptor location off-site. An example is; if the noise level before the addition of the new noise source was 70 dBA, and the addition of the new source results in the cumulative (overall) noise level of 73 dBA; then the source is considered compliant as it relates to noise. This is allowed as most persons will not perceive a change in noise levels at 3 dBA.

Table 3.3 IFC/World Bank Noise Guidelines

RECEPTOR	ONE HOUR L_{Aeq} (dBA)	
	DAYTIME 07:00 - 22:00	**NIGHTTIME 22:00 - 07:00**
Residential; institutional; educational	55	45
Industrial; commercial	70	70

Source: (International Finance Corporation, 2007)

3.2.4.1.3 European Night Noise Guideline

The Regional Office for Europe of the WHO developed a health-based limit value as the Night Noise Guidelines (NNG) of 40 dB $L_{night,outside}$, necessary to protect the public (Table 3.4), including most of the vulnerable groups such as children, the chronically ill and the elderly, from the adverse health effects of night noise. Health effects are observed at the level above 40 dB$L_{night,outside}$, such as self-reported sleep disturbance, environmental insomnia, and increased use of somnifacient drugs and sedatives (World Health Organization, 2009).

An interim target (IT) of 55 dB $L_{night,outside}$ (Table 3.4) is recommended in the situations where the achievement of NNG is not feasible in the short run for various reasons. It should be emphasized that it is not a health-based limit value by itself. Vulnerable groups cannot be protected at this level as at 55 dB, the cardiovascular effects become the major public health concern, which are likely to be less dependent on the nature of the noise (World Health Organization, 2009).

Table 3.4 Recommended night noise guideline for Europe (Source: World Health Organization, 2009)

GUIDELINE	GUIDELINE LEVEL
Night noise guideline (NNG)	$L_{night,outside}$ = 40 dB
Interim target (IT)	$L_{night,outside}$ = 55 dB

3.2.4.1.4 United States Environmental Protection Agency (USEPA)

The USEPA identified noise levels consistent with the protection of public health and welfare against hearing loss, annoyance and activity interference (Table 3.5). The established levels factors in the balance between costs and benefits associated with setting standards at particular noise levels, the nature of the existing or projected noise problems in any particular area, the local aspirations and the means available to control environmental noise (Office of Noise Abatement and Control 1974).

Table 3.5 Yearly average equivalent sound levels identified as requisite to protect the public health and welfare with adequate margin of safety

AREAS		INDOOR			OUTDOOR		
	Measure	Activity interference	Hearing loss considerations	To protect against both effects	Activity interference	Hearing loss considerations	To protect against both effects
Residential with Outside Space and Farm Residences	L_{dn} $L_{eq(24)}$	45	70	45	55	70	55
Residential with No Outside Space	L_{dn} $L_{eq(24)}$	45	70	45			
Commercial	$L_{eq(24)}$	a	70	70c	a	70	70c
Inside Transportation	$L_{eq(24)}$	a		a			
Industrial	$L_{eq(24)}$	a	70	70c	a	70	70c
Hospitals	L_{dn} $L_{eq(24)}$	45	70	45	55	70	55
Educational	$L_{eq(24)}$ $L_{eq(24)}$	45	70	45	55	70	55
Recreational Areas	$L_{eq(24)}$	a	70	70c	a	70	70c
Farmland and General Unpopulated Land	$L_{eq(24)}$				a	70	70c

Code: a – Since different types of activities appear to be associated with different levels, identification of a maximum level for activity interference may be difficult except in those circumstances where speech communication is a critical activity. c – Based on hearing loss. Source: (Office of Noise Abatement and Control, 1974)

3.2.4.2 *Local*

In Jamaica, there are two pieces of legislation that govern the regulation of noise pollution. These are the Noise Abatement Act and the National Resources Conservation Authority's (NRCA) Standard.

3.2.4.2.1 Noise Abatement Act (March 26, 1997)

This Act is otherwise known to the public as the "Night Noise Law". It defines public and private places, outlines what is considered annoyance, the time period in which these noise generating activities can take place, at what distance from a receptor it can take place and the penalties for contravening the Act.

A criticism of the Act is that it does not outline a quantitative noise level by which the Act is to be enforced but instead is subjective to the enforcer as it outlines if the noise is heard within 100m from the source in such a manner that its audible then it is reasonably capable of causing annoyance to persons in the vicinity (Government of Jamaica [GoJ] 1997).

3.2.4.2.2 National Resources Conservation Authority (NRCA)

There are two sets of Standards, first for the environment/occupational (Table 3.6) and the other for traffic. For the environment, areas are divided into zones which generally define the area (NRCA 1999).

Table 3.6 NRCA recommended zone noise limits

ZONE	7 a.m. to 10 p.m.	10 p.m. to 7 a.m.
Industrial	75	70
Commercial	65	60
Residential	55	50
Silence	45	40

Notes: The measurements are to be made at the property line from which the sound is emitted or at the nearest point possible beyond that line. If the source of the sound is on public property then measurements are to be made at a distance of between 3 m and 4 m from the source. This excludes the mechanical noise made by moving vehicles but includes other noise (such as music) from such vehicles. Source: (National Resoures Conservation Authority, 1999)

The zones are defined below:

Industrial Zone

Lands designated *Industrial Zone* shall generally be industrial where protection against damage to hearing may be required, and the necessity for conversation is limited. The land uses in this category would include, but not be limited to, manufacturing activities, transportation facilities, warehousing, mining, and other lands intended for such uses (National Resoures Conservation Authority, 1999).

Commercial Zone

Lands designated *Commercial Zone* shall generally be commercial in nature, areas where human beings converse and such conversation is essential to the intended use of the land. The land uses in this category would include, but not be limited to, retail trade, personal, business and professional services, government services, amusements, agricultural activities, and lands intended for such commercial or institutional uses (National Resoures Conservation Authority, 1999).

Residential Zone

Lands designated *Residential Zone* shall generally be residential areas where human beings sleep or areas where quiet is essential to the intended use of the land. The land uses in this category would include, but not be limited to, single and multiple family homes, hotels, prisons, religious facilities, cultural activities, forest preserves, and land intended for residential or special uses requiring such protection (National Resoures Conservation Authority, 1999).

Silence Zone

Lands designated *Silence Zone* shall generally be special areas where peace, tranquillity and extreme quiet is essential to the intended use of the land.

The land use in this category would include, but not be limited to, hospitals, educational institutions and courts. In order to ensure silence at such premises the zone should extend to an area of 100 metres around such institutions. Certain activities (e.g. the use of car horns and loudspeakers) are banned in a silence zone (National Resoures Conservation Authority, 1999).

For traffic, the noise limits for moving vehicles are outlined in Table 3.7. The measurements for moving vehicles should be made at a distance of 7.5 m from the centre of the roadway and using the FAST setting on the sound meter (National Resoures Conservation Authority, 1999). This is similar to the US Department of Transportation Federal Highway Administration REMEL curves pass by at 15m.

Table 3.7 NRCA noise limits for moving vehicles

VEHICLE	NOISE LIMIT
Motorbike	85 dBA
Motorcar	85 dBA
Small Commercial Vehicle	90 dBA
Large Commercial Vehicle	95 dBA

Source: (National Resoures Conservation Authority, 1999)

The limits for stationary vehicles are the same as in table 9 but the noise is measured at a distance of 7.5 m from the side of the vehicle and with the engine at half maximum revs. The definition of a small commercial vehicle is one of gross (unloaded) weight of less than 5000 kg (National Resoures Conservation Authority, 1999).

3.3 Approach and Methodology (measurements)

Noise level readings were taken using Brüel & Kjaer (B&K) Type 2250 and 2270 with real time frequency analyser, connected to outdoor weatherproof kit. The octave band analysis (dBL scale) was conducted concurrently with the noise level measurements. Measurements taken were in the third octave which provided thirty-three (33) octave bands from 12.5 Hz to 20 kHz (low, medium and high frequency bands).

The noise meters were calibrated pre and post noise assessment by using a Brüel & Kjaer Type 4231 sound calibrator (Calibration Certificate can be seen in Table 3.8. The Brüel & Kjaer analyser was programmed to log every second with signal recording set at various night-time and daytime threshold values according to the location. This feature allowed the sound level meter to record the noise at the time when the various thresholds were exceeded. This helped in identifying the source of the noise exceedance whether it be abnormal activity for example excessive barking of dogs, "crickets", loud music etc. Average noise levels over the measurement period was calculated within the B&K BZ 5503 Measurement Partner Suite. A windscreen (sponge) was placed over the microphone to prevent measurement errors due to noise caused by wind blowing across the microphone. The microphone of the meters was at a height of approximately 1.5m above ground. There were no vertical reflecting surfaces within 3 m (10 feet) of the microphone.

The averaged noise levels were compared with the National Resources Conservation Authority (NRCA) daytime and night-time noise guidelines, according to the land-use zone in which each noise station fell (Table 3.8).

Table 3.8 NRCA Recommended Zone Noise Guidelines

STATION	ZONE	Daytime (7 a.m. to 10 p.m.)	Night-Time (10 p.m. to 7 a.m.)
Airport Runway 12	Industrial	75	70
Airport Runway 30	Industrial	75	70
Caribbean Maritime University (CMU) - Petro Caribe Development Fund Building	Silence/Educational	45	40
Harbour - Port Authority Harbour Dept.	Commercial	65	60
Harbour View - Martello Drive	Residential	55	50
Port Henderson - Royal View Hotel	Commercial	65	60
Port Royal - Grand Port Royal Harbour Hotel	Commercial	65	60

Seven (7) noise meters with outdoor monitoring kits were set up at each location (see Table 3.9) to collect data every second for twelve (12) days (March 13 – 24, 2020). The Global Positioning System (GPS) locations for each noise monitoring station are listed in Table 3.10 and depicted in Figure 3.1.

Table 3.9. Showing noise meters deployed

 ***(a) Harbour View Martello Drive***	 ***(b) Port Henderson Royal View Hotel***
 ***(c) Port Authority Harbour Dept.***	 *(d) CMU Petro Caribe Development Fund Building*
 ***(e) Grand Port Royal Harbour Hotel***	 *(f) Runway 30 (102m from centreline)*

(g) Runway 12 (145.27 m from centreline)

Table 3.10 GPS locations of the noise stations in JAD2001

STATION	EASTINGS	NORTHINGS
Airport Runway 12 (145.27 m from centerline)	771407.609	643550.672
Airport Runway 30 (102m from centerline)	773872.501	642672.128
Caribbean Maritime University (CMU) - Petro Caribe Development Fund Building	774352.724	643996.575
Harbour - Port Authority Harbour Dept.	770825.401	646172.566
Harbour View - Martello Drive	779694.590	645052.406
Port Henderson - Royal View Hotel	764791.619	645816.657
Port Royal - Grand Port Royal Harbour Hotel	767045.404	643427.568

Figure 3.1 Map depicting the locations of the noise survey stations

3.4 Results

3.4.1 24-Hour Average Noise Levels

Table 3.11 shows the 24-hour average noise levels for each survey day at each location.

1. Overall, average noise levels (LAeq) for the entire 12-day assessment ranged from a low of 46.2 dBA (CMU) to a high of 60.7 dBA (Runway 12). Runway 12, which had the highest average noise level (60.7 dBA), had average daily noise levels ranging from a low of 57.4 dBA on March 22nd to a high of 63.3 dBA on March 13th. CMU, which was the quietest site (46.2 dBA), had average daily noise levels ranging from a low of 44.3 dBA on March 20th and 24th to a high of 51.7 dBA on March 13th.
2. Runway 30 had the second highest average noise level (60.3 dBA), with average daily noise levels ranging from a low of 57.4 dBA on March 22nd to a high of 63.1 dBA on March 13th, similar to Runway 12.
3. The Port Henderson Royal View Hotel had the third highest average noise level (56.2 dBA), with average daily noise levels ranging from a low of 52.3 dBA on March 24th to a high of 63.8 dBA on March 23rd.
4. The Port Authority Harbour Department had the fourth highest average noise level (54.9 dBA), with average daily noise levels ranging from a low of 49.8 dBA on March 22nd to a high of 59.3 dBA on March 17th.
5. The Grand Port Royal Harbour Hotel had the fifth highest average noise level (50.9 dBA), with average daily noise levels ranging from a low of 49.5 dBA on March 23rd to a high of 53.6 dBA on March 16th.
6. The residence at Martello Drive in Harbour View had the sixth highest average noise level (50.7 dBA), with average daily noise levels ranging from a low of 48.6 dBA on March 15th to a high of 57.2 dBA on March 19th.

Table 3.11 Showing 24-Hour Average Noise Levels for each location

DATE LOCATION	13.3.20 FRI	14.3.20 SAT	15.3.20 SUN	16.3.20 MON	17.3.20 TUES	18.3.20 WED	19.3.20 THURS	20.3.20 FRI	21.3.20 SAT	22.3.20 SUN	23.3.20 MON	24.3.20 TUES	OVER ALL AVG LAeq
Airport Runway 12 (145.27 m)	63.3	62.9	60.3	62.2	60.4	60.5	62.2	61.4	61.1	57.4	59.6	57.7	**60.7**
Airport Runway 30 (102.0 m)	63.1	61.1	58.1	60.5	61.0	60.1	61.7	60.5	60.3	57.4	59.5		**60.3**
CMU - Petro Caribe Development Fund Building	51.7	44.8	47.1	**N/A**	**N/A**	**N/A**	46.7	44.3	**N/A**	45.9	44.9	44.3	**46.2**
Harbour - Port Authority Harbour Dept.	57.2	53.6	51.5	57.3	59.3	55.7	56.0	**N/A**	**N/A**	49.8	56.0	52.2	**54.9**
Harbour View - Martello Drive	51.1	50.5	48.6	49.6	51.8	49.7	57.2	49.6	49.4	49.6	50.5	50.3	**50.7**
Port Henderson - Royal View Hotel	55.9	55.9	55.1	55.5	54.8	**N/A**	**N/A**	56.3	**N/A**	**N/A**	63.8	52.3	**56.2**
Port Royal - Grand Port Royal Harbour Hotel	49.8	49.7	51.6	53.6	51.7	50.4	51.4	51.6	49.8	53.3	49.5	48.3	**50.9**

N/A – No data availabl

3.4.2 Minimum and Maximum Noise Level

Table 3.12 shows the minimum and maximum noise levels for each survey day at each location.

1. Runways 12 and 30 had the greatest range of all stations (75.6 dBA and 68.9 dBA respectively). The lowest minimum noise level at Runway 12 was 25.4 dBA on March 15th, while the highest maximum noise level was 101.0 dBA on March 13th. For Runway 30, the lowest minimum noise level was 33.3 dBA on March 13th, while the highest maximum noise level was 102.2 dBA on the same day.
2. The narrowest noise range (45.6 dBA) was observed at the Port Authority Harbour Department

Table 3.12 Showing minimum and maximum noise levels at each location

DATE	13.3.20 FRI		14.3.20 SAT		15.3.20 SUN		16.3.20 MON		17.3.20 TUES		18.3.20 WED		19.3.20 THURS		20.3.20 FRI		21.3.20 SAT		22.3.20 SUN		23.3.20 MON		24.3.20 TUES		OVERALL		RANGE
LOCATION	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	
Airport Runway 12 (145.27 m)	101.0	27.0	95.0	26.7	93.5	25.4	98.6	27.7	96.5	27.6	97.1	26.6	100.3	28.0	99.3	28.0	98.8	27.0	95.7	27.7	95.9	29.8	92.8	31.3	**101.0**	**25.4**	**75.6**
Airport Runway 30 (102.0 m)	102.2	33.3	95.5	35.0	94.7	34.8	96.0	36.6	94.4	37.2	94.9	36.4	98.0	37.5	93.3	36.3	95.1	37.4	92.0	38.0	97.6	41.3	**N/A**	**N/A**	**102.2**	**33.3**	**68.9**
CMU - Petro Caribe Development Fund Building	83.9	33.9	76.9	35.1	75.0	35.1	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	75.3	35.2	70.9	34.6	**N/A**	**N/A**	78.5	34.8	71.1	34.4	70.8	36.2	**83.9**	**33.9**	**50**
Harbour - Port Authority Harbour Dept.	79.3	45.2	77.1	41.6	75.6	40.9	85.8	42.5	85.7	40.9	74.1	42.7	79.5	40.2	**N/A**	**N/A**	**N/A**	**N/A**	72.7	41.0	74.3	42.7	80.4	43.5	**85.8**	**40.2**	**45.6**
Harbour View - Martello Drive	77.3	35.9	76.6	35.6	80.6	36.2	84.3	36.7	86.5	36.0	80.4	36.1	76.6	36.5	79.4	34.7	81.0	36.6	76.1	35.4	77.7	36.5	84.4	37.1	**86.5**	**34.7**	**51.8**
Port Henderson - Royal View Hotel	85.9	37.6	88.6	40.0	77.8	40.2	84.2	39.8	83.2	40.0	**N/A**	**N/A**	**N/A**	**N/A**	84.0	41.3	**N/A**	**N/A**	76.4	23.6	80.9	21.3	76.1	24.5	**88.6**	**21.3**	**67.3**
Port Royal - Grand Port Royal Harbour Hotel	72.8	39.3	72.1	32.9	75.0	31.0	74.1	37.2	69.5	29.3	68.6	38.1	77.2	38.2	75.5	33.8	73.6	31.8	75.0	37.6	72.3	37.8	66.1	33.5	**77.2**	**29.3**	**47.9**

N/A – No data available

3.4.3 Sound Exposure Level (SEL)

1. The Sound Exposure Level (SEL) is the constant sound level that has the same amount of energy in one second as the original noise event. Table 3.13 shows the SEL for each survey day at each location.
2. Both runways had the highest SEL of all stations, with Runway 12 having the highest SEL of 96.7 dBA followed by Runway 30 with a SEL of 96.1 dBA. The stations with the lowest SEL was the CMU which had a SEL of 82.5 dBA. The commercial noise stations had overall SEL values ranging from 86.7 – 93.3 dBA. The residential station (Martello Drive) had a SEL value of 87.0 dBA.

Table 3.13 SEL for each location

DATE LOCATION	13.3.20 FRI	14.3.20 SAT	15.3.20 SUN	16.3.20 MON	17.3.20 TUES	18.3.20 WED	19.3.20 THURS	20.3.20 FRI	21.3.20 SAT	22.3.20 SUN	23.3.20 MON	24.3.20 TUES	OVER ALL AVG SEL
Airport Runway 12 (145.27 m)	98.9	98.4	95.9	97.8	95.9	96.0	97.8	97.0	96.7	93.0	95.1	93.3	**96.7**
Airport Runway 30 (102.0 m)	98.7	96.7	93.7	96.1	96.6	95.7	97.3	96.0	95.8	92.9	95.1		**96.1**
CMU - Petro Caribe Development Fund Building	87.3	80.3	82.7	**N/A**	**N/A**	**N/A**	82.3	79.8	**N/A**	81.4	80.4	79.8	**82.5**
Harbour - Port Authority Harbour Dept.	92.8	89.1	87.1	92.9	94.8	91.2	91.5	**N/A**	**N/A**	85.4	91.5	87.8	**91.2**
Harbour View - Martello Drive	86.7	86.1	84.1	85.2	87.4	85.3	92.7	85.1	84.9	85.1	86.1	85.8	**87.0**
Port Henderson - Royal View Hotel	91.5	91.4	90.7	91.1	90.4	**N/A**	**N/A**	91.8	**N/A**	**N/A**	99.4	87.8	**93.3**
Port Royal - Grand Port Royal Harbour Hotel	85.4	85.2	87.1	89.2	87.2	86.0	87.0	87.2	85.4	88.9	85.0	83.9	**86.7**

N/A – No data available

3.4.4 Day-Night Average Sound Level (DNL)

The Federal Aviation Administration (FAA) has established a DNL (Ldn) noise guideline (Ldn < 65 dBA) for land-use compatibility (see Figure 3.2). Residential and other noise sensitive uses (areas where people spend widely varying amounts of time and other places in which quiet is a basis for use) are considered compatible land-use when the DNL is 65 dBA or less. The DNL within the confines of the airport is ≥ 75 dBA.

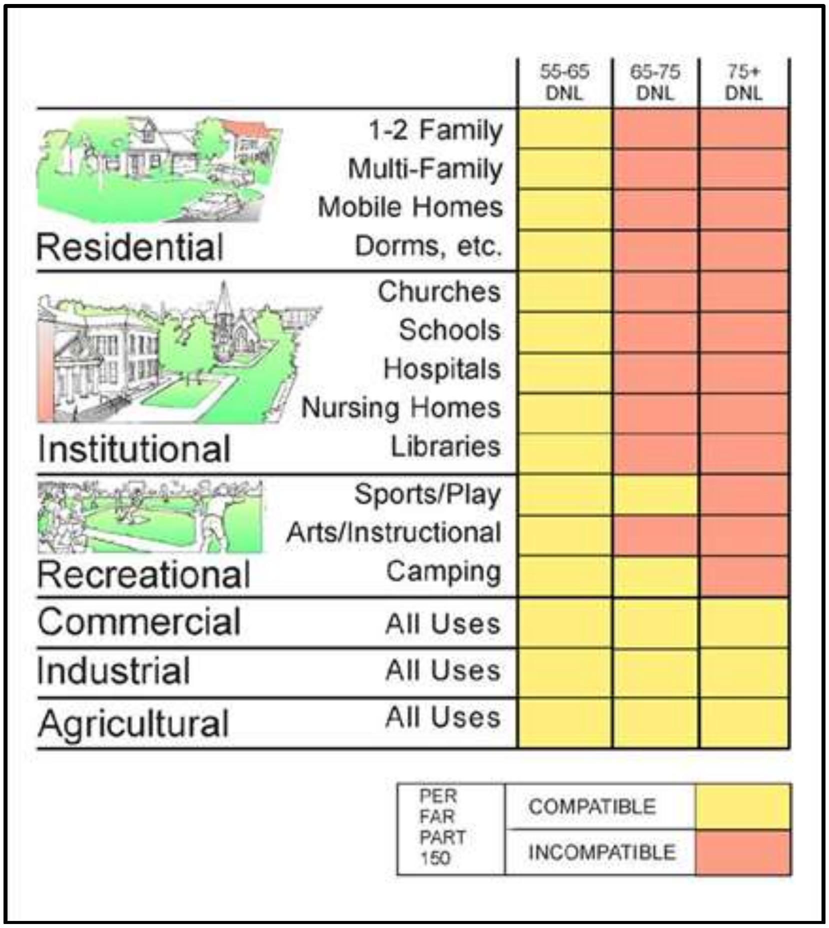


Figure 3.2 FAA Land-Use Noise Sensitivity Matrix

Table 3.14 shows the DNL for each survey day at each location. It shows that the residential, commercial and educational/institutional stations were compliant with the 65 dBA FAA L_{dn} guideline. Both airport runways had noise values compliant with the 75 dBA L_{dn} guideline.

Table 3.14 DNL for each location

DATE LOCATION	13.3.20 FRI	14.3.20 SAT	15.3.20 SUN	16.3.20 MON	17.3.20 TUES	18.3.20 WED	19.3.20 THURS	20.3.20 FRI	21.3.20 SAT	22.3.20 SUN	23.3.20 MON	24.3.20 TUES	OVER ALL AVG DNL
Airport Runway 12 (145.27 m)	67.1	70.5	65.2	65.0	66.6	64.0	64.6	63.7	64.3	57.7	59.9	58.3	**65.2**
Airport Runway 30 (102.0 m)	65.5	66.9	62.1	64.7	65.1	64.5	64.4	64.4	64.0	61.7	62.9	57.8	**64.1**
CMU - Petro Caribe Development Fund Building	56.0	50.3	54.9	45.8	48.7	50.5	50.8	48.9	**N/A**	52.0	49.2	50.1	**51.6**
Harbour - Port Authority Harbour Dept.	62.0	57.8	57.0	61.9	62.9	61.0	59.1	**N/A**	**N/A**	55.4	59.8	58.4	**60.1**
Harbour View - Martello Drive	56.0	54.6	53.1	53.5	55.3	54.3	58.2	53.0	54.8	53.2	54.6	55.8	**55.0**
Port Henderson - Royal View Hotel	60.8	62.1	60.5	60.5	59.8	**N/A**	**N/A**	60.8	**N/A**	55.8	64.0	55.8	**60.7**
Port Royal - Grand Port Royal Harbour Hotel	56.2	54.8	55.6	57.6	56.1	56.1	55.5	56.6	54.0	56.3	54.1	53.8	**55.7**

N/A – No data available

3.4.5 Community Noise Equivalent Levels (CNEL)

The CNEL levels can give an indication of the likelihood of community complaints about a noise source (see Figure 3.3).

Table 3.15 shows the CNEL for each survey day at each location. The calculated CNEL level at the residential station (Harbour View-Martello Drive) was compared with the guideline level that it is expected to have sporadic complaints from the community (range 55-65 dBA). This residential station was compliant with the US EPA Sporadic Complaints Guideline level.

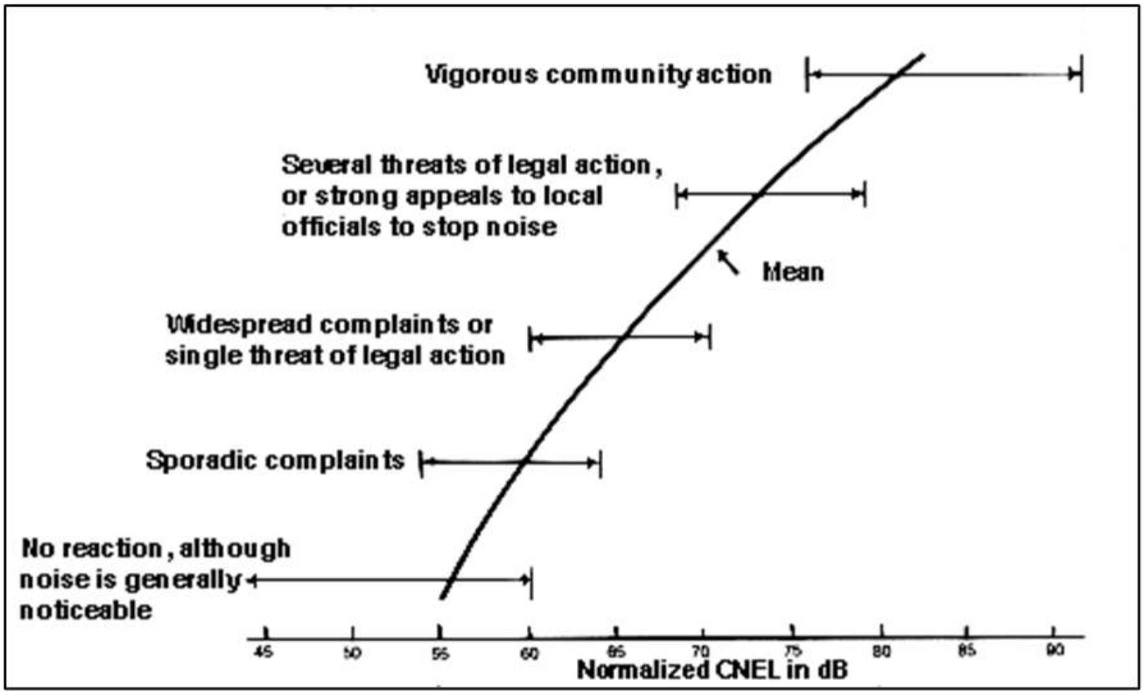


Figure 3.3 Anticipated community reaction versus normalized CNEL (dBA)

Table 3.15 CNEL for each location

DATE LOCATION	13.3.20 FRI	14.3.20 SAT	15.3.20 SUN	16.3.20 MON	17.3.20 TUES	18.3.20 WED	19.3.20 THURS	20.3.20 FRI	21.3.20 SAT	22.3.20 SUN	23.3.20 MON	24.3.20 TUES	OVER ALL AVG CNEL
Airport Runway 12 (145.27 m)	67.6	70.8	65.7	65.6	66.8	65.1	65.1	64.6	64.2	60.1	61.3	58.3	**65.7**
Airport Runway 30 (102.0 m)	66.2	67.5	62.8	64.8	65.3	65.0	64.9	64.8	63.9	61.6	62.9	57.9	**64.5**
CMU - Petro Caribe Development Fund Building	56.8	51.1	55.0	48.3	48.6	50.6	51.0	49.0	**N/A**	52.0	49.2	50.2	**52.0**
Harbour - Port Authority Harbour Dept.	61.9	58.0	57.0	61.9	62.7	60.8	59.1	**N/A**	**N/A**	55.5	59.9	58.5	**60.1**
Harbour View - Martello Drive	**56.0**	**55.3**	**53.2**	**53.7**	**55.4**	**54.7**	**58.2**	**53.2**	**55.0**	**53.5**	**54.5**	**56.0**	**55.1**
Port Henderson - Royal View Hotel	61.0	62.2	60.5	60.7	60.1	**N/A**	**N/A**	61.0	**N/A**	56.4	64.0	56.1	**60.8**
Port Royal - Grand Port Royal Harbour Hotel	56.2	55.1	56.3	57.7	56.5	56.3	56.4	57.1	54.7	58.2	54.3	54.3	**56.3**

N/A – No data available

3.4.6 National Resources Conservation Authority (NRCA) Daytime and Night-Time Noise Standards

Table 3.16 shows the NRCA daytime (7am – 10pm) and night-time (10pm – 7am) noise values for each survey day at each location.

Runways 12 and 30 had the highest average daytime and night-time noise levels of all the stations surveyed. Runway 12 had an average daytime noise value of 62.2 dBA and an average night-time value of 52.4 dBA. Runway 30 had an average daytime noise value of 61.7 dBA and an average night-time value of 55.4 dBA. Noise values on all survey days at these two locations were compliant with the respective NRCA daytime guideline value of 75 dBA and night-time guideline value of 70 dBA for industrial zones.

The highest daytime value at Runway 12 was 65.0 dBA on March 13th, while the highest night-time value was 63.7 dBA on March 14th. The highest daytime value at Runway 30 was 65.0 dBA on March 13th, while the highest night-time value was 59.2 dBA on March 14th, similar to Runway 12.

CMU had the lowest daytime and night-time noise levels of all the stations surveyed. CMU had an average daytime noise value of 46.8 dBA and an average night-time value of 44.2 dBA. These average noise values were however, non-compliant with the respective NRCA daytime guideline value of 45 dBA and night-time guideline value of 40 dBA for educational institutions. Both daytime and night-time noise values exceeded the respective NRCA noise guidelines on all survey days except for March 14th and March 24th. On March 14th, the daytime noise value of 44.9 dBA was compliant but the night time value of 43.2 dBA was not. On March 24th, the daytime noise value of 44.9 dBA was compliant but the night time value of 42.9 dBA was not.

Both the Port Authority Harbour Department and the Grand Port Royal Harbour Hotel had daytime and night time noise values on all survey days compliant with the respective NRCA daytime guideline value of 65 dBA and night-time guideline value of 60 dBA for commercial zones.

For the Harbour View Martello Drive residence, both daytime and night-time noise values were compliant with the respective NRCA residential noise guidelines (55 dBA daytime; 50 dBA night-time) on all survey days except for March 19th. On March 19th, the daytime noise value of 59.1 dBA was non-compliant, but the night-time value of 45.0 dBA was compliant with the NRCA guideline value.

For the Port Henderson Royal View Hotel, both daytime and night-time noise values were compliant with the respective NRCA commercial noise guidelines (65 dBA daytime; 60 dBA night-time) on all survey days except for March 23rd. On March 23rd, the daytime noise value of 65.8 dBA was non-compliant, but the night-time value of 43.4 dBA was compliant with the NRCA guideline values.

Table 3.16 NRCA daytime and night-time noise levels for each survey day at each location

DATE	13.3.20 FRI		14.3.20 SAT		15.3.20 SUN		16.3.20 MON		17.3.20 TUES		18.3.20 WED		19.3.20 THURS		20.3.20 FRI		21.3.20 SAT		22.3.20 SUN		23.3.20 MON		24.3.20 TUES		OVERALL	
LOCATION	NRCA DAY	NRCA NIGHT	NRCA DAY	NRCA NIGHT	NRCA DAY	NRCA NIGHT	NRCA DAY	NRCA NIGHT	NRCA DAY	NRCA NIGHT	NRCA DAY	NRCA NIGHT	NRCA DAY	NRCA NIGHT	NRCA DAY	NRCA NIGHT	NRCA DAY	NRCA NIGHT	NRCA DAY	NRCA NIGHT	NRCA DAY	NRCA NIGHT	NRCA DAY	NRCA NIGHT	NRCA DAY	NRCA NIGHT
Airport Runway 12 (145.27 m)	65.0	56.4	62.3	63.7	61.6	56.7	64.0	54.4	61.2	58.6	62.1	53.9	63.9	55.4	63.1	54.2	62.6	56.0	59.4	38.0	61.6	38.9	59.7	42.5	62.2	52.4
Airport Runway 30 (102.0 m)	65.0	53.8	62.0	59.2	59.5	54.3	62.1	54.4	62.6	55.3	61.6	55.3	63.3	55.6	61.8	56.7	61.7	56.1	58.6	54.1	61.0	54.5	**N/A**	**N/A**	61.7	55.4
CMU - Petro Caribe Development Fund Building	**53.0**	**48.3**	44.9	**43.2**	**45.6**	**48.8**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**48.0**	**43.0**	**45.5**	**40.8**	**N/A**	**N/A**	**46.3**	**45.0**	**46.1**	**41.5**	44.9	**42.9**	**46.8**	**44.2**
Harbour - Port Authority Harbour Dept.	58.6	53.1	54.9	49.8	52.3	49.8	58.7	52.7	61.0	52.4	56.8	52.5	57.6	50.3	**N/A**	**N/A**	**N/A**	**N/A**	50.8	47.6	57.6	49.8	52.6	51.3	56.1	50.9
Harbour View - Martello Drive	52.2	48.3	51.9	46.5	49.8	45.3	51.0	45.3	53.3	46.8	51.0	46.3	**59.1**	45.0	51.1	44.3	50.2	47.4	51.0	44.8	51.9	46.6	51.8	45.3	52.0	46.0
Port Henderson - Royal View Hotel	57.2	52.5	57.0	53.1	56.0	53.0	56.6	52.7	56.1	51.2	**N/A**	**N/A**	**N/A**	**N/A**	57.6	52.7	**N/A**	**N/A**	**N/A**	**N/A**	**65.8**	43.4	53.7	47.7	57.5	50.8
Port Royal - Grand Port Royal Harbour Hotel	50.5	48.4	50.8	46.5	53.0	47.1	55.0	49.7	53.1	47.0	51.5	47.6	52.8	47.4	52.8	48.3	51.1	45.8	55.0	46.5	50.7	46.2	49.3	45.9	52.1	47.2

N/A – No data available.

Values in **red** are non-compliant with respective NRCA Guidelines

3.4.7 Noise Fluctuations with Aircraft Arrival and Departure Times

Appendix 8.1.3 shows the aircraft arrival and departure dates and times at NMIA during noise assessment. Some of the larger noise fluctuations at the various off-site (non-runway) noise monitoring stations can be attributed to noise from aircraft arrival and/or departure based on the date and time when the noise level went above the NRCA Land-Use Noise Guideline value for that particular station. The noise signature recorded also gives an indication whether the noise can be attributed to an aircraft.

The following sections discuss the noise fluctuations/spikes (if any) based on aircraft arrival and departure times at each station. It must be noted that the times of the spikes in noise levels observed at the various stations may not exactly coincide with aircraft arrival/departure times due to the fact that noise takes time to travel through space based on the distance from source to receptor. In addition, the times on the noise meters were not synchronized with the time at the airport Control Tower. The maximum noise level for each sampling day was extracted and evaluated to determine if the noise was attributed to an aircraft.

Other noise fluctuations observed (where the noise level went above the NRCA Land-Use Noise Guideline) that do not coincide with aircraft arrival/departure times, were due to other noise sources such as noise from motor vehicles, loud music, bird calls, dogs barking, crickets chirping and loud talking, based on the noise signature recorded during monitoring.

Information on aircraft model and the runway from which the aircraft departed or on which the aircraft landed, is also presented.

3.4.7.1 *Grand Port Royal Harbour Hotel*

Table 3.17 shows information on noise spikes related to aircraft noise at the Grand Port Royal Harbour Hotel. From the information gleaned, aircraft noise levels above the NRCA guidelines for this location (65 dBA daytime, 60 dBA night-time) tend to be prevalent when aircrafts are departing from Runway 12. There was one incident (March 16) where a departure from Runway 30 resulted in noise levels above the NRCA guideline. From the samples evaluated, there were no incidences of any arrivals on Runway 30 which resulted in noise levels above the NRCA Guideline.

Aircrafts contributing to these noise levels included small single-engine (DA40) and twin-engine crafts (DA42) as well as mid-sized corporate jets (C560). Larger commercial aircrafts such as the E145, B738 and B763 also contributed to the elevated noise levels, as well as a Jamaica Defence Force helicopter.

Non-aircraft noise sources at this station, which were above the NRCA Noise Guideline, were mainly attributed to the playing of loud music, calls from seabirds, barking of dogs, motor vehicles speeding along the Port Royal main road and honking from motor vehicle horns.

Table 3.17 Noise level spikes due to aircraft arrival and departures (Grand Port Royal Harbour Hotel)

Date	Noise Level (dBA)	Time of Noise Spike	Time of Aircraft Arrival/Departure	Arrival or Departure	Aircraft Model	Runway	Non-aircraft Noise Sources
March 13	68.6	4:12 pm	4:12 pm	Departure	JDF Heli	12	Loud music, Seabirds, Dogs barking, Motor vehicle noises,
March 13	65.4	7:32 pm	7:29 pm	Departure	C560	12	
March 15	65.1	2:06 pm	2:04 pm	Departure	E145	12	
March 16	67.3	8:53 pm	8:54 pm	Departure	DA40	30	

March 18	65.6	7:49 pm	7:48 pm	Departure	DA40	12	car horns honking
March 21	61.1	1:35 am	1:40 am	Departure	B738	12	
March 23	66.3	8:07 pm	8:04 pm	Departure	B763	12	
March 24	64.7	2:56 pm	2:56 pm	Departure	DA42	12	

N.B. Time of noise spike and time of arrival/departure may not coincide because of time taken for noise to travel through space based on the distance from source to receptor. Also, the times on the noise meters were not synchronized with the time at the airport Control Tower

3.4.7.2 *Port Henderson Royal View Hotel*

Table 3.18 shows information on noise spikes related to aircraft noise at the Port Henderson Royal View Hotel. From the information gleaned, aircraft noise levels above the NRCA guidelines for this location (65 dBA daytime, 60 dBA night-time) tend to be prevalent when aircrafts are departing from and arriving on Runway 12. There was also one incidence of departure from Runway 30 (on March 17) which resulted in elevated noise levels above the NRCA Guideline. From the samples evaluated, there were no incidences of any arrivals from Runway 30 which resulted in noise levels above the NRCA Guideline.

Aircrafts contributing to these elevated noise levels included small single-engine crafts (DA40) as well as mid-sized corporate jets (C560, C56X). Larger commercial aircrafts such as the L135, ATR42, A321 and B738 also contributed to the elevated noise levels.

Non-aircraft noise sources at this station, which were above the NRCA Noise Guideline, were mainly attributed to calls from seabirds, motor vehicles noises from the main road, trucks using engine brakes and honking from motor vehicle horns.

Table 3.18 Noise level spikes due to aircraft arrival and departures (Port Henderson Royal View Hotel)

Date	Noise Level (dBA)	Time of Noise Spike	Time of Aircraft Arrival/Departure	Arrival or Departure	Aircraft Model	Runway	Non-aircraft Noise Sources
March 13	67.1	10:38 am	10:35 am	Arrival	B738	12	Seabirds, Motor vehicle noises, Truck engine brakes, car horns honking
March 13	71.0	12:34 pm	12:35 pm	Arrival	B738	12	
March 13	68.3	4:09 pm	4:09 pm	Departure	C56X	12	
March 13	72.4	4:44 pm	4:46 pm	Arrival	ATR42	12	
March 13	70.9	6:23 pm	6:24 pm	Arrival	C560	12	
March 14	70.4	7:21 pm	7:21 pm	Departure	B738	12	
March 17	71.2	12:40 pm	12:41 pm	Departure	B738	12	
March 17	71.8	6:05 pm	6:03 pm	Departure	A321	30	
March 19	72.6	8:28 pm	8:26 pm	Departure	B738	12	
March 20	70.0	3:12 pm	3:13 pm	Departure	DA40	12	
March 20	72.8	8:41 pm	8:43 pm	Departure	L135	12	

N.B. Time of noise spike and time of arrival/departure may not coincide because of time taken for noise to travel through space based on the distance from source to receptor. Also, the times on the noise meters were not synchronized with the time at the airport Control Tower

3.4.7.3 *Caribbean Maritime University*

Table 3.19 shows information on noise spikes related to aircraft noise at the Caribbean Maritime University. From the information gleaned, aircraft noise levels above the NRCA guidelines for this location (45 dBA daytime, 40 dBA night-time) tend to be prevalent when aircrafts are departing from and arriving on Runway 12. There were also a few departures from

Runway 30 which had elevated noise levels above the NRCA guidelines. From the samples evaluated, there were no incidences of any arrivals on Runway 30 which resulted in noise levels above the NRCA Guideline.

Aircrafts contributing to these elevated noise levels included small twin-engine crafts (DA42), small commercial aircrafts (E120) and large commercial aircrafts such as the E145, A320, A321 and B738.

Non-aircraft noise sources at this station, which were above the NRCA Noise Guideline, were mainly attributed to calls from birds, dogs barking, crickets chirping (during the night-time), loud talking and construction noises. March 13th was the final day of regular school and activities before a lockdown of the campus due to Covid-19.

Table 3.19 Noise level spikes due to aircraft arrival and departures (Caribbean Maritime University)

Date	Noise Level (dBA)	Time of Noise Spike	Time of Aircraft Arrival/Departure	Arrival or Departure	Aircraft Model	Runway	Non-aircraft Noise Sources
March 14	51.1	1:59 pm	1:59 pm	Departure	E145	12	Bird calls, Dogs barking, Crickets chirping, Loud talking, Construction noises (power saw-March 13 only)
March 14	48.2	2:09 pm	2:11 pm	Departure	E120	12	
March 14	57.2	2:20 pm	2:21 pm	Departure	A321	12	
March 14	59.2	4:01 pm	4:03 pm	Arrival	A320	12	
March 15	48.2	11:14 am	11:14 am	Departure	B738	30	
March 15	55.5	12:43 pm	12:42 pm	Departure	B738	30	
March 19	48.6	8:15 am	8:15 am	Departure	A321	12	
March 19	47.8	10:29 am	10:30 am	Arrival	B738	12	
March 19	51.5	7:03 pm	7:06 pm	Arrival	B738	12	
March 22	58.3	2:10 pm	2:10 pm	Departure	A321	30	
March 23	50.0	3:00 pm	3:00 pm	Departure	DA42	12	

N.B. Time of noise spike and time of arrival/departure may not coincide because of time taken for noise to travel through space based on the distance from source to receptor. Also, the times on the noise meters were not synchronized with the time at the airport Control Tower

3.4.7.4 *Port Authority Harbour Department*

Although noise levels at this location exceeded the respective NRCA guidelines (65 dBA daytime, 60 dBA night-time), none of the noise spikes were found to be attributed to aircrafts. Instead, the following noise sources were contributing to the elevated noise levels: motor vehicles, truck engine brakes, vehicle horns honking, seabird calls, emergency vehicle sirens, marine traffic noise and noise similar to gunshots.

3.4.7.5 *Harbour View – Martello Drive*

Although noise levels at this location exceeded the respective NRCA guidelines (55 dBA daytime, 50 dBA night-time), none of the noise spikes were found to be attributed to aircrafts. Instead, the following noise sources were contributing to the elevated noise levels: motorcycles, motor vehicles, truck engine brakes, vehicle horns honking, dogs barking, crickets chirping, birds chirping and construction noises (power saw).

3.4.7.6 *Runways 12 and 30*

Noise levels at the airport boundaries by Runways 12 and 30 exceeded the NRCA guidelines (75 dBA daytime, 70 dBA night-time) whenever aircrafts departed or landed at that specific runway. All noise which exceeded the NRCA guidelines at Runway 12 was attributed to aircrafts. At Runway 30 however, in addition to aircraft noise, motor vehicle noises along the Port Royal main road also caused noise levels to exceed the NRCA guidelines throughout the monitoring period.

3.4.7.7 *Comparison of Stations which Exceeded NRCA Guidelines*

Table 3.20 gives an indication of the percentages of aircraft and non-aircraft noise sources which exceeded the respective NRCA Land Use Noise Guidelines at each monitoring location. These percentages are based off the sample of maximum noise levels extracted and evaluated.

Table 3.20 Percentage of Noise Sources contributing to exceedance of NRCA Noise Guidelines

Location	% of Noise from Aircraft	% of Noise from Non-Aircraft Sources
Airport Runway 12	100%	0%
Airport Runway 30	100%	0%
CMU - Petro Caribe Development Fund Building	42%	58%
Port Authority Harbour Dept	0%	100%
Harbour View - Martello Drive	0%	100%
Port Henderson - Royal View Hotel	44%	56%
Grand Port Royal Harbour Hotel	30%	70%

3.5 NMIA Zonation and Ecological Inventory

3.5.1 Biological Literature Review - Palisadoes Port Royal Protected Area

The Palisadoes-Port Royal Protected Area (P-PRPA) is approximately 7,523 hectares (75.23 km^2) and includes both terrestrial and marine areas. The Port Royal Protected Area was established on 8 May 1967 under the Beach Control Act. On 18 September 1998, The Palisadoes Port Royal Protected Area (P-PRPA) was declared under the Natural Resources Conservation Authority (NRCA) Act Order, (No. 73 of 1998). P-PRPA was also designated as a Ramsar site (Wetland of International Importance) under the Convention on Wetlands of International Importance especially as a Waterfowl Habitat on 22 April 2005.

The Palisadoes tombolo (15km long), is considered an area of national importance owing to the various ecological, economic and social functions that it supports. The main roadway running along the Palisadoes represents the only access point to the town of Port Royal, its historic sites and fishing beaches; Norman Manley International Airport (NMIA), one of the island's international airports; the Caribbean Maritime Institute (CMI) now University (Caribbean Maritime University); the Royal Jamaica Yacht Club (RJYC); and the Plumb Point Lighthouse. Kingston Harbour is the seventh largest natural harbor in the world, sheltered by the tombolo, barrier reefs and cays which also provide protection for land and infrastructure.

Although P-PRPA has both national and international protection status, it has been negatively impacted by; coastal modification (including major road works), solid waste, pollution, sand mining, general habitat degradation and climate change. Natural disaster has also greatly affected the area, ranging from the massive earthquake in the 17th century which resulted in part of the city of Port Royal sinking, to major hurricanes and storms.

The dunes and mangroves in the protected area have been identified as conservation and rehabilitation priorities by multiple agencies and organizations. The maintenance, enhancement and protection of these habitats are essential for Jamaica. Several ecological sensitive and significant species and systems are found here, including the last major roosting area for some seabirds, endemic flora and the nearby coral reefs and cays. Sea turtles and crocodiles have been known to utilize various areas including nesting along the coastline.

3.5.1.1 *Proposed Zonation of the P-PRPA*

In order to effectively manage the P-PRPA, the National Environmental Planning Agency (NEPA) has prepared a revised draft zonation plan "*REVISED DRAFT ZONING PLAN FOR THE PALISADOES-PORT ROYAL PROTECTED AREA 2014-2019*"

- The P-PRPA consists of four (4) major zones.
- Restricted Use Zone – Airport Lands
- Conservation Zone
- Multiple-use Zone
- Core Heritage Special Purpose Zone (SPZ)

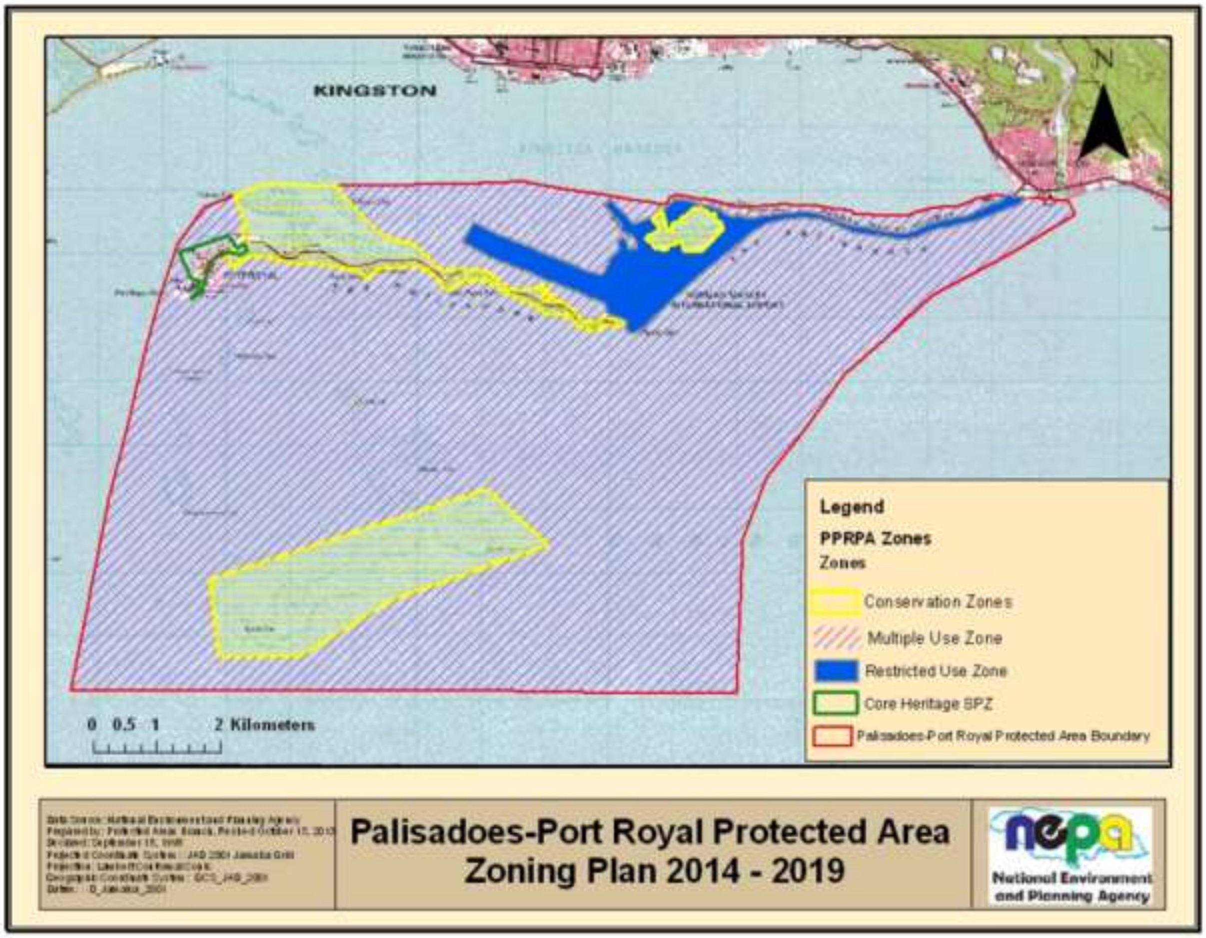


Figure 3.4 Proposed Zonation of P-PRPA

3.5.2 Policy, Legal and Administrative Framework

3.5.2.1 *National Environment and Planning Agency*

The National Environment and Planning Agency (NEPA) is the government executive agency and represent a merger of the Natural Resources Conservation Authority (NRCA), the Town Planning Department (TPD) and the Land Development and Utilization Commission (LDUC). Among the reasons for this merger was the streamlining of the planning application process in Jamaica. NEPA has therefore been given responsibility for environmental management in Jamaica under the NRCA Act of 1991. Since the promulgation of the Act, the NRCA has been developing local standards. The Act was strengthened by supporting regulations, which became effective in January 1997. The underlying principles, which have been used in the development of the Act, are:

- The Polluter pays Principle
- The Cradle to Grave approach to waste management

3.5.2.2 *Permits and Licenses*

The Environmental Permit and License System (P&L) is administered by NEPA through the Applications Section. It was introduced in 1997 to ensure that all developments meet required standards and negative environmental impacts are minimized. Under the NRCA Act of 1991, the NRCA has the authority to issue, suspend and revoke environmental permits and licenses. An applicant for a Permit or License must complete a Permit Application Form (PAF) as well as a Project Information Form (PIF) for submission to the NRCA/NEPA.

3.5.3 National Legislation

The following sections include a discussion of relevant national legislation, regulations/standards, policies and other material thought to be relevant to the area. The following main areas are covered:

- *Development Control*: construction (including building codes and site management controls) and subsidiary inputs (quarry material, etc.), public safety and vulnerability to disasters.
- *Environmental Conservation*: forestry, wildlife and biodiversity, protected areas and species, water resources, heritage and cultural resources.
- *Public Health & Waste Management*: air quality, noise levels, public health, solid waste, storm water, etc.

3.5.3.1 *Development Control*

The applicability of these laws is dependent on the location of the development chosen, social and socio-economic issues as well as the availability of land for acquisition. Described in subsequent sections below are the relevant legislations and regulations that may affect the project. The following agencies are those that may be encountered for planning and development approvals:

- Municipal Corporation (Local Planning Authority - LPA) – All development applications are made through the LPA which include enquiries, planning, building and subdivision approvals. The Municipal Corporations wear two hats in relation to Building & Planning. It is the Local Planning Authority under the Town & Country Planning Act 1957 (amended 1999), and it is also the Local Building Authority under the Building Act 2018.
- National Environment and Planning Agency (NEPA) - Applications reviewed by NEPA include enquiries, planning applications, and building and subdivision applications.

3.5.3.2 *Local Improvement Act 1914*

The Local Improvements Act is the primary statute that controls the subdivision of land.

3.5.3.3 *The Local Improvement Act, 2016*

The Local Governance Act of 2016 repealed the Parish Councils Act, the Kingston & St. Andrew Corporation Act, and the Municipalities Act. Under the Parish Council Act each Local Planning Authority Each Municipal Corporation may revoke or alter regulations concerning the construction and restrictions as to the elevation, size and design of buildings built with the approval of the relevant Minister. It may also make regulations concerning the installation of sewers on premises.

3.5.3.4 *Town and Country Planning Act (TCP Act), 1957 (Amended 1999)*

The Town and Country Planning Act (TCP Act) 1957 (Amended 1999) provides the statutory requirements for the orderly development of land through planning, as well guidelines for the preparation of Development Orders. A Development Order is a legal document which is used to guide development in the area to which it applies and the TCP Act is only applicable in an area where a Development Order exists. It constitutes land use zoning map/s, policy statements and standards relating to land use activities. Tree Preservation Areas and Conservation Areas (as specified areas the gazetted Development Orders) are two types of protected areas associated this Act.

The TCP Act establishes the Town and Country Planning Authority, which in conjunction with the Local Planning Authorities (Municipal Corporation) are responsible for land use zoning and planning regulations as described in their local Development Orders. The TCP Act is administered by the National Environment and Planning Agency.

3.5.3.5 *The Building Act, 2018*

The Building Act repeals the Kingston and St. Andrew Building Act and the Parish Councils Building Act and makes new provisions for the regulation of the building industry. It aims to facilitate the adoption and efficient application of national building standards (National Building Code of Jamaica) for ensuring safety in the built environment, enhancing amenities and promoting sustainable development. A "building" is described as a domestic building, a public building, a building of the warehouse class and any other physical structure, whether a temporary structure or not, any part of the structure, and any architectural or engineering product or work erected or constructed on, over or under land or the sea or other body of water.

3.5.3.6 *The Jamaica National Heritage Trust Act 1985*

The Jamaica National Heritage Trust Act established the Jamaica National Heritage Trust (JNHT) and has been in operation since 1985. The main goal is the preservation and protection of the country's national heritage. The Act states the following offences are liable to a fine and/or imprisonment:

- Wilfully defacing, damaging or destroying any national monument or protected national heritage;
- Wilfully defacing, destroying, concealing or removing any mark affixed or connected to a national monument or protected national heritage;
- Altering any national monument or marking without the written permission of the Trust;
- Removing any national monument or protected national heritage to a place outside of Jamaica.

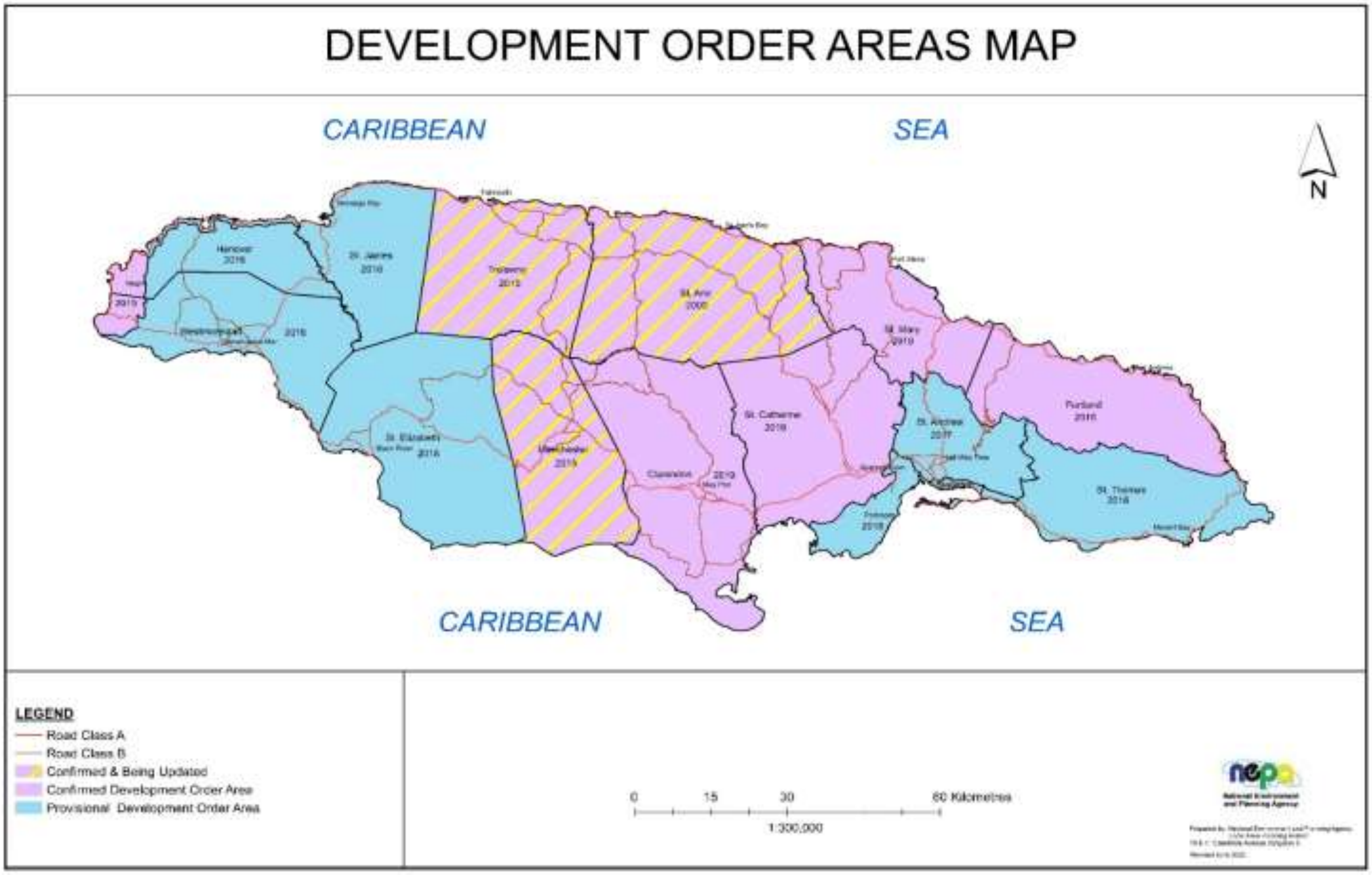


Figure 3.5 Development Order Areas in Jamaica (National Environment and Planning Agency, 2020)

3.5.3.7 *Vision 2030 Jamaica- National Development Plan*

Vision 2030 Jamaica is a National Development Plan for the country, promoting four National Goals as well as associated National Outcomes for each goal, to be achieved by 2030, with the objective of developing Jamaica into a country with a vibrant and sustainable economy, society and environment; a high level of human capital development; greater opportunities and access to these opportunities for the population; and a high level of human security.

3.5.3.8 *Environmental Conservation*

3.5.3.8.1 Policy for the National System of Protected Areas 1997

The system of protected areas should be an essential tool for environmental protection, conserving essential resources for sustainable use, helping to expand and diversify economic development, and contributing to public recreation and education. The Palisadoes and Port Royal Protected Area encompass, diverse natural resources and landscape, and are comparable to those of the IUCN (International Union for Conservation of Nature)[3]: Managed Resource Protected Area (Equivalent to IUCN Category VI)

This legislative instrument is a White Paper and essentially proposes a comprehensive protected areas system for Jamaica, with varying responsible agencies and legislative tools.

Table 3.21 Existing categories of protection in the area (as at 1 January 2012) - protected area system categories (Protected Areas Committee, 2012)

CATEGORY	RESPONSIBLE AGENCY	LAW
Protected Area	Forestry Department: Water, Land, Environment and Climate Change (MWLECC)	Forest Act, 1996 and Forest Regulations
	NEPA: MEGJC	NRCA Act, 1991
	NEPA: MEGJC	Beach Control Act, 1956

Table 3.22 Existing categories of protected areas in Jamaica (as at 1 January 2012) - other designations not considered part of the system (Protected Areas Committee, 2012)

CATEGORY	RESPONSIBLE AGENCY	CONVENTION
Ramsar Site	NEPA (NRCA): MEGJC	Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention)
World Heritage Site	Jamaica National Heritage Trust: MYC	World Heritage Convention

The Natural Resources Conservation Authority (NRCA)/National Environment and Planning Agency (NEPA) is the lead agency with responsibility for the protected area system; however a number of other government , local management entities, non-governmental entities, privet sector and individuals are outlined as important role players as well.

As seen in Figure 3.6, the proposed study falls within an area protected under various legal instruments and agreements – Palisadoes and Port Royal Protected Area under Natural Resources Conservation Authority (NRCA) Act) and Ramsar Site.

[3] It should be noted that since the publication of the Policy for Jamaica's System of Protected Areas 1997, the IUCN has revised the categories system and guidelines (http://cmsdata.iucn.org/downloads/guidelines_for_applying_protected_area_management_categories.pdf)

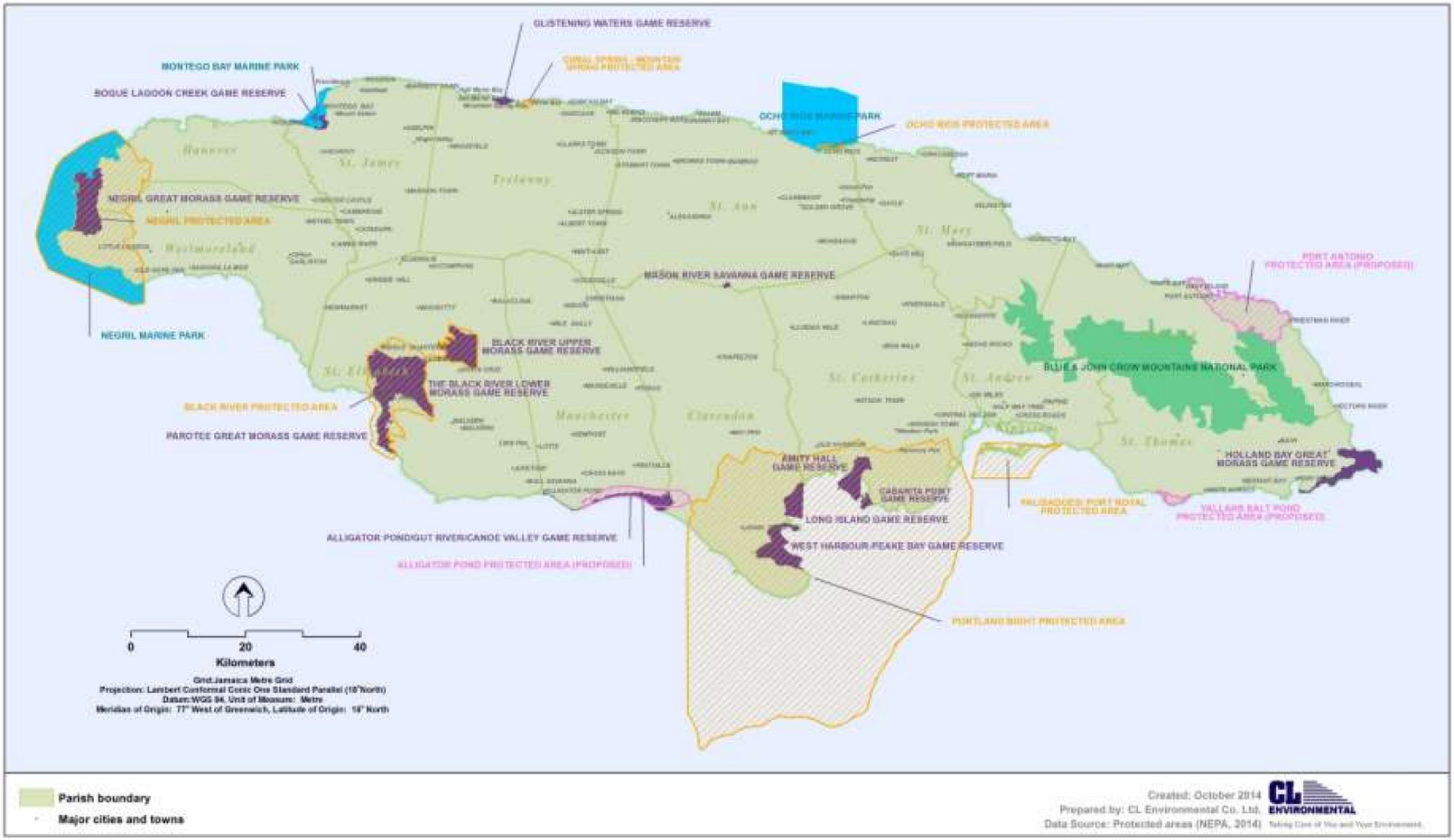


Figure 3.6 Protected areas system in Jamaica

3.5.3.8.2 Natural Resources Conservation Authority Act 1991

The Natural Resources Conservation Authority Act (NRCA) may be considered Jamaica's umbrella environmental law. The purpose of the Act is to provide for the management, conservation and protection of the natural resources of Jamaica. This Act was passed in the Jamaican Parliament in 1991 and subsequent to this; the Natural Resources Conservation Authority (NRCA) was established. The NRCA Act, under Sections 9 and 10 specifies that an Environmental Impact Assessment (EIA) is required from an applicant for a permit for undertaking any new construction, enterprise or development. It also speaks to the designation of national parks, protected areas etc.

The Act also gave power of enforcement of a number of environmental laws to the NRCA, namely the *Beach Control Act*, *Watershed Act* and the *Wild Life Protection Act*, as well as a number of regulations and orders including *The Natural Resources (Permit and Licences) Regulations (1996), The Natural Resources (Marine Park) Regulations 1992, The Natural Resources (Marine Park) (Amendment) Regulations 2003* and *The Natural Resources (Prescribed Areas) (Prohibition of Categories of Enterprise, Construction and Development) Order 1996.*

3.5.3.8.2.1 The Natural Resources Conservation (Permit and Licences) Regulations 1996 (Amended 2015)

A permit and licencing system was established under these regulations in order to control the undertaking of any new construction or development of a prescribed nature in Jamaica and the handling of sewage or trade effluent and poisonous or harmful substances discharged into the environment. As part of the April 2015 amendment, regulations 3, 7 and 24, concerning permit application forms, duration and fees respectively, were substituted.

3.5.3.8.2.2 The Natural Resources (Prescribed Areas) (Prohibition of Categories of Enterprise, Construction and Development) Order 1996 (Amended 2015)

The Natural Resources (Prescribed Areas) (Prohibition of Categories of Enterprise, Construction and Development) Order (1996) and the Permits & Licensing Regulations was passed as a result of section 9 of the NRCA Act. Section 9 of the NRCA Act declare the entire island and the territorial sea as a 'prescribed area', in which specified activities require a permit, and for which activities an environmental impact assessment may be required. The major amendment made in 2015 was the substitution of the Categories of Enterprises, Construction and Development (Column A), which lists the various activities, by category, for which a permit is required. As discussed previously, an EIA was required for the proposed project and this report fulfils one component of the EIA process.

3.5.3.8.3 The Fishing Industry Act 1975

The Fishing Industry Act 1975 is the overarching instrument relating to fishing activities within Jamaica. The Act speaks to registration and licensing, fisheries protection, prohibited activities and the declaration of an area as a fish sanctuary. Under the most recent Fishing Industry (Special Fishery Conservation Area) Regulations 2012, Special Fishery Conservation Areas (SFCAs), more commonly known as fish sanctuaries, are declared. As mentioned previously, the Galleon Harbour SFCA and the Salt Harbour SFCA are located to the southwest and southeast of the project area. Further, although fishing is not an activity to be carried out intentionally during the proposed project, it must be kept in mind during construction activities that it is an offence, during closed seasons, to take, disturb or injure fish, as well as to destroy or land berried lobster and spiny lobster smaller than 3 inches (7.5 cm).

3.5.3.8.4 Wild Life Protection Act 1945

The Wild Life Protection Act of 1945 is mainly concerned with the protection of specified faunal species and is the only statute in Jamaica specifically designated to this. This Act protects several rare and endangered faunal species including six species of sea turtle, one land mammal, one butterfly, three reptiles and a number of game birds. A list of these protected species is provided in this Act under the Second and Third Schedules. The establishment of two types of protected areas, namely Game Sanctuaries and Game Reserves is authorized under this Act. As mentioned previously, two game reserves are located to the southwest and southeast, namely Long Island Game Reserve (declared August 21, 1998) and Amity Hall Game Reserve (declared August 22, 1997, amended July 28, 2004) respectively.

3.5.3.8.5 The Endangered Species (Protection, Conservation and Regulation of Trade) Act 2000 (Amended 2015)

The Endangered Species (Protection, Conservation and Regulation of Trade) Act was created in 2000 in order to ensure the codification of Jamaica's obligations under the Convention for the International Trade in Endangered Species of Wild Fauna and Flora. This Act governs international and domestic trade in endangered species in and from Jamaica. The regulations associated with this Act were amended in 2015, and include updated fees for the various permits and certificates granted through this legislation.

3.5.3.8.6 The Forest Act 1996

The 1996 Forest Act repealed the 1937 legislation and was the legal basis for the organization and functioning of the Forestry Department. The Forestry Department is the lead agency responsible for the management and conservation of the forest resources in Jamaica. A "Forest Reserve" is defined to be any area of land declared by or under this Act to be a forest reserve. In 1938, the Forest Branch gazetted some 78,800 hectares of Crown Lands as forest reserves, this making up more than 75% of the present day forest reserves. The Great Goat Island forest reserve is situated 4km southeast of the project area.

3.5.3.8.7 The Beach Control Act 1956

This Act was passed to ensure the proper management of Jamaica's coastal and marine resources by means of a licensing system. This system regulates the use of the foreshore and the floor of the sea. In addition, the Act speaks to other issues including access to the shoreline, rights related to fishing and public recreation and establishment of marine protected areas. The Beach Control Authority (Licensing) Regulations of 1956 require a permit for any works on a beach, coastline or foreshore. Application for this permit must be made to NEPA.

3.5.3.9 *Public Health & Waste Management*

3.5.3.9.1 Water Quality Standards

The NRCA has primary responsibility for control of water pollution in Jamaica. National Standards for industrial and sewage discharge into rivers and streams, in addition to standards for ambient freshwater exist. For drinking water, World Health Organization (WHO) Standards are utilized and these are regulated by the National Water Commission (NWC). Since 1996, Jamaica has had draft regulations governing the quality of the effluent discharged from facilities to public sewers and surface water systems. These draft guidelines require the facility to meet certain basic water quality standards for trade effluent including sewage

Table 3.23 Draft national ambient marine water quality standards for Jamaica (National Environmental and Planning Agency (NEPA), 2009)

Parameter	Measured as	Standard Range	Unit
Phosphate,	P*	0.001-0.003	mg/L
Nitrate,	N**	0.007-0.014	mg/L
BOD_5	O	0.0-1.16	mg/L
pH		8.00-8.40	
Total Coliform		2-256	MPN/100mL
Faecal Coliform		<2-13	MPN/100mL

*Reactive phosphorus as P
**Nitrates as Nitrogen

3.5.3.9.2 The National Solid Waste Management Authority Act 2001

The National Solid Waste Management Authority Act of 2001 is "an act to provide for the regulation and management of solid waste; to establish a body to be called the National Solid Waste Management Authority and for matters connected therewith or incidental thereto". The National Solid Waste Management Authority (NSWMA) was established in April 2002 as a result of this Act to effectively manage and regulate the collection and disposal of solid waste in Jamaica.

3.5.3.9.3 Public Health Act 1985

The Public Health Act is administered by the Ministry of Health through Local Boards, namely the Municipal Council. *The Public Health (Nuisance) Regulations 1995* aims to, control reduce or prevent air, soil and water pollution in all forms. Under the regulations:

- No individual or organization is allowed to emit, deposit, issue or discharge into the environment from any source;
- Whoever is responsible for the accidental presence in the environment of any contaminant must advise the Environmental Control Division of the Ministry of Health and Environmental Control, without delay;
- Any person or organization that conducts activities which release air contaminants such as dust and other particulates is required to institute measures to reduce or eliminate the presence of such contaminants; and
- No industrial waste should be discharged into any water body, which will result in the deterioration of the quality of the water.

3.5.3.9.4 The Natural Resources (Hazardous Waste) (Control of Transboundary Movement) Regulations 2003

These regulations seek to implement the *Basel Convention on the Transboundary Movement of Hazardous Waste* and control transboundary movement and prevent the illegal trafficking of certain hazardous wastes. It is an offence to unlawfully dump or otherwise dispose of hazardous waste in area under jurisdiction of Jamaica. Waste resulting from the proposed project should be properly disposed of, and special attention should be paid to those considered hazardous under these regulations and as listed above.

3.5.4 Regional and International Legislative and Regulatory Considerations

3.5.4.1 *Cartagena Convention (Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region), 1983*

Adopted in March 1983 in Cartagena, Colombia, the Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region, more commonly referred to as the Cartagena Convention, is the sole legally binding environmental treaty for the Wider Caribbean. The Convention came into force in October 1996 as a legal instrument for the implementation of the Caribbean Action Plan and represents a commitment by the participating countries to protect, develop and manage their common waters individually and jointly. The Convention is currently supported by three Protocols as follows:

- *The Protocol Concerning Co-operation in Combating Oil Spills in the Wider Caribbean Region* (The Oil Spills Protocol), which was adopted and entered into force at the same time as the Cartagena Convention;
- *The Protocol Concerning Specially Protected Areas and Wildlife in the Wider Caribbean Region* (The SPAW Protocol), which was adopted in two stages, the text in January 1990 and its Annexes in June 1991. The Protocol entered into force in 2000;
- *The Protocol Concerning Pollution from Land-based Sources and Activities in the Wider Caribbean Region* (LBS Protocol), which was adopted in October, 1999.

3.5.4.2 *United Nations Convention on Biological Diversity*

Signed by 150 government leaders at the 1992 Rio Earth Summit, the Convention on Biological Diversity (CBD) is committed to promoting sustainable development. The CBD is regarded as a means of translating the principles of Agenda 21 into reality and recognizes that "biological diversity is about more than plants, animals and microorganisms and their ecosystems – it is about people and our need for food security, medicines, fresh air and water, shelter, and a clean and healthy environment in which to live". Jamaica's Green Paper Number 3/01, 'Towards a National Strategy and Action Plan on Biological Diversity in Jamaica', is evidence of Jamaica's continuing commitment to its obligations as a signatory to the Convention.

3.5.4.3 *Convention on Wetlands of International Importance especially as Waterfowl Habitat, "Ramsar Convention" 1971*

The Ramsar Convention is an intergovernmental treaty that focuses on maintaining ecological wetland systems and planning for sustainable use of their resources. It was adopted on 2 February 1971 in Ramsar, Iran. The mission of the Convention was adopted by the Parties in 1999 and revised in 2005 - "the conservation and wise use of all wetlands through local, regional and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world". Under Article 2.2 it is stated:

Wetlands should be selected for the List on account of their international significance in terms of ecology, botany, zoology, limnology or hydrology" and indicates that "in the first instance, wetlands of international importance to waterfowl at any season should be included. Jamaica became a contracting party on 7 February 1998 and has 4 sites covering a combined total of 37,847 hectares (378.47 km^2). Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) CITES generally seeks to protect endangered plants and animals and owing to the cross boundary nature of animals and plants, this protection requires international cooperation. It aims to ensure that international trade of wild animal and plant species does not threaten the survival of the species in the wild, and it accords varying degrees of protection to over 35,000 species. This convention was drafted in 1963 at a meeting of members of the International Union for Conservation of Nature (IUCN) and finalised in 1973. After being opened for signatures in 1973, CITES entered into force on 1 July 1975.

3.5.5 Description of the Existing Environment

3.5.5.1 *Physical*

3.5.5.2 *Climate and Meteorology*

The nearest meteorological station to the site is at the Norman Manley International Airport (NMIA). The meteorological data from NMIA between 1951 and 1980 is shown in Table 3.24. The temperature values show a minimum temperature range of 22.3-23.1 °C and a maximum temperature range of 29.8-30.5 °C. The data also shows the warmest months of the year being July, August, and September. A mean annual rainfall of 62.1 mm was recorded, with the October being the month with the highest rainfall and the most days of rain (167 mm and 10 days respectively). Weather Data was also collected from the West Kingston Power Station, for 2016 to 2020 shown below in Table 3.25. These results show a minimum temperature of 27.42°C and a maximum temperature of 28.51°C for 2016-2020.

The main regional scale weather features that affect the island are upper level pressure troughs (an elongated area of low atmospheric pressure at high altitude), tropical waves and incipient storms and cold fronts. Upper level troughs occur year round but are more frequent in the winter when there are more frequent temperate latitude low-pressure systems and fronts.

Table 3.24 Monthly mean and annual mean values for selected meteorological parameters at Norman Manley International Airport 1951 to 1980

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual Mean
Maximum Temp. (°C)	29.8	29.6	29.8	30.3	30.8	31.2	31.7	31.9	31.7	31.3	31.1	30.5	30.8
Minimum Temp. (°C)	22.3	22.3	22.9	22.6	24.7	25.3	25.6	25.3	25.3	24.8	24.1	23.1	24.0
Rainfall (mm)	18	16	14	27	100	83	40	81	107	167	61	31	62.1
No. of rain days	4	4	3	5	5	6	4	6	8	10	6	4	5.4
Rel. Hum. 7am (%)	80	78	77	77	76	73	76	76	78	80	79	78	77.3
Rel. Hum. 1pm (%)	61	62	64	60	66	65	65	68	68	65	65	64	64.4
Sunshine (Hours)	8.3	8.6	8.5	8.7	8.2	7.7	8.2	8	7.2	7.4	7.8	7.8	8.0

Table 3.25 WKPS Weather Data Annual Means for 2016 to 2020

Year	Maximum Temp(C)	Minimum Temp(C)	Rainfall(m)	Rain Rate	Hum	Wind Speed	Wind Dir
2016	28.42	28.14	0.03	0.76	76.55	1.24	E
2017	27.99	27.72	0.08	0.67	77.52	1.25	NW
2018	28.07	27.80	0.01	0.32	76.36	1.57	E
2019	28.50	28.21	0.04	0.61	73.69	1.66	W
2020	27.51	27.24	0.01	0.12	72.67	1.87	NE

The summer troughs are fewer but can be more persistent. The troughs sometimes interact with the easterly waves (a wavelike disturbance in the tropical easterly winds that usually moves from east to west) and tropical storms to produce intense rainfall. Tropical waves and incipient storms occur in the summer and move from east to west and are good rainfall producers. A tropical wave is a kink or bend in the normally straight flow of surface air in the tropics that form a low-pressure trough, or pressure boundary, and showers and thunderstorms. It can develop into a tropical cyclone. The dominant winds over Jamaica are the northeast trade winds whose strength is governed by the strength and location of the Azores-Bermuda sub tropic high-pressure cell. During the summer months the high-pressure cell is weaker and farther north (than in summer) and consequently the trade winds are broad, persistent and extend further south. In the winter months, the central pressure of the cell is higher and further south and the winter trade winds are weaker and have a more northerly component

Meteorological data was obtained from the Meteorological Service station at the Norman Manley International Airport, A dataset of at least one year was used to develop a wind rose for the project site and provide a statement on current meteorological conditions at the site. The wind rose for the site is shown in Figure 3.7 is the output wind rose:

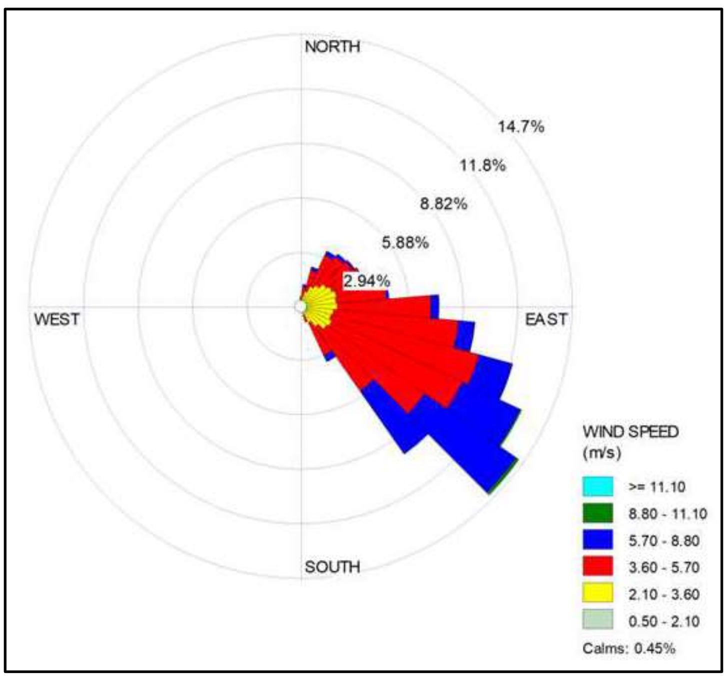


Figure 3.7 Wind Rose for MM5 Data 2013-2017

3.5.5.3 *Water Quality*

3.5.5.3.1 Introduction

The varying conditions of the marine environment surrounding the NMIA facility are like the conditions found throughout Kingston Harbour which has been studied by numerous authors (Dunbar and Webber 2003, Bigg and Webber 2003, Webber, and Kelly 2003). The main sources of pollutants within the harbour originate mainly from run off and fluvial input (D.F. Webber and Kelly 2003), which contributes to the harbour being generally eutrophic. These pollutants are mainly input along the Norther coastline of the harbour which is associated with multiple industries and communities (Bigg and Webber 2003).

Water quality analysis was conducted across the harbour and within the vicinity of the airport environment by CL Environmental Consultants Ltd on three occasions, February 26, 2020, March 26, 2020, and April 9, 2020. Seawater temperatures ranged from 27.96 – 29.21 ºC, and samples collected showed no significant freshwater influences as salinity ranged from 35.23 – 37.06 ppt. Total Suspended Solid (TSS) values ranged from <5 – 10.5 mg/l, indicating clear waters, Biochemical Oxygen Demand (BOD) at all sampling locations were non-compliant with the NEPA Marine Water Quality Standard of 1.16 mg/l. BOD values ranged from 1.57 – 7.93 mg/l. Nitrate concentrations were non-compliant with NEPA Marine Water Quality Standards of 0.007-0.014 mg/l, Nitrate values at the sampling locations were 1.5 – 3.2 mg/l. These values are in the same ranges recorded in previous studies, (Cowell Lyn, 2013, CL Environmental, 2014)

Faecal coliform values were all compliant with the NEPA Marine Water Quality Standard all were lower than 13 MPN/100ml MPN/100ml at the sampling locations, these faecal coliform values were unexpected compared to previous values found in the same area, faecal coliform results from a study done in 2011 which is close to stations 1,2,3 and 4 saw values of 22 – 920 MPN/100ml within the vicinity of the NMIA while a study in 2013 saw faecal coliform values below the standard at all stations(Cowell Lyn., 2013). Another study done in 2015 showed faecal coliform levels to the East of the harbour along the Palisadoes strip, close to stations 10 and 11, to have coliform levels between 22- 69 MPN/100ml in February 2015,which fell to <11 at the same sites on March 2015(CL Environmental, 2014). These results may be the result of multiple factors, the repair of the NMIA sewage treatment plant and reduced water traffic and discharge into the harbour because of the COVID-19 lockdown in 2020.

3.5.5.3.2 Methodology

Whole water quality samples were collected at twelve (12) locations. Samples were collected in pre-cleaned plastic bottles. Surface samples were collected with the use of a boat and stored on wet ice and taken to the Caribbean Environmental Testing and Monitoring Services Limited for analysis of BOD, Total Suspended Solids (TSS), Nitrates, Phosphates and Faecal Coliform. Temperature, salinity, pH, turbidity, Total Dissolved Solids (TDS) and dissolved oxygen (D.O.) were measured in situ using a Hydrolab DS5 water quality multi-probe. The locations of the stations are listed in Table 3.26 and shown in Figure 3.8. The locations of each water quality station are illustrated in Figure 3.8

Table 3.26 Location of the water quality stations in JAD2001

STATION #	LOCATION (JAD2001)	
	NORTHINGS	EASTINGS
1	642582.661	772293.320
2	643454.087	770990.274
3	643352.304	772499.598
4	643310.956	770434.623
5	643848.808	768739.733
6	644396.974	767622.428

7	643683.591	767699.684
8	643647.748	766336.833
9	644845.742	770067.871
10	644404.144	773558.092
11	644306.429	777397.959
12	642235.936	766541.748

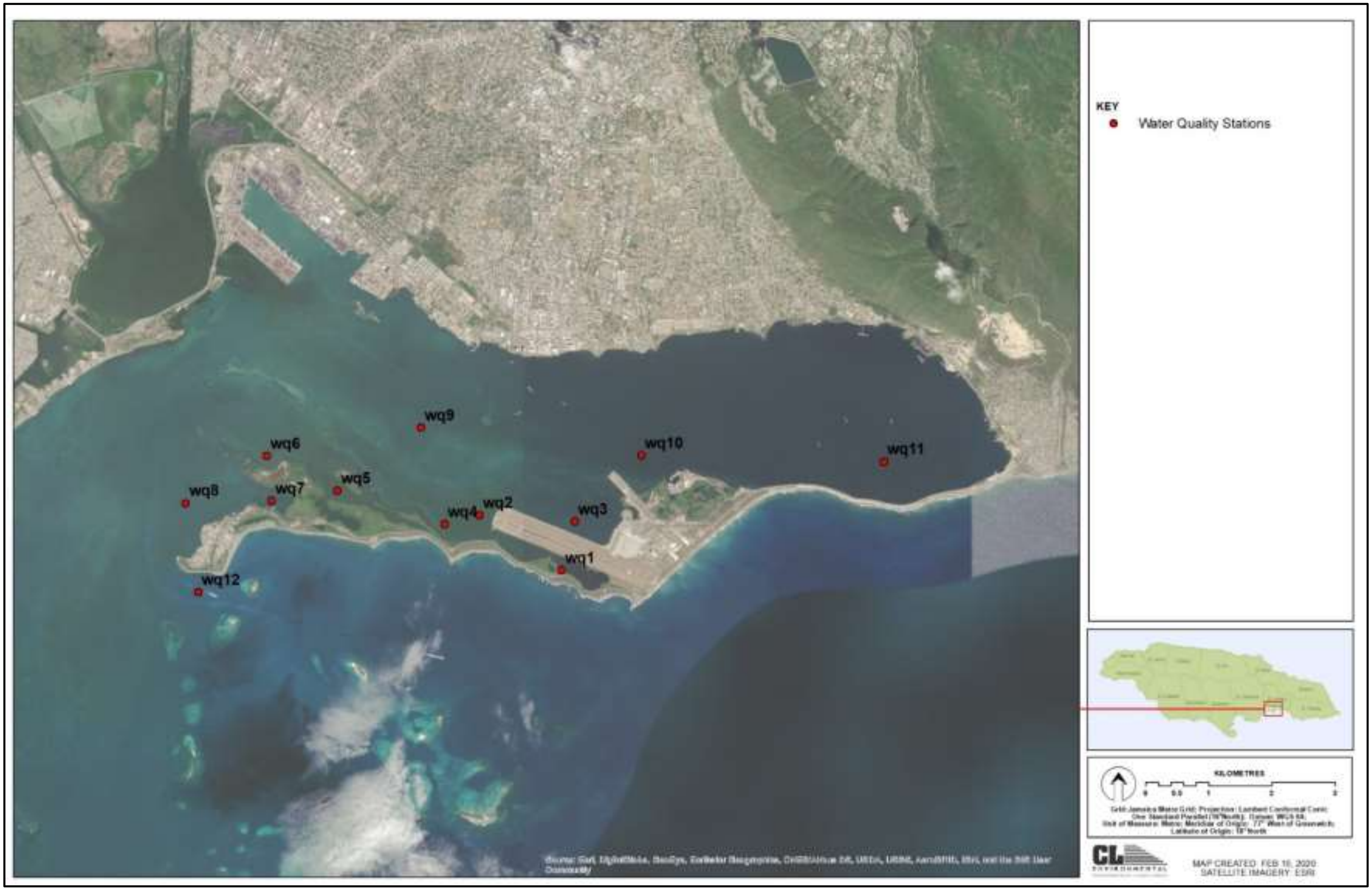


Figure 3.8 Map showing water quality sampling locations

3.5.5.4 *Results*

Table 3.27 shows the average results for the in situ physio-chemical data, Table 3.28 shows the average results for the biochemical data for each stations sampled.

Table 3.27 Average Physio-chemical results for each station

Station	TEMP. °C	COND (mS/cm)	SAL (ppt)	pH	D.O. (mg/l)	Turb (NTU)	TDS (g/l)
1	29.21	55.74	37.06	7.95	5.25	3.34	35.68
2	28.45	53.93	35.72	8.20	5.98	0.61	34.52
3	28.18	53.89	35.70	8.19	5.53	0.69	34.49
4	28.18	54.05	35.63	8.20	5.75	0.42	34.42
5	28.27	53.52	35.44	8.16	5.46	1.17	34.25
6	28.43	53.26	35.23	8.22	5.83	1.08	34.09
7	28.15	54.23	35.84	8.14	5.23	0.03	34.68
8	28.20	53.02	35.87	8.22	6.09	0.22	34.64
9	28.60	53.92	35.64	8.24	5.87	0.37	34.51
10	28.45	53.98	35.68	8.20	5.35	0.53	34.48
11	28.40	53.87	35.70	8.20	4.99	0.81	34.49
12	27.96	54.42	36.09	8.22	6.46	0.10	34.83
NEPA Marine Standard	-	-	-	8 – 8.4	-	-	-

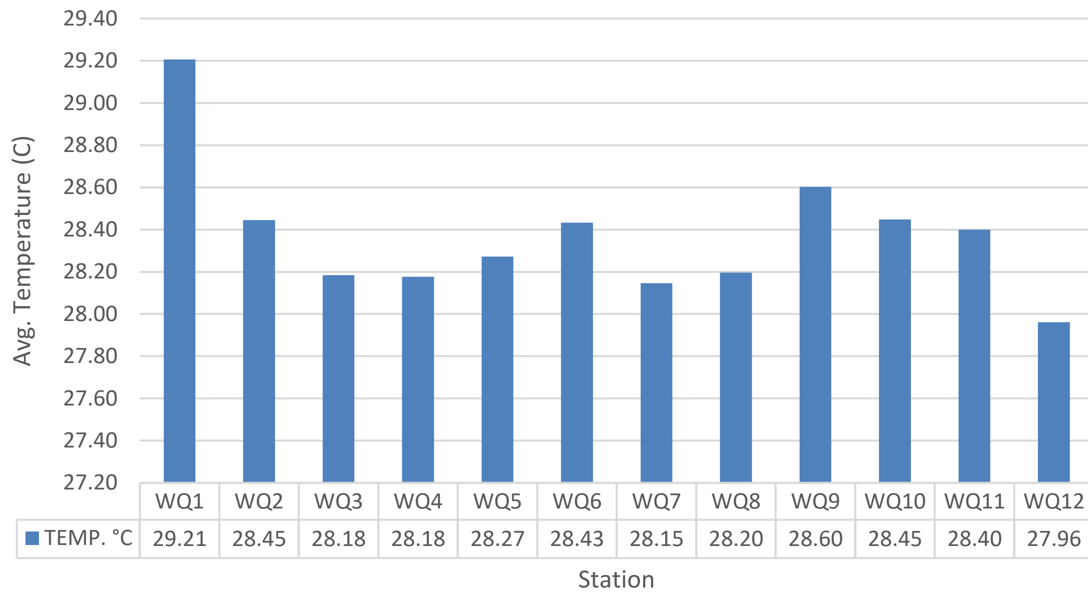
Table 3.28 Average Biochemical data for each station

Station	BOD (mg/l)	TSS (mg/l)	NITRATE (mg/l)	Faecal Coliform (MPN/100ml)	PHOS (mg/l)
1	3.59	<4	1.73	<11	0.66
2	3.65	<4	3.20	<11	0.69
3	3.45	<4	1.93	<11	0.50
4	3.80	<4	1.83	<11	0.16
5	3.50	<4	1.83	<11	0.26
6	4.58	<4	1.83	<11	0.15
7	1.57	<4	1.50	<11	0.22
8	6.61	<4	1.97	<11	0.06
9	6.68	<4	1.77	<11	0.17
10	7.21	<4	1.53	<11	0.15
11	7.93	<4	1.60	<11	0.21
12	5.04	10.50	2.27	<11	0.82
NEPA Marine Standard	1.16		0.007 – 0.014	13	0.001 – 0.003

N.B. Values in red are non-compliant with respective NEPA standards

<u>Temperature</u>

Seawater temperature values varied across the stations ranging from 27.96 – 29.21°C. Highest temperatures were obtained at station 1 whereas the lowest was obtained at station 12, located furthest offshore, outside of the harbour. The water temperatures recorded were expected in a tropical marine area influenced by the Trade Winds (27 - 30°C).



	WQ1	WQ2	WQ3	WQ4	WQ5	WQ6	WQ7	WQ8	WQ9	WQ10	WQ11	WQ12
TEMP. °C	29.21	28.45	28.18	28.18	28.27	28.43	28.15	28.20	28.60	28.45	28.40	27.96

Figure 3.9 Average temperature values for each station

Specific Conductivity (SpC)

Specific conductivity varied across the stations ranging from 53.02 – 55.74 mS/cm which are deemed normal for a tropical marine area. Highest specific conductivity was obtained at station 1 whereas the lowest specific conductivity was obtained at station 8. All the stations except for station 12 were located within the harbour and are potentially impacted by land run-off.

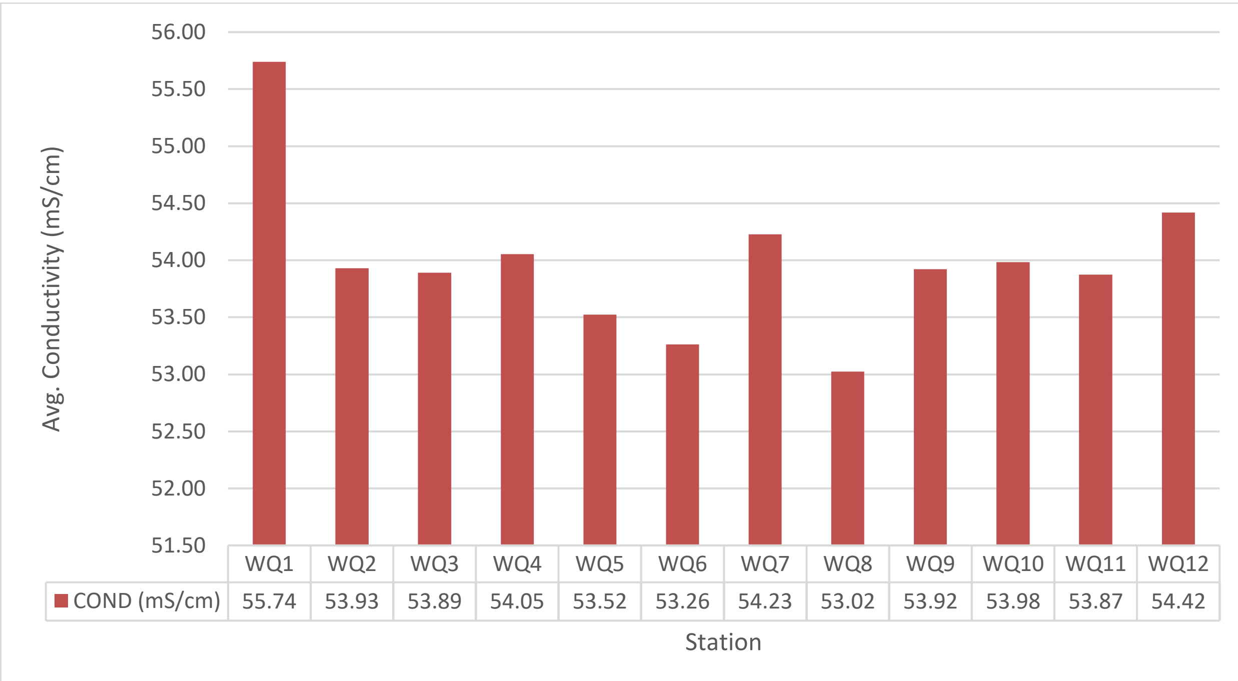


Figure 3.10 Conductivity values at various stations

Salinity

Salinity varied across the stations ranging from 35.23 – 37.06 ppt, which are deemed normal for a tropical marine area. Station 1 had the highest salinity value whereas station 6 had the lowest value.

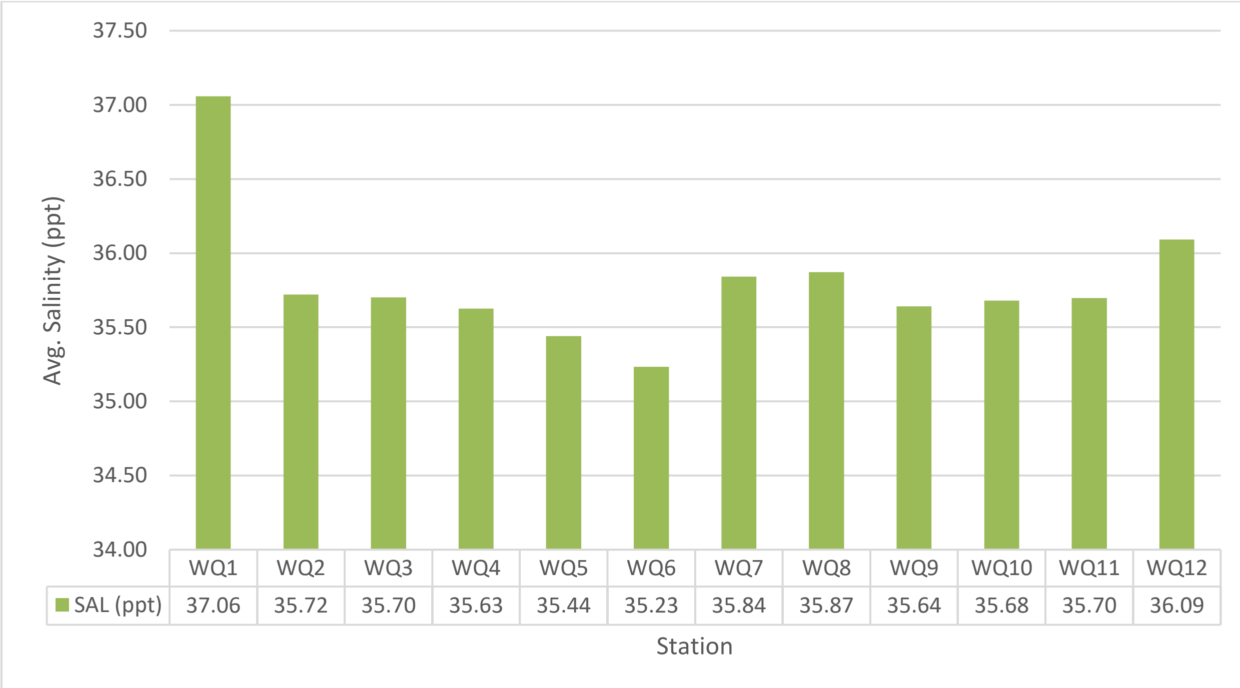


Figure 3.11 Salinity values at the various stations

pH

The pH values showed some variation across the stations ranging from 7.95 - 8.24. The highest pH values were obtained at Station 9 whereas the lowest pH obtained at Station 1. In marine waters, pH levels tend to range between 8-9 pH units. Higher pH indicates the possibility of photosynthesis changing the pH within the zone. One pH value obtained (Station 1) was non-compliant with the respective NEPA marine standard (8 – 8.4).

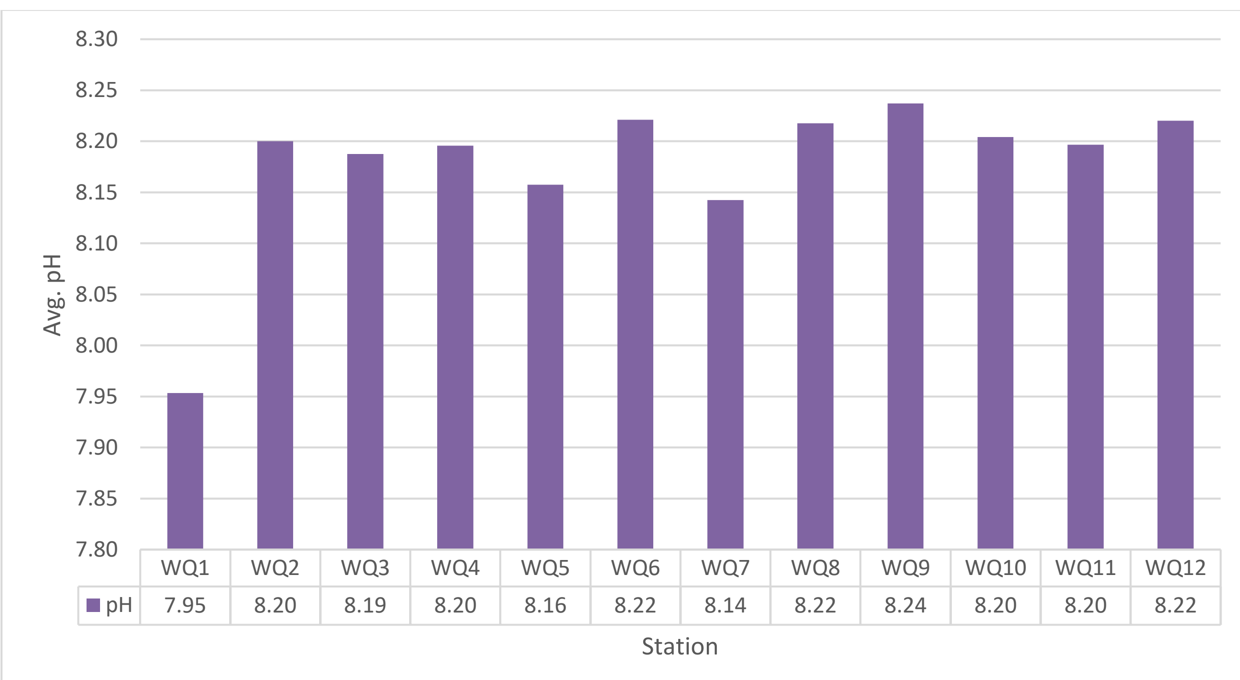


Figure 3.12 pH values at the various stations

Dissolved Oxygen (DO)

Dissolved oxygen is the amount of elemental oxygen dissolved in water. Dissolved oxygen values varied across the stations ranging from 4.99 – 6.46 mg/l. Station 11 had the lowest dissolved oxygen value whereas the highest value was obtained at Station 12. Dissolved oxygen levels at marine locations were all within acceptable levels (>4 mg/l). All D.O. concentration were also greater than 3 mg/l, which is the concentration considered to be detrimental to aquatic life.

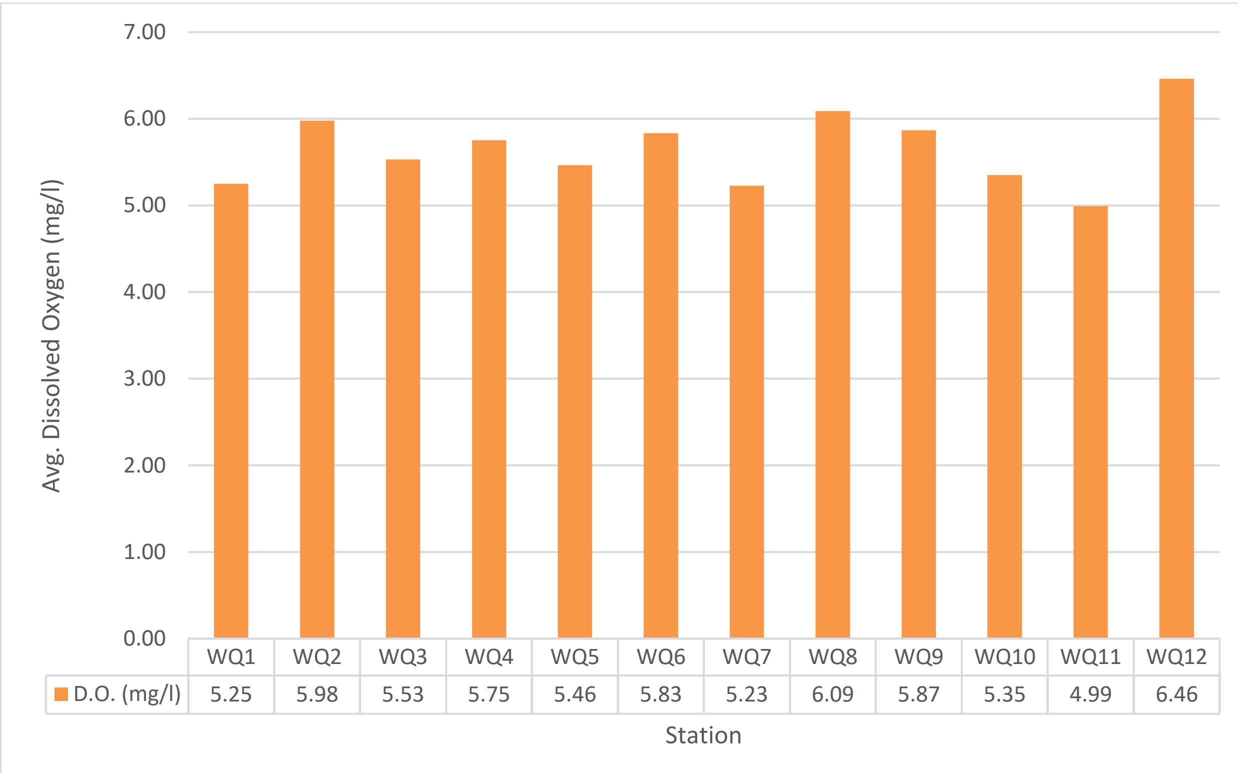


Figure 3.13 Dissolved oxygen values at the various stations

Turbidity

Turbidity varied across the stations ranging from 0.03 NTU at Station 7 to 3.34 NTU at Station 1. The lowest turbidity occurred at station (Station 7), the higher turbidity value (Station 1) was observed closer to shore and was affected by shallow depth.

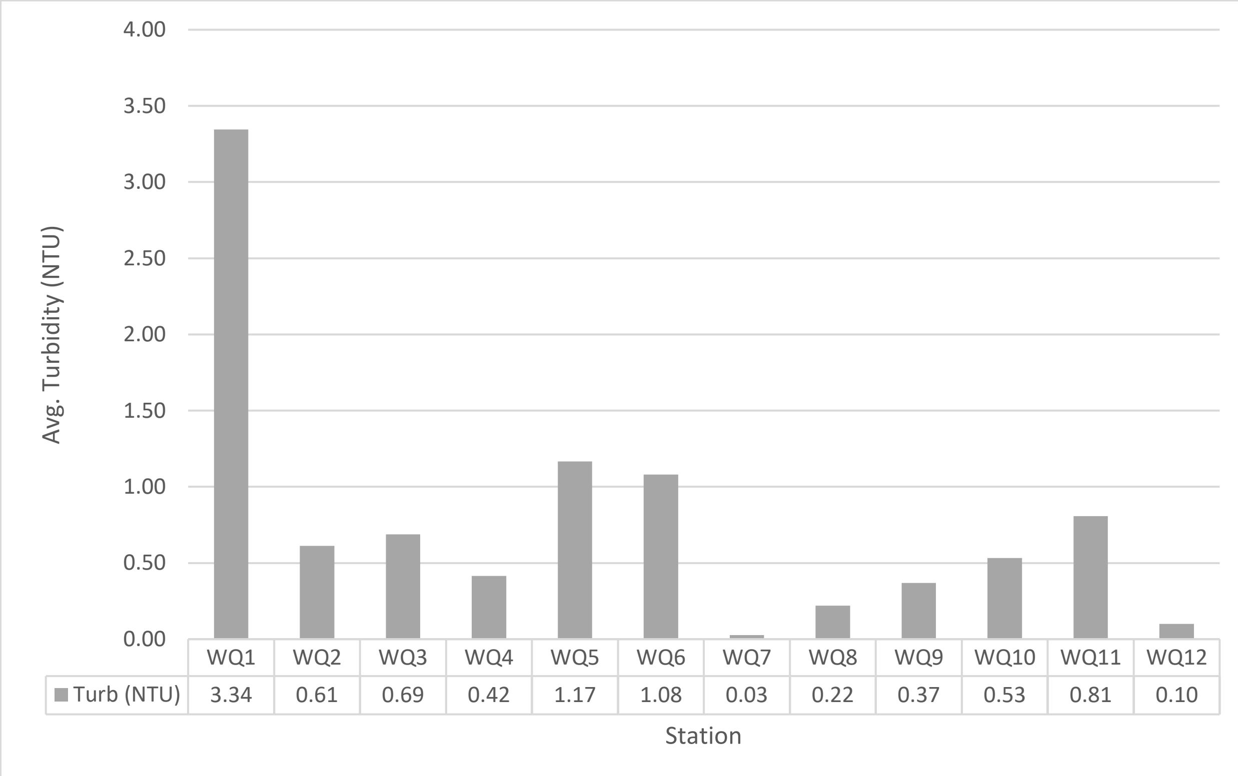


Figure 3.14 Turbidity values at the various stations

Total Dissolved Solids (TDS)

Total dissolved solids is a representation of the combined inorganic and organic dissolved content in the water, such as minerals and salts. The TDS values varied across the stations ranging from 34.09 – 35.68 g/l. The highest values were obtained from station 1 whereas the lowest values were obtained at station 6. These TDS values are normal for seawater.

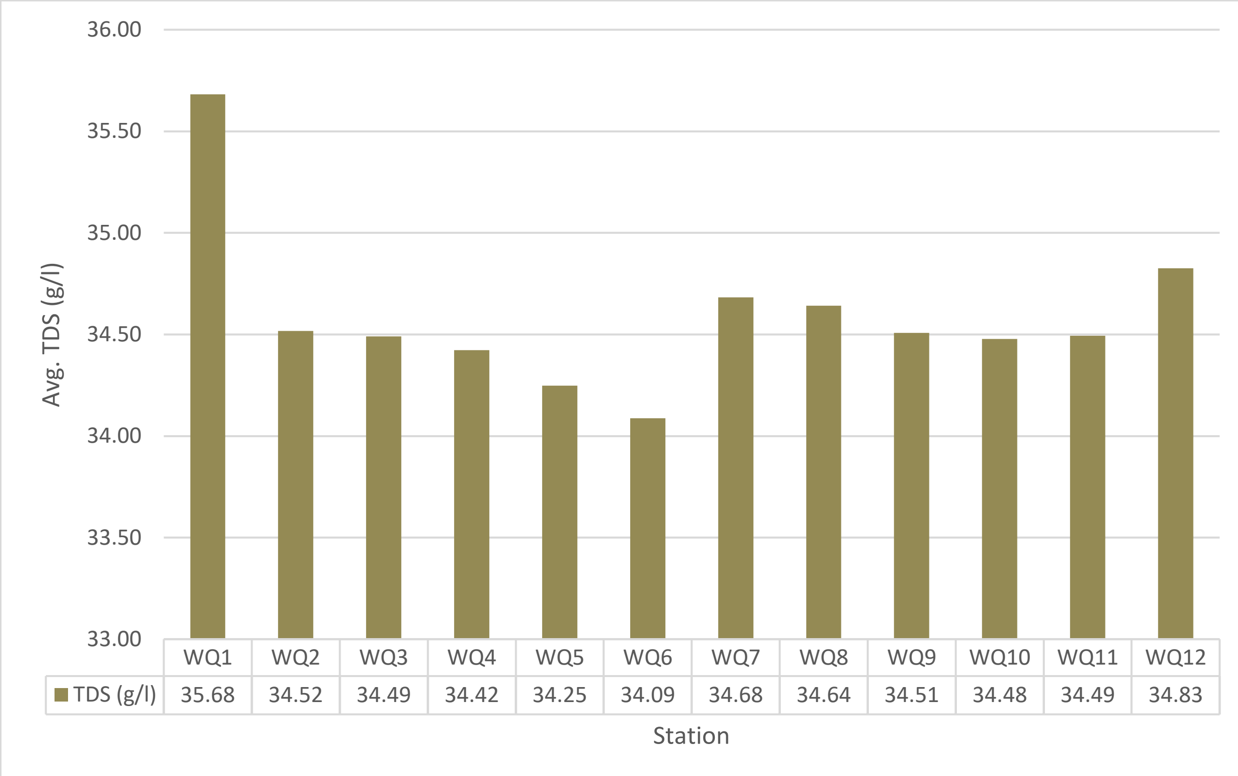


Figure 3.15 TDS values at the various stations

<u>BOD</u>

Biological oxygen demand is a measure of the oxygen used by microorganisms to decompose organic waste. BOD values varied across the stations ranging from 1.57 – 7.93 mg/l. All stations had values above NEPA marine standards for BOD for nitrates. The more organic waste present in water, the higher the BOD level will be the highest BOD values were obtained from stations 8, 9, 10 and 11, which were the stations found further out in the harbour. The high BOD values in the harbour are mainly impacted by land run off and discharge by the factories and communities to the North of the harbour.

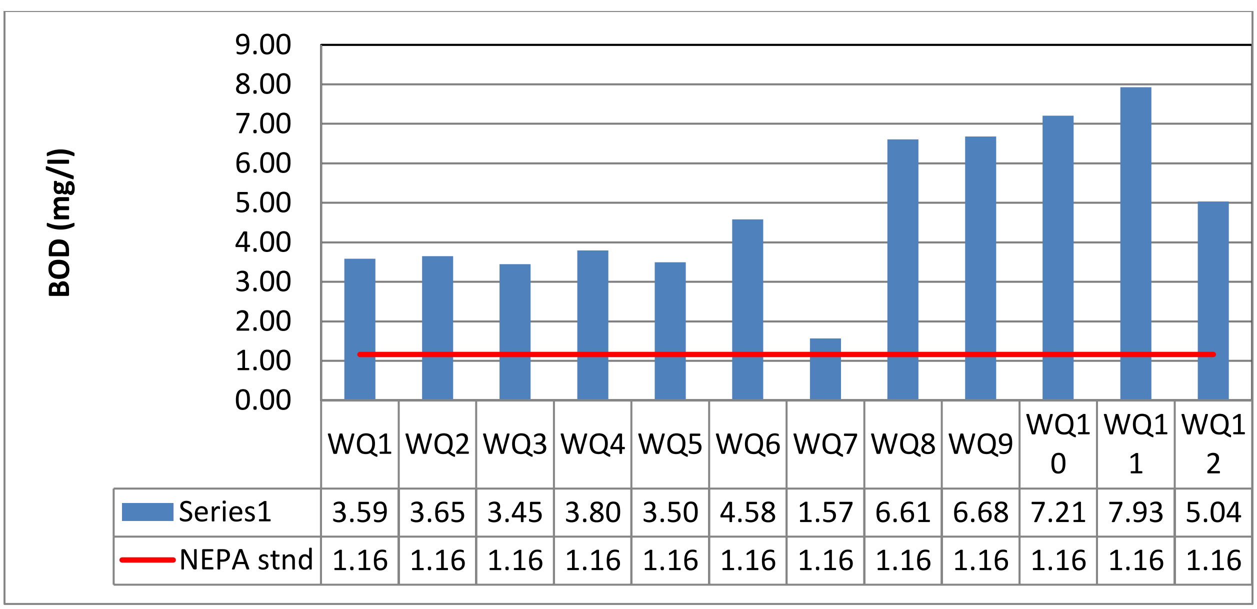
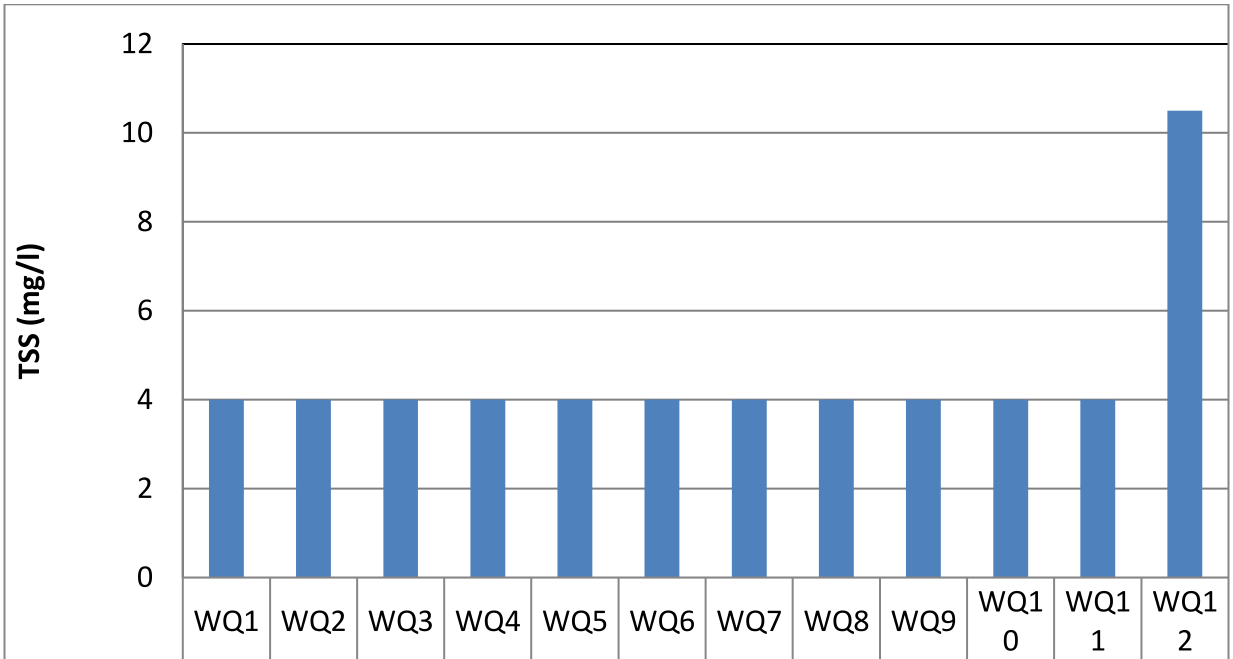


Figure 3.16 BOD values at the various stations

Total Suspended Solids

TSS concentrations was <5 mg/l at stations 1, to 11 with station 12 being 10.5 (mg/l). TSS concentrations indicate clear water conditions when below 20mg/l, indicating that all stations sampled had clear waters, which the highest stations being station 12. The higher value at station 12 may be due to it being within the shipping channel and is affected by significant wave action.

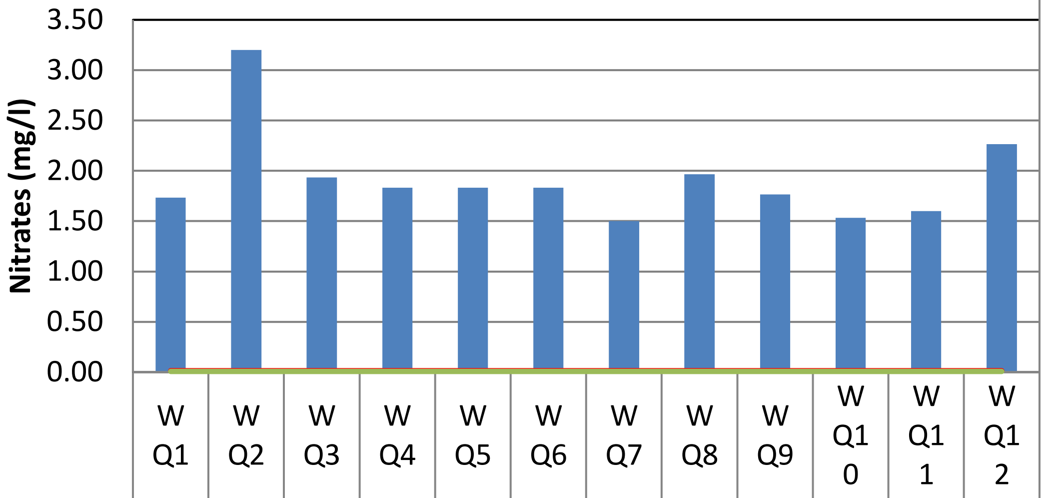


	WQ1	WQ2	WQ3	WQ4	WQ5	WQ6	WQ7	WQ8	WQ9	WQ10	WQ11	WQ12
Series1	4	4	4	4	4	4	4	4	4	4	4	10.50

Figure 3.17 TSS values at the various stations

Nitrate

Nitrate values varied across the stations ranging from 1.5 – 3.2 mg/l. All stations were above the NEPA marine standard for Seawater for nitrates. These nitrate values are typical for Jamaican coastal waters and seldom vary outside this range. High nitrate levels are due to water contamination from wastewater or fertilizer. The highest value was at station 2 which is located directly in front of the NMIA runway.

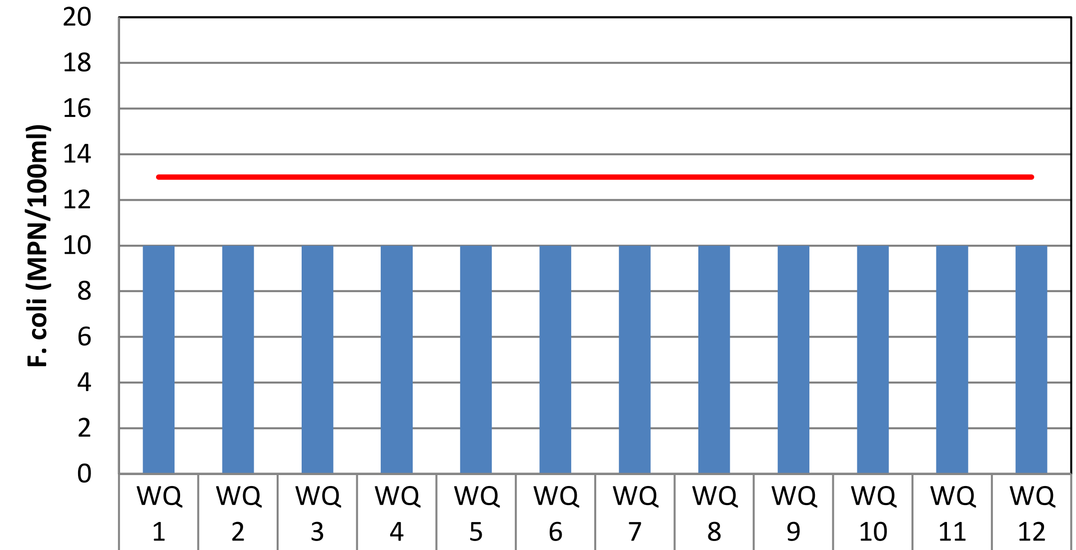


	WQ1	WQ2	WQ3	WQ4	WQ5	WQ6	WQ7	WQ8	WQ9	WQ10	WQ11	WQ12
Series1	1.73	3.20	1.93	1.83	1.83	1.83	1.50	1.97	1.77	1.53	1.60	2.27
NEPA Std (upper)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
NEPA Std (lower)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Figure 3.18 Nitrate values at the various stations

<u>Faecal Coliform</u>

Faecal coliform values were <11 mg/l at all stations sampled. These Faecal coliform results were compared to a study done in 2011 by Environmental Solutions Ltd. which is close to stations 1,2,3 and 4, which saw values of 22 – 920 MPN/100ml within the vicinity of the NMIA, while another study done in 2015 by Cl environmental showed faecal coliform levels to the East of the harbour along the Palisadoes strip, close to stations 10 and 11, to have coliform levels between 22- 69 MPN/100ml in February 2015. These and other studies have observed that coliform levels within the harbour in general exceed NEPA standards. However fluctuations In coliform levels have been observed within the harbour, in 2013 the study area sampled in 2011 by Environmental Solutions Ltd, was resampled and faecal coliform values were recorded below the standard at all stations and during the study done by Cl Environmental in March 2015 coliform levels sampled were <11 at all sites CL Environmental 2015). These studies observed high fluctuations in coliform levels going above and below the NEPA standard at various points, therefore coliform levels within the South of the harbour are in keeping with fluctuations observed in the past.



	WQ 1	WQ 2	WQ 3	WQ 4	WQ 5	WQ 6	WQ 7	WQ 8	WQ 9	WQ 10	WQ 11	WQ 12
Series1	10	10	10	10	10	10	10	10	10	10	10	10
NEPA Std (mpn/100ml)	13	13	13	13	13	13	13	13	13	13	13	13

Figure 3.19 Faecal coliform values at the various stations

3.5.5.5 *Biological*

3.5.5.5.1 Palisadoes and Port Royal Protected Area and Ramsar site

The Palisadoes is a 16 km tombolo, forming the south border of Kingston Harbour, characterised by dune vegetation on the southern windward side and mangrove thickets on the northern leeward side (Webber, 2003). The Palisadoes and Port Royal Protected Area (PPRPA) also includes a Ramsar site. The airport lands include the built environment (the airport and associated facilities) and the natural environment; a collection of divers ecosystems with varying degrees of conservation importance, climate resilience, shoreline protection and ongoing anthropogenic sources of degradation and pollution. Table 3.21 and Table 3.22 identifying various sensitive ecosystems/habitats and species found in the protected area.

Table 3.29 Sensitive Habitats/Areas, found in or nearby Airport lands, Potential Development Areas and Zone of Influence

Sensitive Areas/Habitat	Location	Airport lands and Potential development Areas	Zone of Influence	Potential Impacts
RAMSAR Wetlands and Mangrove Habitats	The mangroves of the PPPR received international recognition when they were designated RAMSAR site (i.e. Wetland of international importance) under the RAMSAR Convention for the Protection of Wetlands and Waterfowl.	yes	yes	Potential habitat and species loss of Mangrove areas with Conservation significance Mangrove areas with major anthropogenic influences
Seagrass Beds	Along sections of the Palisadoes, around sections of the cays and in nearshore sections around NMIA	yes	Yes	Major anthropogenic influences. Potential habitat and species loss
Reef/Coral Areas	Coral Cays, Barrier Reef, Along the seaward side Palisadoes and extremely limited on the harbour side	Yes	Yes	A poor to moderate coral reef community located along the seaward side, near the runway - within the zone of influence but with limited hard corals and other species. Currently having both natural and anthropogenic influences
Beach and Dune Habitats	Along the seaward side Palisadoes and limited on the harbour side	Yes	Yes	Potential habitat and protected species loss anthropogenic influences

Table 3.30 Sensitive/Endangered Fauna, found in or nearby Airport lands, Potential Development Areas and Zone of Influence

Sensitive/Endangered Fauna	Occurrence/ Location	Airport lands and Potential development Areas	Zone of Influence	Impacts
American Crocodile (Crocodylus acutus)	PPRA and NMIA marine environment and lands	Yes	Yes	Limited- slightly positive- afforded some protection by reduced human access to breeding areas
Hawksbill Turtle (Eretmochelys imbricata)	Nests on many of the Coral Cays and Parts of the Mainland	Yes	Yes	Limited- slightly positive- afforded some protection by reduced human access to nesting areas Possible loss of habitat with future developments
Green Turtle (Chelonia mydas)	Nests on many of the Coral Cays and Parts of the Mainland	Yes	No	Limited- slightly positive- afforded some protection by reduced human access to breeding areas Possible loss of habitat with future developments
West Indian Manatee (Trichecus manatus) Endangered	Historically observed within PPRA	Historically	Historically	Manatees have not been reported in this area in a very long time and are unlikely to return
Magnificent Frigatebirds (Fregata magnificens)	PPRA and NMIA marine environment and lands	Yes	Yes	None- expected similarity in noise climate to the current state

3.5.5.5.2 Flora - Mangrove, Wetland and Dune Communities

3.5.5.5.2.1 Methodology

Surveys were conducted over a four-day period; April 4-5 and May 2-3, 2020.

To sample various forested areas of the property, data was collected from twenty-four (24) discrete belt transects at select locations on the property. The box or rectangular transects were ideally laid as 10m x 10m plots(100m^2), but the sizes were varied to enable sampling in very dense forested areas(-5m x 20m) or made larger in very sparse areas to maximize sampling footprint(25m x 25m). The following data was collected within each transect:

- Standing water depth and salinity (middle of the transect)
- Visible fauna noted
- Mangrove tree species and numbers within sample area
- Mangrove tree heights (m) for up to 5 of each species present inside each transect
- Diameter at breast height (DBH) in cm, for up to 5 of each species present
- Density of mangrove seedlings within 1 m2. This was conducted in a randomly selected patch within the sample area.
- Non-mangrove tree species presence, summarized in the Dominant, Abundant, Frequent, Occasional, Rare (DAFOR) ranking

Figure 3.20 Flora Survey Transect Locations

Figure 3.21 Flora Survey Transect Locations

3.5.5.5.2.2 Results

Based on the density of trees recorded in each zone, a mangrove tree density was recorded for each sector. The mean tree density derived from all areas was 0.13 adult mangrove trees per m2.

The Western area West of Runway, towards Port Royal) is mostly previously reclaimed lands with a primarily tidal mangrove forest. The Eastern NMIA coastal forest areas (East of Airport buildings and Go-Kart track) are dominated by tidal mangrove forest, interspersed with raised sand dune/beach scrub in the interiors. This mangrove forest system is characterized by small and large ponds, which mostly have a common tidal connection to Kingston Harbour. However, some sections are not well drained and are showing signs of hyper-salinity and a resulting dwarf mangrove ecology.

This forested area may not appear to be a very mature mangrove forest system based on the tree heights(mean- less than 8 m) , but this may be explained by the prevailing water salinity that influences this forest , in Kingston Harbour(34 ppt and above, minimal fresh water influx).

The mangrove forest exhibits the expected Caribbean mangrove forest tree zonation (from land to sea: Rhizophora; Avicennia: Laguncularia progression) with a low species diversity as very few non-mangrove species are found within the mangroves areas (likely due to lack of fresh water influence). Rhizophora mangle dominates the majority of the mangrove forest, however there was strong evidence of a transition to Black mangroves in some areas based on that species more capable of adapting to anthropogenic pressures.

The Port Royal mangroves shows very little evidence of recent reclamation or development activities, with the exception of the major infrastructure which were developed over 30 years prior(airport, Yatch club, roadway). Due to the protected status of the JNHT (refs) and ecological protection (Ramsar- refs), the area is void of small, informal development. This notion is supported by very little changes observed in observing land use changes via satellite imagery.

The prevailing human disturbance in this area is the persistent pollution from Kingston and St. Andrew and St. Catherine waterways. Figure 3.22 below illustrates the impact of marine litter on this coastal environment; mangrove seedlings have low rates of establishment due to solid waste entanglement and disturbance. Therefore, previously disturbed areas show little or no natural regeneration while mature forest areas show healthy but comparatively shorter adult trees.

Figure 3.22 Mangrove coastline with adult trees dwarfed and low seedling count, resulting from high marine litter load

Table 3.31 Table Showing Adult Mangrove Tree Density, Transect areas and Coordinates

Transects	Avicennia germinans (Black)	Laguncularia racemosa (White)	Rhizophora mangle (Red)	Conocarpus erectus (Buttonwood)	Transect area	Coordinates
Transect 1	3	9	7		5m x 20m	N17° 55.870' W76° 46.948'
Transect 2	1	2	14		5m x 20m	N17° 55.915' W76° 47.126'
Transect 3	_	_	12+		10m x 10m	N17° 56.022' W76° 47.206'
Transect 4	8	1	8	4	5m x 20m	17°56'7.41"N 76°47'27.23"W
Transect 5	1	5	12		10m x 10m	17°56'2.47"N 76°47'29.43"W
Transect 6	1	2	19		10m x 10m	17°55'57.73"N 76°47'25.06"W
Transect 7	4	3	9	1	5m x 20m	17°56'14.51"N 76°47'45.86"W
Transect 8	11	8			10m x 10m	17°56'12.41"N 76°48'19.29"W
Transect 9	4	3	2	6	25m x 25m	17°56'18.94"N 76°47'59.44"W
Transect 10	1	4	19		20m x 5m	N17° 55.798' W76° 47.076'
Transect 11	1	9	14		20m x 5m	N17° 55.945' W76° 47.327'
Transect 12			8		10m x 10m	N17° 56.053' W76° 47.585'
Transect 13		2			20m x 5m	N17° 56.225' W76° 48.150'
Transect 14	5	15			10m x 10m	N17° 55.823' W76° 46.856'
Transect 15			23		10m x 10m	17°56'37.89"N 76°46'15.11"W
Transect 16	1		6		10m x 10m	17°56'36.45"N 76°46'13.57"W
Transect 17	1	5	30		10m x 10m	17°56'28.53"N 76°46'26.36"W
Transect 18	27				10m x 10m	17°56'35.70"N 76°46'28.95"W
Transect 19			12		10m x 10m	17°56'35.58"N 76°46'48.68"W
Transect 20	4	1	5		10m x 10m	17°56'24.98"N

						76°46'44.14"W
Transect 21	2	2	29		10m x 10m	17°56'27.95"N 76°46'14.66"W
Transect 22	5	4	11		10m x 10m	17°56'32.76"N 76°46'23.23"W
Transect 23	11	9	>100		10m x 10m	17°56'28.36"N 76°46'3.18"W
Transect 24	3	2	26		10m x 10m	17°56'39.22"N 76°45'58.69"W

Based on the results presented in Table 3.31above, the mangrove forest area had an average of 23.5 mangrove trees in each 100m^2 sample plot. Transect 23 had the highest density of trees, while the most sparse mangrove area exists near transect 13-which is an ongoing mangrove restoration site (refs).

There were 3-4 times as many Rhizophora mangle (red mangrove) trees and seedlings, than other true mangrove species (Black and white) present in the majority of transects and the general area. This is an expected result as red mangroves have larger propagules with other adaptations which allows them to establish more easily along tidal shorelines, and travel further distances to be recruited throughout the Port Royal and Palisadoes area.

Buttonwood/button mangroves are not true mangrove species, but numbers were recorded in this study. Very few were found in only 3 of the overall sample plots.

As stated earlier, the mangrove forest area in the Palisadoes and Port Royal Protected Area (PPRPA) is strongly influenced by salt water, with minimal and occasional fresh water from rains. The metropolitan area water ways, though bringing much nutrient pollution and moderate amounts of fresh waters, do not strongly influence Port Royal and Palisadoes as the prevailing currents move fresh waters towards to the Hellshire and St. Catherine coastline (Harbour, Bigg, and Webber 2003)

Table 3.32 Field investigation: (a) Interior of fringing mangrove forest at Transect one (T1); (b) Adult white mangrove being measured at transect 13(restoration site), with solid waste fencing to reduce marine litter; (c) 4 Algal bloom within mangrove lagoon, near T6; (d) Interior of mangrove forest at T5, showing high density of Red mangrove seedlings; (e) Sparse vegetation and high marine litter along runway revetment.

 (a)	 (b)
 (c)	 (d)
 (e)	

Table 3.33 The Average heights and Average DBH (diameter at Breast Height) for survey plots

Transects	Avicennia germinans (Black)		Laguncularia racemosa (White)		Rhizophora mangle (Red)	
	Avg. Tree height (m)	Avg. DBH (cm)	Avg. Tree height (m)	Avg. DBH (cm)	Avg. Tree height (m)	Avg. DBH (cm)
Transect 1	7.3	38	6.6	20.2	9.2	20.8
Transect 2	4.5	10	4.3	12.8	4.6	15
Transect 3	_	_	_	_	6.9	8.7
Transect 4	8	18	8	25	8	13.3
Transect 5	6	4.5	6.9	32.3	6.7	13.3
Transect 6	4	4	5.3	7.5	11	15.4
Transect 7	7.1	14.6	7.5	12.5	8.5	15.5
Transect 8	5	11.9	4	4		
Transect 9	2.3	11	2.8	8.7	1.3	2
Transect 10	5	21	5.3	6.6	6.7	12.4
Transect 11	5.5	10	5.3	16.4	5.3	9.3
Transect 12					5.5	17.3
Transect 13 (Restoration site)			3.7	8.7		
Transect 14	6	25	6.5	25+		
Transect 15					7.6	9.3
Transect 16	7	34			11.6	16.2
Transect 17	4	11	4.5	3.2	6.5	4
Transect 18	4	6.7				
Transect 19					7.5	7
Transect 20	10	28.8	10	25	10	16.6
Transect 21	8.5	14.5	8	27	5.4	10

Transect 22	5	8.4	4.5	10.6	4.5	10.2
Transect 23	3.6	3.7	3	2.8	3	1.6
Transect 24	6.1	7.7	6 5	22.5	5.7	7.2

The mangrove forest structure in the PPRPA shows trees reaching a maximum of 11.6 m (Red mangrove at transect 16) and 10m (Black mangrove at transect 20). T 20 was located close to the airports water treatment system and may be influenced by the fresh water discharges, though no active water release was observed. The Red mangrove with height over 11m was an anomaly, found in a very undisturbed area near the Yacht club, within a drainage path which may provide it with additional nutrients and occasional surface water.

The average tree height for the property is 6.05 m. This figure is expected based on previous studies within the PPRPA, EFJ and chin-refs), further supporting the salinity observed within the water of the areas sampled (table 4 below). The trees in this area are expected to be shorter and less robust that their counterparts across the island (Chin-refs).

Table 3.34 The Average heights and Average DBH (diameter at Breast Height) for Buttonwood mangrove in the survey plots.

Transects	Conocarpus erectus (Buttonwood)	
	Avg. Tree height (m)	Avg. DBH (cm)
Transect 4	8	35
Transect 7	7.5	15
Transect 9	2.2	9.3

Table 3.35 Salinity, Water Depth, Seedling Density and Solid Waste Density

Transects	Water depth (cm)	Salinity (ppt)	Seedling Density (per m2)	Solid Waste Density
Transect 1	_	35	29 Red	Low
Transect 2	20	39	_	_
Transect 3	2	36	2 Red	Low
Transect 4	5	36	6 Red	Medium
Transect 5	_	36	134 Red	_
Transect 6	_	36	1 Red	Medium
Transect 7	_	34	1 Red	Medium to High

Transect 8	_	34	7 Black 2 Red recruits	Very High
Transect 9	_	35	_	Medium to High
Transect 10	3	35	9 Red 2 Black	Low
Transect 11	_	36	29 red 1 White	Medium
Transect 12	10	35	_	Low
Transect 13 (Restoration Site)	_	_	_	Low (garbage screen)
Transect 14	_	>100	_	_
Transect 15	1	38	7 Red	
Transect 16		35	10 Red	Very low
Transect 17		35	27 Red	
Transect 18			4 Black	
Transect 19		35	1 Red	Medium
Transect 20	10	35	8 Red	High
Transect 21	3	37	63 red	Low
Transect 22	2		6 red	
Transect 23		75 (soil water)	8 red	

The majority of the plots had low seedling recruits. This is expected based on the marine litter load in the area.

The only exception is T5 which has ample seedlings in the interior-this is a semi-enclosed lagoon with no solid waste occurrence.

As indicated in Table 3.35 above, the area had no detectable fresh water influence on the survey dates. The majority of the sites had salinities close to sea-water or marginally above. Only 2 sites showed water with hypersalinity, (T 14 and T 23), with no standing water.

This salinity was extracted from the soil in these sample plots.

T 23 also showed evidence of dwarfism in mangroves, which is an expectation with consistent high salt conditions.

Refuge Cay Restoration Area

It is noteworthy that although not found in the immediate area of the airport or potential development areas (Figure 3.23)the major bird nesting and roosting habitat for sea-birds in this area is Refuge Cay found approximately 2 km away from current runway tip. This Cay is heavily impacted by solid waste currently, especially on its north shore which faces Kingston Harbour's polluted waterways. This degraded area continues to expand, where it was 200m2 (1968) to 1560m2 (1986), an increase in the degraded area of 680% in 18 years (Alleng, 1990). A restoration effort in the area was begun which has removed several tons of marine litter, but this cay should be flagged as a sensitive habitat, housing the majority of the areas protected pelicans, Magnificent frigate birds, egret and heron species (Green, 2013; Thomas, 2019).

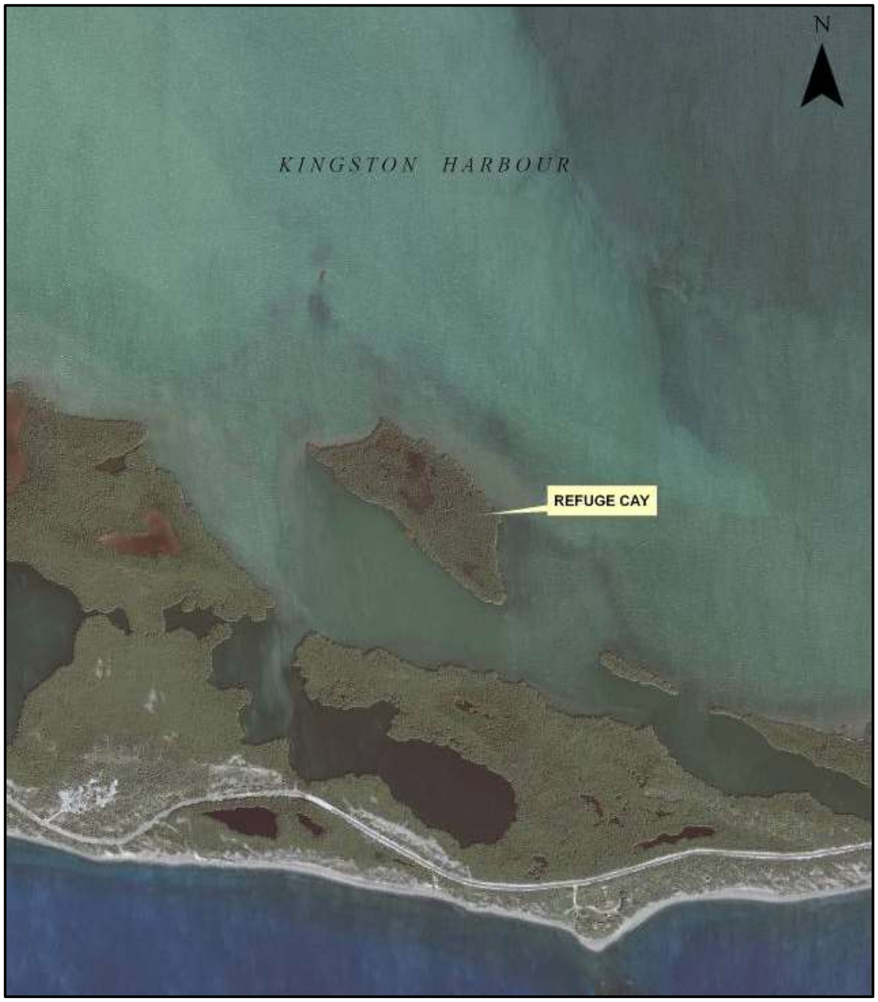


Figure 3.23 Refuge Cay exhibiting degraded areas in the centre

3.5.5.5.2.3 Sand Dune Community

The Palisadoes was previously characterized as having dune vegetation on the windward side and mangrove thickets on the leeward/harbour side (Thompson and Webber, 2003). However, the conducted field surveys indicate "sand dune "vegetation occurring on the interior raised sections of the mangrove forest assemblages. Thompson and Webber identified three sub-zones within the beach scrub/sand dune forest, based on dominant species assemblages (strand beach, strand dune and strand thorn-scrub). For the purpose of practicality, this forest structure will be referred to as the beach scrub or sand dune area in this report.

The area closest to the Airport Runway "lights/AA crash site" was dominated by low relief runners and succulents and grasses, which are regarded as Pioneer species. These species included Ipomea pes-caprae, Cannavalia and Sessuvium.

A more mature "climax" beach/sand dune community occurs on the majority of this area extending from the runway lights towards the Airport round-about. The area is dominated by taller Acacia and/or Coccoloba trees with occasional cacti and have a variety of runners and grasses in the understorey. These climax communities along the Palisadoes are characteristically less than 3m high due to consistent stresses from salt spray and low organic matter (Thompson and Webber, 2003).

The sand dune vegetation along the Palisadoes and Port Royal road is vital to the stabilization of the tombolo. Thompson and Webber (2003) concluded that Kingston harbour's existence is dependent on the stability of the dune and associated vegetation

Drought tolerant/dry species like cacti, Acacia, grasses dominate the land-locked interior dune areas, while Acacia, cacti and runners are more commonly found in the beach areas with some tidal influence. Over 25 species of non-mangrove plants were found in the beach scrub areas or transitional areas of degraded mangrove forest and Salinas.

This community includes a few endemic and/or protected species like cacti and the Lignum vitae, as seen in Table 3.37.

Table 3.36 Species encountered during field reconnaissance: (a) A variety of cacti found within Airport property dune areas (b) Walteria sp. which is very prevalent at grasslands along airport boundary fence.

(a) (b)

DAFOR occurrence rank: usually a subjective scale of species occurrence within an area of study. The acronym refers to, Dominant, Abundant, Frequent, Occasional, Rare.

Table 3.37 List of Flora observed throughout the survey area along with a DAFOR Index and Conservation status

Flora Observed	DAFOR Index	Growth Form	Status (IUCN Red List)
Acacia sp.	D	Tree	Least concern
Agave sp.	F		Least concern
Aloe vera	O	Shrub	Least concern
Avicennia germinans (Black Mangrove)	A	Tree	Endemic/Protected

Batis sp.	O	Shrub	Least concern
Capparis sp.	R	Shrub	Least concern
Cereus triangularis	R		Endemic/Protected
Conocarpus erectus (Buttonwood mangrove)	O	Tree	
Coccothrinax jamaicensis (Thatch palm)	R		
Cyperus sp. (sedge)	F	Grass	Least concern
Donax sp(wild cane)		Grass	Least concern
Guiacum officinale(Lignum vitae)	R	Tree	Endemic/Protected
Ipomoea pes-caprae	O	Climber/Twiner	
Laguncularia racemosa (White Mangrove)	A	Tree	Endemic/Protected
Leucaena sp. (Lead tree)	F	Shrub/tree	
Melocactus (Turks Head)	R		Endemic
Opuntia ficus-indica(tuna)	R		
Pilosocereus royenii(dildo cactus)	O		Protected
Rhizophora mangle (Red mangrove)	D	Tree	Least Concern (Population Decreasing)
Saccharum spontaneum	O		Least concern
Sedge			
Sesuvium portulacastrum (Sea purslane)	A	Twiner	Least concern
Sporobolus sp.	D	Grass	Least concern
Tamarindus indica(tamarind)	R	Tree	Least concern
Terminalis catappa(Almond)	R	Tree	Least concern
Thespesia populnea (Seaside Mahoe)	F	Tree	Least Concern
Thrinax parviflora	R	Tree	
Waltheria indica	R	Shrub	Least concern

The PPRPA is a well-known habitat for numerous species terrestrial and wetland of birds. Several bird nests were observed, in addition to roosting birds such as the brown pelican.

3.5.5.5.3 Fauna

3.5.5.5.3.1 Site description

The project area was surveyed according to vegetation/habitat type. This includes Mangroves acacia/scrub vegetation and built-up areas. The mangroves were found on the periphery of the coastal section of the property.

The scrubland vegetation can be described as dry species mainly growing on the sand substrate, which is common in the project area. The plant species height ranges 1-5m and the crowns not touching. The plants are mainly growing on dunes, where the area is impacted by drought conditions and salt sprays. Several dryland species such as several species cactus, Agaves, Acacia sp, and the Lignum vitae were encountered in the project area. Faunal surveys were conducted within each area (Figure 3.24)

Figure 3.24 Faunal survey areas

3.5.5.5.3.2 Method

Faunal surveys were carried via walk troughs, boat/windscreen surveys and transects (Figure 3.25) over a two-day period. The DAFOR Index was used to categorize each species (Table 3.38). No night-time surveys were conducted as a result of an island wide curfew in response to the global pandemic.

Table 3.38 DAFOR scale used to categorize the fauna in the study area

Frequency	Total numbers observed during the survey
Dominant	≥ 20
Abundant	15 – 19
Frequent	10 – 14
Occasional	5- 9
Rare	< 4

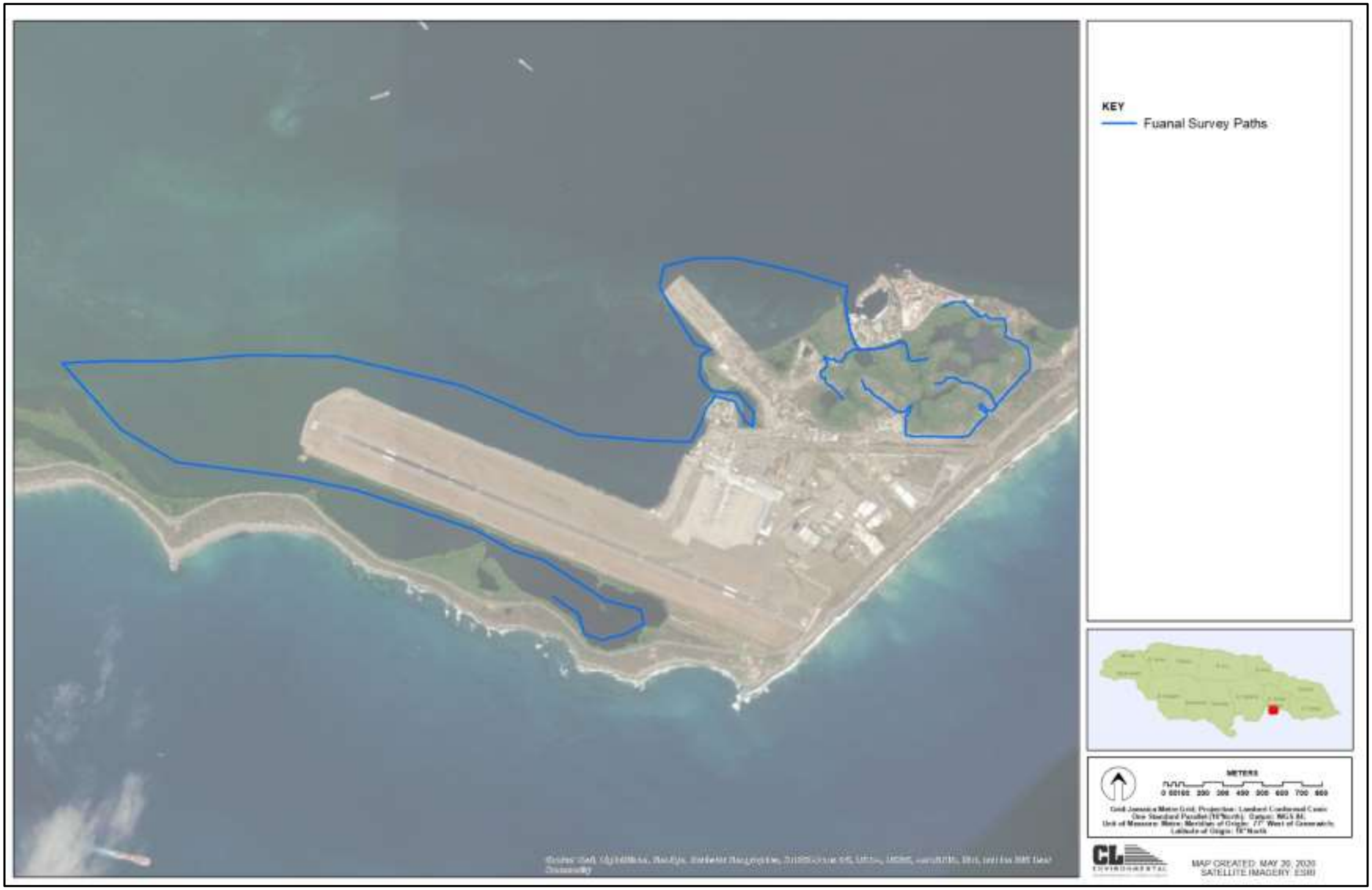


Figure 3.25 Paths used to carry out the fauna survey

<u>Avifauna survey</u>

The Line transect method was selected for the bird survey as a result of the homogeneity of the vegetation. The survey was conducted on land and also in the water via a boat (Figure 3.25). The survey methodology on land entailed walking along the road/footpath at a steady pace for a given distance noting all birds seen or heard. The study on water entailed moving a steady speed along the periphery of the mangroves on the property. Bird surveys were also carried out at the saltwater lagoons on the property from a vantage point for 20 minutes.

The bird species encountered using both methods were recorded on Ebird App by Cornel Lab. The Merlin App by Cornel Laboratory was used in the bird identification, with its extensive library of Jamaican bird species including pictures and audio. The bird surveys were carried out over 3 days. No nocturnal surveys could be carried as a result of the night curfews as a result of the Covid19 control measures.

<u>Herpeto-fauna Assessment</u>

The Herpeto-fauna assessment was carried out in along and areas adjacent to the trails over 2 days. The surveys were also conducted within the mangroves where there were no trails. The areas mainly searched include trees, stone piles, small water bodies, and rock piles. All specimens encountered were identified to the species level as best as possible. If they could not be classified in the field, specimens were captured and photographs were taken for further identification using Amphibians and Reptiles of Caribbean Islands keys (CaribHerp, 2020) and Amphibians and reptiles of the West Indies (Schwartz & Henderson, 1991). The specimens were then released after examination.

A crocodile assessment was also carried out in the wetland on foot and via a boat where applicable. The survey was also carried out on the coastal area of the property. The crocodile study was only carried out in the day because of the night curfew due to the Covid19 pandemic. The day's activity included walking along the coast of the project area to note crocodile presence and/or activity such as tail drag, footprints, basking areas, and nesting areas. In general, crocodiles are more difficult to detect during the day than at night because of their secretive habits (Figure 3.25).

<u>Insect survey</u>

The insect survey was carried out during the day. The assessments were carried out in habitats and possible hiding places where they will likely be found (Figure 3.25). This includes tree trunks, leaves, and dry wood and sticks. Insects in flight were recorded. A sweep net was used to collect insects from the foliage. Most of the arthropods encountered in the field were identified on the spot; however, arthropods that could not be identified in the field were identified using collections at the University of the West Indies.

3.5.5.5.3.3 Result and discussion

<u>Avifauna</u>

A total of 51 species of birds (29 are terrestrial and 22 coastal/ wetland) were observed during the assessment of the area. The majority of the species were found in the Mangroves, where both terrestrial and wetland species were observed.

<u>*Terrestrial Birds Species*</u>

Of the 29 terrestrial species identified, 5 were endemics, 3 endemic subspecies, 15 residents, 1 introduced, and 5 migrants (Table 3.39). Most of the terrestrial birds were observed in the acacia shrubland. Several Columbids including, White-crowned Pigeon, Zenaida Dove, Common Ground-Dove, and Mourning Doves were observed on the property. The mourning doves were encountered in the grassland areas near the runway and the vicinity of the warehouses on the property.

The introduced Great-tailed Grackle was the most dominant species on the property. They were seen in great numbers in the car park and now in the mangrove swamp. They were observed nesting in the coconut trees in the NMIA car park and also in the mangroves. The introduced Grey-tailed, which is larger than the Great Antillean Grackle could be out-competing it for resources, as only a few of them were encountered during the survey.

The Jamaica Euphonia, Jamaica Vireo, Jamaica Mango Hummingbird, Olive throated Parakeet and Red-billed Streamertail were the only 5 endemic bird species observed on the property. Of note all the endemics observed are all non-forest specialists. The Jamaica Mango Hummingbird was the most abundant of the endemics. They are typically found in acacia shrubland vegetation. There were observed feeding on the flower of the cactus in the forest.

Only 5 migrant birds were observed this includes the Black Whiskered Vireo, Antillean Nighthawk, American Redstart, Northern Waterthrush, and the Gray King Bird. The majority of the American Redstart that is found in Jamaica are winter migrants and a few of them remain on the island. It should be noted that the study was carried out in July after the departure of most of the winter migrant birds from North America. This means that the bird species list will increase as early as August when the migrants are expected to arrive. The summer migrants include the Black Whiskered Vireo and the Gray Kingbird.

Table 3.39 The terrestrial birds observed during the bird survey on the NMIA property

Proper Name	Scientific Name	Occurrence	IUCN Conversation Status	DAFOR
American Kestrel	Falco sparverius	Resident	Least Concern	R
American Redstart	Setophaga ruticilla	Migrant	Least Concern	O
Antillean Nighthawk	Chordeiles gundlachii	Migrant	Least Concern	R
Antillean Palm-Swift	Tachornis phoenicobia	Resident	Least Concern	O
Bananaquit	Coereba flaveola	Endemic subspecies	Least Concern	R
Barn Owl	Tyto alba	Resident	Least Concern	R
Black-faced Grassquit	Melanospiza bicolor	Resident	Least Concern	F
Common Ground Dove	Columbina passerina	Resident	Least Concern	A
Gray Kingbird	Tyrannus dominicensis	Migrant	Least Concern	F
Greater Antillean Grackle	Quiscalus niger	Resident	Least Concern	O
Great-tailed grackle	Quiscalus mexicanus	Introduced	Least Concern	D
Jamaican Euphonia	Euphonia jamaica	Endemic	Least Concern	R
Jamaican Mango	Anthracothorax mango	Endemic	Least Concern	O
Jamaican Oriole	Icterus leucopteryx	Endemic subspecies	Least Concern	R
Jamaican Vireo	Vireo modestus	Endemic	Least Concern	O
Loggerhead Kingbird	Tyrannus caudifasciatus	Resident	Least Concern	O
Mourning Dove	Zenaida macroura	Resident	Least Concern	O
Northern Mockingbird	Mimus polyglottos	Resident	Least Concern	O
Northern Waterthrush	Parkesia noveboracensis	Migrant	Least Concern	R
Olive-throated Parakeet	Eupsittula nana	Endemic	Not Threatened	O
Red-billed Streamertail	Trochilus polytmus	Endemic	Least Concern	R
Smooth-Billed Ani	Crotophaga ani	Resident	Least Concern	R
Turkey Vulture	Cathartes aura	Resident	Least Concern	R
Vervain Hummingbird	Mellisuga minima	Endemic subspecies	Least Concern	O
White-crowned pigeon	Patagioenas leucocephala	Resident	Near Threatened	R
White-winged dove	Zenaida asiatica	Resident	Least Concern	O
Yellow Warbler	Setophaga petechia	Migrant	Least Concern	F
Yellow-faced Grassquit	Tiaris olivacea	Resident	Least Concern	O
Zenaida Dove	Zenaida aurita	Resident	Least Concern	R

Wetland and coastal birds

Twenty-two wetland species were encountered during the study; 19 species are resident and 3 migrants (Table 3.40). The majority of the species were encountered in the mangroves. This includes herons, pelicans and frigate birds.

Table 3.40 The Wetland / Coastal birds observed during the survey of the NMIA property

Proper Name	Scientific Name	Occurrence	IUCN Conversation Status	DAFOR
Belted kingfisher	Megaceryle alcyon	Migrant	Least Concern	R
Black-crowned Night Heron	Nycticorax	Resident	Least Concern	R
Black-necked Stilt	Himantopus mexicanus	Resident	Least Concern	O
Brown Pelican	Pelecanus occidentalis	Resident	Least Concern	F
Cattle Egret	Bubulcus ibis	Resident	Least Concern	A
Glossy Ibis	Plegadis falcinellus	Resident	Least Concern	R
Great Blue Heron	Ardea herodias	Migrant	Least Concern	O
Green Heron	Butorides virescens	Resident	Least Concern	O
Killdeer	Charadrius vociferus	Resident	Least Concern	R
Laughing Gull	Leucophaeus atricilla	Resident	Least Concern	A
Least Bittern	Ixobrychus exilis	Resident	Least Concern	R
Least Tern	Sternula antillarum	Resident	Least Concern	O
Little Blue Heron	Egretta careulea	Resident	Least Concern	O
Magnificent Frigatebird	Fregata magnificens	Resident	Least Concern	O
Royal Tern	Thalasseus maximus	Resident	Least Concern	O
Ruddy Turnstone	Arenaria interpres	Migrant	Least Concern	R
Snowy egret	Egretta thula	Resident	Least Concern	O
Spotted sandpiper	Actitis macularius	Resident	Least Concern	R
Tricolored heron	Egretta tricolor	Resident	Least Concern	R
White Ibis	Eudocimus albus	Resident	Least Concern	R
Wilson's Plover	Charadrius wilsonia	Resident	Least Concern	O
Yellow-Crowned Night Heron	Nycticorax violaceus	Resident	Least Concern	R

Several Brown Pelicans were observed roosting in the mangroves (Figure 3.26). However, they were not nesting at the time the survey was carried out. Several herons were also observed foraging at the edge of the saltwater lagoons/ ponds found on the property. Of note, a Least Bittern was observed flying from the foliage at the edge of one of the Lagoon. These lagoons may be used by several migrant waterfowls such as ducks during the winter season.

The birds observed on the coast include Brown Pelican, Frigate Birds, Laughing Gull, Least Tern, and Royal Tern. It should be noted that the coastal bird species increase during the winter season when several migrants arrive in the area from the Americas.

It should be noted that no wetland species with special conservation status were observed on the property. Caribbean endemics such as the West Indian Whistling duck have special conservation status, however there are no reported sightings in the area.

Figure 3.26 Pelicans roosting in the mangroves on the property

<u>Insects</u>

Twenty-six insect species from 11 families were identified on the property (Table 3.41). The insect fauna overall was very low, which could be a result of the drought conditions in the area. The insect fauna species diversity and numbers should increase in the rainy season, when several plants are flowering, increasing the availability of the food.

Table 3.41 The insects observed

ORDER	FAMILY	SPECIES	COMMON NAME	DAFOR	STATUS
Lepidoptera	Lycaenidae	Leptotes cassius	Cassius Blue	F	Widespread locally and throughout the Americas
Lepidoptera	Lycaenidae	Brephidium exilisxilis	Pygmy Blue	D	Widespread locally and throughout the Americas.
Lepidoptera	Pieridae	Ascia monuste	Antillean great White; Cabbage White	O	Wide spread locally and throughout the Americas
Lepidoptera	Pieridae	Phoebis agarithe	Apricot sulphur	R	Wide spread locally and throughout the Americas
Lepidoptera	Pieridae	Eurema nise	Cramer's Little Sulphur	O	Wide spread locally and throughout the Americas
Lepidoptera	Pieridae	Kricogonia lyside	Lignum vitae butterfly	A	Wide spread locally and throughout the Americas
Lepidoptera	Nymphalidae	Euptoieta hegesia	Tropical Fritillary	O	Wide spread locally and throughout the Americas
Lepidoptera	Nymphalidae	Junonia evarete	Mangrove Buckeye	F	Wide spread locally and throughout the Americas
Lepidoptera	Hesperidae	Wallengrenia ortho vesuria	Vesuria	O	Endemic sub-species.
Blattodea	Termitidae	Termite 1	Mangrove termite	F	
Hymenoptera	Vespidae	Polisties crinitus	Red wasp	F	Widespread
Hymenoptera	Vespidae	Polisties hunter	Red wasp	R	Introduced & widespread
Hymenoptera	Megachilide	Megachile concina	Leaf cutter bee	O	Widespread in all parishes
Hymenoptera	Apidae	Bombus sp	Bumble-bee	R	Widespread in all parishes
Hymenoptera	Formicidae	3 spp. ants		O	

Hymenoptera	Apidae	Apis mellifera	Common Honeybee	O	Widespread in all parishes
Diptera	Culicidae	2spps		O	Widespread in all parishes
Odonata	Libellulidae	Erythemis simplicicollis		R	Widespread in all parishes
Odonata	Libellulidae	Tramea sp.		O	Widespread in all parishes
Odonata	Libellulidae	Erythrodiplax umbrata		F	Widespread in all parishes
Odonata	Libellulidae	Odonata 1		R	Widespread in all parishes
Odonata	Libellulidae	Anisoptera sp		O	Widespread in all parishes
Hempitera	Pyrrhocoridae	Dysdercus mimulus	Lovebugs	D	Widespread in all parishes

Insect diversity was very limited, consisting of 9 species of butterflies, 2 species of wasps, 3 species of bees, 3 species of ants, 1 species of termite, and 5 species of dragonflies. It should be noted that no endemic insects were recorded during the study. Wallengrenia ortho vesuria, is an endemic subspecies of the butterfly that was observed during the survey. The dominant species was Ascia monuste, large swarms were observed during the survey. Several of the Lignum vitae butterflies were seen foraging and could be laying their eggs on the lignum vitae trees observed in the study. The common butterfly observed in the mangrove swamp was the Mangrove Buckeye.

Large termite nesting mounds were observed within the mangrove wetland (Table 3.42). This termite plays an important role in the recycling of nutrients where they break down the wood material.

Table 3.42 Termite mounds observed: (a) large-sized; (b) small-sized

(a) (b)

Herpetofauna

No amphibians were encountered during the survey. However, during a survey 2018 survey, two species of amphibians were observed. This includes the introduced cane toad and Lesser Antillean Frog which were observed in the airport parking lot and also at the Go-cart race track. The low density and diversity of amphibians is typical of very dry areas. Suitable habitat such as, bromeliads were not observed. A total of 3 species of reptiles were observed during the study. This includes the introduced Hemidactylus mabouia, and the endemic Anolis grahami and Anolis lineatopus. Both endemic species are widely distributed in Jamaica and not of major conservation concern.

Table 3.43 Herpetofauna Recorded

Species	Common name	Species Status	IUCN Status	DAFOR
AMPHIBIANS				
***Rhinella marina**	Cane Toad	Introduced	Least concern	O
***Eleutherodactylus johnstonei**	Lesser Antillean Frog	Introduced	Least concern	A
REPTILES				
Anolis grahami	Jamaican Turquoise Anole	Endemic	Near threatened	O
Anolis lineatopus	Jamaican Gray Anole	Endemic	Near threatened	D
Hemidactylus mabouia	Croaking lizard, Tropical House Gecko, Wood slave	Introduced	Least concern	F

*species reported in the area but was not observed in the study

Crocodiles have been previously reported nesting on the banks of Kingston Yacht club as well as within the Rosie Hole area of the Port Royal mangroves. Crocodiles move around in the wetland and coastal area in the Palisadoes area and are likely present in the wetlands on the NMIA property. No crocodiles were observed during the assessment of the lagoons and also the coastal area of the NMIA property. This was expected as crocodiles are more difficult to see in the day vs the night. The night survey could not be carried out as a result of the national curfew.

The day assessment was mainly focussed in lagoon areas shown in Figure 3.27 (possible nesting areas for crocodiles). Crocodile nesting usually occurs as early as February in Jamaica they build their nest in the substrate along the beach or the lagoons. No tail drags or nests mounds including eggshells were encountered at the banks of the lagoons and along the coast that was surveyed. It should be noted that the banks of the lagoons consist of soft mud which would not make a good nesting site for the crocodiles. It was expected that the crocodiles would most likely nest on small beaches in the coastal area on the property. These areas are overrun with solid waste. No crocodile nests or nestlings/ juveniles were observed in the area.

Figure 3.27 The lagoons surveyed for the presence of crocodiles

Mammals

During the survey, the Indian Mongoose, dogs, and cats were encountered on the property. They were mainly observed in the built-up areas, with an emphasis on the car park. Proper garbage management on the property will discourage these animals on the property.

Sea Turtles

The main nesting season for sea turtles in Jamaica is between July- October (National Environment and Planning Agency, 2002). Sections of the seaward (dune/beach areas) along Palisadoes are active turtle nesting beaches, however the actual activity and nesting in or near the runway is not known.

3.5.5.5.3.4 General Mitigation Measures

General mitigation measures should be implemented both for current operations as well as any future developments

A proper garbage management plan for the facility as fish guts and meat kind will encourage crocodiles in the area.Climate change would result in the sea level rise which could flood the potential crocodile nesting area on the property.

The draining of the wetland could result in a reduction of the mangrove wetland. This would affect the services provided by the mangroves. Terrestrial species such as grasses would expand their range in the wetland which could become a fire hazard in the future.

3.5.5.5.4 Intertidal/ Rock Revetment Community

Sections of the airport have varying coastal modification including rock revetment and seawall areas. These areas provide habitat for various intertidal species, fish and marine invertebrates. These are modified communities with low density and diversity, often inundated with solid waste, and marine debris. Water quality in these areas tends to be poor.

Table 3.44 Field observations: (a) rock revetment along runway (b) intertidal species

 (a)	 (b)

3.5.5.5.5 Benthic Community

The benthic community assessment included habitat identification and assessment, along with creating a species list and photo inventory. Special emphasis was placed on the recording and identification of rare, threatened, endemic, protected, endangered, and economically important species and habitat. Sensitive habitats and species near airport lands were assessed in detail where possible.

3.5.5.5.6 Grab Samples

3.5.5.5.6.1 Introduction

A grab sample is any individual sample collected in one instance, without adding any other samples, this method creates snap shots for substrate composition at each location. The marine environment surrounding the NMIA facility was probed in order to inspect its substrate composition Figure 3.28.

3.5.5.5.6.2 Methodology

Substrate samples were collected using a grab sampler which was operated by hand, it was lowered into the water, from a boat above each sample location. Once it met the seafloor, the sampler closed and was hauled back to the surface where its contents were inspected and displayed with a photo inventory and its GPS coordinates were mapped using a Trimble Table 8.3.

Figure 3.28 Grab Sample Locations

3.5.5.5.6.3 Results

The data observed from the grab samples indicated a mostly mud and silt substrate to the West of the airport runway Table 3.44 slowly transitioning into a mixture of mud, silt, sand and stone and a predominantly sand and shell substrate exists to the North West directly in front of the North of the runway (e) and sand rock and algae to the East (g). Many of the grab samples also indicated a large volume of solid waste around the entire perimeter of the sample site, see Table 3.46 (d), (f) and (h). The area to the West of the runway is also composed of substantial areas of seagrass, along most of the runways length. Table 3.45 shows the general substrate composition located in the NMIA sample area.

Table 3.45 Grab Sample General Substrate Composition

Substrate Composition	Grab Sample Number
Silt	82,
Silt, Mud	1, 5, 8, 9, 10, 11, 14, 16, 17, 18, 23, 26, 30, 34, 37, 38, 40, 44, 48, 58,
Silt, Sand	84,
Sand, Mud	13, 20, 21, 24, 35, 46,
Mud, Algae	6, 14,
Mud, Shell	3, 4, 12, 15, 22, 39, 53,
Shell, Silt	41, 42. 56
Sand	63, 66, 70,
Sand, Silt	27, 33
Shell, Silt, Stone	32
Shelly Sand	28, 51, 54, 64, 67, 68, 69, 81, 83, 85, 86, 88, 89, 90
Algae(mud/sand)	29, 62, 65, 87
Seagrass(mud/sand)	19, 31, 36, 43, 45,
Garbage	49,50, 52, 61, 80

Table 3.46 Grab samples collected: (a) Grab Sample 1 example of silt and mud; (b) Grab Sample 13 example of sand and mud; (c) Grab Sample 19 sea grass (Thalassia); (d) Grab Sample 27 sand and silt; (e) Grab Sample 32 shell, silt and stone; (f) Grab Sample 50 solid waste; (g) Grab Sample 51 shelly sand; (h) Grab Sample 61 solid waste and algae; (i) Grab Sample 70 sand; (j) Solid Waste captured by grab sample

(a)

(b)


(c)


(d)

(e)

(f)

(g)

(h)


(i)


(j)

3.5.5.5.7 Soft Sediment Communities

Soft sediments include mud, silt, and sand, these cover a large portion of the world's estuarine benthic environments and provide habitat for a multitude of benthic invertebrate species, Meiofauna. It is well documented that soft sediment communities are not only influenced by environmental factors (e.g., sediment size, pH, organic content) but also by biotic factors (e.g., bioturbation). (Barros, 2016)

As defined in (Bastida-Zavala R., 2016), meiofauna are small mobile and sometimes sessile benthic organisms ranging in size between that of the microfauna and macrofauna. Meiofauna are often found moving between sediment interstices, but also occur on hard surfaces, algae, coral rubble, or other surfaces. There are both temporary and permanent members of meiofaunal communities in estuarine environments. Although the meiofauna are tiny, they can play a role in the bioturbation of bottom sediments. Important groups of meiofauna found in include the rotifers, gastrotrichs, nematodes, polychaetes, tartigrades, copepods, turbellarians, and ostracods

Varying soft sediment communities make up most of the benthic survey area, each impacted by varying degrees of solid waste, water quality and pollution sources. See Table 3.47 (a), (b) and (c) for examples of soft silty sediment with burrows made by species living and in and on the substrate. Table 3.50 has species observed in the general area:

Table 3.47 Species observed in the general area: (a) Sandy substrate with macroalgae, rubble, shells and solid waste; (b) Sections of the substrate with a large collection of solid waste; (c) Evidence of in fauna in soft, silty sediment

(a)

(b)

(c)

3.5.5.5.8 Seagrass Beds

3.5.5.5.8.1 Introduction

Seagrass communities within PPRA are dominated by Thalassia testudinum, however all three species are known to be present. Seagrass beds play vital roles in the wider marine ecosystem. The extent of the seagrass beds in the harbour is not fully known, more data is available for beds associated with the nearby Cays. Seagrass communities surrounding the airport are intact and thriving. Seagrass locations determined in or nearby proposed future developments and project area maybe impacted, including the Airport Lagoon, Old Runway and the seagrass meadows just west to the beginning of the Airport Runway.

Seagrass beds provide key functions include: a marine nursery, feeding grounds, habitats, and coastal protection Seagrass 'meadows' or 'beds' refer to large, dense and typically but not exclusively contiguous areas of these plants. Seagrass meadows are known to provide physical structure on otherwise largely featureless bottoms (Duffy, 2006) and serve as an important factor in stabilizing the sediment upon which they grow as they possess an extensive system of branching rhizomes which holds the otherwise silty or sandy material below the bed, together. As a result, these systems prevent siltation within highly trafficked areas such as shipping channels and significantly reduce the rate of erosion from coastal areas such as beaches (Kirkman, 2000).

The proficiency at which this ecosystem carries out its function is directly related to how healthy the seagrass communities are. Seagrass health is shown in many different parameters between the seagrass themselves and the immediate environment in which the seagrass community resides. These include blade length and width, seagrass biomass and density, water quality, productivity and epiphyte load. Healthy ecosystems supports high biodiversity resulting from biotic influences such as feeding relationships, grazing and epiphyte interaction. All these influences directly affect the morphological features of the entire seagrass plant and by extension the seagrass community. Morphological parameters such as blade length, biomass, epiphytes etc, are important in assessing seagrass health.

Seagrasses provide a substratum for growth of epiphytic microalgae which fuels food webs; additionally the canopy of these grasses provides a shelter for many invertebrates and fishes that reach substantially greater densities than in un-vegetated benthic habitats (Heck & Orth 1980). As a result, these systems are often seen as not only a critical component of the marine coastal environment worldwide; as they provide some of the most economically and environmentally valuable ecosystem services of any marine habitat by supporting commercial fisheries and providing ecosystem services such as improving water quality, providing food and habitat and acting as a biological indicator to the scientific community but also an essential factor in carbon storage (Short et al., 2007).

<u>Role of seagrasses in carbon storage</u>

Carbon forms the basic building block of life on Earth, and is stored in the atmosphere, land and ocean. Blue carbon refers to carbon which is stored in mangroves, salt tidal marshes and seagrass meadows within the soil, the living biomass aboveground, that below ground as well as the non-living biomass (Mcleod et al.., 2011). Coastal communities are metabolically responsible for 85% of the organic carbon and 45% of the inorganic carbon (Ciorg) buried in coastal sediments (Bergstrom et al., 2019).

Seagrass beds are natural carbon sinks and are considered among the most efficient on Earth (Macreadie et al., 2015). Being a part of the coastal ecosystem family, the organic carbon buried by seagrasses (also referred to as 'blue carbon') occurs at a rate of thirty-five (35) times faster than tropical rainforests (McLeod et al., 2011). These systems are also capable of storing carbon for millennia. Though these systems are thought to store a vast amount of organic carbon into their associated soils, concern in their ability to retain these stocks amidst disturbances are high as the release of vast amounts of carbon upon damage to these systems could lead to irreversible long term impacts upon global communities. Within Jamaica, there are three (3) species of seagrasses, namely Thalassia testudinum (turtle grass), Syringodium filiforme (manatee grass) and Halodule wrightii (shoal grass); T. testudinum being the most dominant of the three (3) (NRCA, 1996).

These species can be found in most if not all marine areas under suitable conditions island wide. Of these the seagrass species, Thalassia testudinum, also known as "Turtle Grass" (De Kluijver et al., 2016) possesses the largest growth form.

Notwithstanding the importance of seagrass meadows, high rates of loss are being experienced globally due to increases in eutrophication, sedimentation and dredging as well as diffuse threats such as reductions in water quality inadvertently rendering surroundings uninhabitable by these communities as well as the influences of climate change (Short et al., 2007).

Studies conducted within Kingston Harbour regarding seagrasses have often noted its relationship with areas characterized by their eutrophic waters. In a study conducted by Green and Webber in 2003, it was concluded that seagrasses within the eutrophic areas of Old Coal Warf and Fort Augusta had an observed reduced vegetative biomass and in turn, reduced productivity was seen in these systems. Kingston Harbour is estimated to have approximately 1,000 hectares of seagrass area (Margaret Greenway, 1977). Recent studies on this area are scarce and as a result the expanse of the seagrass ecosystem within Kingston Harbour is widely unaccounted for and unknown

3.5.5.5.8.2 Methodology

Field Work

Mapping

Seagrass Beds were located using a grab sampler and previous known locations. Each bed was then mapped with a Trimble Geo 7x series GPS. Weather conditions were fair and sunny with calm seas during the surveys conducted.

Core Samples

A PVC tube of dimensions 2.5 meters length by 8centimeters width, was then slowly lowered from the side of the boat and into the water column and unto the substrate with slow swaying motions in order to reduce chances of cropping seagrass blades. The core was then, by hand, forced into the substrate until resistance was achieved, after which a mallet was used to pound the core deeper into the substrate until resistance was achieved. A PVC cap was then placed atop the core - tube and pounded until an airtight seal was created. The core was then removed, and contents placed into site specific labeled buckets and covered for later in-lab processing. This process was repeated at each site.

Figure 3.29 Location of Seagrass cores and mapped areas

Lab Analysis

Vegetative Biomass Processing

Seagrass samples were carefully separated into below and above ground sections and placed into separate labeled Ziploc bags for later processing.

Above Ground Biomass Processing

Seagrass samples (each blade from each sample) were removed and measured individually for length and width. After measuring, samples were then weighed for wet weight and recorded with epiphytes still attached. Epiphytes were then removed by immersing the samples in ten percent (10%) hydrochloric acid (HCL) for twenty (20) minutes. Blades were then carefully wiped clean of all remaining epiphytes and weighed and recorded once more for weight after epiphytes removal.

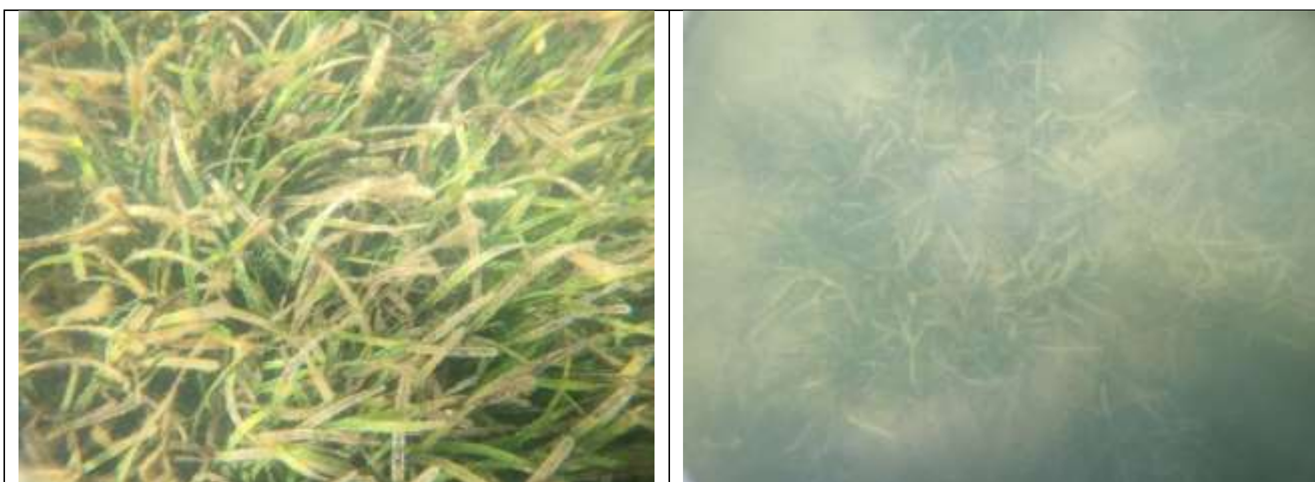
3.5.5.5.8.3 Results

Seagrass beds were found around the airport and associated mangrove areas. Beds were dominated by Thalassia testudinum with varying density and distribution, shown in Table 3.49. Four (4) main areas were identified (Table 3.48).

Table 3.48 Areas (ha) and Lengths (m) of seagrass in Airport Zones and associated Mangroves

Location	Area/Length
Old Runway	3.95 ha
SGC1	0.7 ha
SGC3	0.3 ha
Lagoon bed length	1384.23m

Table 3.49 Thalassia testudinum with varying density and distribution: (a) Dense section of a Seagrass bed; (b) Sparse sections the Lagoon Seagrass bed



(a) (b)

Seagrass Health

Airport lagoon 2

Had the longest blade length of 37.74cm with a blade width of 0.98cm. This location was also seen to have the highest mean vegetative wet weight of 23.03g. The heaviest epiphyte weight was also found on the seagrass at this location with a value of 5.34. Overall, this location had the longest and heaviest seagrass.

Airport grass 2

Had the shortest blade length of 14.44cm with a blade width of 0.91cm. The seagrass in this location had the lightest mean vegetative wet weight of 5.9g. The epiphytes found on the blades in this location were the lightest in comparison to other areas of only 0.09g. Overall, this location had the shortest and lightest seagrass.

Airport grass 1

Had no significant figures for blade length, blade width and mean vegetative wet weight; the seagrass in this area appeared to have the highest density of blades with a number of 14 blades.

Airport Lagoon 1, 2 & 3

Most of the filamentous and fleshy epiphytes were observed on the seagrass blades. Another seagrass species, S. filiforme and scale worms were also observed within the Airport Lagoon sites. Additionally the most visible peat content was also observed within the Airport Lagoon sites.

Old Runway 1 and Airport Grass 1

Calcareous epiphytes were mostly seen.

Airport Grass 1 and 2

Was observed to have mostly T. testudinum in higher densities and many different urchins interspersed within the seagrass bed.

Mean Blade Density (numbers/m2)

Highest Blade Density was found within the Airport Grass meadows. There were approximately fourteen (14) blades/ m2 in this region sampled. The seagrass meadows at Airport Lagoon were observed to have the lowest density numbers of the three sites. Among the three meadows, Airport Lagoon accounted for 29% of the combined seagrass density which accounted for approximately five (5) blades/m2 on average as seen in Figure 3.30.

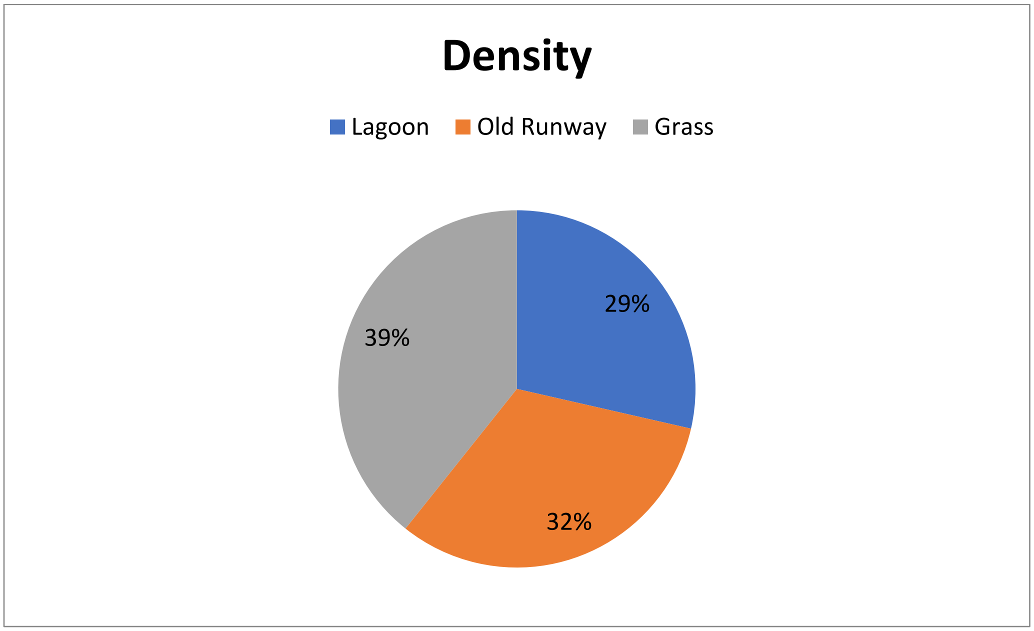


Figure 3.30 Pie chart with relative density of seagrass meadows sampled

Mean Blade Length (cm)

Among the three sites sampled seagrass blades ranged approximately from 14.44 cm - 37.74 cm in length (Figure 3.31). Airport Lagoon was the site with the highest mean blade length of the three meadows sampled which was recorded at approximately 28.28cm. Conversely the Airport Grass meadows had the shortest blade lengths on average in comparison to the other two seagrass communities. The mean blade length here was 16.02cm.

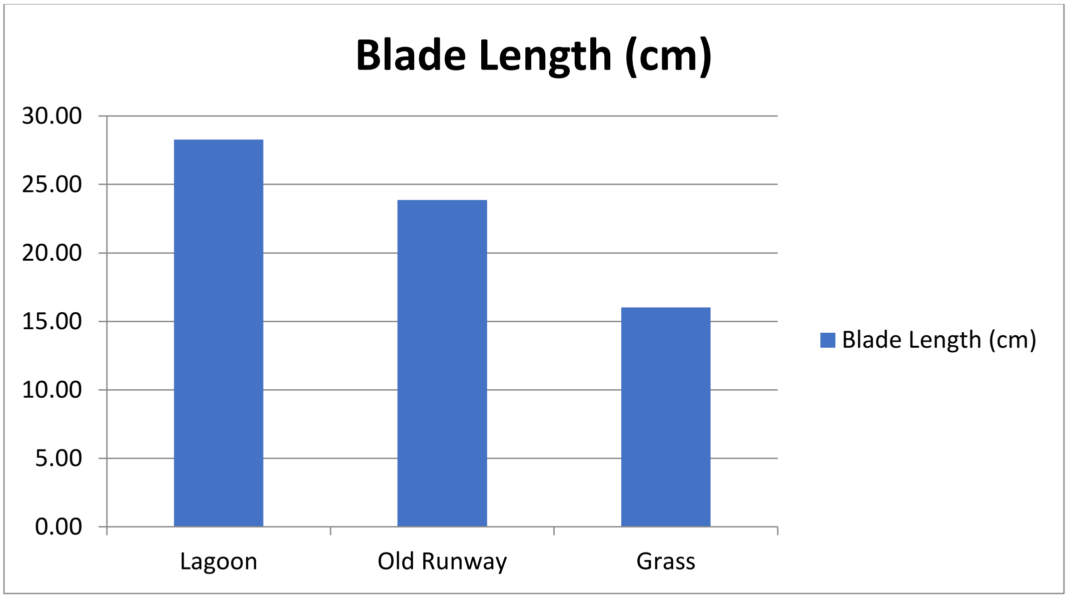


Figure 3.31 Graph of average blade length (cm) between seagrass meadows sampled.

Figure 3.32 Seagrass sample from study site with long blade length

Mean Blade Width (cm)

Blade width per site indicated variations between mean values of 0.76 cm and 1.43cm (Figure 3.33). Compared to blade length, blade width saw a reverse trend in mean values obtained at the three study locations. Airport seagrass meadows had the broadest leaves of the three sites recorded at approximately 1.17cm on average. However, Airport Lagoon had the thinnest leaves at 0.89cm on average.

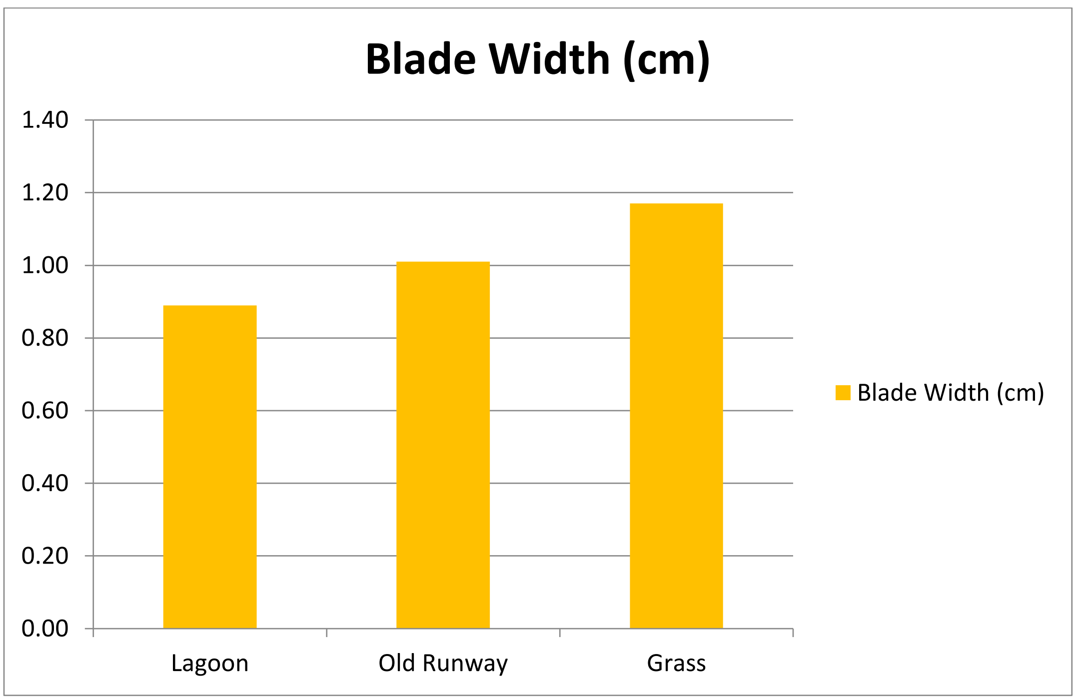


Figure 3.33 Graph of average blade width (cm) between three main stations.

Epiphyte Weight (g)

Epiphytes showed a similar trend among the sites as blade length. Airport Lagoon had the highest mean weight of epiphytes recorded at approximately 3.92g. On the other hand, Airport Seagrass meadows were the seagrasses with the least epiphyte load of the three sites measuring at approximately 1.48g on average.

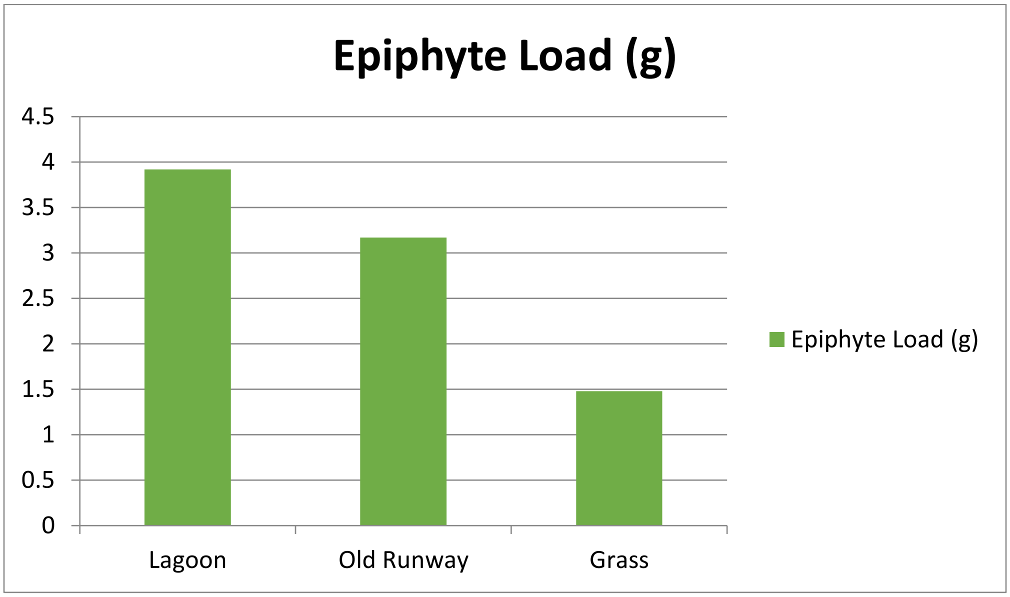


Figure 3.34 Mean Epiphyte Load between the three main sites sampled.

Figure 3.35 Seagrass showing epiphyte interaction on blades

3.5.5.5.8.4 Discussion

The three sites sampled surrounding the Normal Manley International Airport is a good representation of the seagrass communities within that area of the inner Kingston Harbour. Assessing these seagrass meadows to ascertain their overall health was the primary focus of this study and most of the data analyzed in this section will be based on the morphological and physical parameters of these seagrasses. These sampled seagrass meadows appear to be visibly healthy; this may be as a result of the naturally sheltered or enclosed nature of the surrounding landform as well as the associated minimal disturbances experienced within these areas (Airport Lagoon, Old Airport Runway and Airport Grass). These southern seagrass meadows within harbour have been described as more clustered and dense than other seagrass communities seen in the northern harbour and along the shoals. Based on the data, the three sites had slight variations in density as seen represented Figure 1. Across the three zones which were sampled, there was very little variability in the spatial distribution of seagrasses observed, this may be due to a number of factors such as wind and water currents, solid waste pollution and disturbances caused by vessels. With limited disturbances seagrasses are more likely to grow, establish their community and become more dispersed. Other key factors that play a vital role in seagrass density include: light availability, type of substrate, water quality and below ground biomass of that seagrass meadow.

Within Airport Lagoon and Old Airport Runway, blade lengths were in excess of twenty centimeters (20cm). Factors that affect blade length are also similar to factors previously stated that affect shoot density within the seagrass meadow in addition to depth and nutrient availability. According to the Figures 3 and 6, both blade length and epiphyte load among all three locations have the same trend of an increasing gradient which hints at a possibly close relationship between these two parameters. It shows that where there are lengthier seagrass blades there is a higher associated epiphytic mass. This is because as the blade grows longer and the plant gets older, there is more space for epiphytes to settle and a longer period for them to do so thereby increasing in mass over time.

Though epiphytes are promoters of biodiversity within the seagrass community, they also act as indicators of the physical and chemical conditions within the seagrass meadow. A high epiphyte load can result from high levels of eutrophication in the surrounding environment. Heavy epiphyte loads are also dangerous to seagrass blades overtime as they can increase in the hydrodynamic drag of the seagrass blades increasing the risk of leaf loss during wave or current action in the seagrass bed. These parameters can indeed show that the seagrass bed around the NMIA is relatively healthy however their health and success is also credited to another external factor. This external factor is that these seagrass meadows are closely associated with mangroves. All three locations are a part of their own mangrove-seagrass complex. One of the main reasons why these seagrass meadows thrive as stated before is due to the limited disturbances that occur within the seagrass bed. That limited disturbance is due to the presence of mangrove forests within the environs of the seagrass meadows. Therefore disturbances from wave energy, pollution and humans are relatively low due to the buffering effect of mangrove forests and the seagrass communities also protect the mangroves as well from similar disturbances.

Consequently, being a part of the mangrove-seagrass complex these three locations will also share in the responsibility of carbon sequestration. This was evident in Airport Lagoon which had visibly high peat content. This site is almost completely surrounded by mangroves and is one of the few well sheltered seagrass meadows within Kingston Harbour. Kingston Harbour is upwards of one hundred and eighty hectares (180 ha). Of this amount, approximately sixty-two (62ha) hectares were sampled and analyzed for the storage of carbon (Green, 2019). According to Green 2019, the total seagrass cover within Kingston Harbour was estimated at 258.9 ha. Of this, peat carbon was found to be the highest with a value of (28.07 ± 0.7MgC/ha). Total vegetative carbon for the sampled sites was 15.1 ±0.05 MgC/ha of which carbon within the root/rhizome layer was greater than that located within shoots (10.2 ±0.05 and 5.05 ± 0.01 MgC/ha respectively) (Green, 2019). These seagrass meadows are in a relatively healthy state due to the relationship between mangrove forests in their immediate environment.

Therefore within the mangrove-seagrass complexes of the surrounding environs of NMIA, the seagrass meadows play a pivotal role in not only protecting the mangroves and providing shelter for many organisms but also potentially hold many milligrams of Carbon that if they should be removed will have irrevocable consequences on the greater Palisadoes ecosystem and Kingston Harbour.

3.5.5.5.8.5 Recommendations

Seagrass meadows closely associated with the NMIA are relatively the healthier seagrasses found within Kingston Harbour. Losing these habitats will have a tremendous effect of many ecological communities and may also have negative economic effects in the future. Seagrass plants are not easily transplanted and not as resilient as land based plants therefore this is not an easy fix compared to other environmental issues that occur due to habitat loss or degradation. It is highly recommended that:

- More research be done on the seagrass communities of Kingston harbour and the surrounding area to see how resilient these communities really are and how quickly they can potentially bounce back from major disturbances.

Construction of any kind near the marine environment will lead to issues such has high turbidity and sedimentation. These issues can ultimately weaken ecosystem functioning and resilience, thereby compromising the ability of the ecosystem to continue providing ecosystem-related goods and services for present and future generations. Therefore it is recommended that:

- Silt screens be placed at strategic areas to protect the seagrass meadows from being smothered.
- Special modifications should also be made to ensure that there is no significant loss or damage to the mangrove environment as well.
- If mangrove forests need to be removed, it is recommended that this removal be kept as minimal as possible and replanting exercises done at suitable places along the Palisadoes coastline.
- Additionally, it is suggested that good construction practices are employed in how materials are disposed of in the construction site to limit the amount of potential solid waste being washed into the mangroves and the seagrass.

Table 3.50 Benthic Species List

Common Name	Scientific Name	IUCN Status
	TAXA- Crustaceans	
Blue swimming crab	Portunus armatus	Least Concern
Green swimming crab	Callinectes ornatus	Least Concern
Southern White Shrimp	Penaeus schmitti	Least Concern
Mysid shrimp	Mysidium spp.	Least Concern
Grass shrimp	Penaeus	Least Concern
	Family- Echinoderms	
Jewel Urchin	Lytechinus williamsi	Least Concern
Green Sea Urchin	Lytechinus sp	Least Concern
Sea Cucumbers	Holothuroidae	
Five toothed sea cucumber	Actinopyga agassizii	Least Concern
Reticulated starfish	Oreaster reticulatus	Least Concern
Striped sea star	Luidia clathrata	Least Concern
	Worms	
Scale Worm	Phyllodocida	Least Concern
Feather duster worm	Sabellidae sp.	Least Concern
	Mollusks	
Oysters	Bivalves	
Mud conch		Least Concern
Sea hare	Aplysia dactylomela	Least Concern
Tulip Shell	Fasciolaria tulipa	Least Concern
	Tunicates	
Mangrove tunicate	Ecteinascidia turbinata	Least Concern

Table 3.51 Fish Species List

Family	Common Name	Scientific Name	IUCN Status
Scorpaenidae	Spotted scorpionfish	Scorpaena plumieri	Least Concern
Sparidae	Sea bream	Archosargus rhomboidalis	Least Concern
Gerreidae	Silver jenny	Eucinostomus gula	Least Concern
	Yellowfin mojarra	Gerres cinereus	Least Concern
Dasyatidae	Yellowspotted stingray	Urolophus jamaicensis	Least Concern

Diodontidae	Balloonfish	Diodon holacanthus	Least Concern
	Porcupinefish	Diodon hystrix	Least Concern
	Web burrfish	Chilomycterus antillarum	Least Concern
Grammistidae	Greater soapfish	Rypticus saponaceus	Least Concern
Lutjanidae	Yellowfin snapper	Ocyurus chrysurus	Least Concern
	Lane snapper	Lutjanus synagris	Least Concern
	Grey snapper/mangrove snapper	Lutjanus griseus	Least Concern
	Schoolmaster snapper	Lutjanus apodus	Least Concern
	Mutton snapper	Lutjanus analis	Least Concern
Haemulidae	Bluestriped grunt	Haemulon sciurus	Least Concern
	Tomtate grunt	Haemulon aurolineatum	Least Concern
	Black grunt	Haemulon bonariense	Least Concern
	White grunt	Haemulon plumierii	Least Concern
Tetraodontidae	Checkered puffer	Sphoeroides testudineus	Least Concern
Sciaenidae	Sand drum	Umbrina coroides	Least Concern
	Reef croaker	Odontoscion dentex	Least Concern
Holocentridae	Longjaw squirrel fish	Holocentrus ascensionis	Least Concern
Bothidae	Eye flounder	Bothus ocellatus	Least Concern
Sygnathididae	Lined seahorse	Hippocampus erectus	Least Concern
Serranidae	Goliath grouper	Epinephelus itajara	Least Concern
	Tobaccofish	Serranus tabacarius	Least Concern
Scaridae	Redtail parrotfish	Sparisoma chrysopterum	Least Concern
Monacanthidae	Fringed filefish	Monacanthus ciliatus	Least Concern
	Orangespotted filefish	Cantherinus pullus	Least Concern
Mugilidae	Mullet	Mugilidae	Least Concern
Hyporhamphus	Piper fish		Least Concern
Atherinidae	Silver sides	Membras gilberti	Least Concern

3.5.5.5.9 Plankton Communities

Plankton samples were collected at each water quality stations by varying methods shown in Figure 3.36 along with in situ parameters; Temperature, salinity, pH, turbidity, Total Dissolved Solids (TDS) and dissolved oxygen (D.O.) using a Hydrolab DS5 water quality multi-probe.

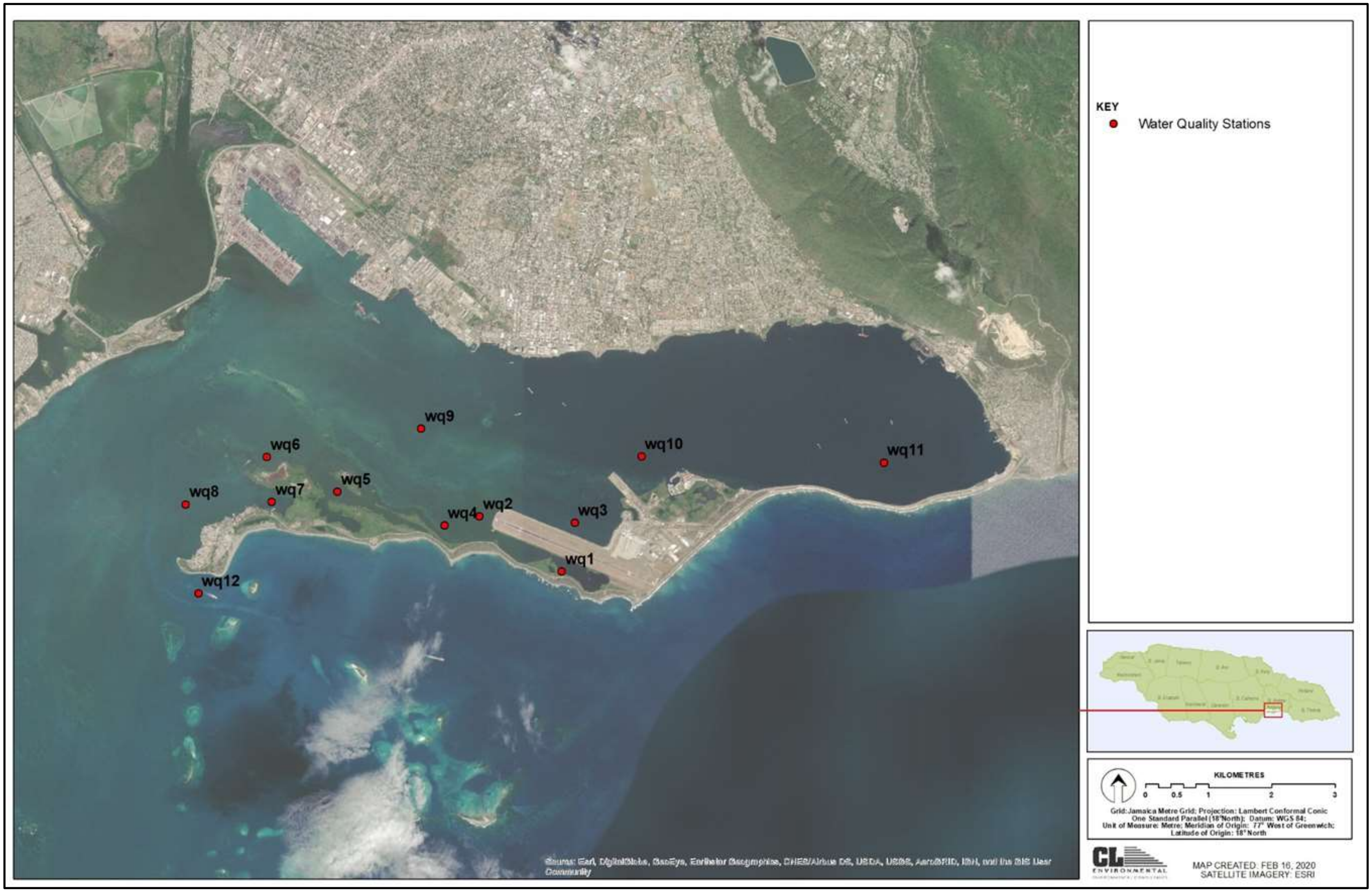


Figure 3.36 Water quality and Plankton sampling locations

3.5.5.5.9.1 Zooplankton

Background

Kingston Harbour is a semi- enclosed bay situated on the south coast of Jamaica between 17o56' and 17o58N and 76o48' to 76o52W. It is approximately 16.5km long and between 2.7 and 6.5 km wide; covering an area of more than 51km2 (Wade et al.,1972). Kingston Harbour is one of the most polluted harbours in the Caribbean and with an increasing population rate in Metropolitan Kingston found north of the Harbour, it poses an immediate threat to the marine community. Kingston Harbour is lined with several manufacturing complexes and is also a major trans-shipment port and as such plays an important role in the supply of goods for the island as well as the earning of foreign exchange. The degree of pollution suffered by Kingston Harbour has important consequences for those using it, and as pollution levels increase, discharge into Kingston Harbour has also affected the nearby Port Royal Cays (Webber et al., 1996).

Kingston Harbour is frequently affected by freshwater from different sources depending on the prevalent weather conditions. In 1976, Wade estimated that 662km^2 of land drained directly into the Hunts Bay and only 52km^2 drained into the inner harbour. Since then, an increase in development of urban areas and changes in land use patters has taken place however the impact of these drainage systems remains significant through time (Goodbody, 2003). The major fluvial in-puts to the harbour are in the region of Hunt's Bay where Rio Cobre, Duhaney River and the Sandy Gully drainage system enter. The Harbour has 28 minor gullies and storm drains that enter on its northern shore and culverts from two of Kingston's sewage treatment systems entering into the Harbor in the region of Newport west (near Hunts Bay). These and other inputs have been characterized by Webber and Wilson-Kelly (2003).

As a result, studies within Kingston Harbour have mainly focused on pollution and eutrophication. The abundance of zooplankton can often be used to describe water quality and dates as far back as Agassiz (1833) (Dunbar et al., 2003). Zooplankton (zoo= animal, plankton= wandering) also referred to as heterotrophic plankton are organisms that cannot produce its own food and relies instead on food produced by other organisms. These organisms are key components of many marine ecosystems as they form the base of most marine food webs as secondary producers. A study of the trends in zooplankton spatial distribution in Kingston Harbour indicated that maximum zooplankton abundance was found within the inner harbour regions. This was related to a decrease in species diversity among the 24 stations that were analyzed. This area was identified as being most associated with high levels of eutrophication. Kingston Harbour was reported to be eutrophic as far back as 1968 (Moore and Sander, 1979) and nutrient loading has gone unabated since then.

Extensive studies of zooplankton distribution in the eutrophic Kingston Harbour established that the harbour was being continuously contaminated (Grahame, 1974; Dunbar, 1997). Based on the different zooplankton communities, the harbour was zoned with the Upper Basin and Hunts Bay being the most eutrophic, the Inner Harbour, showing less contamination and the Outer Harbour least eutrophic (Dunbar, 1997; Dunbar & Webber, 2003).

Grahame 1974 describes the plankton community of the Upper basin is seen to be the "most diverse and biologically accommodating, offering the largest number of niches available to the zooplankton in the Harbour". It was therefore expected that the zooplankton community observed in this area would be different from the other areas of the Harbour. This suggests that relative stability in the water quality within the Upper Basin, which could be explained by a lack of any major inputs to that area. The upper basin has no major rivers or gullies but is influenced by a series of small gullies (22), which, as shown by Webber and Wilson-Kelly (2003), are only of significance during periods of heavy rainfall (Francis et al, 2014).

Copepods have generally been considered the most important metazoan secondary producers in pelagic marine ecosystems, both in terms of abundance and biomass (Hopcroft and Roff 1998). Zooplankton studies have often suggested that these organisms will respond to subtle influences such as inorganic micronutrients and organic growth factors which affect species composition and proportions of species (Dunbar and Webber 2003).

In total, 73 different taxa of zooplankton were identified throughout Kingston Harbour with the copepods being the dominant group with 38 species. Approximately half of the 73 taxa (35) occurred throughout the Harbour. However, a common pattern was for particular species to occur only in the Outer harbour: e.g., Aglama sp., Labidocera sp., Undinula vulgaris, Temora stylifera, Oithona oculata, Microsetella / Macrosetella spp. and salps. Only Pseudocyclops sp. seemed to show the reverse pattern of being largely absent from the Outer harbour and present in the Inner harbour and Upper basin. Consequently, the Outer harbour stations generally had the highest average number of species (33–38), followed by the Inner harbour (30–32 spp.), while the Upper basin and Hunts Bay had the lowest number, approximately 22–24 species. The average number of species ranged from a minimum of 22 species to a maximum of 38 species. Hunts Bay had 23 species (Dunbar and Webber 2003).

According to (Dunbar and Webber 2003) average abundances were generally lower in the Upper basin and the Outer harbour than in the Inner harbour. There was a gradual increase in abundance moving towards the Inner harbour stations and a decrease moving towards the Harbour Mouth. This decrease in abundance associated with Hunts Bay may be attributable to the poor water quality in that area of the Harbour (Dunbar and Webber 2003) with the extreme conditions having a deleterious effect on the zooplankton. Hunts Bay has experienced frequent phytoplankton blooms, and species of toxic algae (e.g., Alexandrium minutum; (Ranston 1998), and high pesticide levels (Mansingh and Wilson 1995) have been reported from this area. Hunts Bay has been classified as the most eutrophic area of Kingston Harbour (Dunbar and Webber 2003).

The consistent dominance of particular species (A. tonsa in Hunts Bay, Paracalanus crassostris in the Outer harbour, P. avirostris and Lucifer faxoni in the Inner harbour and T. turbinata in the Upper basin) further established the prevailing eutrophic conditions of these areas. It is therefore expected that the abundance of zooplankton observed will differ throughout the harbour as water quality fluctuates in accordance with inputs from major rivers or gullies (Dunbar and Webber 2003).

Commercially important species such as the Queen Conch (Strobus gigas) inhabit a range of habitat types during their life cycle. During the planktonic life stage, queen conch larvae (veliger) feed on phytoplankton. To metamorphose into juveniles, veligers most often settle in seagrass areas, which have sufficient tidal circulation, and high macroalgae production. The success of nursery areas are influenced by physical and oceanographic processes, level of larvae retention and settlement, predator abundance, and related survivorship (Stoner et al. 1998; Stoner et al. 2003). Jones and Stoner (1997) found that optimal nursery habitat occurred in areas of medium density seagrass, particularly along the seagrass gradient. In The Bahamas, juveniles were only found in areas within 5 km from the Exuma Sound inlet, emphasizing the importance of currents and frequent tidal water exchange that affects both larval supply and growth of their algal food (Jones and Stoner 1997). Due to mangrove areas being commonly used as a nursery for a multitude of marine species, it is expected that an increase in the abundance Ichthyoplankton are seen within relatively calm mangrove areas. There is no published information in the past reporting the occurrence of conch larvae being located within Kingston Harbour, this may be attributed to the poor water quality experienced here.

Ichthyoplankton is the collective term used to describe fish eggs and fish larvae. The assessment of Ichthyoplankton is important as the abundance of eggs and larvae can be used to determine key nursery grounds and as a result, reduce the amount of disturbance which these areas experience so as to protect commercially important species. The same premise follows Lobster and Conch Larvae, species considered to be of commercial importance to the Jamaican economy.

<u>Methodology</u>

At each site, a five (5) minute tow just below the surface of the water was conducted using a 0.5 metre hoop diameter plankton net of mesh size two hundred microns (200 µm) equipped with a flow meter which was used to calculate the volume of water sampled for each tow. Samples were then removed from the cod end and the contents were poured into numbered one (1) litre bottles and stored in seventy five percent (75%) ethyl alcohol.

Lab Analysis

Each sample was decanted to a volume of about 200ml. Samples were then agitated after which a 20ml was removed and poured evenly in a Bogorov tray. Dense samples were split to yield a lower density by agitating and pouring a known amount (2ml) of the original sample into the Bogorov tray. The tray was then placed under a microscope (Figure 3.37) and the zooplankton organisms were identified and counted.

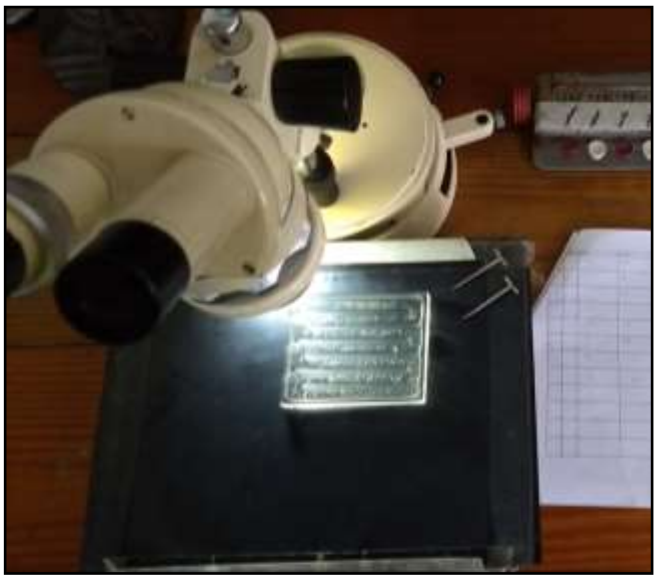


Figure 3.37 Zooplankton in Bogorov tray prepared for counting

Results

Zooplankton samples had varying species density and abundance, however, commercially important species; fish larvae, lobster larvae and conch larvae were very low across stations. The results are summarized in Table 3.52.

Table 3.52 Mean numbers of organisms per station

STATION	Mean Zooplankton	Mean Lobster Larvae	Mean Fish Larvae	Mean Conch Larvae
1	6169	0	23	0
2	6239	1	141	0
3	6504	1	100	0
4	5335	0	33	0
5	9935	1	59	0
6	9956	0	49	0
7	10650	1	71	0
8	7484	0	56	0
9	3954	4	75	0
10	7443	1	298	0
11	6909	1	212	0
12	990	0	49	0

General Zooplankton

The mean abundance of zooplankton was highest at stations 7 with a total of 10,650 organisms while the lowest mean was located at Station 12, located outside Kingston Harbour (Figure 1). An example of species seen in samples

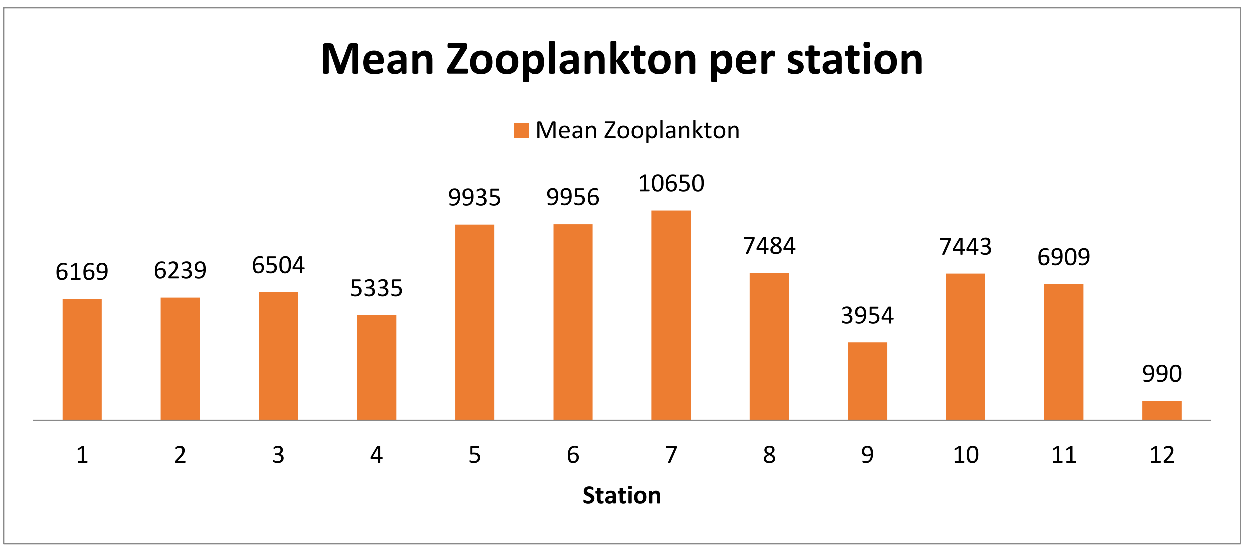


Figure 3.38 Mean Zooplankton per Station

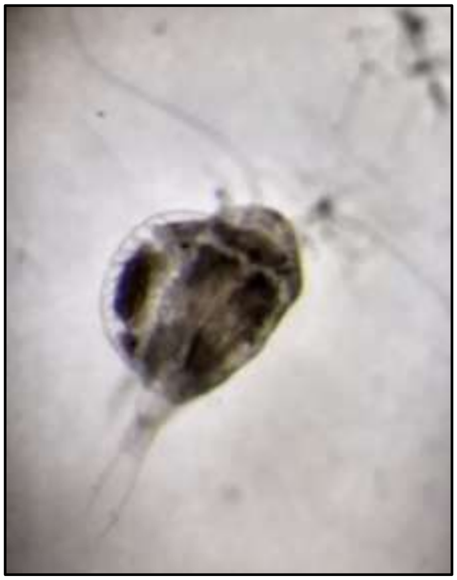


Figure 3.39 Temora turbinata with a microscopic ectoparasite attached

Fish Larvae

Stations 10 and 11 had the highest mean fish larvae (298 and 212 respectively). Stations 1 and 2 had the lowest count. Most stations had mean larval count less than 100 (Figure 3.40).

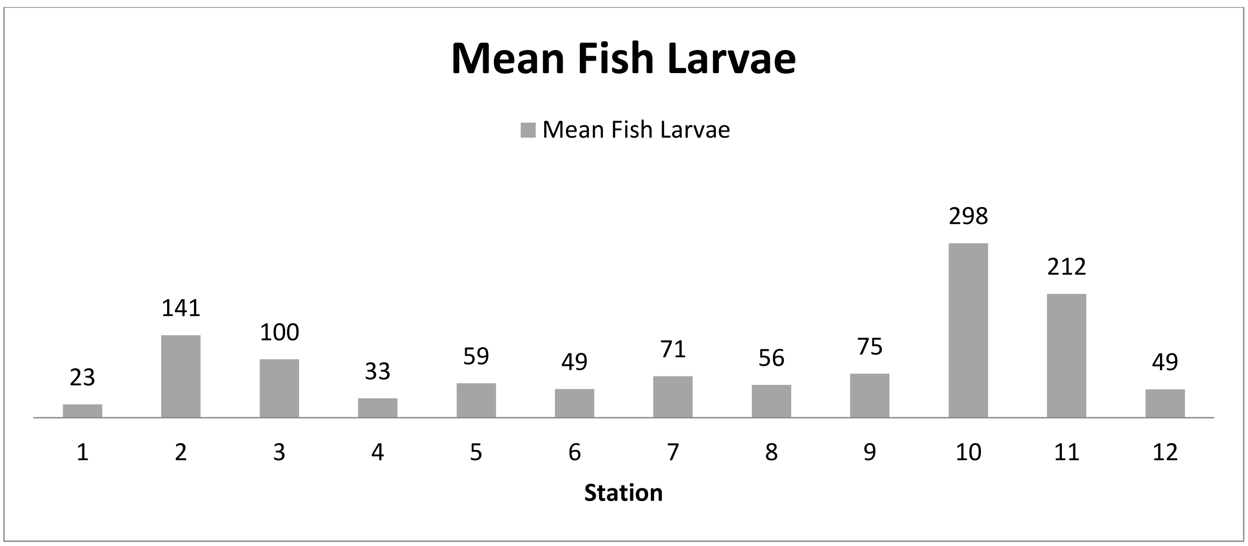


Figure 3.40 Mean Fish Larvae per station

Lobster Larvae

Though sparsely distributed, lobster larvae were found in most sites on various occasions. The highest mean number of lobster larvae was located at Station 9. No lobster larvae were observed at Stations 4, 6 and 8 on any occasion (Figure 3.41). No Conch Larvae/Eggs were found during the survey.

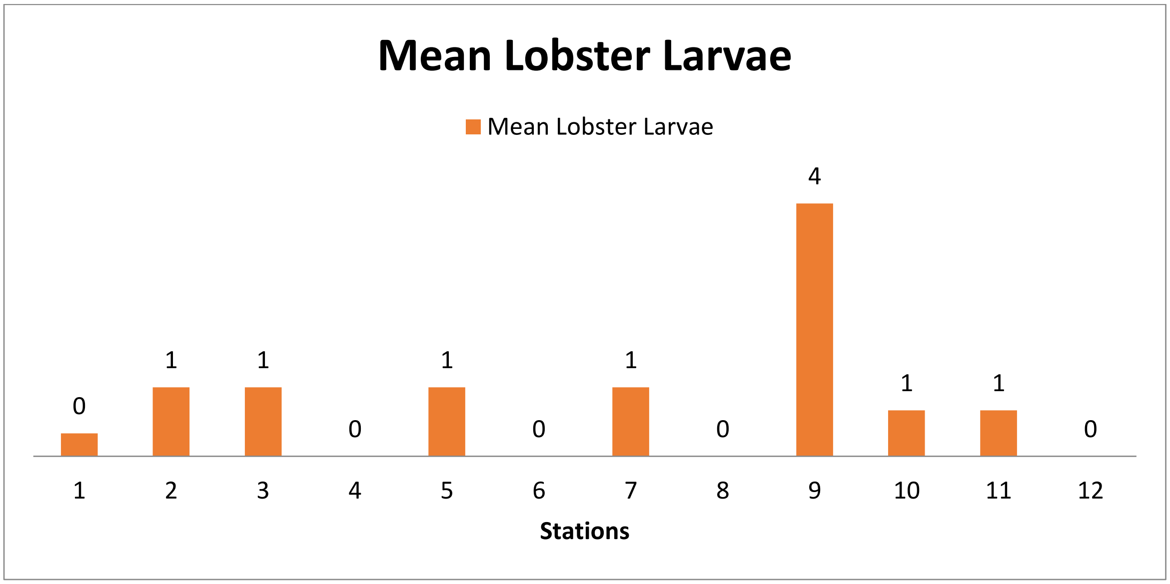


Figure 3.41 Mean Lobster Larvae per station

3.5.5.5.10 Discussion

Zooplankton

Kingston Harbour is classified as highly polluted with major sources of pollution including: major and minor gullies; rivers which enter the harbour at Hunts Bay (Goodbody, 2003). Solid waste is often introduced in large quantities after heavy rainfall events after which water currents distribute the debris within various sections of the harbour. The direction of wind and water currents often results in various areas within the harbour being more affected by debris than others and therefore differences in nutrient content may be seen.

Results attained by Dunbar and Webber further corroborate this information as it is stated that the possibility of various levels of pollution are experienced at different zones within the harbour (upper basin, inner harbour and outer harbour). The study stated that the mean total zooplankton abundances for the area sampled were generally lower in the upper basin and the outer harbour than towards the inner harbour as the upper basin is influenced by a series of small gullies (22), which, are only of significance during periods of heavy rainfall (Francis et al, 2014).

It is expected that a decreasing trend in mean total zooplankton would be observed as stations progress from the inner harbour towards the outer harbour as a result of mixing and the out washing of nutrients takes place however the inner harbour stations 10 and 11 experienced the fifth and sixth highest average abundance of zooplankton of the sites sampled while stations 5 to 8, all located closer to the harbour mouth experienced the highest mean total zooplankton (Figure 1). According to a study conducted by Webber and Dunbar, 2003 it was seen that similar stations to those identified in this study showed much greater variations in mean total zooplankton (Appendix IX and X) , there was also no general trend between the two studies. This may be due to the previous study having a longer sampling period (1 year).

Zooplankton was most abundant along the southern and outer sections of the Harbour (stations 5, 6 and 7). An increase in the abundance of zooplankton is often associated with poor water quality and increased eutrophication. Within Kingston Harbour, this often occurs as currents carry and deposit nutrients and solid waste from Kingston Metropolitan Area to the southern coastline of the harbour. These sites, Refuge Cay and Gallows Point respectively are often affected by the deposition of solid waste and may therefore account for the high levels of zooplankton observed as these species tend to be located in nutrient rich waters. The areas in closest proximity to the proposed construction, stations 1, 2, 3 and 4 were seen to have fairly average amounts of zooplankton as they ranged from mean total numbers of 6169 to 6509 organisms.

Commercially Important Species

The marine fisheries of Jamaica are almost entirely artisanal, with at least 15 000 fishers and an annual catch of approximately 7 000 t. A recent development is a small industrial fishery for queen conch and spiny lobster that earns significant foreign exchange for the country. The major aquatic resources are coral reef fishes, conch, lobster, small pelagic (Ichthyoplankton) and seasonal large pelagics. The major fishing grounds are the southern island shelf and Pedro Bank, a large oceanic bank 150 km to the southwest of Kingston (Aiken and Kong, 2000). With a high prominence of mangroves trees being located along the southern coastline of the harbour, it is expected that areas experiencing calmer conditions, typical sites used as nurseries would have the highest abundance of larvae.

According to a study conducted by Aiken in 2008 on the community structure (species composition) of certain stations within Kingston Harbour (Appendix XI), a total of forty two (42) species of finfish, crustaceans and molluscs, of which 66% were fishes were found. Most notable within the full species list provided within this study (Appendix XII) the species previously thought to be locally extinct, the Goliath Grouper was found along with locally important species of snapper, grunt and parrotfish.

Ichthyoplankton

With the majority of mangrove associated areas being utilized as nurseries for pelagic species along the coastline, it is often expected that a high abundance of larval juvenile species be found here. The presence of fish larvae within the stations sampled was most abundant at stations 10 and 11 both located away from nursery ground and within the upper basin.

The Upper basin is unique in that it is at the 'closed' end of the harbour and is an area with the longest residence time and lowest mixing with other water masses in the Harbour (Williams, 1997; Webber et al., 2003); this area is not exposed to the high levels of inputs (nutrients) experienced by Hunts Bay (Webber and Wilson-Kelly, Characterization of sources of organic pollution to Kingston Harbour, the extent of their influence and some rehabilitation recommendations 2003)

The direction of wind and water currents often results in various areas within the harbour being more affected by debris than others and therefore differences in nutrient content may be seen. This may also affect the presence of organisms which are drift driven or incapable of swimming such as fish eggs. In a study determining the variations in currents within the Kingston Harbour under various conditions, it became evident that during the dry season, where strong winds exist and there is a prevalent ebb tide, two gyres are present within the Kingston Harbour, located within the upper basin and closer to the mouth of the harbour respectively (Webber, Webber and Williams, The Relative Importance of Meteorological events, tidal activity and bathymetry to circulation and mixing in Kingston Harbour, Jamaica 2003).Therefore the high concentration of fish eggs at stations 10 and 11 may be as a result of the presence of this gyre moving these organisms further into the harbour thus preventing their outward movement..

These stations were located within the innermost sections of the harbour and are therefore least affected by wind and water currents within the harbour. Closer to the proposed construction site, Stations 2 and 3 also reflect relatively high numbers of Ichthyoplankton; with mean totals of 141 and 100 respectively. This may be directly associated to the location of these sites closer to the inner harbour as well their close proximity to the surrounding shallow and mangrove populated coastline. Notably, Station 1 is seen to possess the lowest abundance of fish larvae within the study. This area is located within a semi enclosed portion of the harbour, and experiences very little anthropogenic disturbances however, wind speeds are strong here alongside a fair amount of noise pollution from the nearby airport which may place stress on fish and so result in lower abundance.

Should these organisms be affected by development within the harbour, it is most likely that areas immediately surrounding the proposed construction site may become smothered with sediments as fallout occurs within the water column. Such areas include stations 4, 5 and 6 in particular as currents move towards the mouth of the harbour. These stations possessed low amounts of fish larvae however the mangroves along the coastline of the harbour and those associated with the cays within Kingston Harbour are often areas of high fish recruitment and productivity.

Lobster Larvae

The spiny lobster, Panulirus argus, is widely distributed in the coastal waters and on the offshore banks around Jamaica. This resource is a delicacy and therefore highly priced and lobsters represent an important component of the total landings of the Jamaican commercial fishery. Six species of lobsters are found in Jamaican waters viz., Panulirus argus, Panulirus guttatus, Justitia longimanus, Palinurellus gundlachi, Scyllarides aequinoctialis and Parribacus antarcticus, of which P. guttatus and P. argus are the only two species that are commercially valuable (Aiken, 1984).

The recruitment of lobster larvae is highly dependent on prevalent water quality. These animals are typically found in seagrass beds among sponges and soft corals. There is an overall low abundance of these animals within samples with the highest numbers being found at Station 9 located just across from the Airport Runway. Total numbers ranged between 0-4 organisms over the duration of sampling. Samples closest to the proposed construction had very few occurrences of lobster larvae.

Conch Larvae

With optimal conditions for the survival of these species being clean shallow coastal waters that have sandy substrate (Weil and Laughlin 1984), it is expected that with the characteristic mud and peat substrate alongside the poor water quality experienced within Kingston Harbour, there would be little to no sign of these species within this area. Within this study, none were observed.

3.5.5.6 *Recommendations*

The most abundant organisms found were zooplankton, which make up the majority of Kingston Harbour community and were spatially distributed throughout the entirety or the stations sampled. Of the commercially important species identified, fish larvae were the most abundant with a highest to number being found within inner most designated stations (10 and 11). Due to the movement of currents and wind action on the harbour, should turbidity be increased as a result of development within the harbour, it is likely that sediments will be carried westbound into the cays within the harbour and towards the harbour mouth. This will affect mangrove trees, corals which may become smothered by sediment fallout as well as marine species found here. Therefore it is highly recommended that:

- Silt screens are utilized to reduce the impact of sediments on surrounding communities.
- Routine monitoring of marine communities surrounding the development should be conducted to track the impact of construction of the community.
- Where mangroves are removed, replanting should take place to facilitate continued fish recruitment.
- Only when necessary, areas consisting of high commercial species abundance should be disturbed with caution
- Soft engineering should be utilized where possible including replanting of mangroves along the length of the new structure for structural support as well as its associated ecosystem function in substrate stabilization and ecosystem productivity.

3.5.5.6.1.1 Phytoplankton

Three sets of Lugol's preserved whole water samples collected from Kingston Harbour, Jamaica in the vicinity of the Norman Manley International Airport on February 26, March 26 and April 9, 2020 were received for analysis of the phytoplankton community. This analysis was conducted in order to produce a baseline data set on the phytoplankton community of the area before future expansion of the airport. This baseline data will allow for comparisons with data recorded for water samples collected during and after the expansion process in order to assist with the identification of any impacts of the project on the species concentrations and composition of the phytoplankton community.

3.5.5.7 *Methodology*

Each water sample was gently homogenized by inversion approximately 100 times, in order to randomly distribute the phytoplankton cells throughout the samples. Based on the visible density of the phytoplankton cells within each sample, 5 - 50 ml aliquots of each homogenized sample were used to fill Utermöhl sedimentation chambers.

The chambers were left to stand overnight to allow settling of the phytoplankton before examination using a Leitz Labovert (model no. 020-435.025) inverted microscope. The settled phytoplankton throughout the base of each sedimentation chamber were examined and phytoplankton species were identified and enumerated in thirty random fields of view using a X20 objective lens. The entire base of the settling chamber was then scanned using the same lens in order to record phytoplankton species that were not present in the thirty fields of view.

The abundance of each phytoplankton species in each sample was calculated and recorded as the number of cells per litre of seawater (Tables 1 - 3). The species diversity index of the phytoplankton community recorded for each sample set was calculated using the Shannon-Weaver (1949) formula - $H = -\Sigma pi(\ln pi)$. Where, $pi = Ni/N$ represents the proportion of species in the community, Ni = number of individuals of a species i, N = total number of individuals.

3.5.5.8 *Results*

Phytoplankton composition:

One hundred and seventy-five species of phytoplankton comprising thirty-six genera were identified in the water samples. Based on percentage composition, the diatoms formed the dominant group, comprising 60% of the total species composition (Figure 1). The diatoms were followed by the dinoflagellates (31.4%), blue-green algae (5.7%), green algae (1.1%), euglenoids (0.6%), zooflagellate species (0.6%) and unidentified unicellular flagellate species (0.6%) in percentage composition.

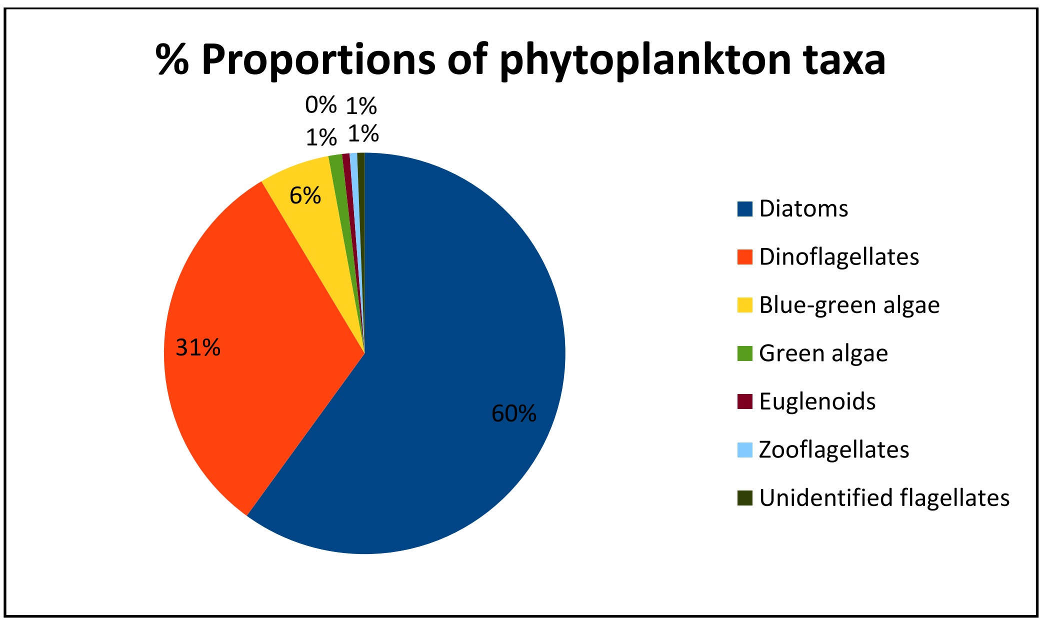


Figure 3.42 Pie chart showing the % proportions of each phytoplankton taxa comprising the phytoplankton community

Diatom dominance of the phytoplankton community of Kingston Harbour was also reported by Simmonds (1998) and Ranston et al. (2003) and is usually indicative of nutrient rich water and thus poor or eutrophic water quality (Sarthou et al. 2005). According to Kilham and Kilham (1980) diatoms tend to dominate algal communities in nutrient rich environments as they are classified as r-selected species which have high maximum growth rates, usually requiring high concentrations of nutrients to sustain those rates. Margalef (1978) also found that coastal (turbulent and nitrate rich) phytoplankton communities are dominated by diatoms, while low-nutrient concentrations and turbulence conditions are often dominated by dinoflagellates. Simmonds (1998) concluded that Kingston Harbour was more eutrophic than reported in the 1970's and the diatom dominance of the phytoplankton community in the present investigation suggests that the harbour continues to be a eutrophic body of water.

3.5.5.9 *Species Diversity:*

A diversity index is a mathematical measure of species diversity in a community. Species diversity relates to the number of the different species and the number of individuals of each species within any one community. Diversity indices can be used to define the water quality of an area. A high value suggests a rich diversity and therefore healthier, more stable ecosystem with less pollution, whereas a low value suggests a poor diversity and thus a less healthy or stressed, highly disturbed ecosystem with more pollution (Wilhm, 1975). Environmental change is less likely to be damaging to the ecosystem with a higher diversity, as a whole.

According to Shekhar et al. (2008) the Shannon-Weaver diversity index proposed that a diversity index greater than 4 (> 4) indicates clean water; between 3 - 4 is mildly polluted water; between 2 - 3 is moderately polluted water and less than 2 (< 2) is heavily polluted water. The indices computed in the present analysis show that the phytoplankton species diversity has an average value of 2.84 which according to Shekhar et al. 2008 indicates that the area sampled in Kingston Harbour is comprised of moderately polluted water.

3.5.5.10 *Species Similarity*

Calculation of the Jaccard Community Coefficient (JCC) which determines the % similarity between the species of two sample sites indicates that stations1 and 12 are most dissimilar to other stations. The table below needs to be converted into a dendrogram to determine which stations are similar to which.

Jaccard Community Coefficient Similarity Matrix

Stations	1S	2S	3S	4S	5S	6S	7S	8S	9S	10S	11s	12S
1S	100	33	24	27	36	24	35	11	19	16	15	22
2S		100	44	48	48	40	25	29	38	38	34	24
3S			100	36	37	29	26	25	30	33	34	24
4S				100	38	30	27	24	29	33	32	22
5S					100	35	31	32	27	24	26	21
6S						100	33	29	35	35	25	18
7S							100	35	35	29	27	34
8S								100	33	42	26	24
9S									100	55	40	38
10S										100	29	34
11S											100	24
12S												100

Phytoplankton Abundance:

The total phytoplankton abundance values for each station sampled during run 1 (February 26, 2020) ranged between 3 x 104 to 1.83 x 105 cells/L (Table 1). Total phytoplankton abundance values for each station sampled during run 2 (March 26, 2020) showed an increase over values recorded for run 1, with abundance ranging from 6.91 x 104 to 2.98 x 106 cells/L (Table 2). This could be due to an increase in nutrient input to the area from various land based sources. Total phytoplankton abundance values for each station sampled during run 3 (April 9, 2020) showed an compared to values recorded for run 2, with abundance ranging from x 102 to x 103 cells/L (Table 3).

3.5.5.11 *Economically Important Phytoplankton Species:*

Nine potentially toxic phytoplankton species were identified in the water samples, with all stations having at least one potentially toxic species (Table 5). These are species which may have the ability to produce toxins that can cause human poisonings and fish and shellfish kills (Tindall et al., 1984; Juranovic and Park, 1991; Kao, 1993; Steidinger, 1993; Anderson, 1996; Zingone and Enevoldsen, 2000; Anderson et al., 2001; Hallegraeff, 2004; Moestrup, 2004; Lansberg et al., 2006; Ranston, 2008).

The concentration values of these potentially toxic species presently exceed acceptable concentration limits for these species in other countries and are high enough to result in the implementation of restrictions on the shellfishery in these countries (Anderson, 1996). It is possible for anthropogenic disturbance of an area to lead to changes in physico-chemical parameters such as increased nutrient loading, which can result in the concentration values of these potentially toxic phytoplankton species further exceeding acceptable limits and even forming blooms (Anderson, 1989; Hallegraeff, 2004). These blooms could lead to severe economic losses to fisheries and tourism operations in the area and have major environmental and human health impacts. The abundance of the potentially toxic species should therefore be carefully monitored during and after construction activities and any measures that can be put in place to reduce changes in physico-chemical parameters during construction, such as the use of sediment screens should be deployed.

Table 3.53 Concentration values (cells/L) of potentially toxic phytoplankton species and cell concentrations (cells/L) of these species that result in implementation of restrictions on the shellfishery of other countries.

Potentially Toxic Species	Concentration (cells/L)	Concentration levels used to implement restrictions in other countries (cells/L)	Station	Implemented actions in other countries
Alexandrium minutum	6 X 103	103	6, 7, 9, 10	Intensified monitoring/close shellfisheries
Alexandrium sp. A	6 X 103	103 - 104	2, 9, 10, 11, 12	Restrictions or closure of shellfisheries
Alexandrium sp. B	3 X 103	103 - 104	2, 4, 5, 6	
Dinophysis caudata	8 X 104	103	2 - 12	Restrictions or closure of shellfisheries
Prorocentrum lima	5 X 102	500	5	Intensified monitoring/close shellfisheries
Prorocentrum mexicanum	5 X 102	-	12	-
Pseudo-nitzschia sp. A	2 X 104	104 - 105	2 – 8, 12	Restrictions alert/ intensified monitoring/close shellfisheries
Pseudo-nitzschia sp. B	7 X 104	104 - 105	2, 3, 4, 5, 8	
Pseudo-nitzschia sp. C	1 X 105	104 - 105	1 – 9, 12	

3.5.5.12 *Conclusion*

In summary it can be deduced that the phytoplankton community of Kingston Harbour area is presently typical of the area with a moderately low diversity, high abundance values and dominated by diatom species which indicates that the area continues to be a eutrophic body of water (Simmonds, 1998; Ranston et al. 2003). There is potential for the proposed development to impact negatively on the phytoplankton community of the harbour primarily via reduction of abundance and community diversity and stimulation of blooms particularly of potentially toxic species via dredging and other construction activities. These primary impacts can lead to important secondary environmental and human health impacts. The phytoplankton community should therefore be carefully monitored during and after construction phases and any measures that can be put in place to reduce changes in physico-chemical parameters of the site waters during construction, should be deployed.

3.5.6 Risk Assessment

3.5.6.1 *Generally*

The hazards presented by the findings:

1. Potential environmental impacts on the phytoplankton community include:
2. Decreased light availability due to increased turbidity of the water column as a result of the disturbance of sediment due to dredging.
3. Increase in the nutrient loading of the water column due to the disturbance of settled nutrients in the sediment.
4. Reduction of the oxygen concentration of the water column if oxygen-demanding substances are released from disturbed sediments and mixed into the water column by dredging.
5. Addition of chemicals to the water column via spillage or leakage from equipment.
6. Release of natural and anthropogenic contaminants from any dredged or dumped sediment and uptake by the cells

Potential impacts of the hazards:

1. Increased turbidity of the water column has the potential to reduce the quality of light received by the phytoplankton community resulting in a decrease in phytoplankton productivity as well as diversity due to loss of rare species and reduction of the abundance of the more common species. This can negatively impact organisms of higher trophic levels that depend on phytoplankton as a direct or indirect source of food (Jabusch, 2008, OSPAR, 2008).
2. Increased nutrient concentrations within the water column can result in blooms of various phytoplankton species which can reduce the light intercepted by other non-bloom phytoplankton species and larger marine plants and thus reduce the productivity of these species and species of higher trophic levels (Anderson et al., 2002). Decaying blooms can reduce the oxygen concentrations within the water column causing indiscriminate kills of fish and invertebrates due to oxygen depletion. Phytoplankton blooms can also reduce the recreational and aesthetic value of the area via reduced visibility, unpleasant odours and altered seawater colour (Anderson, 1996; Hallegraeff, 2004, OSPAR, 2008). Increased nutrient concentrations and changes of other physico-chemical parameters can also result in an increase in abundance and even blooms of potentially toxic phytoplankton species. These can negatively impact on marine organisms of higher trophic levels, restrict the exploitation of commercially important marine species in the area, lead to the loss of fishermen's livelihood and negatively impact on the tourist industry, through reduced aesthetic and recreational value of the area as well as via the possibility of human poisonings, through the consumption of fish and shellfish that have directly and indirectly ingested the potentially toxic species (Anderson, 1996; Anderson et al., 2001; Hallegraeff, 2004).
3. Reduction of the oxygen concentration of the water column through disturbance of the seafloor sediment and addition of chemicals to the water column via spillage or leakage from equipment may impact phytoplankton abundance and productivity. This can negatively impact organisms of higher trophic levels that depend on phytoplankton as a direct or indirect source of food (Jabusch, 2008, OSPAR, 2008).
4. These impacts can result in blooms or a die-off of dinoflagellates creating a change in the community structure and an increase in the abundance of potentially toxic dinoflagellates in the area.
5. Evaluation of the risks:
6. There is a risk of decreasing the diversity of the phytoplankton community through loss of rare species and other species with low abundance values as a result of the impact of changes in the physico-chemical parameters such as increased turbidity. This risk is considered to be moderate and the impact generally short term but this is dependent on the extent of the areas dredged (in terms of area and depth), the frequency and duration of construction and dredging activities, the characteristics and the

sensitivity of the areas disturbed and their surroundings (in terms of distribution and importance of phytoplankton species), and the techniques applied (OSPAR, 2008).

7. There is a risk of the creation of phytoplankton blooms through increased nutrient enrichment of the water column via sediment disturbance. This risk is considered to be moderate but short term and is dependent on the extent of the areas disturbed (in terms of area and depth), the frequency and duration of dredging activities, the dredging techniques applied and most importantly the concentration of nutrients in the sediment that can stimulate the production of phytoplankton blooms. Related to this, is the potential risk of the production of blooms of potentially toxic phytoplankton species.
8. Disturbance of an area can lead to changes in physico-chemical parameters which can result in the concentration values of the potentially toxic species exceeding acceptable limits and even forming blooms (Anderson, 1989; Hallegraeff, 2004). These blooms can have long term impacts especially on the tourism industry of the area. The acceptable concentration limits for many of the potentially toxic species present in Jamaican waters have not yet been determined (Ranston, 2008).
9. Concentration limits have been determined in other countries but these vary from country to country and even within single species primarily due to geographical variability in toxicity of the species and the environmental conditions (Anderson, 1996). These concentration limits can however be used as a general guideline for determination of acceptable limits for Jamaican species and on this basis the present concentration values are low and within acceptable concentration limits (Anderson, 1996).
10. The level of the risk of potentially toxic phytoplankton concentrations exceeding acceptable limits or blooming is difficult to determine and dependent on the level of disturbance of the physico-chemical parameters of the area and the toxic potential of the Jamaican species which is presently unknown, however, as long as a species has the potential to be toxic then its presence alone must be taken into consideration as important and presenting a risk factor.

Mitigation measures:

1. Monitoring of the water quality and phytoplankton community of the area should be conducted fortnightly during and after the construction phase of the proposed development, up to a period of one month after completion to detect any progressing unacceptable changes in the phytoplankton community. This will allow any increases or decreases in phytoplankton species concentrations to be detected early before reaching critical stages. If critical stages are exceeded mitigation measures would depend on the species that have exceeded the concentration limits as some are more harmful than others, as well as the extent of the increased concentration of the species over the limits. The extent of blooms of species would also be taken into consideration as some blooms can be isolated while others may travel with the currents and impact fishing areas and high human use areas. Mitigation in such cases can include closure of fishing and swimming areas and beaches. In very serious cases a stop work order may need to be issued on the construction site.
2. Use of techniques or mechanisms such as silt screens or curtains to reduce impacts of suspended solids and increased turbidity.

3.5.6.2 *Chlorophyll a*

Phytoplankton form the base of most marine food webs and are considered extremely essential primarily because of their ability to utilize nutrients (in the water column), chlorophyll and sunlight to synthesize simple compounds into organic matter and food reserves. The rapid nutrient uptake kinetics, short generation times, motility, and (quick) reactions to pollutants, also make these organisms excellent indicators of environmental conditions by examining their community structure in the waters they inhabit (Hecky and Kilham 1988; Webber and Webber 1998; Hughes et al. 2005). Research has long suggested a direct relationship between nutrients in the water column and phytoplankton size (Brooks and Dodson 1965; Lehman and Cáceres 1993; Finkel et al. 2010), and so the assessment of phytoplankton communities in specific/categorized size-classes is important in investigating and deriving accurate implications about the productivity and trophic status of the marine environments that they inhabit. Indeed, nutrient concentrations in coastal waters are what remain (residual nutrients) after uptake and utilization by phytoplankton.

Chlorophyll standards have been indicated for areas where recreational activities are planned (Webber, D. 1990). These are as follows:

1. Bays with < 1.0 mg/m3 of Chlorophyll a, no unnatural nutrient sources and short retention times – safe for bathing
2. Bays with 2 – 7 mg/m3 of Chlorophyll a, < 1.5 ug at/L of nitrates and 0.1 ug at/L phosphate with less than three days retention time may be developed cautiously and with limited in-water activities.
3. Bays with > 8 mg/m3 Chlorophyll a and > 1.5 and 0.1 ug at/L of nitrates and phosphates, respectively are only recommended for boating activities and water recreation that does not involve body/skin contact.

3.5.6.2.1 Aims/objectives:

1. To rapidly determine the total phytoplankton concentrations (Chlorophyll a in mg m-3) at 12 selected stations in Kingston Harbour, near the Norman Manley International Airport (NMIA)
2. To rapidly determine the specific size-fractions of phytoplankton: netplankton (20µm), nanoplankton (2.7µm) and picoplankton (0.7µm), at selected stations near the NMIA.

3.5.6.2.2 Methods

3.5.6.2.2.1 Field

1. One liter (L) of surface water was collected at each station (at 0.5m) using a 3L Niskin bottle.
2. Samples were stored away from direct sunlight (in an igloo) to prevent photolysis, and filtered within 6 hours of collection (Parsons, Maita, and Lalli 1984).

3.5.6.2.2.2 Laboratory

1. Each 1 L whole water sample was filtered through a Nalgene size-fractionating tower separating the phytoplankton into three sizes.
2. The porosity of the filter sizes used was: Nitex screening - 20µm, Whatman glass-fibre filters, GF/D - 2.7µm and Whatman glass-fibre filters, GF/F - 0.7µm.
3. Chlorophyll a was extracted using 6ml of 90% acetone and left for 24hrs at 250 C (Lorenzen and Jeffrey 1978; Herve and Heinonen 1984; Arar and Collins 1997)
4. Chlorophyll a concentration per m3 of seawater was determined using a Turner TD700 fluorometer as well as the equation:
5. Chlorophyll a (mg/m3) = Fluorometer Reading X Extract Volume (v) / Sample Volume (V) (both in Litres)

3.5.6.2.3 Results/analysis

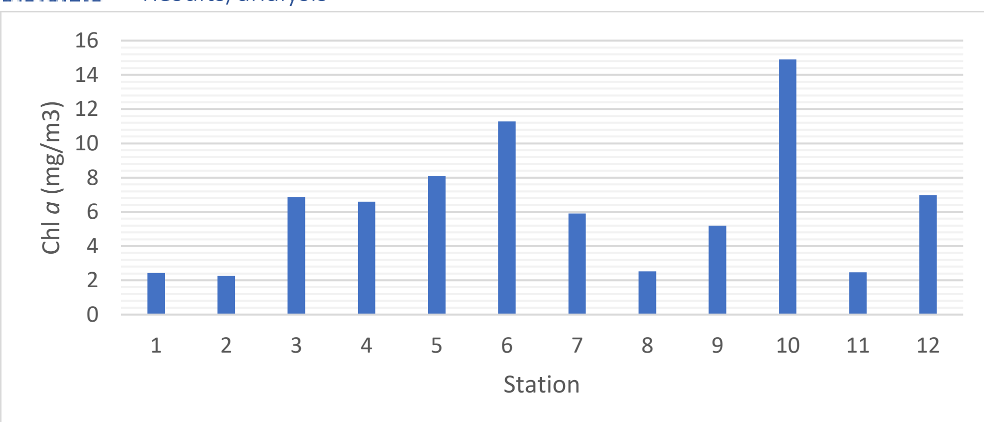


Figure 3.43 Total Chlorophyll a (mg m-3) at each station -February 2020

The mean total Chlorophyll a concentration between stations in February 2020 was: 6.28 mg m-3. Some stations, namely: 1, 2, 8 and 11 displayed much lower (Chlorophyll a) concentrations (2.42, 2.25, 2.52 & 2.45 mg m-3 respectively) compared to the mean. Station 10 displayed the highest total Chlorophyll a concentration between stations (14.9 mg m-3) followed by stations: 6 and 5, which also had relatively high concentrations (11.28 and 8.1 mg m-3 respectively). All other stations had < 7 mg m-3 total Chlorophyll a.

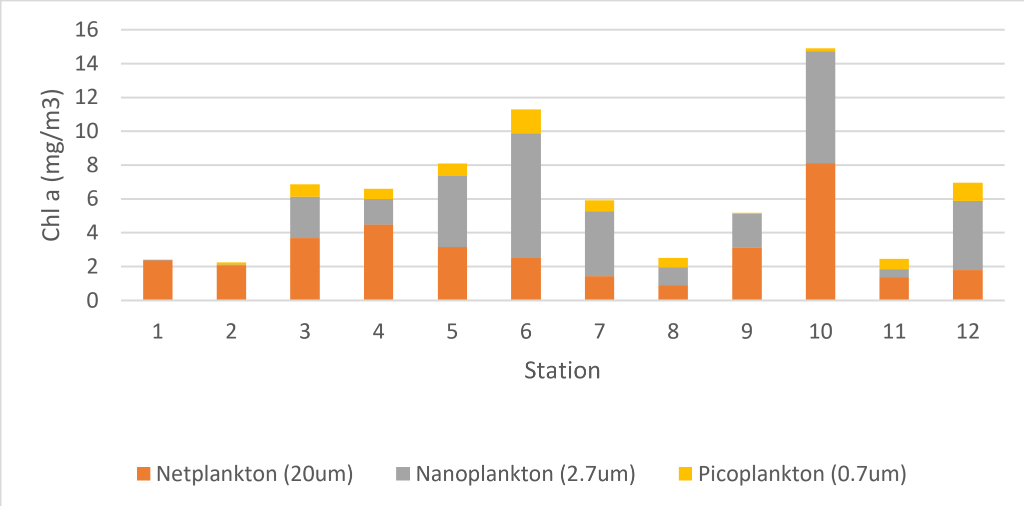


Figure 3.44 Size-fractionated phytoplankton (Chlorophyll a in mg m-3) at each station- February 2020

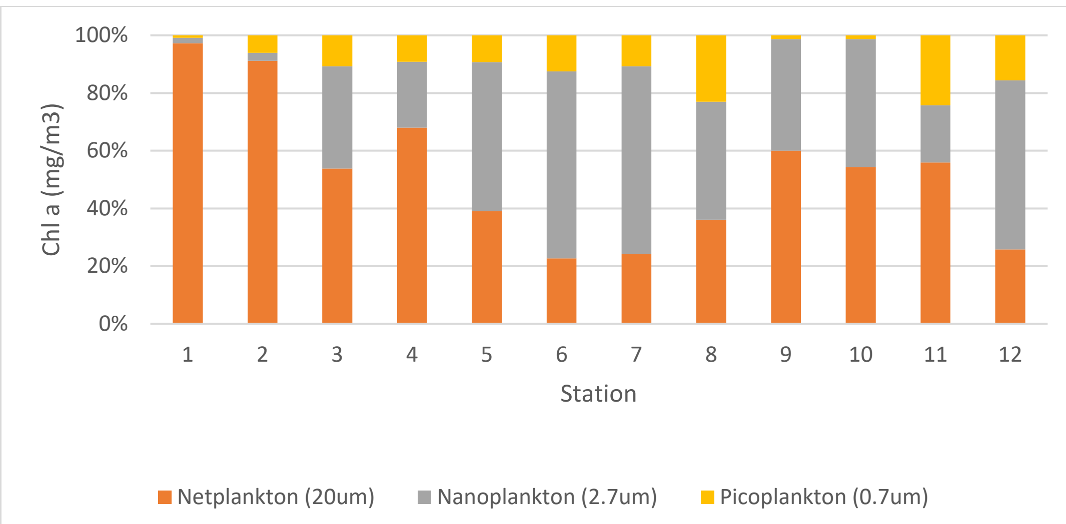


Figure 3.45 Percentage (%) size-fractioned Chlorophyll a at each station- February 2020

Size-fractionation shows that stations 1 and 2- which had noticeably lower total Chlorophyll a concentrations compared to the mean- were both dominated by the netplankton (20µm size-fraction), which accounted for over 90% of the total Chlorophyll a at both stations (Figures 2a, 2b). This size-fraction dominates in very high nutrient areas. Stations 8 and 11, which also had comparatively low total Chlorophyll a, had higher proportions of the smaller phytoplankton size-fractions (pico- and nanoplankton), which (combined) accounted for 65% and 45% of the total Chlorophyll a at those stations (8 and 11) respectively. Station 10, which had the highest total Chlorophyll a concentration was also dominated by the netplankton size-fraction, which accounted for 55% of the total Chlorophyll a. It was also noteworthy that:

The smallest picoplankton (0.7um) size-fraction was the least dominant proportion of the total Chlorophyll a at most stations.

Stations: 6, 7 & 12 were the only stations with under 30% netplankton in the total Chlorophyll a.

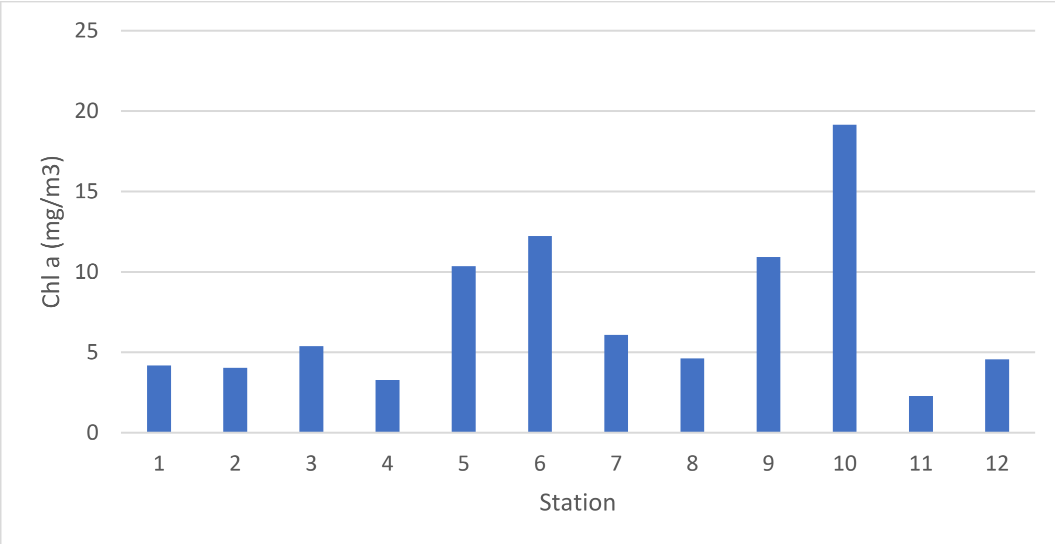


Figure 3.46 Total Chlorophyll a (mg m-3) at each station -March 2020

The mean total Chlorophyll a between stations in March 2020 was: 7.25 mg m-3. Station 11 had the lowest total Chlorophyll a concentration between stations (2.26 mg m-3), while station 10 recorded the highest (19.15 mg m-3). Stations 6, 9 and 5 also recorded relatively high total Chlorophyll a concentrations (12.23, 10.91 and 10.34 mg m-3 respectively), while all other stations had < 7 mg m-3 Chlorophyll a.

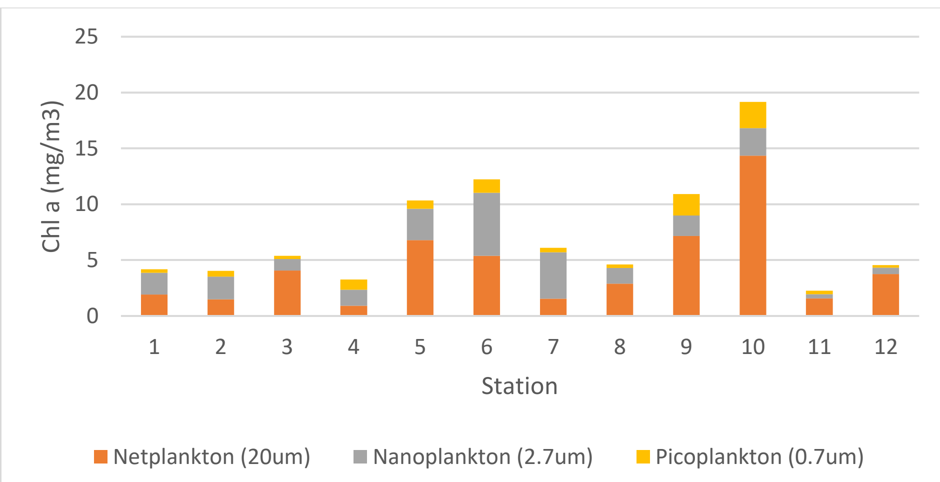


Figure 3.47 Size-fractionated phytoplankton (Chlorophyll a in mg m-3) at each station-March 2020

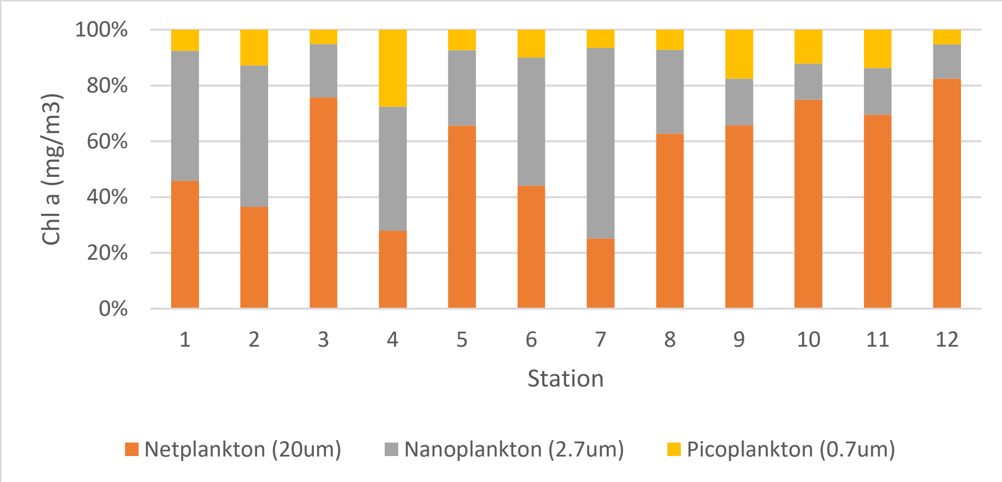


Figure 3.48 Percentage (%) size-fractioned Chlorophyll a at each station- March 2020

Size fractionation (Figures 4 a & b) again showed a dominance of the larger (20µm), nutrient-loving netplankton size-fraction at most (7 of 12) stations. At station 10, which had the highest total Chlorophyll a concentration (19.15 mg m-3), 14.35 mg m-3 or ~ 75% of the total Chlorophyll a consisted of netplankton. Station 11, which had the lowest total Chlorophyll a concentration, also recorded over 60% netplankton. Stations: 2, 4 and 7 had the least proportions of netplankton (all <40%), while the picoplankton was again least dominant at almost all stations.

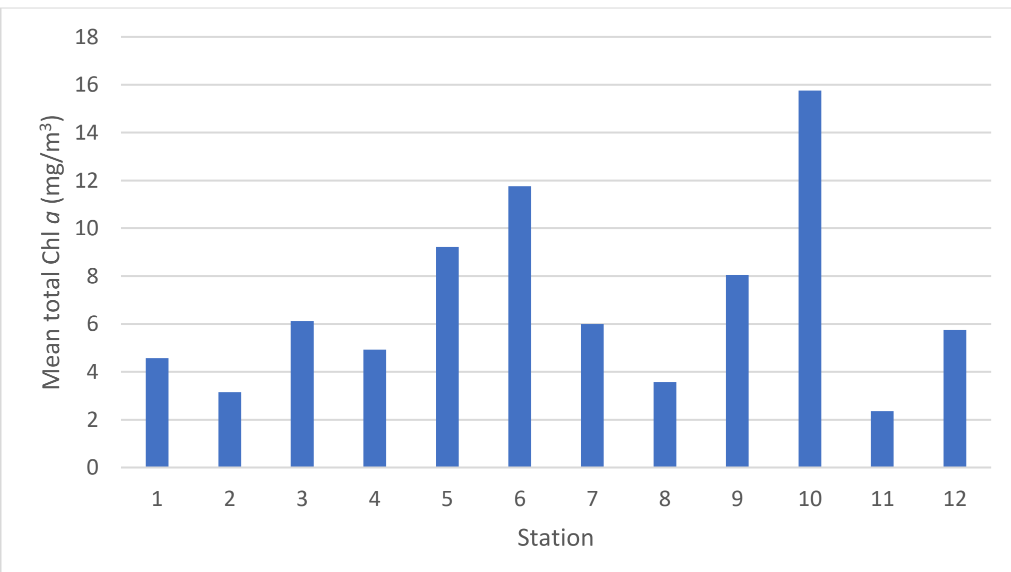


Figure 3.49 Mean total Chlorophyll a at each station over the sample period (February and March).

The mean total Chlorophyll a concentrations over the sample period (February and March) indicated that station 10 had the highest Chlorophyll a levels, while on the other hand station 11 displayed the lowest mean total concentration. Stations 5 and 6 were also worthy of mention because of the high specific values observed at these stations, while at stations: 2 and 8, values were notably lower than mean value between stations (6.77 mg/ m3).

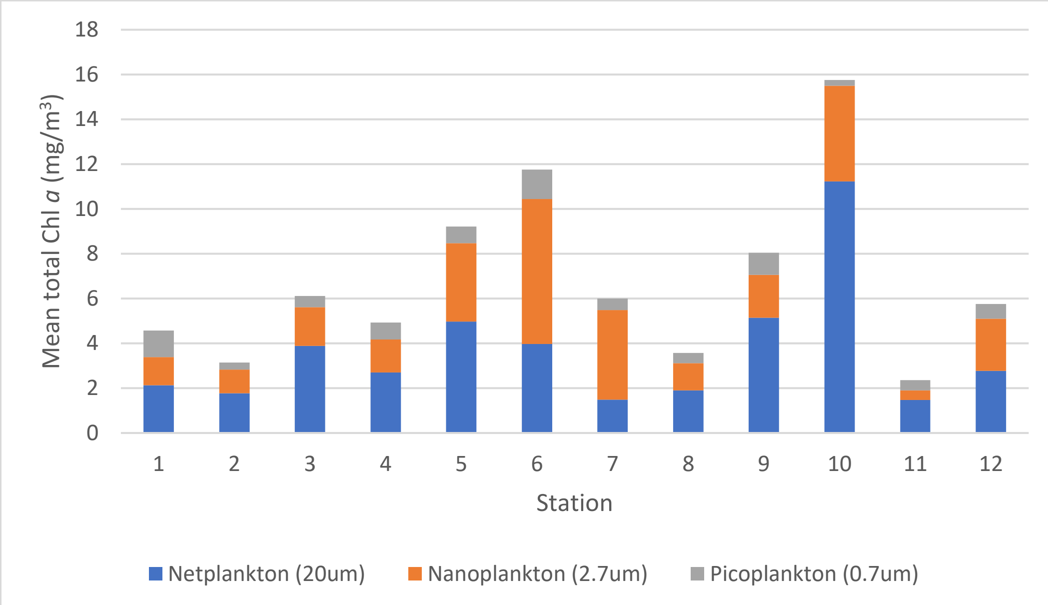


Figure 3.50 Mean size-fractionated phytoplankton (Chlorophyll a in mg m-3) at each station.

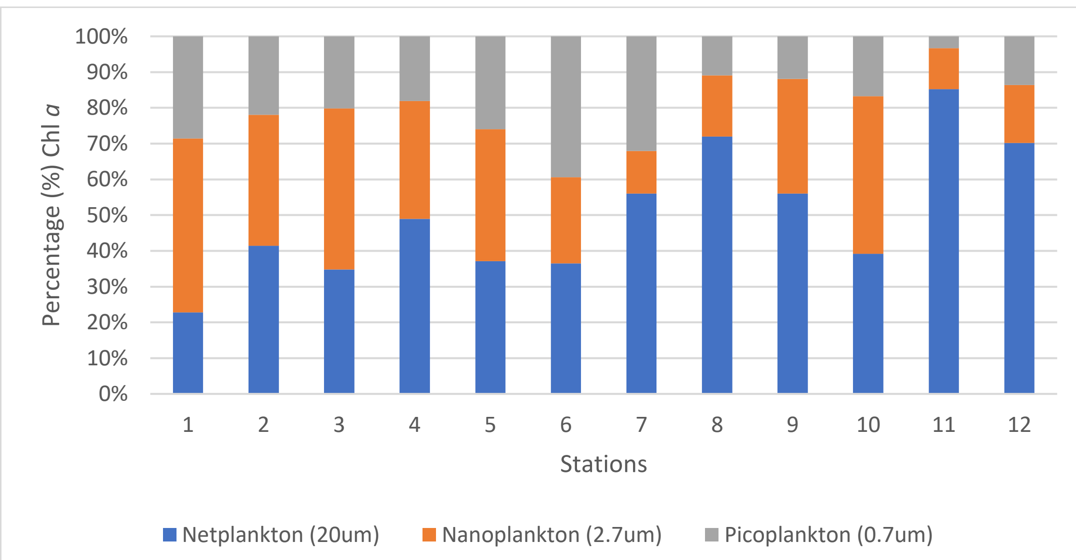


Figure 3.51 Mean percentage (%) size-fractioned Chlorophyll a at each station.

The mean total size-fractionated Chlorophyll a concentration again indicated a dominance of the netplankton size-fraction (i.e. >50% of the total Chlorophyll a), particularly at the following stations: 11, 8, 12 and 7 (in descending order of netplankton concentrations). Stations 1, 3, 5, 6 appeared to be more pristine based on the comparatively low netplankton concentrations and dominance of the smaller (nanoplankton and picoplankton) phytoplankton size-fractions (Figures 6a, 6b).

3.5.6.2.4 Conclusions

The following are concluded to date:

- The mean total Chlorophyll a concentration for the entire sampled area was similar in February and March (6.28 and 7.25 mg m-3 respectively).
- The mean total Chlorophyll a concentration for the sample period was 6.77 mg/ m3.

- These values were low compared to previous work done in Kingston Harbour, which recorded mean Chlorophyll a concentrations of ~20mg m-3 in the Harbour (Francis, Maxam, and Webber 2014). However, individual numeric values at particular stations were representative of the area.
- The dominance of the (20µm) netplankton size-fraction at most stations was similar in both months and may be indicative of high (possibly recent) nutrient loading and or regeneration at or near these stations.
- The dominance of the netplankton size-fraction at stations with low total Chlorophyll a concentrations (e.g. Stations 1& 2 in February; Stations 8 &11 in March) also indicated eutrophic conditions.
- The low proportions of the picoplankton size-fraction- which was least dominant at most stations (in both months), indicated eutrophic conditions.
- The high Chlorophyll a concentration at station 10 in both February and March, could indicate a major source of eutrophication at or near this station.
- Station 7 could be considered the most pristine station based on the relatively low netplankton and total Chlorophyll a concentrations in both months.
- Stations: 1, 2, 8, and 11 also had low total Chlorophyll a specific concentrations in both months

<u>Limitations</u>

The following limitations are noted:

- Samples were not replicated (due to slow filtration process).
- Statistical analyses were not conducted based on the limited sample period/data set (2 months).
- Results difficult to interpret without insight into where stations were located (e.g. near mangroves or plumb point lagoon vs in open water, near the runway etc.).
- Chlorophyll a data most reliable when analyzed in conjunction with other biological (zooplankton), hydrographic (physicochemical) and nutrient data.

3.5.7 Habitat maps and zonation

The current global biodiversity crisis is magnified in small islands and as such biodiversity should be systematically accounted for in land-use planning (Newbold T, 2015). Spatial conservation prioritization must consider occurrences of species and habitats inside protected areas with multiple and complex uses.

Land conversion should be avoided in areas of highest ecological services (such as climate resilience and shoreline protection as NMIA in a high-risk area) and priorities. Both restoration and conservation are essential in with complex demands such as PPRPA, balancing and prioritize areas for development and conservation.

Figure 3.52 shows the various ecologically sensitive habitats mapped near the Airport in PPRPA. This information was then used to recommend zonation of the Airport and its associated ecological habitats and development (Figure 3.53) and the considerations of needs for future developments, climate resilience and shoreline protection unique to NMIA and within the protected area.

Figure 3.52 Ecologically Sensitive Habitats in PPRPA

Figure 3.53 Recommended zonation of Airport lands and Ecologically Sensitive Habitat

3.6 Summary and Conclusion

3.6.1 Noise

The data showed that three out of the five non-runway monitoring stations had noise levels attributed to aircrafts, which exceeded the respective NRCA guidelines. These three stations were: Grand Port Royal Harbour Hotel, Port Henderson Royal View Hotel and the Caribbean Maritime University (CMU). The CMU and Grand Port Royal Harbour Hotel are the two closest receptors to the airport runways. A trend was noticed whereby departures from Runway 12 were the most frequent occurrence resulting in elevated noise levels at these two locations, which is expected since they are the closest. When an aircraft is departing and ascending it employs roughly 70% thrust power (depending on the weight/load of the aircraft), therefore noise levels would be at their highest during ascent. Grand Port Royal Harbour Hotel is in the direct departure flight path after an aircraft departs from Runway 12 and makes the right turn to loop around and head in a north north-westerly direction. Although CMU is not in the direct departure flight path from Runway 12 or 30, it is still in close enough proximity to the airport to detect elevated noise levels during departure, regardless of which runway the aircrafts depart from. CMU is also zoned as an educational institution, therefore the NRCA Noise Guidelines are much lower compared to the other residential and commercial locations and noise impact would be higher during class time. However, Friday March 13th was the final day of regular school activities before a lockdown of the entire campus due to Covid-19.

Port Henderson Royal View Hotel is also in the Runway 12 and 30 departure flight path, as well as the Runway 12 arrival flight path. Elevated noise levels at this location were mainly attributed to both arrivals and departures to and from Runway 12, as well as departures from Runway 30. As previously mentioned, a lot of thrust power is needed when an aircraft departs and ascends, hence the elevated noise from the aircraft upon reaching in the vicinity of this monitoring location. A large commercial aircraft approaching to land at Runway 12 will be at an altitude of approximately 610 m (2,000 ft.) when it is directly over the Port Henderson Royal View Hotel. Even though the aircraft engines are not producing any thrust power for landing, the aircraft altitude is still low enough to cause significant noise impact at this location. Aircraft arrivals onto Runway 30 would not have any noise impact at this location since it is not in the arrival flight path.

Noise levels at Port Authority and Harbour View do not exceed the NRCA standards for arriving and departing flights, see Figure 3.54 and Figure 3.55 respectively.

3.6.2 NMIA Zonation

Water Quality around the airport boundaries had high levels of phosphates and nitrates which indicate eutrophic conditions and can result in toxic plankton or algal blooms. Zooplankton abundance and size classes around the airport also indicated eutrophic conditions typical of Kingston Harbour. There were potentially toxic phytoplankton species identified in the water samples within the direct vicinity of the Airport. These species have the ability to produce toxins which may poison fish and shellfish. No conch larvae were found and lobster larvae counts were very low in the vicinity of the surrounding mangrove areas.

The mangrove forest exhibits the expected Caribbean mangrove forest tree zonation with a low species diversity as very few non-mangrove species are found within the mangroves areas. Red Mangrove dominates the majority of the mangrove forest, however there was strong evidence of a transition to Black mangroves in some areas based on that species more capable of adapting to anthropogenic pressures. The majority of bird species were found in the Mangroves and were both terrestrial and wetland species. The intertidal rock revetment community was often inundated with solid waste and marine debris. Water quality in these areas tends to be poor. Seagrass beds were noted along sections of the Palisadoes tombolo, around sections of the cays and in nearshore sections around the airport. Coral cays, barrier reefs and beach/dune habitats are located along the seaward side of the Palisadoes tombolo but are extremely limited on the Kingston Harbour side and around the airport.

Proposed zonation areas include: Restricted Areas (NMIA property); Conservation Areas (mangrove forests and beach/dune communities); Future Development Areas (for shoreline protection); and other Future Development Areas (for runway extension).

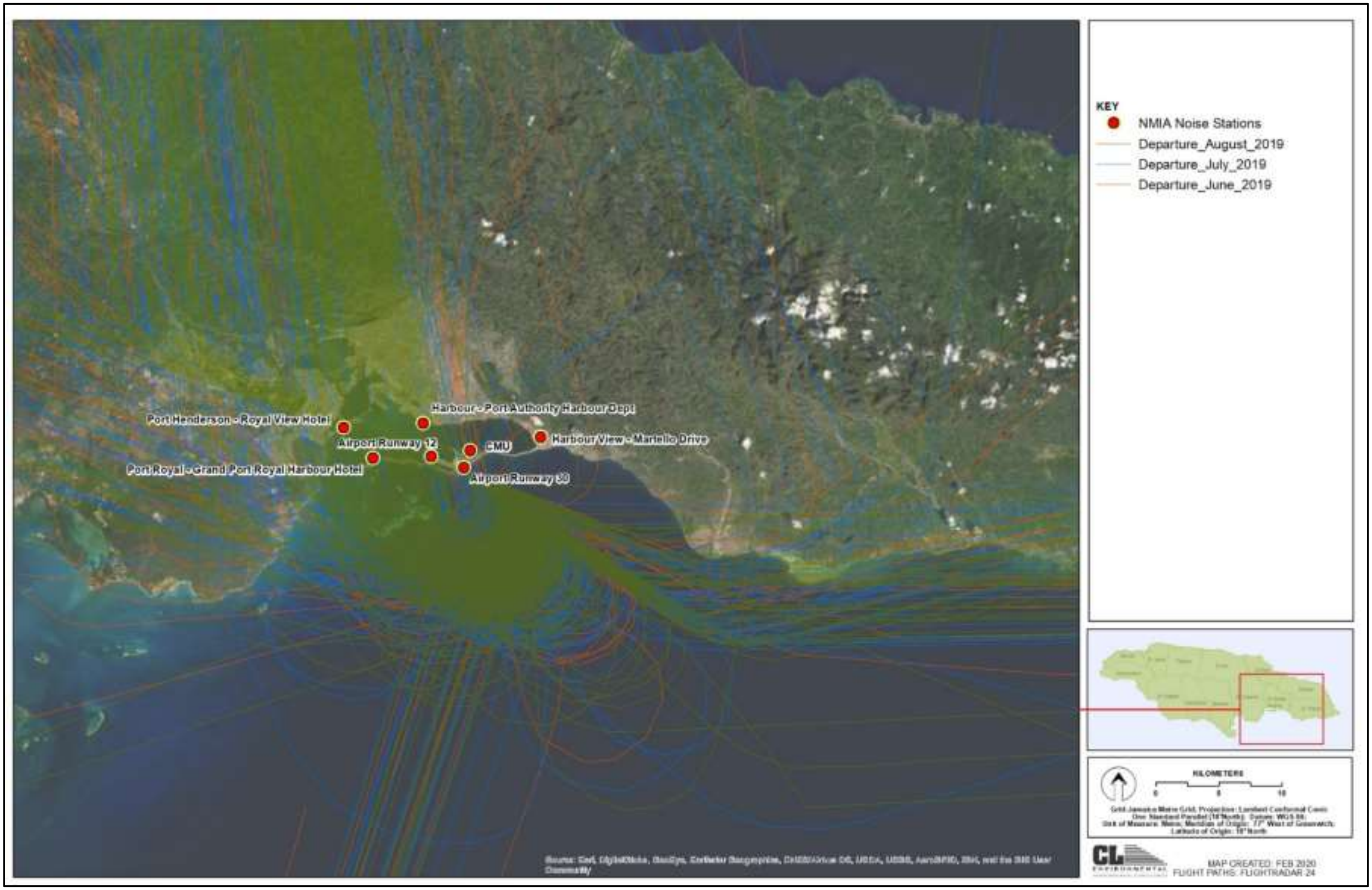


Figure 3.54 Aircraft departure flight paths at NMIA

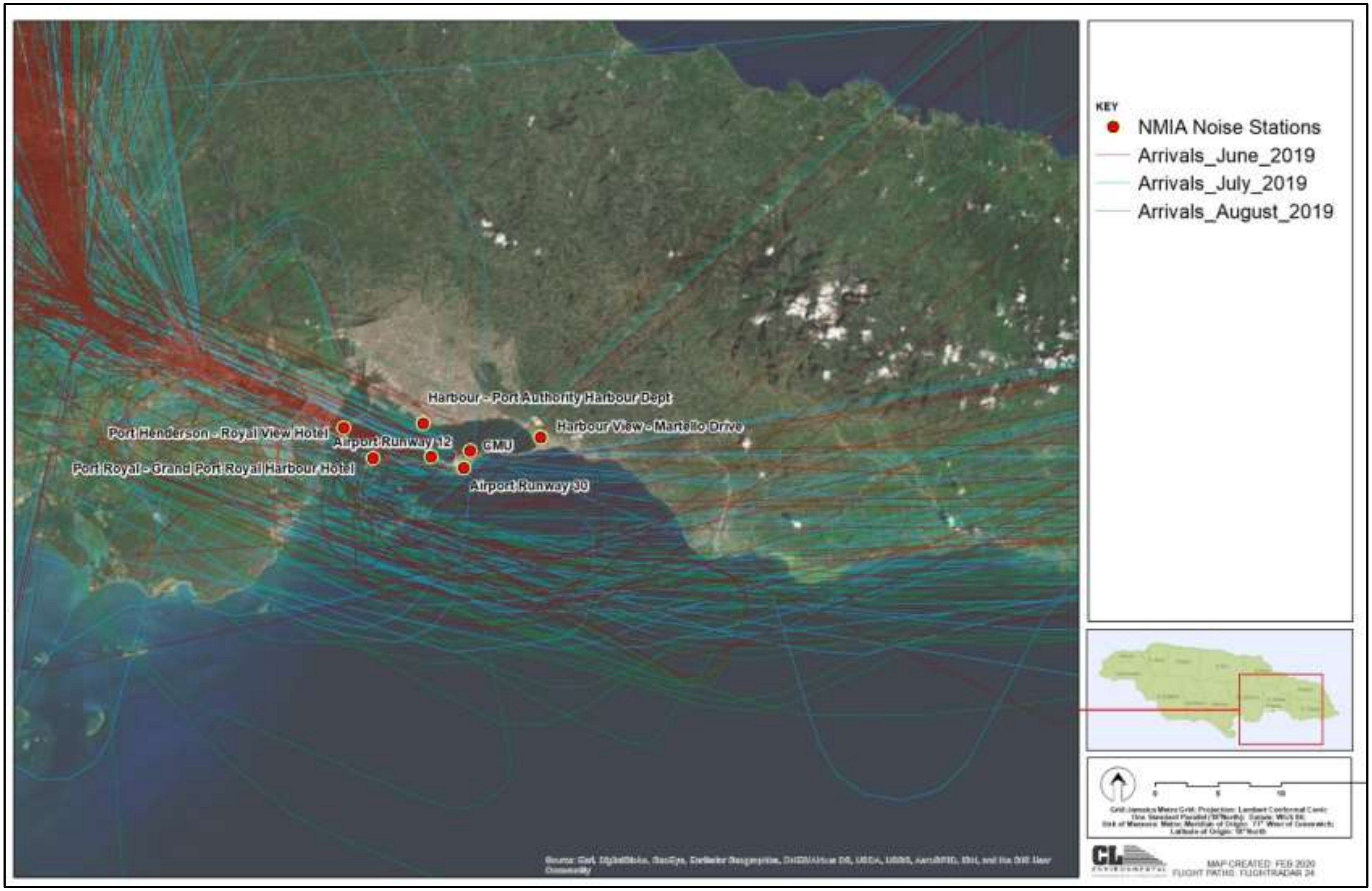


Figure 3.55 Aircraft arrival flight paths at NMIA

4 Airport Zoning

4.1 Assessment of Existing Airport Zone Parameters

4.1.1 Airport Zone Parameters

4.1.1.1 *Background*

Airports provide significant employment and economic benefits to communities through the movement of people and goods, promotion of tourism and trade, stimulation of business development, and the opportunity for a wide variety of jobs. The flying public and local communities do not readily discern the huge size and scale of economic development that airports provide and stimulate.

Land use decisions that conflict with aviation activity and airport facilities can result in undue constraints being placed on an airport. In order to enable this sector of the economy to continue to expand, to provide for a wide variety of job opportunities, and to meet the needs of the traveling public, it is vitally important that airports operate in an environment that maximizes the compatibility of the airport with off-airport development.

Zoning is a preventive technique of land use planning that ensures land use compatibility around airport is achieved to eliminate the costly corrective measures required to keep an airport viable.

Zoning may be required for varying reasons. For all that is required to implement zoning, compelling arguments must be brought to the fore to impress upon the local planning authority the importance or urgency of zoning as the only/best option to remedy the situation.

4.1.2 Methodology for the Zoning Plan

The book "Guidebook on Effective Land Use Compatibility Planning Strategies for General Aviation Airport (2019) The National Academics of Sciences Engineering Medicine- Research sponsored by the FAA" provides sound strategies to start the process of enacting, adopting and implementing zoning legislation. Their following strategies and questions will help to identify the appropriate form and adoption process for the proposed zoning. This project has already initiated parts of some steps, while others can be used as a guide to complete the next stages towards the Airport Zoning Ordinance (AZO).

Step 1: Why is Zoning Needed?

A checklist of arguments for zoning will foment from:

A review of recent land use actions and trends in the vicinity of the airport:

1. by assessing the state or effect of obstructions; by considering development trends - is development, particularly residential or other sensitive uses, getting too close to the airport, is the RPZ being threatened by inappropriate development;
2. by evaluating noise complaints – are complaints coming from a specific area or associated with specific operations; and,
3. By understanding the potential implications of future airport development plans – is property acquisition contemplated to preserve a buffer or expand within.

An assessment of the existing system of land use review for airport impacts:

1. By understanding the land use development review process – is airport management or oversight formally part of this process or unaware of development proposals, is the onus on airport personnel to watch out for cranes or new construction that could affect the airport;

2. By reviewing current zoning – does the Development Orders address airport land use compatibility, is it working for the airport;
3. By evaluating zoning enforcement – are they effective in preventing compatibility conflicts, are administration & enforcement responsibilities codified, should the zoning be modified, does the zoning anticipate the effects of future growth;
4. By reviewing comprehensive plans – do they address airport preservation and compatible land uses, is the comprehensive plan integrated with the airport's master plan.

An evaluation regulatory options:

1. By considering other ways to control compatibility other than with Zoning – do permits provide a level of land use review

Step 2: What are the Logistics of producing an Airport Zoning Ordinance

Even with consensus among stakeholders, the airport zoning ordinance (AZO) will require several steps between adoption and implementation – drafting, review by planning and legal teams; public hearings, debate and adoption.

1. Drafting the zoning ordinance:

a) By providing examples of other successful models for airport zoning to use as a template so that the ordinances can be expedited.

Be aware of funding issues: costs of mapping

Costs of implementation

Zoning ordinances should be drafted to reflect the local planning authority's ability to administer it without the need for extra staff by training Planners to become familiar with airport issues.

Step 3: What are the key components of Effective Zoning.

It is important to choose the appropriate format that will fit the ordinances into the existing code and the resources available to formulate and administer the regulations. These may be either:

1. Airport zone which identifies airport property and surrounding land, and also identifies permitted, prohibited uses and limitations, or
2. Airport overlay zone that identifies an airport influence that are subject to additional criteria beyond the underlying zoning district, or
3. Specific restrictions included in applicable sections of the Development orders

The airport overlay zone is the most frequently used form of compatibility ordinance because it provides clarity and adaptability. Airport overlay zones also provide additional or supplemental restrictions to those that already apply to the area of underlying zoning. The overlay zone restrictions or conditions apply only to the designated overlay area, or the area in which the airport compatibility factors are applicable.

A template or basic format identifies the critical elements that should be included in the ordinance as well as identify the components that are most significant to the airport

1. Know the framework:

a. By reviewing the existing laws that govern zoning.
b. By evaluating regulatory options: is trying to adopt airport zoning even permissive. If zoning is permitted, this is a great medium for the airport to bring the need for airport compatibility to the country's attention. Even if

there is inactive enforcement, the presence and reference to the law will lend some weight as the resource already exists to reinforce the airport's position. Permissive laws may not have the urgency of mandates, but they still set out the purpose and goals to communicate and build support for compatibility zoning.

c. By examining the guidelines: are there guidelines that pertain to airport land use compatibility. These guidelines may dictate the required elements of a new law or outline principles to consider in preparing the law. If there is no guidance available, explore templates from other countries to start the process.

2. Make the zoning law context specific to the airport

So that the elements included respond to the characteristics of the airport. Use the level of development activity, potential for obstruction and the character of the airport setting to inform what specific controls are needed.

a. By reviewing the current issues and plan ahead to what exactly the ordinances should respond to as well as being visionary. Trends may indicate interest in cell towers, wind farming, or other potential conflict. It is better to be proactive with what is the next trend than reactive when conflicts occur.
b. By identifying the relevant compatibility issues, namely, airspace protection, safety hazards, noise impacts, overflight annoyance, etc.
c. By considering the political environment, in that, if there is resistance to regulations, significant groundwork will be needed to point out the benefits of zoning in terms of safety and economic development. The political environment may be closely related to the municipality and community standing. These public relations issues will have to be worked out before starting any zoning discussion.
d. By identifying implementation resource, since this will help to propel the zoning efforts. If NEPA do not have staff/time to dedicate to the process of determining the complexity of a proposed law, the airport sponsor should encourage training of local officials who would administer the ordinances as part of the adoption effort.

3. Make the ordinances clear and comprehensive

a. By making the ordinances transparent and understandable. Airport issues are highly technical by they must be clear to both development applicants as well as the administrators responsible for enforcement.

b. By including all essential elements in a single report, this way, the zoning ordinances will be complete and self-contained as far as possible. As much as possible, ensure whatever is included in the zoning code can refer to other parts of legislation; the report should be complete with definitions, standards, procedures and implementation.

4. Define the 14 CFR Part 77 airspace protection surfaces and airport zoning boundary.

a. By basing the ordinances upon this compulsory guideline defined by the FAA. Every airport must prevent obstructions to navigable airspace and hazards to aircraft operations. The ordinance should establish height limitations for permanent objects that would penetrate those surfaces; and, trees. The ordinance must also make clear that temporary objects, such as cranes and balloons, are subject to the ordinance.
b. By using Part 77 definitions of airspace protection surfaces. Part 77 regulations are the uniform basis for establishing airspace protection areas, therefore, definitions in the ordinance should be consistent with the current definition of Part 77. Even better, quote the same language used by the FAA.
c. By defining height limitations that require permits as well as those that do not.
d. By including maps and graphics. Diagrams of the imaginary surface and the horizontal limits will be more effective if the public can clearly see whether they are in contravention/observation of any regulations. Also useful is a map that compares Part 77 surface elevations with ground elevations, resulting in indication of the allowable height of objects within the airport's established locality.

e. By replicating the process U.S. development applicants must adhere to when proposing construction or an alteration that may affect navigable airspace. The JCAA or AAJ can conduct an aeronautical study to determine whether the proposed structure or object would represent a hazard or "no Hazard to Air Navigation". The zoning ordinance should require that a copy of the notice sent to the AAJ/JCAA be included in any land use application over a certain height and require the AAJ/JCAA determination prior to any decision. This decision should not be the final word on compliance, but it should be considered as a component of the development application review process (much like the existing Fire department application that is part of the development approval process)

5. Consider other compatibility factors.

Though paramount, airspace obstruction is not the topic that must be addressed in a zoning ordinance. The ordinance must also address the following:

a. Restriction of uses that attract wildlife in the vicinity of the airport. Uses such as stormwater detention ponds, landfills, landscape water features can increase the risk of wildlife strikes or attract hazardous wildlife to navigable airspace and aircraft movement areas on the ground.
b. Prevent navigation hazards. Uses that can adversely affect navigation through generating glare, smoke emission, confusing lights, or electronic interference should be prohibited.
c. Avoid noise sensitive uses. This can be based on day-night level noise contour such as 65 DNL and prohibit the development of noises sensitive land uses within the contour. Noise contours should not be the basis of and airport overlay zone by themselves, but they can be considered within the overlay area that is developed based on Part 77.
d. Minimise risks on the ground. Ordinance elements that address land use types around the airport are aimed at reducing risks to people on the ground in the event of an aircraft accident.
e. Anticipate and address overflight annoyance. With foresight, these issues can be addressed by requiring buyer awareness measures, such as avigation easements, recorded overflight notifications, or real estate transaction disclosure.

Figure 4.1 Example of conflict in compatibility of land use (National Academies of Sciences, Engineering, and Medicine)

6. Include procedures for administering the ordinance.

   a. By including specific land use referral procedures. The ordinance should specify that development applications to the municipality for properties situated in the airport overlay zone should be referred to either AAJ or JCAA for review and comment. The ordinance should stipulate if it has to be passed through the municipality channels or submitted directly by the applicant, and the approval/disapproval result be included in the development application.
   b. By setting-up processes for permits and variances. Typically, the airport zoning ordinances establishes an area (airport overlay zone) in which proposed development projects require special permits. This allows local agencies to determine whether a development proposal complies with the ordinance or requires certain conditions to be acceptable. The ordinances should include procedures for variances if an application cannot comply the standards for the zone. Specific criteria for granting the variance, such as marking obstructions or mitigating hazards, can be included in the ordinance.
   c. By identifying potential mitigation measures for the issuance of permits and variances. The ordinance can identify certain conditions required for the approval of permits or variances such as sound insulation, occupancy restriction, hazardous storage prohibitions, or avigation easements.
   d. By identifying enforcement and review responsibilities. The ordinance should be clear on what office or individual (position) will review and grant permits. Those responsible should have training or familiarity with airport issues and understand the objectives of the zoning ordinance. Potential reviewers could include a planning officer or a specific airport zoning administrator. Review responsibilities could also be assigned to the airport sponsor or manager.
   e. By integrating the overlay zone requirements with land use application material and checklists. For effective implementation land use application forms and checklists should identify the AZO. Application information should enable an applicant or reviewer to determine whether the proposed project is within the overlay area and, if so, identify the specific information that will be required from the applicant to assess compliance, such as height of proposed structures above mean sea level and the airport runway elevation.
   f. By remembering to address temporary structures or building reuse. The ordinance should make clear that it applies to temporary structures, such as cranes, and the reuse of existing structures. In the latter case, applications must be reviewed to make sure that the proposed reuse is compatible with the airport and does not violate safety or noise standards

Step 4: Assess Potential Challenges to AZO Support and Adoption

While an airport sponsor or manager readily understands the value of an airport compatibility ordinance, other community members or stakeholders may not share that understanding of the AZO and land use compatibility goals. Non-aviation stakeholders may regard an ordinance as just another layer of regulation that hinders growth or adds to bureaucracy. The sponsor of an AZO should anticipate potential opposition and be proactive in dispelling rumours or clarifying misunderstandings.

1. Review community context and the airport's standing.

   a. By improving relationships with stakeholders. If adversarial relationships exist between the airport and either the governing body or community, improve those connections before an AZO effort begins.
   b. By stressing the economic importance of airport operations. Underpinning the need for the AZO is the protection of the airport's business. Outreach articulating the number of jobs, tax revenue, or other direct and indirect economic impact of the airport will set the stage for communicating the importance of the AZO.

Illustrating a specific past or potential incompatible land use impact example on operations and local business may also assist in communicating the airport's economic importance.

Anticipate opposing arguments.

a. By addressing fears of expansion. The community may perceive the proposed AZO as a way to allow the airport to expand, host larger aircraft, and create more or greater impacts. To dispel these perceptions, clarify from the start of the process what the airport's plan proposes. If the airport is contemplating growth, the AZO should be positioned as a way to maintain safety and prevent community impacts.
b. By responding to development concerns. Development interests may view the AZO as discouraging real estate activity. An effective argument may be that protecting the airport's viability will maintain economic development opportunities. In addition, without appropriate controls, risks to safety may dampen local real estate markets in the long run.
c. By addressing overregulation concerns. To counter this perspective, the AZO sponsor can point out that airport zoning is a tool used worldwide to prevent conflicts between airport operations and other land uses. An AZO draft proposing conditions that are too restrictive may be so strongly opposed that it never gets adopted.

Step 5: Engage in a Collaborative Planning Effort

Ideally, developing and adopting an AZO should be a collaborative project through which key stakeholders review alternatives and achieve consensus on an ordinance that is workable, acceptable, and achieves the goals of protecting the airport and maintaining safety. Providing the opportunity to discuss the proposed AZO will encourage buy-in and increase the likelihood of consensus as to the form, content, and implementation of the ordinance.

1. Determine a context specific planning effort.

For Jamaica, a collaborative process may be less formal and involve few participants.

a. By initiating discussions with the Planners. The director of planning will be an important ally and starting point for the AZO sponsor to introduce the concept in an initial meeting. While the planner may not be familiar with the details of airport operations or the Part 77 surfaces, he or she should be aware of previous airport issues. The planner should be encouraged to view the airport as part of the community and share concerns about proliferation of incompatible land uses or patterns of development that result in conflicts or complaints. If the comprehensive plan speaks to development goals in and around the airport, it will be a touchstone for a conversation about implementing those goals with the AZO. Conversations with the local planner will alert the sponsor to the schedule for revising or updating a comprehensive plan, which could be a vehicle for introducing the AZO.
b. By identifying other key stakeholders to involve in the AZO. The ordinance will be voted on by elected officials who may hear feedback from their constituents before deciding. Constituents can include airport users, members of the governing body, economic development agencies, neighbourhood groups, or special interest groups. An aviation representative can also participate. The sponsor should be aware that a greater number of participants will result in a longer planning processes.
c. By preparing to explain the need for and benefits of the AZO. While the planner may quickly understand the nature of ordinances and impacts of incompatible land use, others may be not be familiar with the concept. The airport manager can point to past occurrences of land use conflicts, complaints, or impacts on airport operations as illustrations of the hazards of inaction.

d. By identifying common goals. Can all constituents agree on goals to grow the economy and enhance livability? If so, airport protection could be important for achieving those goals. Maintaining aviation safety and reducing risks by restricting land use conditions that could pose hazard to flight should be principles that are agreeable to stakeholders as well. The stakeholders should share the goal of avoiding conflicts, even if they do not understand the details of approach and departure patterns.
e. By providing a draft or model ordinance for reference. Discussions will be more productive if they are grounded in a basic proposal of elements to be included in the ordinance. An illustration of the proposed overlay area is equally important.
f. By contacting the governing body. If the planner agrees with the concept and rationale for the AZO, the planner may agree to set up a meeting with key officials to explain the proposal. Engage those charged with adoption of the ordinance as early in the process as possible. If the airport manager already has established a good line of communication with an elected official, the manager should reach out to the official directly.
g. By finding a champion. Promotion of the AZO should not come only from the airport manager or sponsor. AZO support should be broad-based and positioned as a benefit to the community, not just the airport. The AZO sponsor should try to identify an individual who can publicly support the AZO and help to pursue its adoption.
h. Work out differences. Disagreements about the scope and details of the proposed AZO are likely. A stakeholder group or committee offers a forum to discuss and achieve consensus following effective compromises before presenting the proposal to the governing body. Successful cooperation among the stakeholders, planners, and the airport sponsor should produce an ordinance that addresses community needs and gains acceptance.

4.1.2.1 *Compatible and Incompatible Land Uses*

4.1.2.1.1 Compatible Land Use

These include:

1. Most commercial and industrial uses, especially those associated with airports

Land uses, which are responsive to the demands created by the presence of the airport such as, motels, restaurants, warehouses, shipping agencies and aircraft related industries

Large parks, conservatory areas and other open spaces

Forestry services, landscape services, game preserves, agriculture

Some extractive industries such as mining and excavation.

4.1.2.1.2 Characteristics

Compatible land use must:

1. Not obstruct the aerial approaches of the airport

Not interfere with aircraft radio communications

Not affect the pilots' vision due to glare or bright lights

Be sound proofed (buildings) to make them comfortable for occupants

4.1.2.1.3 Non-Compatible Land Use

These include:

1. Residential development, schools, community centres, libraries, hospitals, religious service buildings and tall structures

Wetland mitigation banking, retention ponds and landfills

Forestry services, landscape services, game preserves, agriculture

Industries like pulp mills, steel mills, quarries, municipal or other incinerators, cement plants, saw mills and refineries.

4.1.2.1.4 Characteristics

Non-compatible land use must:

1. Promote or encourage wildlife hazards;

Interferes with obstruction surfaces, radio transmissions;

Affect the pilots' vision due to glare or bright lights;

Smoke from stacks that hinder visibility;

Industrial and manufacturing processes that generate dust or steam in sufficient volume to constitute a restriction to visibility;

Activities that attract birds, such as, landfills.

4.1.3 Parameters

Government level airport land use compatibility standards and oversight to develop an Airport Zoning Plan are beneficial to both the industry and the country. Zoning is the most effective means of compiling all airport land use compatibility related standards into one set of regulations that simplifies and improves implementation. At a minimum, these regulations should address airspace hazards; end eventually noise and safety factors. An airport zoning plan should follow from a review of current requirements, land use decision in the airport area and the effects each of these has on airport operations.

The greatest advantage of zoning is that it is helpful in raising awareness of the importance of protecting airport from the encroachment of incompatible land uses and airspace hazards. Zoning has to be approached comprehensively, not only addressing airspace protection, but also other parameters that are not yet planned for but will be contemplated at some later time.

A single local planning authority can overlook the unique circumstances and challenges facing the airport and put the airport at a disadvantage when trying to negotiate amendments or a vision for the airport. However, when coordinated at the national level, the airport can promote adoption of context specific zoning regulations.

To comprehensively plan for the airport, three levels of planning are required:

1. Airport Zoning Ordinance (AZO) (from NEPA national level): this is the legal form of land use regulation enacted through Development Orders (DO). Though the guidelines in DO for airport seldom consider aviation concerns or address the specific issue of compatibility with aviation activities, the Order can adopt an overlay zoning district that modify the conditions of the base Order by adding criteria specifically addressing airport issues.

Comprehensive plans (from the municipality): that articulates the goals of the parish to address the airport and surroundings.

Airport land use compatibility plans (from the industry) where all the major aspects of airport land use as well as noise, safety, airspace protection, overflight criteria are addressed in a single document targeted at the airport.

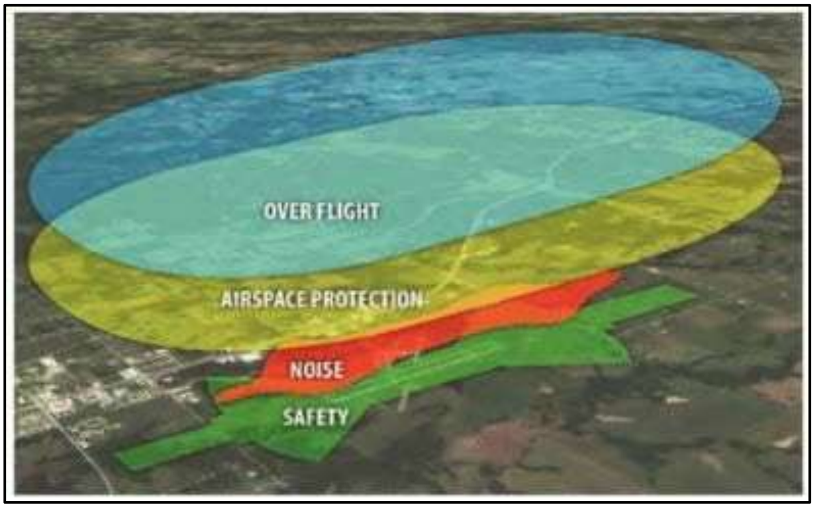


Figure 4.2 Layers of Risk at Airports: Compatibility factors and Geographic Areas (National Academies of Sciences, Engineering, and Medicine)

A solid understanding of airport compatibility factors, which serves as the basis for airport zoning is essential for decision makers and stakeholders.

The main parameters that influence airport zoning includes:

Establishing the airport's locality

a. To identify properties that are included or excluded;
b. To identify land features such as roadways and waterways.

Legislative framework

a. Laws enabling local authorities to adopt, administer and enforce airport zoning regulations

Runway Protection Zone (RPZ)

a. To reduce the danger from accidental overruns and aborted take-off Airspace

obstruction (OLS) from tall structures and vegetation.

a. This is applicable to permanent man-made structures, chimneys, cell towers and trees;
b. Applicable to other temporary structures such as cranes and balloons.

Wildlife hazards

a. Uses that may increase the risk of bird strikes and
b. Land use features that attract birds and other species, namely landfills and storm-water impoundments.

Flight hazards that may interfere with aircraft operations (electrical interference, glare, smoke)

a. Thermal plumes for example, water used for cooling by power plants that is discharged into the Harbour or heated air above an urban area created by conditions in an urban environment. These produce highly unstable air that can send smaller aircrafts out of control.
b. Visual hazards that produce smoke, steam glare or dust.
c. Lights that can be mistaken for airport lights when aircrafts are at low altitude.
d. Electronic hazards are any type of transmission that can interfere with aircraft navigation or communications Safety on the ground typically in off runway accidents.

e. Uses that would increase injury on the ground or to aircraft occupants or damage to property, in the event of an accident are typically residential uses or those where large numbers of people congregate.

f. Certain land uses that present special risks regardless of the number of people present, like places with vulnerable occupants (schools, hospitals, nursing homes);

g. Places where hazardous materials are stored; critical community infrastructure (power plants, electrical substations, public communication, the damage or destruction of which would cause significant adverse effects to public health and welfare well beyond the immediate vicinity of these facilities.

Noise Impacts

a. On sensitive uses, including residential, schools and hospitals
b. Overflight annoyance from routine aircraft operations that may result in pressure to limit the airport's activity

4.1.4 Zone of Influence (Locality)

Aviation is one aspect of a country's transportation system therefore; the goals of airport development should be established in the framework of an area's comprehensive plan.

Airport Zoning is required to make guidelines for and regulate the type of land use, building heights, building size, bulk, density and other aspects of land use, not only at the airport but also in the airport's locality for parameters that are profoundly related to an aircraft's take-off and landing. Zoning used to guide urban land use plans, is the regulatory process that the municipal authority can use to ensure land use compatibility in and around the airport vicinity as well as to employ corrective mechanisms associated with existing uses either by land acquisition and investment infrastructure. The overarching aim of all this is to insulate airport operations for safety both for people on the ground as well as in the air. Regulations and guidelines covered by zoning often include:

1. Allowable Land Use
2. Development Standards: building - size, height, placement, setbacks, and various other standards
3. Parking Requirements
4. Design Standards or Guidelines

4.1.4.1 *The Airport Locality*

ICAO Annex 14 (1999) noted that the airspace around the aerodrome should be maintained free from obstacles. This will permit the intended aeroplane operations at the aerodromes to be conducted safely and to prevent the aerodromes from becoming unusable by the growth of obstacles around the aerodromes. This can be achieved by establishing a series of obstacle limitation surfaces that define the limits to which objects may project into the airspace. This Annex 14 Vol. 1 will be used to establish the airport locality boundary.

In order to carry out zoning for the airport, the airport's locality is established to be the different use sectors operating within and around the aerodrome, the height limitations applicable to these different use sectors along with all other minimum standards regulating zoning.

This locality extends to the regional area that may experience the broader socio-economic and environmental impacts on and from airport operations and may have potential direct negative impacts on airport operations and development reciprocally (Hunter, 2007).

4.1.4.2 *NMIA Airport Locality Boundary*

The airport's runway is closely tied to the delineation of the airport's locality, since the runway's size/rating will dictate the required space for both take-off and landing.

NMIA operates a Precision Approach Category 4 Runway that can accommodate Code C aircrafts. Based on ICAO guidelines, the approach and take off horizontal surface should extend a radius of 15,000m (Hunter, 2007) from the airport. This is established through a series of obstacle limitation surfaces (OLS) that define the limits to which objects may project into the airspace.

The OLS is divided into three sections. The first section extends to a horizontal distance of 3,000m with divergence of 15 % on each side and has a 60m height from the runway threshold with a 2 % slope. The second section starts directly after the first section at a slope of 2.5 % and extends horizontally 3,600m. The horizontal section then extends to 8,400m and has a 90m height from the runway threshold - for a total approach length [and radius] of 15,000m.

Table 4.1 Dimensions and slopes of obstacle limitation surfaces (abridged)

Runway Classification			
Approach Runways	Precision approach category		
	I Code Number		II or III Code Number
Surface and dimensions [a]	1,2	3,4	3,4
(9)	(9)	(10)	(11)
Conical			
Slope	5%	5%	5%
Height	60 m	100 m	100 m
Inner Horizontal			
Height	45 m	45 m	45 m
Radius	3 500 m	4 000 m	4 000 m
Inner Approach			
Width	90 m	120 m	120 m
Distance from threshold	60 m	60 m	60 m
Length	900 m	900 m	900 m
Slope	2.5%	2%	2%
Approach			
Length of inner edge	150 m	300 m	300 m
Distance from threshold	60 m	60 m	60 m
Divergence (each side)	15%	15%	15%
First section			
Length	3 000 m	3 000 m	3 000 m
Slope	2.5%	2%	2%
Second section			
Length	12 000 m	3 600 m[b]	3 600 m[b]
Slope	3%	2.5%	2.5%
Horizontal section			
Length	—	8 400 m[b]	8 400 m[b]
Total length	15 000 m	15 000 m	15 000 m
Transitional			

Slope	14.3%	14.3%	14.3%
Inner Transitional			
Slope	40%	33.3%	33.3%
Balked Landing Surface			
Length Of Inner Edge	90 M	120 M	120 M
Distance From Threshold	[c]	1 800 M[d]	1 800 M[d]
Divergence (Each Side)	10%	10%	10%
Slope	4%	3.33%	3.33%

[a] All dimensions are measured horizontally unless specified otherwise.
[b] Variable length.
[c] Distance to the end of strip. [d] Or end of runway whichever is less.

Table 4.2 Dimensions and slopes of obstacle limitation surfaces (International Civil Aviation Organization, July 2009)

Runways meant for take-off			
	Runway Classification		
Surface and dimensions [a]	Code 1	Code 2	Code 3 or 4
TAKE-OFF CLIMB			
Length of inner edge	60 m	80 m	180 m
Distance from runway end[b]	30 m	60 m	60 m
Divergence (each side)	10%	10%	12.5%
Final width	380 m	580 m	1 200 m, 1 800 m [c]
Length	1 600 m	2 500 m	15 000 m
Slope	5%	4%	2%

[a] All dimensions are measured horizontally unless specified otherwise.
[b] The take-off climb surface starts at the end of the clearway if the clearway length exceeds the specified distance.
[c] 1,800 m when the intended track includes changes of heading greater than 15° for operations conducted in IMC, VMC by night.

This total OLS of 15,000m establishes an approximation of the airport's locality. Zoning efforts are focused around this area.

The first section of 3,000m would extend to Port Royal to the west; crossing Kingston Harbour towards Tower Street to the north; and, the peninsula on Palisadoes Road to the east. Tower Street bounds part of the downtown Kingston business district as well as some residences within Rae Town to the east. The remainder of the first section is the Caribbean Sea that is directly south.

The second section of 3,600m (from the end of the first section) would encompass all areas northwards from the bounds of the first section. This approximate boundary starting west from the Kingston Causeway, towards Newport West Industrial Area, Hagley Park Road; then north along Lyndhurst Road, Oxford Road; then north-easterly along Mountain View Avenue, Windward Road; then easterly from the shallow waters of Harbour Head, towards Palisadoes Road. The remainder of the second section is also the Kingston Harbour. Kingston Causeway connects Kingston with Portmore. Newport industrial zone is the largest cluster of shipping, wharfs & logistics enterprises and site of the major cargo terminals in Kingston.

The horizontal section extends 8,400m (from the end of the second section). This includes the rest of the Kingston Metropolitan Area as far north as Stony Hill, St. Andrew; westwards to St Catherine's built up areas of Hellshire, Portmore, Spanish Town; and, eastwards to include the western flank of the Blue Mountain, Harbour View and as far east as Eleven Miles in St. Thomas. The remainder of the horizontal section is the Caribbean Sea.

Because of transverse or longitudinal slopes within Kingston going northwards to St. Andrew, in certain cases the inner edge or portions of the inner edge of the approach surface may be below the corresponding elevation of the strip.

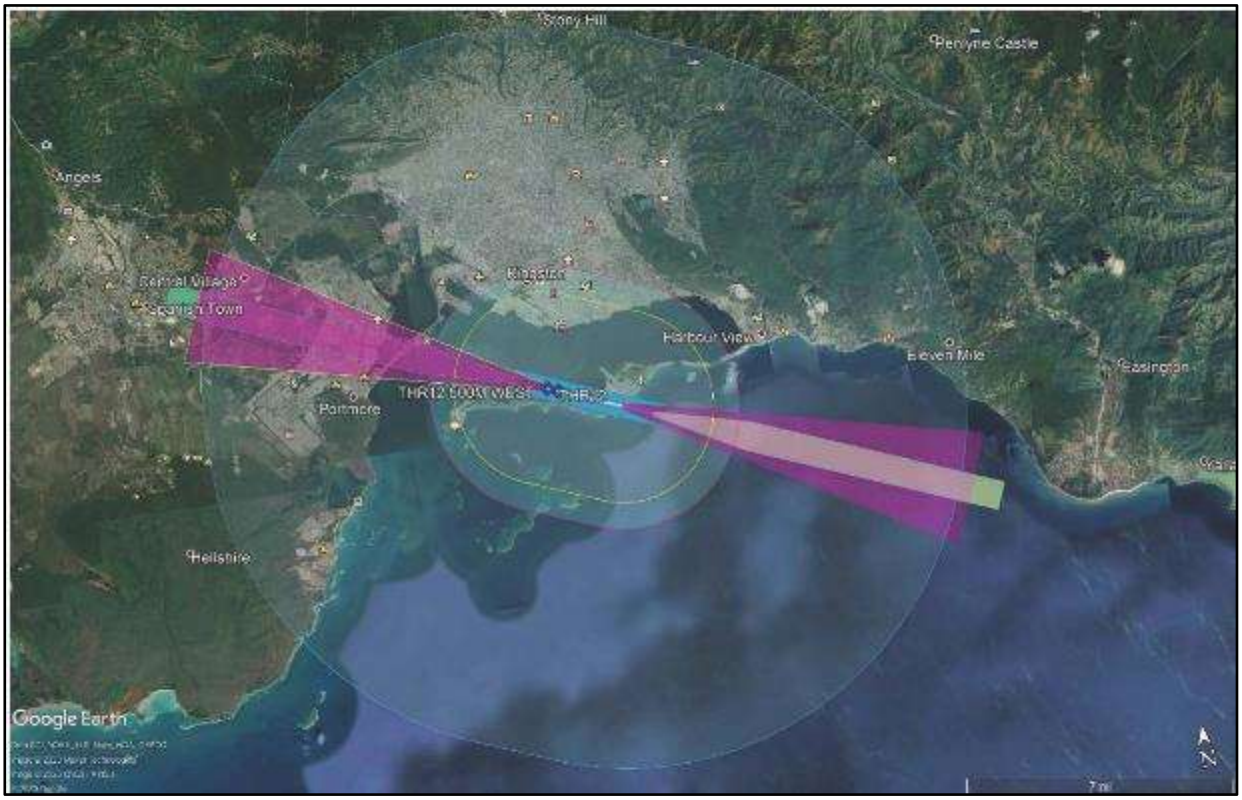


Figure 4.3 Airport Restricted Zones to establish Locality (International Finance Corporation, 2013)

4.1.4.3 *Legislation, Regulation & Authority*

There are several legislation, regulations and authority set up for the airport and mentioned in Legislation. However, with no specific procedures codified and no specific external agency assigned the responsibility for compliance and review, these instruments have little teeth to implement measures to protect the airport. These include: Legislation related to Planning and Zoning

- The Natural Resource Conservation Authority Act 1991
- Use Permits Required under the NRCA Act
- The Town and Country Planning Act, 1957
- The Kingston Confirmed Development Order, 1966
- KSAC Building Act, 1908
- Noise Abatement Act (Night Noise Act), 1997
- The Land Acquisition Act, 1947

Legislation relating to Aviation

- The National Transport Policy, (DRAFT- 2007)

- Jamaica Civil Aviation Act, 1966 • The Airports Authorities Act, 1947:

Legislation relating to Environmental Protection

- NMIA Environmental Programme Manual
- The Beach Control Act (1956)
- The Watersheds Protection Act (1963)
- The Wild Life Protection Act (1945)
- The Endangered Species (Protection, Conservation and Regulation of Trade) (2000)

Conventions, Authority & Responsibility

- Regulatory Authorities (providing related guidance to NMIA)
- Specially Designated Areas
- Responsibility for Airport Land Use Compatibility Planning
- Federal Aviation Authority
- International Civil Aviation Authority

4.1.4.4 *Runway Protection Zone*

NMIA has a 2,716m long runway. The runway does not meet ICAO Annex 14 standards for Runway End Safety Areas (RESAs). These are graded areas of at least 90m in length beyond the runway end strips at each end of the runway to provide a measure of safety for stopping on landing or take-off. This became necessary as a result of an incident in 2009 when an American Airlines aircraft overshot the east end of the runway. (ICAO recommends that as far as practicable, the RESAs should extend at least 240m beyond the end of the runway strip where the code number is 3 or 4.) NMIA is currently noncompliant in this area and JCAA has advised NMIAL that this is a mandatory requirement (P54) or risk downgrading the airport from a 4E to a 4C certification, which would mean that aircraft larger than Code C would be restricted from operating (International Finance Corporation, 2013).

The main aim of establishing Runway Protection Zone (RPZ) is to reduce the danger to other land uses from accidental overruns and aborted take-off. The NMIA runway juts out to the sea from the airport's property. With no other land use type in this region within a radius of 4,000m, zoning efforts are not necessary since the runway extension is already under the purview of NMIA. However, the construction of the RESA will require a permit.

Figure 4.4 Runway expansion into the Kingston Harbour (International Finance Corporation, 2013)

4.1.4.5 *Obstacle Limitation Surfaces*

The Obstacle Limitation Surface (OLS) are a series of surfaces that set the height limits of objects around an aerodrome. Objects that project through the OLS become obstacles. This is relevant to tall structures and vegetation, mainly permanent man-made structures, buildings, chimneys, cell towers; other temporary structures such as cranes and balloons; and trees.

For the Interim RESA project, NMIAL will be submitting the plan for the full 500m extension to JCAA in order to establish the Obstacle Limitation Surfaces (OLS) chart. The purpose of the OLS chart is to clearly define the zoning height limitations of the proposed cranes at the Kingston Container Terminal (KCT) Fort Augusta expansion which lies directly west of NMIA. This plan will also be submitted to NEPA to initiate the environmental review process to obtain a permit which is valid for five years The Master Plan must protect for a runway extension of 500m. This is critical in order to establish the Obstacle Limitation Surfaces (OLS) particularly with regard to the proposed development of the Kingston Container Port at Fort Augustus.

It is important that the planning of NMIA and the Kingston Container Terminal (KCT) Fort Augusta Expansion be carefully coordinated to ensure that vertical clearances are protected for the safe operation of the runway in its existing and proposed extended configuration. The proposed expansion of the KCT is approximately 3 nautical miles west of NMIA (see Figure 4:6 below).

Figure 4.5 Kingston Container Port location relative to NMIA (International Finance Corporation, 2013)

It has been determined that the proposed Super Post Panamax cranes that form part of the KCT Fort Augusta Expansion plans, if operated in traditional procedures with a vertical hurricane stowage position, would exceed the Vertical Operating Distance (VOD) available within the Obstacle Limitation Surfaces (OLS), at NMIA for both the existing runway condition and for the 500m western extension The clear height of the crane in normal operating position or hurricane stowed position (boom down) is 83.2m.

A study by Arup in May 2012 demonstrated that this height would not penetrate the Obstacle Limitation Surfaces for the current or proposed 500m runway extension. The JCAA is responsible for producing the official OLS charts which can be used as technical guidance for Zoning Ordinances for controlling development.

4.1.4.6 *Wildlife hazards*

These include uses that may increase the risk of bird strikes and land use features that attract birds and other species, namely landfills and storm-water impoundments.

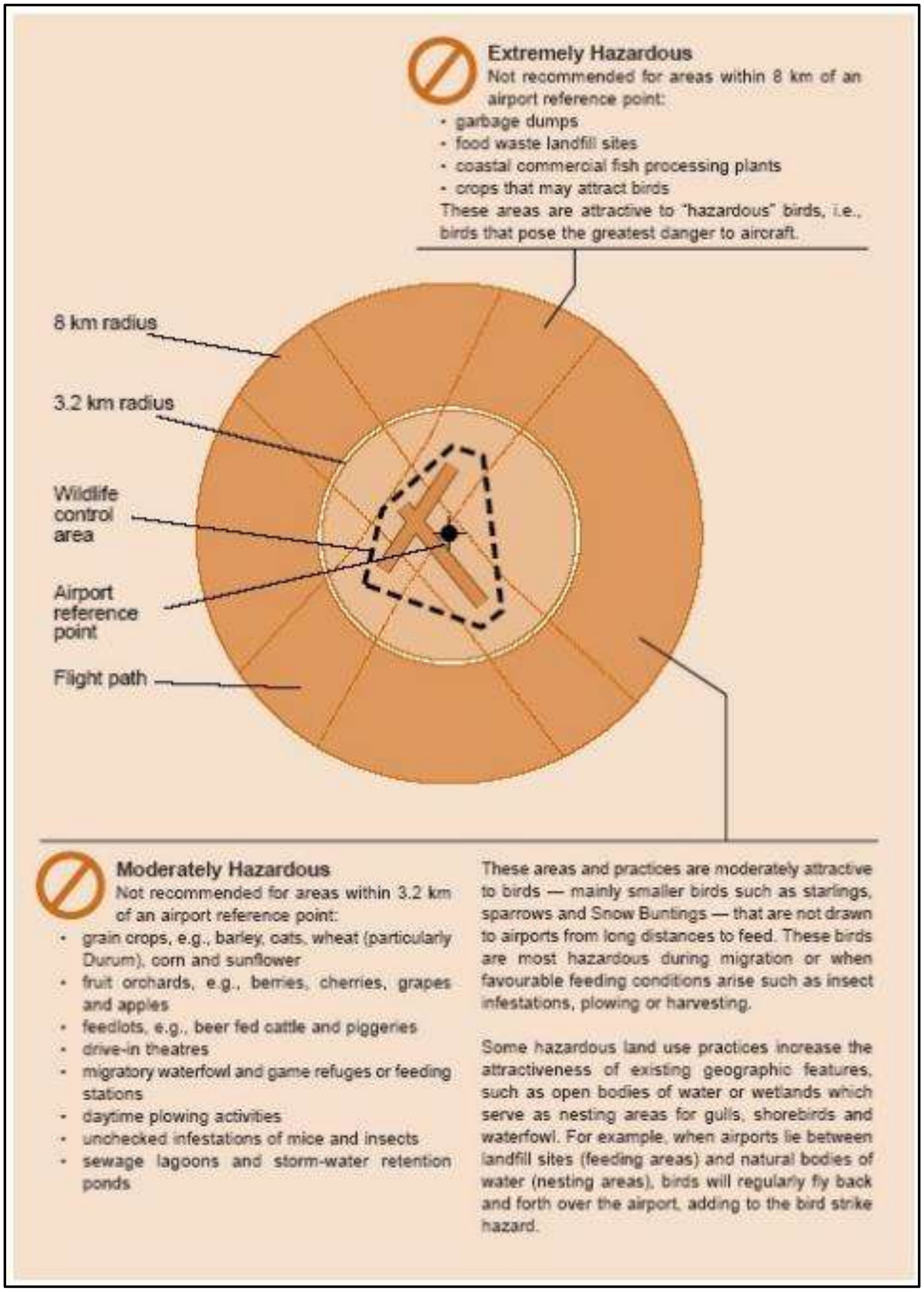


Figure 4.6 Hazard Zones Adjacent to an Airport

(International Civil Aviation Organization, 1975) recommended a minimum distance between dumps and airports of eight miles or such a distance as determined in excess of eight miles. They posited that the goal of airport zoning regulations for birds is to prohibit hazardous land use outside airport properties. These land use include: garbage dumps, food-waste landfill sites, sewage outlets, fish plants, fish piers, abattoirs, pig farms, and bird-attractant agriculture.

ICAO provisions, were originally developed as recommended practices in 1990, but were upgraded to mandatory standards in 2003 as a consequence of the increasing threat to aviation worldwide caused by birds.

(International Civil Aviation Organization, 2002) cited other incompatible land use around airports including wetland mitigation, retention ponds, and landfills. These may appear to be good land use around an airport but are restricted or could possibly be associated with wildlife hazards. (International Civil Aviation Organization, 1991) stated that, caution should also be exercised with wildlife preserves located near airports, due to the possible wildlife hazards associated with them.

The NMIA is located within an environmentally sensitive area with endangered as well as threatened species. There are special declarations in respect of the Palisadoes and Kingston Harbour. These declarations are significant due to potential activity restrictions, approvals required, airport land use planning implications and mitigation activities. These are Palisadoes & Port Royal Protected Area (PPRA) and the Wetland of International Significance – Ramsar Site No.1454.

The entire NMIA is located within the PPRA and the Ramsar site is within 3km of the western edge of the current Runway.

The on-going challenge is to support the implementation of the PPRPA and preserve the Ramsar site that are both inimical to the presence and future development of an airport.

Figure 4.7 Approximate location for Ramsar Site superimposed on satellite imagery

4.1.4.7 *Flight hazards*

Flight Hazards are those that may interfere with aircraft operations such as electrical interference, glare and smoke.

Thermal plumes for example are created from water used for cooling by power plants that is discharged into the Harbour or the heated air above an urban area created by conditions in an urban environment. These produce highly unstable air that can send smaller aircrafts out of control.

Visual hazards are activities that produce smoke, steam, glare or dust. The Caribbean Maritime Institute conducts fire drills where open flames and explosions are used for simulation in training. This is within 3 km of the airport. The smoke stacks at the Caribbean Cement Company should also be assessed, if not for height obstruction, then for visual obstruction.

Lights that can be mistaken for airport lights can be hazardous when aircrafts are at low altitude. The Airport Operators Association and General Aviation Council (2006 August) noted that, lighting columns and masts are as subject to the obstacle limitation surfaces around aerodromes as any other structure and should be evaluated in the safeguarding process. The same process is used to check light proposals. Therefore, full details of any proposed lighting near aerodromes, should be included in any planning application submitted to the local planning authority. In appropriate cases it may be necessary to place controls on the installation and illumination of lighting by the use of conditions on any planning permission that may be granted.

Residential is the largest land use, but other uses such as commercial and retail also pose risks if not properly planned. Electronic hazards are any type of transmission that can interfere with aircraft navigation or communications. Commercial structures like hotels, restaurants and office building all use bright lights to advertise their services. These bright lights can interfere with a pilot's vision. The height of these buildings can also interfere with aircraft radio communications.

4.1.4.8 *Safety on the ground.*

These are typically in off runway accidents in the airport's locality and involves land uses that would increase injury on the ground or to aircraft occupants or damage to property, in the event of an accident. These safety issues are typically concerned with residential uses or those where large numbers of people congregate.

There are also land uses that present special risks regardless of the number of people present, like places with vulnerable occupants such as schools, hospitals or nursing homes.

There are also other land uses of which the damage or destruction would cause significant adverse effects to public health and welfare well beyond the immediate vicinity of these facilities. These are uses that involve storage of hazardous materials; and critical community infrastructure such as power plants, electrical substations, public communication.

4.1.4.9 *Noise Impacts*

Overflight is defined as an aircraft in flight passing an observer at an elevation angle (approximately the angle between the horizon and the aircraft) that is greater than an agreed threshold, and at an altitude below 7,000 ft (Civil Aviation Authority, 2017). Overflight annoyance occurs from these routine aircraft operations over residential uses or other sensitive uses that may result in pressure to limit the airport's activity.

Noise impacts usually affect residential and other sensitive land uses such as schools, nursing homes and hospitals located near an airport. The impact of this is to constrains air traffic growth.

Overlay and analysis of the results of the modelled airport noise scenarios with land use data revealed that for all scenarios population centres such as Port Royal, Harbour View and Kingston, fall outside of the 50 LDN noise contour and as such are only minimally affected by noise from operations at the NMIA. Similarly, the Royal Yacht Club and the Caribbean Maritime Institute which are situated on the only occupied lands within 5.0 km in all directions of the NMIA fall outside of the 50 LDN contour and are minimally affected by noise from NMIA operations. Populated sections of Portmore fell within the 50 LDN noise contour for the Upgraded, Pessimistic Growth Design Day in Year 2022 and Optimistic Growth Design Day in Year 2022 scenarios. However, this is within the 0-55LDN zone of minimal impact and requires no noise controls or land use restrictions (Hunter, 2007).

As there are no impacted development or areas reserved for future development within the 50LDN contour, the noise obstacle from NMIA is not considered as a deterrent.

4.1.5 Summary of existing airport zone parameters

The main parameters that influence airport zoning includes - establishing the airport's locality; review of the legislative framework that will enable the local authorities to adopt, administer and enforce the zoning ordinances; defining the runway protection zone (RPZ) and airspace obstructions (OLS); identifying land use features that promote wildlife hazards; identifying flight hazards that may interfere with aircraft operations; safety on the ground typically in off runway accidents; and, noise impacts and overflight annoyance from routine aircraft operations. These parameters are crucial in order to identify the appropriate format that will fit the ordinances into the existing code and the resources available to formulate and administer the regulations.

4.2 Review & Assess Existing Airfield Analysis

4.2.1 Landside

The landside areas of the Norman Manley International Airport includes the airport access roads, parking lots and public transportation facilities.

4.2.2 Access Roads

The NMIA is accessed directly from the Norman Manley Boulevard via a roundabout. The entrance road is a four lane divided corridor which connects directly to another roundabout, within the airport which has a total of five exits. The roundabout provides direct connections to the terminal building for departures and arrivals, the public car park, the technical services road and the road exiting the airport. The roads, which lead to the terminal and the public car park, run parallel to each other in a southerly direction.

4.2.3 Terminal Road

The terminal road is a two lane, one-way road running in a southerly direction where it provides direct access to both the departures and arrivals curbs at the terminal. At the front of the terminal, the lanes diverge to serve the departures area and the arrivals area.

Figure 4:9 Two-laned Terminal Road leading to Departures and Arrival areas

4.2.4 Departures

There are three lanes directly serving the departures curb, with the curbside lane for parking, the middle lane for through traffic and the outside lane designated for temporary stopping. These arrival lanes are separated from an additional two lanes, which provide ingress and egress to the public car park and direct access to arrivals curb by a raised median. One of the car parks primary exit points is directly along the arrivals lane, approximately 37m before the start of the arrivals curb. At this point, the traffic exiting the departures curb also merges, creating a potential point of conflict with traffic heading to the arrivals curb, exiting the car park or just directly exiting the airport.

4.2.5 Arrivals

The arrivals curb is approximately 100m long. It is served by a wide roadway with no painted line markings. However, it is possible for three lanes of traffic to pass the curb while vehicles are parked.

Analysis

The current arrival/departure road configuration is a source for potential conflict and traffic congestion. At the merge point where several lanes of traffic converge, this presents a potential bottleneck point. This is further exacerbated by the fact that traffic heading to the arrivals curb needs to cross approximately three lanes to do so. The length of the arrivals curb and the fact that there is only one parking lane are also contributory factors to traffic congestion as this provides limited pick up slots, leading to circling and waiting, slowing down on each pass to try to find a slot or parking and waiting, then merging into traffic heading to the arrivals curb.

Figure 4.8 NMIA Existing land Use (Corporation, 2013)

4.2.6 Public Car Park Road

Figure 4.9 Public Car Park Road Departures/Arrivals Roadway

The public car park road is a two lane two-way road which when traversed in a southerly direction provides access to the public car park, overflow car park and the arrivals lane. If traversed in a northerly direction, the public car park road provides access to the parking areas mentioned previously and also back to the roundabout from which any of the other four exits can be taken. It should be noted that while this road runs adjacent to the public car park, direct access to the car park is prohibited by a locked gate. Hence, access to the public car park is via a service road, which runs parallel to the arrivals lanes, separated by a median. Currently, access to the overflow car park is solely from the public car park road.

Figure 4.10 Entrance to Public Car Park

Analysis

The utility this road provides appears to be redundant, as the public car park can already be accessed directly from the arrivals roadway and the roundabout can be accessed by traversing the departures/arrivals road. Therefore, at present except for serving as an entrance into the overflow car park and a road to bypass the departures/arrival curb and the public car park, this road appears to be underutilized.

4.2.7 Technical Services Road

The technical services road is a 2-lane one-way road which provides access to the airside zone, fuel farm, utilities and maintenance area, employee parking lots, as well as, JCAA's air traffic control tower premises. This road intersects with the four lanes exiting the airport from the terminal and public car parking zones.

Analysis

The technical services road enables staff and other service providers, such as fuel tankers to bypass the terminal facility, minimizing the congestion and risk of conflicts within that zone. It also provides an additional safety buffer by diverting the fuel tankers away from the terminal area. However, this road still intersects with the four lanes exiting the airport, creating an additional potential congestion or bottleneck point. Additionally, the fact that vehicles utilizing this road, including the fuel tankers, have to cross four lanes of traffic increases the risk of conflict.

4.2.8 Services

Within the context of this report, the services being analyzed are fuel storage/delivery, waste management and equipment storage.

4.2.8.1 *Fuel*

Aviation fuel at the NMIA is currently stored in a fuel farm compound, located west of the terminal building, along the coastline. The fuel is stored in tanks located above ground with a capacity of 1.85 million litres of fuel. However, ARUP (2013) states that the total weekly fuel consumption at the airport is 2.04 million litres. Therefore, in order to maintain the level of fuel being used by the airlines, a large volume of fuel has to be delivered to the airport. Currently, this delivery is done via fuel tankers, which travel to the airport via the Norman Manley Highway. According to ARUP (2013), fuel is delivered four days per week with approximately 15 to 16 tanker deliveries per day.

Figure 4.11 Fuel storage tanks in Fuel Farm

The large volume of fuel tanker deliveries required presents a safety risk, as these tankers utilize the same roadway as the public travelling to the terminals. Additionally, as stated elsewhere in this report, the fuel tankers utilize the technical services roadway, which creates a potential bottleneck, leading to traffic congestion

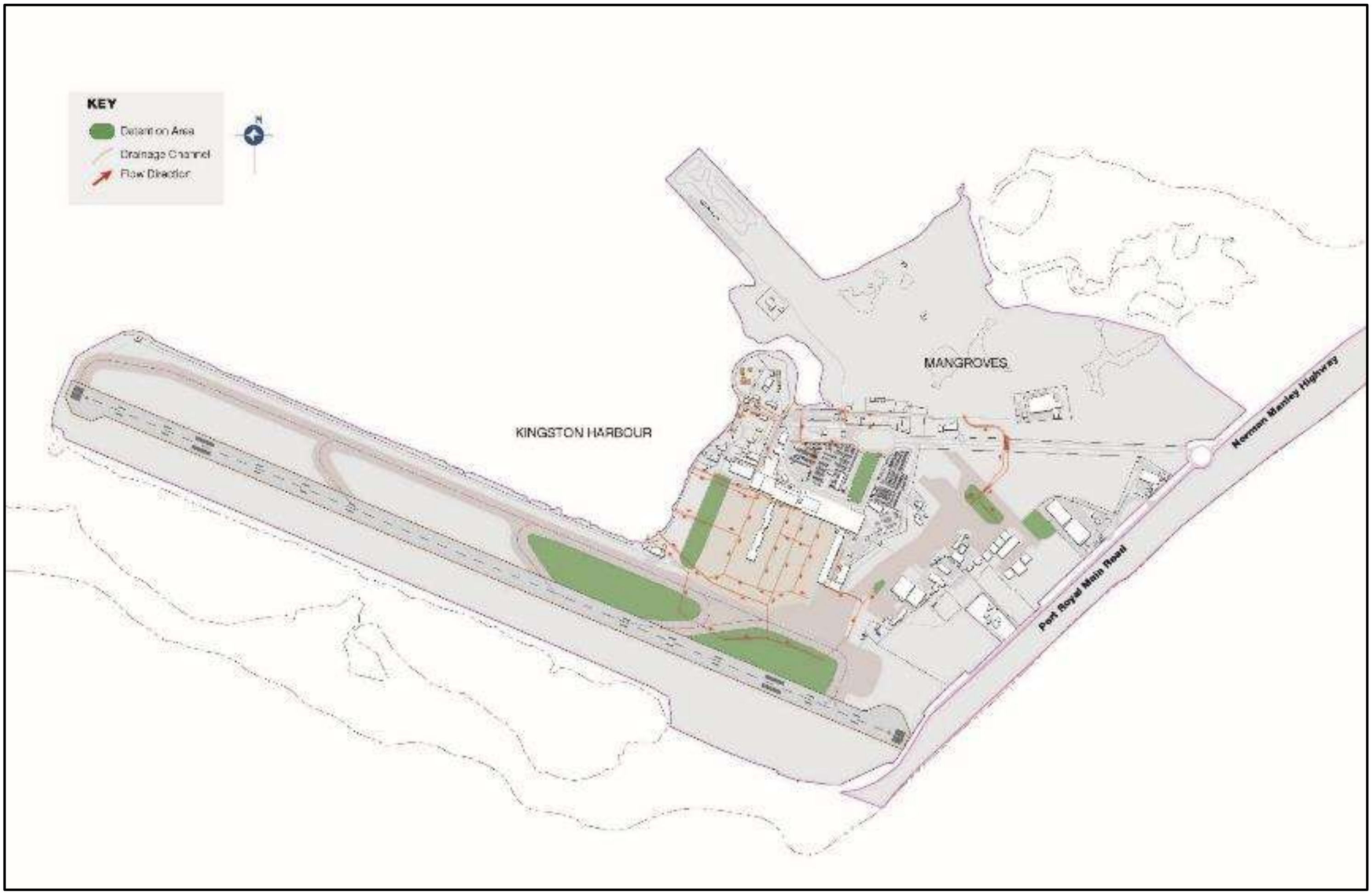


Figure 4.12 NMIA Drainage Map

4.2.8.2 *Waste Management*

Currently, there are two incinerators located at the NMIA, with the capacity to handle 1,500 kg/hr. of waste. These incinerators are predominantly used for the disposal of dry aircraft waste. They are located away from the main airport operations, adjacent to the old runway within the northern section of the site. Additionally, there is a garbage bunker with a capacity of approximately 270 m^3 located within the island adjacent to the road exiting the airport, north of the terminal building. There is also a petrol station located within this same island approximately 40m east of the garbage bunker. This bunker appears to store most of the general waste generated at the airport and its contents are transported to the Riverton Landfill facility. It is accessed via a layby along the exit road.

Figure 4.13 Incinerator building

<u>Analysis</u>

The location of the garbage bunker detracts from the aesthetic appeal of the airport, as it is visible to all users of the road exiting NMIA. The open roof design that is featured on the bunker facilitates the release of unpleasant odours from the waste into the atmosphere and also creates the potential for debris to be blown around. This creates a potential hazard for nearby aircraft. Additionally, the siting and open nature of the bunker can serve as an attraction to birds and other animals, which also have the potential to cause disruption to aircraft operations. The storage of garbage in this location also presents a fire hazard, exacerbated by its open roof and close proximity to the petrol station. Additionally, the entrance and exit of garbage trucks into the garbage bunker has the potential to contribute to traffic congestion along the exit road.

4.2.8.3 *Equipment Storage*

The designated area for the storage and repair of ground service equipment is within the facility located west of the terminal building on the airside of the facility. However, ground service equipment is found in other areas including within the area behind the Rescue & Fire Fighting Services station, adjacent to the external access road.

Figure 4.14 Airport equipment haphazardly stored in area behind RFFS

Analysis

The creation and adherence to more defined storage areas and policies can lead to the availability of additional space that can be efficiently utilized for other purposes.

4.2.8.4 *Cargo*

There are currently two cargo facilities located at NMIA. These are the cargo pier and the cargo and logistics centre.

4.2.8.5 *Cargo Pier*

The cargo pier is connected to the terminal and provides immediate airside access. The cargo pier houses Jamaica Customs offices as well as over 4,400 m^2 of leasable space.

Figure 4.15 Landside access to Cargo Pier adjoining Terminal

Analysis

The existing cargo pier presents limitations for landside access as the area for parking is limited and based on location is not readily conducive to expansion. The location limitations also affect the expansion of the cargo pier facility in general, as due to its location within the apron the building envelope is limited in size. Additionally, according to ARUP (2013) the cargo pier is currently housed within space that has been earmarked for future terminal development meaning existing tenants will need to be relocated.

4.2.8.6 *Cargo and Logistics Centre*

The Cargo and Logistics Centre (CLC) is located along the Port Royal Main Road in the eastern section of the site. Public vehicular access to the site is directly from the Port Royal Main Road, while two cargo roads provide access from the airside. Approximately 5,200 m^2 of leasable space is currently provided in the CLC.

Figure 4.16 Landside access of Cargo and Logistics Centre

Analysis

According to ARUP (2013), there are current plans to completely relocate cargo operations from the cargo pier adjoining the terminal building to the CLC, which has capacity to be expanded to 21,000 m^2 of leasable space. The relocation of cargo operations to this area will provide greater landised accessibility and capacity for expansion than what currently exists. However, the CLC site is approximately 1.25 km from the edge of the runway, accessible to aircraft via taxiway F. ARUP (2013), in the same report also noted that at the time that report was completed taxiway F did not meet Annex 14 standards for object clearance distance from the centerline of the taxiway, necessary for Code E aircraft to operate. This limitation will affect the type of aircraft that can service the CLC, thereby affecting the cargo volume per load.

4.2.9 Summary of existing airfield analysis

The landside areas of the Norman Manley International Airport includes the airport access roads, parking lots and public transportation facilities. The NMIA is accessed directly from the Norman Manley Boulevard via a roundabout. The entrance road is a four lane divided corridor which connects directly to another roundabout, within the airport which has a total of

five exits. The roundabout provides direct connections to the terminal building for departures and arrivals, the public car park, the technical services road and the road exiting the airport. The terminal road is a two lane, one-way road
There are three lanes directly serving the departures curb, with the curbside lane for parking, the middle lane for through traffic and the outside lane designated for temporary stopping. The current arrival/departure road configuration is a source for potential conflict and traffic congestion. At the merge point where several lanes converge, is a potential bottleneck. This is exacerbated by traffic heading to the arrivals curb that needs to cross three lanes. The length of the arrivals curb with only one parking lane and limited pick up slots also contributes to traffic congestion as this results in circling and waiting, slowing down on each pass to try to find a slot or parking and waiting, then merging into traffic heading to the arrivals curb. The public car park road appears to be redundant, as the public car park can already be accessed directly from the arrivals roadway and the roundabout can be accessed by traversing the departures/arrivals road. Therefore, at present except for serving as an entrance into the overflow car park and a road to bypass the departures/arrival curb and the public car park, this road appears to be underutilized.

Aviation fuel at the NMIA is currently stored in a fuel farm compound, located west of the terminal building, along the coastline. Currently, fuel delivery is done via fuel tankers, which travel to the airport via the Norman Manley Highway. According to ARUP (2013), fuel is delivered four days per week with approximately 15 to 16 tanker deliveries per day. The large volume of fuel tanker deliveries required presents a safety risk, as these tankers utilize the same roadway as the public travelling to the terminals. Additionally, as stated elsewhere in this report, the fuel tankers utilize the technical services roadway, which creates a potential bottleneck, leading to traffic congestion.

Currently, there are two incinerators located at the NMIA. These incinerators are predominantly used for the disposal of dry aircraft waste. They are located away from the main airport operations, adjacent to the old runway within the northern section of the site. Additionally, there is a garbage bunker with a capacity of approximately 270 m3 located within the island adjacent to the road exiting the airport, north of the terminal building. There is also a petrol station located within this same island approximately 40m east of the garbage bunker. This bunker appears to store most of the general waste generated at the airport and its contents are transported to the Riverton Landfill facility. It is accessed via a layby along the exit road. The location of the garbage bunker detracts from the aesthetic appeal of the airport, as it is visible to all users of the road exiting NMIA. The open roof design that is featured on the bunker facilitates the release of unpleasant odours from the waste into the atmosphere and also creates the potential for debris to be blown around. This creates a potential hazard for nearby aircraft. Additionally, the siting and open nature of the bunker can serve as an attraction to birds and other animals, which also have the potential to cause disruption to aircraft operations. The storage of garbage in this location also presents a fire hazard, exacerbated by its open roof and close proximity to the petrol station.

Additionally, the entrance and exit of garbage trucks into the garbage bunker has the potential to contribute to traffic congestion along the exit road.

The designated area for the storage and repair of ground service equipment is within the facility located west of the terminal building on the airside of the facility. However, ground service equipment is found in other areas including within the area behind the Rescue & Fire Fighting Services station, adjacent to the external access road. The creation and adherence to more defined storage areas and policies can lead to the availability of additional space that can be efficiently utilized for other purposes.

There are currently two cargo facilities located at NMIA. These are the cargo pier and the cargo and logistics centre. The cargo pier is connected to the terminal and provides immediate airside access. The cargo pier houses Jamaica Customs offices as well as over 4,400 m2 of leasable space. The existing cargo pier presents limitations for landside access as the area for parking is limited and based on location is not readily conducive to expansion. The location limitations also affect the expansion of the cargo pier facility in general, as due to its location within the apron the building envelope is limited in size. Additionally, according to ARUP (2013) the cargo pier is currently housed within space that has been earmarked for future terminal development meaning existing tenants will need to be relocated.

The Cargo and Logistics Centre (CLC) is located along the Port Royal Main Road in the eastern section of the site. Public vehicular access to the site is directly from the Port Royal Main Road, while two cargo roads provide access from the airside. Approximately 5,200 m2 of leasable space is currently provided in the CLC. According to ARUP (2013), there are current plans to completely relocate cargo operations from the cargo pier adjoining the terminal building to the CLC. The relocation of cargo operations to this area will provide greater landised accessibility and capacity for expansion than what currently exists. However, the CLC site is approximately 1.25 km from the edge of the runway, accessible to aircraft via taxiway F. ARUP (2013), in the same report also noted that at the time that report was completed taxiway F did not meet Annex 14 standards for object clearance distance from the centerline of the taxiway, necessary for Code E aircraft to operate. This limitation will affect the type of aircraft that can service the CLC, thereby affecting the cargo volume per load.

4.3 Assessment of Existing Government Processes & Acts

Understanding legislation, regulation, authority and responsibility is essential to regulations aimed at zoning. This will allow decision makers to understand what types of development or land use proposal require Approvals and/or Permits.

4.3.1 Legislation Relating to Planning and Zoning

4.3.1.1 *The Natural Resource Conservation Authority Act 1991*

The Palisadoes-Port Royal Protected Area (PPRA), covers 13,000 hectares which includes the Palisadoes tombolo and Kingston Harbour, as well as offshore cays, reefs, mangroves and areas of historical and archaeological significance. The entire NMIA is located within the boundaries of the Palisadoes-Port Royal Protected Area

The Natural Resource Conservation Authority(NRCA) Act 1991 (Natural Resources Conservation Authority (NRCA), 1991) guides environmental legislation through the National Environment & Planning Agency (NEPA). NEPA is tasked with the responsibility to guide and control development through their Development Orders, specifically (Government of Jamaica, 2017), for prescribed urban areas. Zoning laws are an integral part of this planning instrument. Since the airport is a specialized land use and is governed by international laws for its very existence, it therefore serves the airport's interest to develop an Airport Zoning Plan to be included in the Development Order which will ensure compliance to these international laws.

Parts of the Act that are intrinsically related to the airport's development are:

1. Section 38 used to create regulations for Protected Landscape/Seascape

Section 5 used to declare Protected Areas

18 September 1998 - Minister declares Palisadoes-Port Royal Protected Area , defined as "where the interaction of people and nature over time has produced an area of distinct character with significant ecological, biological, cultural and scenic value: and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area"

22 April 2005 - wetlands and cays designated a Ramsar Site under the Convention on Wetlands of International Importance (especially as Waterfowl Habitat) NRCA manages protected areas.

NRCA can delegate any of its functions except the power to make regulations.

The Authority should consult with interested persons as defined in the regulations before developing and/or revising the following:

1. A management plan;
2. Site specific regulations; and
3. A zoning plan.

The modernization and expansion of the airport contemplates an Airport Zoning Plan. Only the NRCA has the duty to create or revise Zoning Plans on the lands already designated as Protected Areas. However, the NRCA can delegate functions to a Local Management Entity (LME) relating to protected areas management and administration pursuant to section 6 of the NRCA Act. This presents an opportunity for AAJ to directly oversee the zone as a LME since some of the lands required for the airport's expansion includes the Palisadoes Protected Areas. The duties of the LME would include:

1. Implement the proposed Protected Area Management Plan in accordance with the relevant section of these
    a. Regulations;
2. Implement the monitoring programme;
3. Develop an annual operations plan having due regard and in conformity with the approved Protected Area Management Plan;
4. Implement education, public awareness and outreach programmes;
5. Facilitate ecological, economic and social research (e.g. hazard mapping, market research and carrying capacity studies);
6. Develop and implement training programmes;
7. Develop and implement rehabilitation/restoration programmes;
8. Patrol and monitor compliance;
9. Implement sustainable resource use or livelihood projects;
10. Recommend persons to be appointed as protected area rangers;
11. Conduct independent or joint environmental awareness programmes;
12. Train and support Game Wardens;
13. Conduct investigations regarding enforcement issues and make available their findings and recommendations;
14. Participate in monitoring/surveillance activities; and

15. Mobilize among resource users public support and a sense of ownership of the regulations; thus encouraging compliance.

4.3.1.2 *Use Permits Required under the NRCA Act*

Runway expansion is required and entails land reclamation. Activities related to this project type that are prohibited within the Protected Area without a permit from the lawful or relevant authority includes:

1. Dredging, excavation, filling operations or dumping any material in the marine, terrestrial or wetland areas. Conditions for compensation, mitigation, restoration of these areas and contingency plans should be attached to such approvals.
2. The erecting of building or any structure or any public service facility on any beach including the Port Royal Cays;
3. Deposition or discharge of sewage, industrial and other trade effluent

4.3.1.3 *The Town and Country Planning Act, 1957 (amended 1999)*

The TCPA Act is the law which governs land use locally, in accordance to legal instruments known as Development Orders. Development Orders are to control both urban and rural land development, ensure proper sanitary conveniences, coordinate building of roads and other public services, protect public amenities (conservation areas, wetlands, mangroves). The act establishes area- specific standards for land use, density and zoning. At present, Development Orders cover most of the urban areas of Jamaica, as well as the entire coast line up to one mile inland and most parishes.

4.3.1.4 *The Kingston Confirmed Development Order, 1966*

The Town and Country Planning Act, 1957, makes provision by section 5 (1) for the Town and Country Planning Authority, after consultation with the KSAC to establish the Town and Country Planning (Kingston and St. Andrew) Confirmed Development Order of 1966. The Development Order provides an outline of land use permitted in the parish.

4.3.1.5 *Kingston and St. Andrew and the Pedro Cays Provisional Development Order 2017*

The Town and Country Planning Act, 1957, makes provision by section 5 (1) for the Town and Country Planning Authority, after consultation with the KSAC to establish the Town and Country Planning (Kingston and St. Andrew) Provisional Development Order of 2017. The Development Order provides an outline of land use permitted in the parish and supercedes the Kingston Confirmed Development Order, 1966.

4.3.1.6 *The Building Act, 2018*

The Building Act, 2018 and Regulations made under the Act provides detailed construction procedures for buildings in KSA.

4.3.1.7 *Noise Abatement Act (Night Noise Act), 1997*

Jamaica has no national legislation for noise in relation to Aircraft noise, but World Bank guidelines are often used for benchmarking purposes. Therefore airport noise is not regulated locally in Jamaica.

4.3.1.8 *The Land Acquisition Act, 1947*

The 1962 Constitution of Jamaica contains a chapter dealing with the Protection of the Fundamental Rights and Freedoms of the individual. Section 18 of Chapter III determines that no property shall be compulsorily taken into possession and no interest in or right over property shall be compulsorily acquired, except under a law that:

1. Prescribes the principles and manner in which compensation is determined and given and;

2. Provides right of access to a court to determine questions of rights, entitlement and Compensation (The Jamaica Constitution, 1962).

The Land Acquisition Act of 1947 as amended, vests authority in the Commissioner of Lands to acquire all land required by the Government for public purposes. The term "public purpose" is not defined. The Commissioner is empowered to acquire land either by way of private treaty or compulsory acquisition following a gazetted declaration of intent. Rights of appeal relate only to the quantum and apportionment of compensation.

The commissioner of lands may acquire lands on behalf of the Government for the Airports Authority for the purpose of airport activities expansion and also in order to regulate and control future developments that are not compatible with airport activities on lands in the vicinity of the airport.

4.3.2 Legislation relating to Aviation

4.3.2.1 *The National Transport Policy, (DRAFT- 2007).*

1. To engender sustainable environmental practices that are consistent with nationally and internationally accepted standards
2. To promote sustainable management of natural and physical resources will be and
3. To take appropriate action to avoid, alleviate or correct the adverse effects of activities in the aviation industry
4. To ensure that Flight Information Region (FIR) and airport systems are safe and secure – consistent with locally and internationally accepted standards.

4.3.2.2 *Jamaica Civil Aviation Act, 1966*

The Act makes provision through the Land Acquisition Act for the declaration of land for public purposes, under:

1. The condition of establishment and maintenance of the aerodrome, alter, abolish, remove or add to any aerodrome, approach ... and;
2. The purposes of ensuring that land in the vicinity of the site of an aerodrome which the Minister has established or is about to establish shall not be used in such a manner as to cause interference with, or danger or damage to, aircraft, approaching or leaving the aerodrome.

Also, the Civil Aviation Act gives provision for the Minister to give directions towards the following obstacles in the locality of the airport.

1. For restricting the height of buildings or structures. Where or for requiring the total or partial demolition of any building or structure within the area to which the order relates;
2. For restricting the height of trees and other vegetation upon any land within the area, or for requiring any tree or other vegetation upon any such land to be cut down or reduced in height;
3. For extinguishing any private right of way over land within the area;
4. For restricting the installation of cables, mains, pipes, wires or other apparatus upon, across, over or under any land within the area;
5. For extinguishing, at the expiration of such period as may be specified in the directions, any subsisting right of installing or maintaining any such apparatus as aforesaid upon, across, over or under any land within the area.

The Jamaica Civil Aviation Authority (JCAA) the regulators of airports in Jamaica requires each person proposing any kind of construction or alteration of more than 30M (98.4 feet) to give adequate notice specifying the location and dimension of the construction or alteration.

The JCAA is currently a part of the urban planning and building approval process, where they assess planning and building applications and any other such activities which might have the potential to be an obstruction in the airport locality.

Nuisance Caused by Noise and Vibration on Aerodromes: It is restricted to regulating the conditions under which noise and vibration may be caused by aircraft at the aerodrome and not to noise as a result of overflights and within the airport locality as a result of the airport's flight path.

4.3.2.3 *The Airports Authorities Act, 1947:*

This Act forms the mandate under which the AAJ operates and until the promulgation of the NRCA Act of 1991, had complete autonomy over all works taking place on the airport property which was related to the safe and efficient operation of the airport. However, with the enactment of the NRCA Act (which binds the Crown), a permit may have to be issued by the NRCA before any major rehabilitation work with potential negative impact on the environment is undertaken.

4.3.3 Legislation relating to Environmental Protection

4.3.3.1 *NMIA Environmental Programme Manual (Airport Authority of Jamaica, 2016)*

It is NMIAL's mission to operate a safe, profitable and environmentally friendly airport, providing world -class service with a uniquely Jamaican character, and in so doing to find a workable balance between economic gains and the management of the environment and thereby, minimizing potential and actual impacts upon the environment. To this end, NMIAL will comply with all applicable environmental regulations, statutes, and industry standards and will take a proactive approach towards environmental stewardship by meeting and, where possible, exceeding minimum compliance standards as appropriate.

The Environmental Programme Manual (EPM) has been prepared to ensure that corporate commitment to environmental protection and stewardship is undertaken at all levels of NMIAL operations.

The NMIAL has developed an Environmental Policy Statement that affirms the NMIAL's commitment to environmental management. This manual turns the Environmental Policy Statement into practice and has been developed to ensure environmental protection and regulatory compliance during airport operations.

4.3.3.2 *EPM Administration*

The EPM serves as a core document for the ongoing development of the environmental management programme at NMIA. The airport is located within a nationally Protected Area and there are continual efforts to observe, monitor and manage potential interferences between environmental ecology and airport operations on the landside and airside.

The expectation is to have a current and responsive EPM to match the changing conditions at NMIA, as the airport evolves and responds to local and international conditions including new or revised regulations, wildlife migration and master planning project impacts.

4.3.3.3 *EPM Strategic Direction*

The EPM will guide management of the environmental programme such that NMIAL will:

1. Fulfil its corporate leadership in the sustainable protection of the Palisadoes/Port Royal Protected Area (PPRA): NMIAL's goal is to protect the natural environment and leave a legacy of care and concern that reflects the NMIAL's desire to exercise good stewardship of the environment. This level of consideration is exercised when managing its airport business and interacting with the various stakeholders in undertaking activities related to airport operations.
2. Limit Legal Liabilities: NMIAL is committed to incorporating sound environmental practices into major airport operations from planning down to routine daily activities, while managing regulatory compliance and minimising legal liabilities. This is in line with NMIAL's risk management approach that recognizes the benefits of environmental protection and the costs associated with environmental hazards and site remediation.
3. Integrate Environmental Management into Business Operations: NMIAL has adopted ISO14001 as a guide to manage its environmental activities in line with an Environmental Management System (EMS). This method provides a means by which daily environmental management is planned, implemented and reviewed.

4.3.3.4 *The Beach Control Act (1956)*

1. This Act provides for the proper management of Jamaica's coastal and marine resources by a system of licensing activities on the foreshore and the floor of the sea.
2. The Act addresses issues such as access to the shoreline and rights associated with fishing and public recreation, as well as the establishment of marine protected areas.
3. In respect of NMIA, beach licenses are required for operations such as the operation of the wastewater effluent outfall pipe.

4.3.3.5 *The Watersheds Protection Act (1963)*

1. The Act provides for the protection of watersheds and areas adjoining watersheds, and promotes the conservation of water resources.
2. The NMIA falls within the Hope River Watershed and maintain the tenets of this law through its care and protection of the natural environment around NMIA.

4.3.3.6 *The Wild Life Protection Act (1945)*

1. This Act is primarily concerned with the protection of specified species of fauna. It is the only statute in Jamaica specifically designated to protect species of animals and birds. ii. Many of the species on the list of protected animals and species may be resident and/or migratory in relation to NMIA and includes Crocodiles and West Indian Turtles.
2. Birds are of particular importance, especially in regard to birdstrike. Protected birds include Black-billed Parrots, Parakeets, all hummingbirds, and migratory birds. Birds that are not protected include Geese, House Sparrow, Budgerigars, Budgerigars and Cattle Egret.

3. Fines and penalties are codified within the Act.

4.3.3.7 *The Endangered Species (Protection, Conservation and Regulation of Trade) (2000)*

1. Jamaica became a Party to Convention on the International Trade in Endangered Species of Wild Fauna and Flora on June 22, 1997. ii. The Act provides for the management of endangered species of Wild Fauna and Flora and for the regulation of trade in these species.
2. Of particular importance is Schedule 3 of the Act that seeks to manage all species specifically identified in the Act as being subject to regulation to prevent and/or restrict exploitation such as being sold in concessionaire shops in the Terminal Building.

4.3.3.8 *Conventions, Authorities & Responsibility*

The regulatory framework controlling environmental management in regard to the operations at the Norman Manley International Airport (NMIA) includes Jamaican laws as well as international conventions. The most significant local law including substantive regulations is the Natural Resource Conservation Act (NRCA) Act (1991) and the Ramsar Convention.

4.3.3.9 *Regulatory Authorities (providing related guidance to NMIA)*

1. National Environment and Planning Agency (NEPA)
2. National Solid Waste Management Authority (NSWMA)
3. Jamaica Civil Aviation Authority (JCAA): administrates environmental matters related to aviation notably wildlife hazard, greenhouse gas emissions and foreign object debris (FOD).
4. Ministry of Health - Environmental Health Unit (EHU): controls health and sanitation matters, notably disposal of special waste, vector control, and trans-boundary health concerns.
5. International Civil Aviation Organisation (ICAO)
6. Federal Aviation Authority (FAA)

4.3.3.10 *Specially Designated Areas*

The NMIA is located within an environmentally sensitive area with endangered as well as threatened species. There are special declarations in respect of the Palisadoes and Kingston Harbour. These declarations are significant due to potential activity restrictions, approvals required, airport land use planning implications and mitigation activities.

Palisadoes and Port Royal Protected Area (PPRA) : As a Protected Area, the zone is to be managed to ensure the protection and maintenance of ecological systems, biodiversity, cultural or aesthetic resources. The on-going challenge is to support the implementation of the PPRPA alongside the obligation to ensure environmentally sound airport operations in keeping best practices and international standards.

Wetland of International Significance – Ramsar Site No.1454 was declared under the Convention on Wetlands of International Importance on April 22, 2005. The Ramsar site for Palisadoes covers 7,523 hectares and contains cays, shoals, mangrove lagoons, mangrove islands, coral reefs, seagrass beds and shallow water. Endangered and vulnerable species occurring in the Palisadoes area include the American crocodile, Green turtle, Hawksbill turtle, West Indian manatee and Bottlenose Dolphin. Around 26 endemic new species have been discovered in the area.

4.3.3.11 *Responsibility for Airport Land Use Compatibility Planning*

Airport Manager has overall administrative responsibility for the airport which oftentimes extends to securing the interests of the airport. Sometimes the airport manager is the only agency representative advocating the airport's interest and role within the larger context of the community and economy.

Airport Sponsor (owner/operator) must make a concerted effort to inform local government officials, director of planning and citizens of the importance of compatible land use planning within airport environs, as well as, actively participate in comprehensive planning and zoning processes and stay informed about actions regarding land use issues within the airport's proximity.

Support Groups like pilots, NMIA Airports Limited designated Environmental and Occupational Health Manager (Airport Authority of Jamaica, 2016) and businesses that rely on the airport, can support the airport manager in the effort to persuade decision makers to adopt land use compatibility measures and disapprove proposals that can adversely affect the current and future use of the airport.

Municipalities play an administrative role in guiding physical development through master plans, development orders and advising the government on all Planning related issues. Since they're the first group to be presented with a development proposal, they act as the 1st line of defense in that they can advise applicants of potential airport compatibility conflicts and alert an airport sponsor of land use proposals within an airport's locality. Therefore it is vital for Panning professionals to be educated about the importance of compatible and use planning around airports and understand the significance of coordinating with and obtaining input from airport managers.

Local Government is the legislative, policy making branch of government who are vested in land use decisions that are influenced by numerous and often conflicting considerations. It is essential for elected officials to recognise the critical functions that the airport provides and the value of compatible land use decisions for the airport and economy.

Federal Aviation Authority (FAA) globally conducts certain functions for safety in and outside of the United States, such as performing air traffic control handoffs and assessing whether a foreign civil aviation authority complies with international aviation standards (Alexander-Adams, 2018). They also inspect repair stations, oversee navigation and infrastructure, set safety standards, and provide oversight around the world for air traffic. Though the FAA has no authority to mandate land use locally, it provides airport sponsors with guidance focused primarily on the protection of airspace from incompatible uses.

International Civil Aviation Organization (ICAO): In compliance with Article 37 of the Convention on International Civil Aviation in Chicago in 1944, the ICAO adopted Annex 14-Aerodromes to the Convention on 29 May 1951. Annex 14 provides the required set of standards for aerodromes used by international civil air transport. The Annex contains information for planning, designing and operating airports (Kazda & Caves, 2015).

4.3.4 Summary of existing government processes and Acts

The entire NMIA is located within the Palisadoes & Port Royal Protected Area (PPRA), with endangered as well as threatened species. There are special declarations in respect of the Palisadoes and Kingston Harbour. These declarations are significant due to potential activity restrictions, approvals required, airport land use planning implications and mitigation activities. These are Palisadoes & Port Royal Protected Area (PPRA) and the Wetland of International Significance – Ramsar Site No.1454. There are several regulations mentioned in Legislation and authority set up for the airport. However, with no specific procedures codified and no specific external agency assigned the responsibility for compliance and review, these instruments have little teeth to implement measures to protect the airport. Understanding legislation, regulation, authority and responsibility is essential to regulations aimed at zoning. This will allow decision makers to understand what types of development or land use proposal require Approvals and/or Permits. Since the airport is a specialised land use and is governed by international laws for its very existence, it therefore serves the airport's interest to develop an Airport Zoning Plan to be included in the Development Order that will ensure compliance to these international laws. The modernization and expansion of the airport contemplates an Airport Zoning Plan. Only the NRCA has the duty to create or revise Zoning Plans on the lands already designated as Protected Areas. However, the NRCA can delegate functions to a Local Management Entity (LME) relating to protected areas management and administration pursuant to section 6 of the NRCA Act. This presents an opportunity for AAJ to directly oversee the zone as a LME since some of the lands required for the airport's expansion includes the Palisadoes Protected Areas.

Table 4.3 Existing Regulations

Existing Regulations
The Natural Resource Conservation Authority Act 1991
Use Permits Required under the NRCA Act
Use Permits Required under the NRCA Act
Kingston and St. Andrew and the Pedro Cays Provisional Development Order 2017
The Town and Country Planning Act, 1957 (amended 1999)
The Kingston Confirmed Development Order, 1966
The Building Act, 2018
Noise Abatement Act (Night Noise Act), 1997
The Land Acquisition Act, 1947
The National Transport Policy, (DRAFT- 2007).
Jamaica Civil Aviation Act, 1966
The Airports Authorities Act, 1947:
NMIA Environmental Programme Manual (Airport Authority of Jamaica, 2016)
EPM Administration
EPM Strategic Direction
The Beach Control Act (1956)
The Watersheds Protection Act (1963)
The Wild Life Protection Act (1945)
The Endangered Species (Protection, Conservation and Regulation of Trade) (2000)
Conventions, Authorities & Responsibility

5 Obstacle Limit Surface Model Analysis and Lidar Calibration Report

5.1 LiDar Ground Control Points Survey

5.1.1 Introduction

The overall objective was to establish Ground Control Points (GCPs) covering approximately 300 sq. km. for parts of the Parish of Kingston, St. Andrew and St. Catherine. The geographic location of these GCPs can be seen in Figure 5.1. The purpose of these control points was to aid in georeferencing aerial photographs and LiDar data. The survey of the GCP's spanned a total of six day, three days to implement the physical ground control marks and another three days for the Global Navigation Satellite System (GNSS) observations.

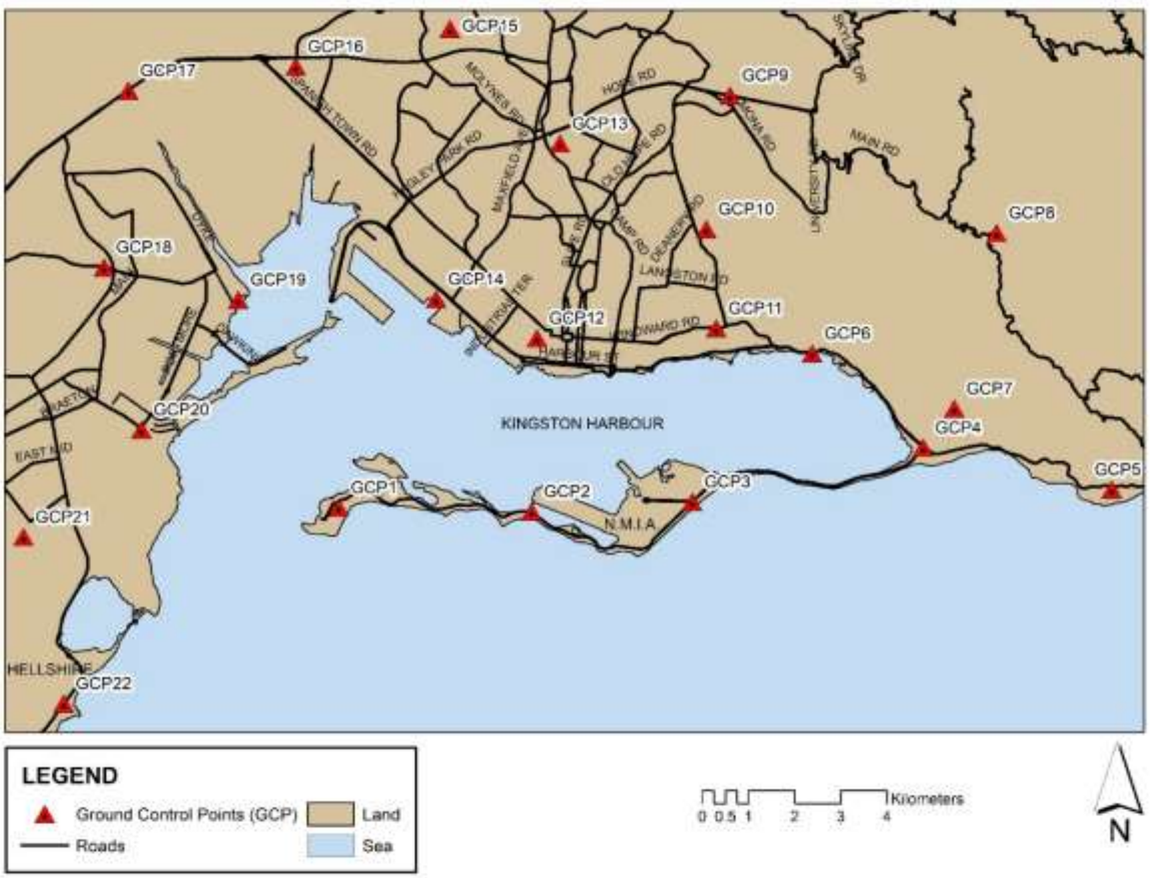


Figure 5.1 Geographic Location of all GCP's

GCP's are large marked targets on the ground, spaced strategically throughout the area of interest see Figure 5.2. One important thing to remember is that the GCPs must be easily visible in aerial imagery. This is achieved by using high-contrast colours and by ensuring that the ground control mark is large enough to be seen from a particular flight altitude. These GCPs were placed in open area free form obstacle.

Figure 5.2 Example of GCP marker

The absolute accuracy of these GCPs are critical for controlling the accuracy of the LiDar data collected. This then makes the measured position of a point on an aerial image corresponds to its actual position in the real world. The approximated GCP accuracy are shown in Table 5.1.

Table 5.1. GPS accuracy for GCP

Approx. GNSS Accuracy		
Horiz. Position	0.050	m
Vert. Position	0.030	m

Fieldwork was carried out between January 14th -January 27th, over a total of eight (8) days. A total of **twenty-two (22) marks were coordinated**. All marks were referred to the JAD2001 datum. Heights (vertical component) were referenced to local mean sea level (MSL).

5.1.2 Methodology

5.1.2.1.1 Horizontal Positioning

This was accomplished through Static Global Navigation Satellite System (GNSS) Surveying with the minimum of four (4) sets of receivers (Trimble 5700 and Topcon), for three days. GCPs were group in three segments to allow for short base line observations. For the assurance of redundancy, for each day of observation two receivers were set up over known National Land Agency (NLA) Control Station simultaneously, used as base stations; namely: 289L, BM LP29, KG49, 537L, 538L, BM LS28 and BM LS25, while GCPs were observed in three sessions for each specific day.

Two receivers positioned over Ground Control Points (GCPs) in the order of GCP 4 and GCP 5 simultaneously with the two base stations (session 1), then these two receivers were moved to GCP 1 and GCP 3 as session 2, maintaining the same two base stations. Then to GCP 7 and GCP 8 for a third session. The height of antenna at each setup was measured and the time started and ended noted and recorded on a GNSS Logging Sheet along with the receiver type and antenna information. This method of observation was repeated for successive GCPs.

Surveying period for each session was observed for a minimum of forty-five (45) minutes. Note that the observation duration at the base stations was over five (5) hours for the NLA Control Stations. For all the observations, the recording interval and the masked angle were set to 15 second logging rate and 15° respectively, yielding centimetre-level accuracy.

5.1.2.1.2 Heighting (vertical establishment)

This was accomplished in one of two ways; [1] Traditional survey methodologies (spirit leveling and/or Trigonometrical leveling) and [2] Local area hybrid geoid modeling. In the case of [1]Traditional survey methodologies; leveling was done from established vertical control stations within the project area; namely: 289L, BM LP26A, BM LP28, BM LP29, BM 5, KG50, 283L, 270L, BM LS27 and BM LS23. A Two Peg Test was carried out on the Leica NA730 Automatic Level at the National Land Agency Office, Charles Street, Kingston, result is 3mm (acceptable) over a distance of 30 metres.

Sprit levelled was done to height some of the GCPs from known control points. Due to the law of error propagation the accuracy is determinant to the distance 'levelled' along with the number of 'setups' hence the vertical accuracy ranged from millimeter-level to centimeter-level.

With regards to [2] Local area hybrid geoid modeling, this was accomplished by determination of the separation between the local vertical datum and the observed ellipsoidal height; "Co-efficient surface". These observations are then averaged (as well as analyzed for outliers) establishing a geoid-ellipsoid separation. The geoid-ellipsoid separation for all the GCPs are then computed through surface interpolated using their unique horizontal position.

Orthometric Heights for the GCPs are then generated by the application of the mathematical model: $H = h - N$

Where:-

H= Orthometric Height

h= Ellipsoidal Height

N= Geoid-Ellipsoid Separation

5.1.3 Data Processing

Trimble Business Centre 2 was used to process all observations. The accuracy of the coordinates of the Base Stations were checked by processing each set of Base Stations with the CORS Stations held fixed; namely: Kingston, Linstead, Lionel Town, Port Antonio, and Morant Bay.

The GCPs including the Base Stations 'Receiver Independent Exchange Format' (RINEX) files imported into the software. Stations name, Instrument height, type of receivers and antenna type all noted and entered. All baselines were process and adjustment was done to compute coordinates with the Base Stations held fixed, see Table 5.4.

Summary of control accuracy achieved:

Table 5.2 Achieved Accuracy from GNSS Observations

Achieved GNSS Accuracy	
Horizontal Position	±0.030m
Vertical Position	±0.025m

Instrumentation: Trimble 5700 receivers, Topcon GRS receivers and Topcon Hiper II receivers and Leica NA730 automatic level with measuring staff

5.1.4 Results

The GCP data observed and processed were requested in three (3) different spatial formats, namely: WGS84 Geographic Coordinate System (GCS) which is an international geodectic system where the curvature of the earth is considered, JAD2001 which is a local grid projection & WGS84 Universal Transvers Mercator (UTM) which is an international grid projection. The GCPs various spatial formats may be seen in Table 5.6 and Table 5.7.

The analysis between spirit levelled elevations may be seen in Table 5.3 which shows the largest difference being 0.76m, which is well within the projects scope of vertical accuracy.

Table 5.3 Differences between Computed Heights & Spirit Levelled Heights

Point ID	Computed GNSS Elev. (m)	Spirit Level Elev. (m)	Difference
GCP1	2.063	2.041	0.022
GCP2	1.218	1.142	0.076
GCP3	4.556	4.513	0.043
GCP4	7.52	7.523	-0.003
GCP5	2.509		NA
GCP7	26.833		NA
GCP8	272.427		NA
GCP10	69.278		NA
GCP11	12.764		NA
GCP12	4.442		NA
GCP13	77.378		NA
GCP14	1.764		NA
GCP15	50.337		NA
GCP16	4.582		NA
GCP6	3.234		NA
GCP9	168.411	168.402	0.009
NLA537L	1.248	1.23	0.018
GCP17	6.635		
GCP20	2.905	2.88	0.025
GCP18	7.966	7.949	0.017
GCP29	1.26		
GCP21	3.261	3.242	0.019
GCP22	1.623	1.637	-0.014

Table 5.4: Accuracy of Base Stations

Point ID	Published Coordinates		Observed Coordinates		Differences	
	Eastings (m)	Northings (m)	Eastings (m)	Northings (m)	Eastings (m)	Northings (m)
NLA289L	779651.836	644430.796	779651.788	644430.800	0.048	-0.004
NLA537L	770507.045	646543.532	770507.032	646543.532	0.013	0.000
NLA538L	770475.146	646567.275	770475.146	646567.306	0.000	-0.031
KG49	775169.968	652122.064	775169.979	652122.064	-0.011	0.000
BMLS25	760753.685	645063.645	760753.671	645063.659	0.014	-0.014

The adjusted grid coordinates as seen in Table 5.4, shows that the processed data was adjusted and shows the data is within the 95% confidence level. In analysing the errors associated for both the northings, eastings and elevations the largest error found was 0.082m which was till within the projects scope of vertical and horizontal accuracies. It should also be noted that the accuracy of the observed data meets the local standard of positional accuracy in urban areas of 0.1m as outlined in the Land Surveyors Regulation.

Table 5.5 Adjusted Grid Coordinates

	Network Reference Factor:		**1**				
	Chi Square Test (95%):		Passed				
	Precision Confidence Level:		95%				
Point ID	Eastings (m)	Easting Error (m)	Northings (m)	Northing Error (m)	Elevation (m)	Elevation Error (m)	Fixed
289L	779651.836	NA	644430.796	NA	7.667	NA	NEe
GCP 1	766999.524	0.003	643122.899	0.002	2.063	0.008	
GCP 2	771182.242	0.003	643038.233	0.002	1.218	0.007	
GCP 3	774660.153	0.002	643247.131	0.002	4.556	0.006	
GCP 4	779665.122	0.002	644422.863	0.001	7.52	0.004	
GCP 5	783756.226	0.003	643514.387	0.002	2.509	0.007	
GCP 7	780340.657	0.002	645270.463	0.002	26.833	0.004	
GCP 8	781257.593	0.002	649079.969	0.003	272.427	0.006	
GCP 10	774963.818	0.027	649163.334	0.036	69.278	0.069	
GCP 11	775181.701	0.031	647012.686	0.024	12.764	0.071	
GCP 12	771297.139	0.022	646800.796	0.018	4.442	0.04	
GCP 13	771796.504	0.035	651017.947	0.021	77.378	0.08	
GCP 14	769108.286	0.019	647643.744	0.014	1.764	0.036	
GCP 15	769410.658	0.033	653508.292	0.031	50.337	0.08	
GCP 16	766070.044	0.039	652690.183	0.044	4.582	0.082	
GCP 6	777262.992	0.036	646466.54	0.031	3.234	0.082	
GCP 9	775479.955	0.026	652061.433	0.015	168.411	0.057	
KG 49	775169.968	NA	652122.064	NA	160.916	NA	NEe
NLA 537L	770507.036	0.021	646543.501	0.015	1.248	0.043	
NLA 538L	770475.146	NA	646567.275	NA	1.29	NA	NEe
BM LS25	760753.685	NA	645063.645	NA	5.183	NA	NEe
BM LS28	763907.308	NA	647101.256	NA	2.073	NA	NEe
GCP 17	762439.17	0.021	652168.362	0.022	6.635	0.042	
GCP 20	762723.467	0.01	644812.754	0.01	2.905	0.026	
GCP18	761914.265	0.011	648336.828	0.01	7.966	0.028	
GCP19	764821.527	0.012	647633.034	0.01	1.26	0.029	
GCP21	760166.114	0.014	642487.551	0.014	3.261	0.029	
GCP22	761036.778	0.022	638873.771	0.023	1.623	0.041	

Table 5.6: GCP XYZ Data referenced to JAD2001 Coordinate System

Point ID	Eastings (m)	Northings (m)	Elevation (m)
GCP 1	766999.524	643122.899	2.041
GCP 2	771182.242	643038.233	1.142
GCP 3	774660.153	643247.131	4.513
GCP 4	779665.122	644422.863	7.523
GCP 5	783756.226	643514.387	2.509
GCP 6	777262.992	646466.54	3.234
GCP 7	780340.657	645270.463	26.833
GCP 8	781257.593	649079.969	272.427
GCP 9	775479.955	652061.433	168.402
GCP 10	774963.818	649163.334	69.278
GCP 11	775181.701	647012.686	12.764
GCP 12	771297.139	646800.796	4.442
GCP 13	771796.504	651017.947	77.378
GCP 14	769108.286	647643.744	1.764
GCP 15	769410.658	653508.292	50.337
GCP 16	766070.044	652690.183	4.582
GCP 17	762439.17	652168.362	6.635
GCP18	761914.265	648336.828	7.966
GCP19	764821.527	647633.034	1.26
GCP 20	762723.467	644812.754	2.905
GCP21	760166.114	642487.551	3.261
GCP22	761036.778	638873.771	1.637

Table 5.7 GCP XYZ Data referenced to WGS84 Geographic Coordinate System

Point ID	Latitude	Longitude	Height (m)	Height Error (m)	Fixed
289L	N17°56'58.12714"	W76°43'12.33956"	-8.668	NA	NEe
GCP 1	N17°56'16.07487"	W76°50'22.34214"	-14.126	0.008	
GCP 2	N17°56'13.18878"	W76°48'00.21313"	-15.132	0.007	
GCP 3	N17°56'19.85145"	W76°46'02.02257"	-11.841	0.006	
GCP 4	N17°56'57.86846"	W76°43'11.88847"	-8.816	0.004	
GCP 5	N17°56'28.10434"	W76°40'52.91357"	-13.884	0.007	
GCP 7	N17°57'25.40411"	W76°42'48.88728"	10.582	0.004	
GCP 8	N17°59'29.26580"	W76°42'17.51962"	256.512	0.006	
GCP 10	N17°59'32.27039"	W76°45'51.44817"	53.202	0.069	
GCP 11	N17°58'22.30912"	W76°45'44.13577"	-3.434	0.071	
GCP 12	N17°58'15.56665"	W76°47'56.17023"	-11.77	0.04	
GCP 13	N18°00'32.71634"	W76°47'39.03911"	61.339	0.08	
GCP 14	N17°58'43.05776"	W76°49'10.53524"	-14.401	0.036	
GCP 15	N18°01'53.79870"	W76°49'00.06095"	34.384	0.08	
GCP 16	N18°01'27.28710"	W76°50'53.66053"	-11.385	0.082	
GCP 6	N17°58'04.45472"	W76°44'33.42366"	-12.971	0.082	
GCP 9	N18°01'06.51254"	W76°45'33.77621"	152.496	0.057	
KG 49	N18°01'08.49762"	W76°45'44.31195"	144.995	NA	NEe
NLA 537L	N17°58'07.22519"	W76°48'23.03269"	-14.968	0.043	

NLA 538L	N17°58'07.99956"	W76°48'24.11569"	-14.926	NA	NEe
BM LS25	N17°57'19.34358"	W76°53'54.54475"	-10.886	NA	NEe
BM LS28	N17°58'25.55491"	W76°52'07.32242"	-14.027	NA	NEe
GCP 17	N18°01'10.40008"	W76°52'57.11194"	-9.292	0.042	
GCP 20	N17°57'11.14474"	W76°52'47.60884"	-13.22	0.026	
GCP18	N17°59'05.78591"	W76°53'15.03589"	-8.063	0.028	
GCP19	N17°58'42.82987"	W76°51'36.23657"	-14.844	0.029	
GCP21	N17°55'55.56307"	W76°54'14.55818"	-12.844	0.029	
GCP22	N17°53'58.00477"	W76°53'45.04222"	-14.604	0.041	

Table 5.8 GCP XYZ Data referenced to Universal Transverse Mercator (UTM) Coordinates

Point ID	Eastings (m)	Northings (m)	Zone	Hemisphere
GCP 1	305166.060	1984267.350	18	N
GCP 2	309347.871	1984137.689	18	N
GCP 3	312827.970	1984309.169	18	N
GCP 4	317845.407	1985430.999	18	N
GCP 5	321926.499	1984478.546	18	N
GCP 6	315465.387	1987500.457	18	N
GCP 7	318530.033	1986271.285	18	N
GCP 8	319487.973	1990070.706	18	N
GCP 9	313742.755	1993114.396	18	N
GCP 10	313195.356	1990221.948	18	N
GCP 11	313390.048	1988069.009	18	N
GCP 12	309503.274	1987898.980	18	N
GCP 13	310048.115	1992110.701	18	N
GCP 14	307323.515	1988765.514	18	N
GCP 15	307689.183	1994626.797	18	N
GCP 16	304339.706	1993844.779	18	N
GCP 17	300703.109	1993362.168	18	N
GCP 18	300136.836	1989536.167	18	N
GCP 19	303036.594	1988801.011	18	N
GCP 20	300908.097	1986003.256	18	N
GCP 21	298325.628	1983705.481	18	N
GCP 22	299157.500	1980082.194	18	N

5.1.5 Typical GNSS Receivers Ground Control Setups

5.1.5.1 *Typical GNSS Receivers Ground Control Equipment Setups*

The following instrumentation was utilized during the Ground Control Point (GCP) surveys:

- Trimble 5700 receivers
- Topcon GRS receivers and Topcon Hiper II receivers
- Leica NA730 automatic level with measuring staff

5.1.6 Summary of GCP Survey

The GCP's surveyed aided in the georeferencing of the LiDar and aerial imagery data. The observations were done over a period of three days using GNSS Static survey method which given the extent of the survey area may have been the most practical method used. The survey yeilded favourable accuracy results which met the national standards of positional accuracy of 0.1m, see

Table 5.9 GNSS Accuracy Summary

Summary on GNSS Accuracy		
	Horizontal Positions	Vertical Positions
Approximate GNSS Accuracy	±0.050m	±0.030m
Achieved GNSS Accuracy	±0.030m	±0.025m

5.2 Obstacle Limitation Surface Model Definition & Analysis

5.2.1 Introduction

The obstacle limitation surface (OLS) is a mathematically derived three-dimensional (3D) model that defines the airspace around the airport which should be free from obstacles, allowing for the safe operations of aircrafts within its zone. The OLS model is made up of several surfaces but comprises of five (5) main surfaces meshed together to form a zone for which aircrafts may operate safely. The 5 surfaces are namely: transitional surface, inner horizontal surface, conical surface, outer horizontal surface & approach surface which aids in defining possible obstructions of manmade and natural terrain features.

There were two (2) OLS models created based on two (2) scenarios for the Norman Manley International Airport (N.M.I.A.). The two (2) scenarios entail an existing scenario for the runway in its present state and a proposed 300m runway extension to the northwestern section of the runway. The 3D OLS models were created based on the ICAO Annex 14[4] 8th edition regulation using a third-party software called SkySafe which runs on Autodesk Civil 3D platform and allows for the definition of the various runway scenarios.

5.2.2 OLS Description

The OLS model for both runway scenarios were developed using the ICAO Annex 14 regulations 8th edition and as such are similar in geometry except for the extent and elevation of the conical surface, transitional surface, approach surfaces, Inner & Outer Horizontal surface.

5.2.2.1 *Existing Runway Scenario*

The elevation reference mark was taken from the Aerodrome Reference Point (ARP) which was measured to be +2.37m (EGM2008), while the South and North end elevations of the runway thresholds were +5.27m (EGM2008) and 2.35m (EGM2008) respectively. The transitional slope starts at an elevation of +2.37m (EGM2008) and rises to an elevation of +47.37m (EGM2008) at a 14.3% slope to the Inner Horizontal surface and had a horizontal extent of 313m per side. The Inner Horizontal surface is shaped like an oval/race course track and has a horizontal radius of 4000m from the ends of the runway. The inner horizontal surface has a width was 8000m, while its length has a distance of 10703m. The surface of the Inner Horizontal surface is a flat plane at an elevation of +47.37m (EGM2008). The Conical surface is a sloping surface starting from the Inner Horizontal surface extending upwards to a height of 100m to the Outer Horizontal surface at a slope of 5%. The width of the Conical surface is 2000m wide and is due to the 5% slope rising to 100m height at an upper elevation of +147.37m (EGM2008). The Outer Horizontal surface is a flat circular plane with an elevation of +147.37m (EGM2008) having a radius of 15000m where its center is located at the ARP. The final surface is the Approach surface which originate from both ends of the runway's inner edge and has a cone shape having a divergence at each side of 15% from the starting width at the inner edge of 300m where the cone extends to 3000m at a 2% slope for its first section, then extends to 3600m at a 2.5% slope for its second section and has a third horizontal section which extends to 8400m giving the approach a minimum length of 15000m and an maximum elevation of +154.97 (EGM2008) for the eastern section and +152.28 (EGM2008) for the western section.

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4 https://www.icao.int/APAC/Meetings/2016%20ICAOPIS/3%20ICAO%20Annex%2014%20Standards%20and%20Aerodrome%20Certification.pdf

5.2.2.2 *Proposed Runway Scenario*

The proposed runway scenario requires that the runway length be extended by 300m. The extension would cause the ARP position to be shifted north-west of its current position and have a new elevation of +2.36m (EGM2008). The elevation reference mark was taken from the Aerodrome Reference Point (ARP) which was measured to be +2.36m (EGM2008), while the South and North end elevations of the runway thresholds were +5.27m (EGM2008) and 2.28m (EGM2008) respectively. The transitional slope starts at an elevation of +2.36m (EGM2008) and rises to an elevation of +47.36m (EGM2008) at a 14.3% slope to the Inner Horizontal surface and had a horizontal extent of 318m per side. The Inner Horizontal surface is shaped like an oval/race course track and has a horizontal radius of 4000m from the ends of the runway. The inner horizontal surface has a width was 8000m, while its length has a distance of 11004m. The surface of the Inner Horizontal surface is a flat plane at an elevation of +47.36m (EGM2008). The Conical surface is a sloping surface starting from the Inner Horizontal surface extending upwards to a height of 100m to the Outer Horizontal surface at a slope of 5%. The width of the Conical surface is 2000m wide and is due to the 5% slope rising to 100m height at an upper elevation of +147.36m (EGM2008). The Outer Horizontal surface is a flat circular plane with an elevation of +147.36m (EGM2008) having a radius of 15000m where its center is located at the ARP. The final surface is the Approach surface which originate from both ends of the runway's inner edge and has a cone shape having a divergence at each side of 15% from the starting width at the inner edge of 300m where the cone extends to 3000m at a 2% slope for its first section, then extends to 3600m at a 2.5% slope for its second section and has a third horizontal section which extends to 8400m giving the approach a minimum length of 15000m and an maximum elevation of +154.97 (EGM2008) for the eastern section and +152.28 (EGM2008) for the western section.

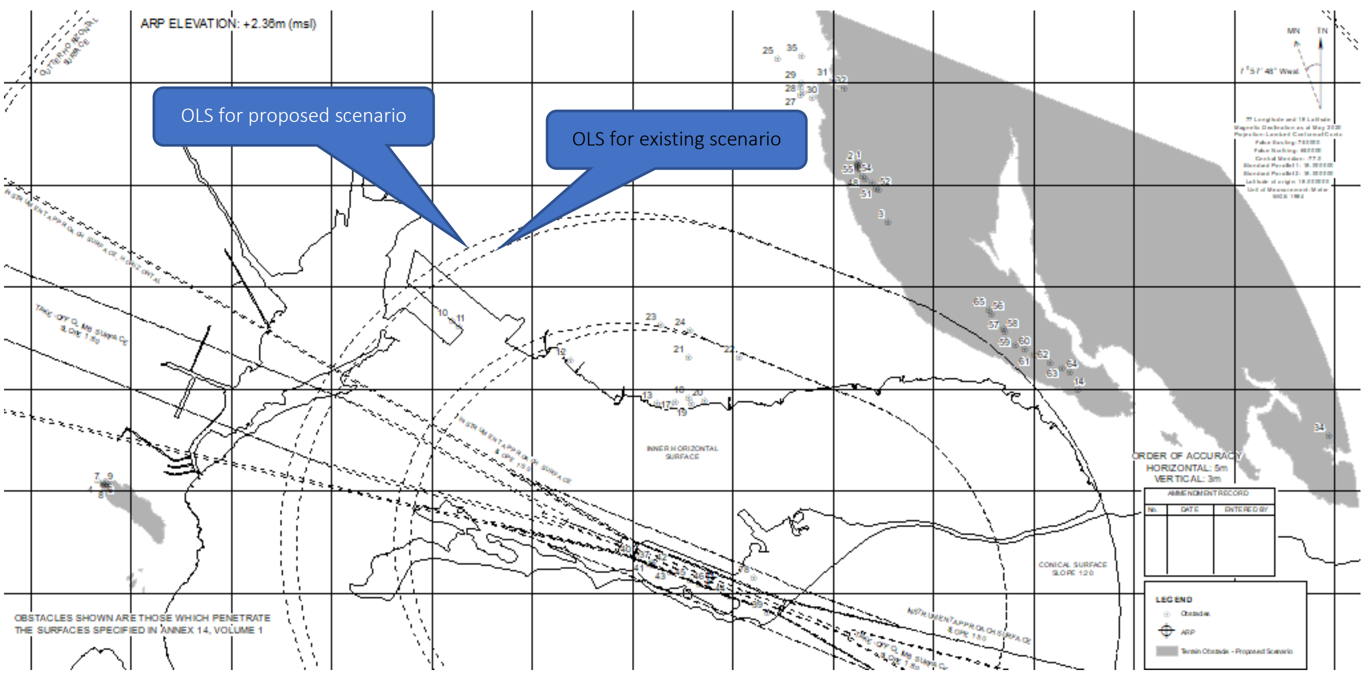


Figure 5.3 Depiction of Difference between OLS Models

5.2.3 OLS Existing Scenario Program Parameters

The OLS model created for the existing scenario was done for a runway in its present state, where the runway length was 2703m in length and 45m wide. The code number and code letter used were 4 and E respectively and the classification and category were precision approach and i respectively. The figures below shows the detailed parameters used for defining the OLS model for the given scenario.

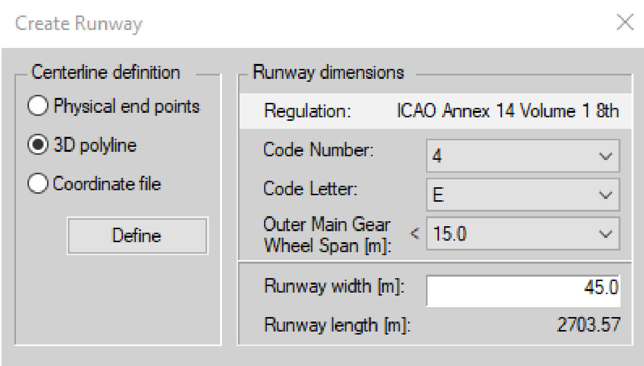
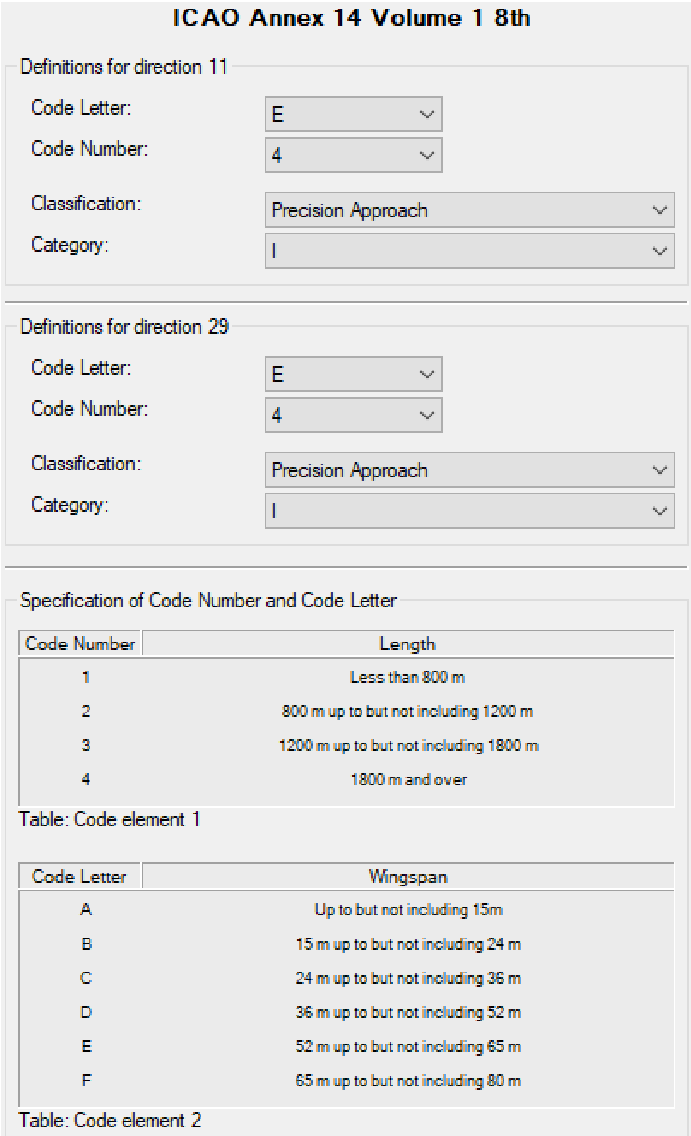


Figure 5.4: SkySafe Runway Definition (Existing Scenario)

Figure 5.5: SkySafe Runway Details (Existing Scenario)



ICAO Annex 14 Volume 1 8th

Definitions for direction 11

Code Letter: E

Code Number: 4

Classification: Precision Approach

Category: I

Definitions for direction 29

Code Letter: E

Code Number: 4

Classification: Precision Approach

Category: I

Specification of Code Number and Code Letter

Code Number	Length
1	Less than 800 m
2	800 m up to but not including 1200 m
3	1200 m up to but not including 1800 m
4	1800 m and over

Table: Code element 1

Code Letter	Wingspan
A	Up to but not including 15m
B	15 m up to but not including 24 m
C	24 m up to but not including 36 m
D	36 m up to but not including 52 m
E	52 m up to but not including 65 m
F	65 m up to but not including 80 m

Table: Code element 2

Figure 5.6: SkySafe Runway ICAO Annex 14 Specifications

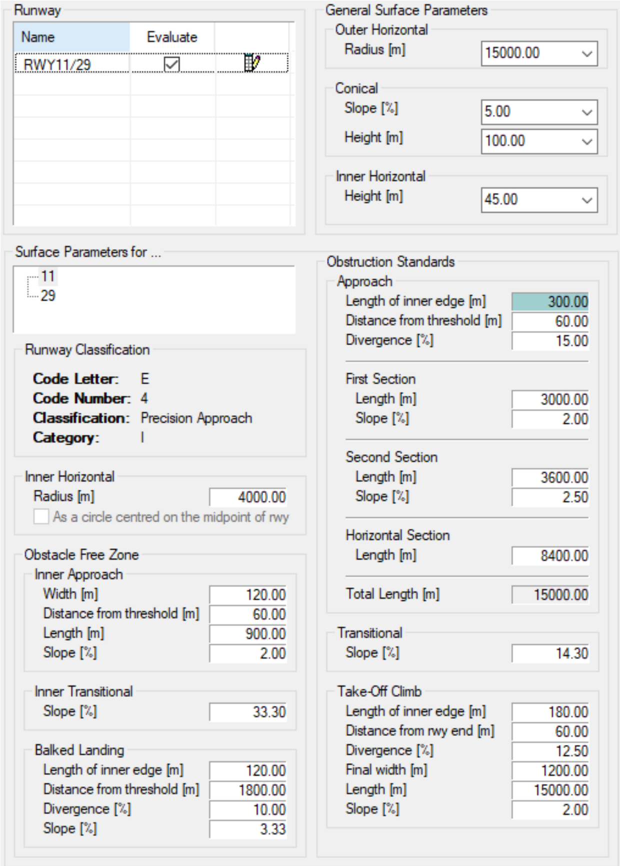


Figure 5.7: SkySafe OLS Properties

Table 5.10 ICAO Annex14 Runway width specification

Width of runways

3.1.10 **Recommendation.—** *The width of a runway should be not less than the appropriate dimension specified in the following tabulation:*

Code number	Code letter A	B	C	D	E	F
1[a]	*18 m*	*18 m*	*23 m*	–	–	–
2[a]	*23 m*	*23 m*	*30 m*	–	–	–
3	*30 m*	*30 m*	*30 m*	*45 m*	–	–
4	–	–	*45 m*	*45 m*	*45 m*	*60 m*

a. The width of a precision approach runway should be not less than 30 m where the code number is 1 or 2.

Table 5.11 CAO Annex 14 OLS Specifications

APPROACH RUNWAYS

	RUNWAY CLASSIFICATION									
	Non-instrument				Non-precision approach			Precision approach category		
								I		II or III
	Code number				Code number			Code number		Code number
Surface and dimensions[a]	1	2	3	4	1,2	3	4	1,2	3,4	3,4
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
CONICAL										
Slope	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Height	35 m	55 m	75 m	100 m	60 m	75 m	100 m	60 m	100 m	100 m
INNER HORIZONTAL										
Height	45 m	45 m	45 m	45 m	45 m	45 m	45 m	45 m	45 m	45 m
Radius	2 000 m	2 500 m	4 000 m	4 000 m	3 500 m	4 000 m	4 000 m	3 500 m	4 000 m	4 000 m
INNER APPROACH										
Width	—	—	—	—	—	—	—	90 m	120 m[e]	120 m[e]
Distance from threshold	—	—	—	—	—	—	—	60 m	60 m	60 m
Length	—	—	—	—	—	—	—	900 m	900 m	900 m
Slope								2.5%	2%	2%
APPROACH										
Length of inner edge	60 m	80 m	150 m	150 m	150 m	300 m	300 m	150 m	300 m	300 m
Distance from threshold	30 m	60 m	60 m	60 m	60 m	60 m	60 m	60 m	60 m	60 m
Divergence (each side)	10%	10%	10%	10%	15%	15%	15%	15%	15%	15%
First section										
Length	1 600 m	2 500 m	3 000 m	3 000 m	2 500 m	3 000 m	3 000 m	3 000 m	3 000 m	3 000 m
Slope	5%	4%	3.33%	2.5%	3.33%	2%	2%	2.5%	2%	2%
Second section										
Length	—	—	—	—	—	3 600 m[b]	3 600 m[b]	12 000 m	3 600 m[b]	3 600 m[b]
Slope	—	—	—	—	—	2.5%	2.5%	3%	2.5%	2.5%
Horizontal section										
Length	—	—	—	—	—	8 400 m[b]	8 400 m[b]	—	8 400 m[b]	8 400 m[b]
Total length	—	—	—	—	—	15 000 m	15 000 m	15 000 m	15 000 m	15 000 m
TRANSITIONAL										
Slope	20%	20%	14.3%	14.3%	20%	14.3%	14.3%	14.3%	14.3%	14.3%
INNER TRANSITIONAL										
Slope	—	—	—	—	—	—	—	40%	33.3%	33.3%
BALKED LANDING SURFACE										
Length of inner edge	—	—	—	—	—	—	—	90 m	120 m[e]	120 m[e]
Distance from threshold	—	—	—	—	—	—	—	c	1 800 m[d]	1 800 m[d]
Divergence (each side)	—	—	—	—	—	—	—	10%	10%	10%
Slope	—	—	—	—	—	—	—	4%	3.33%	3.33%

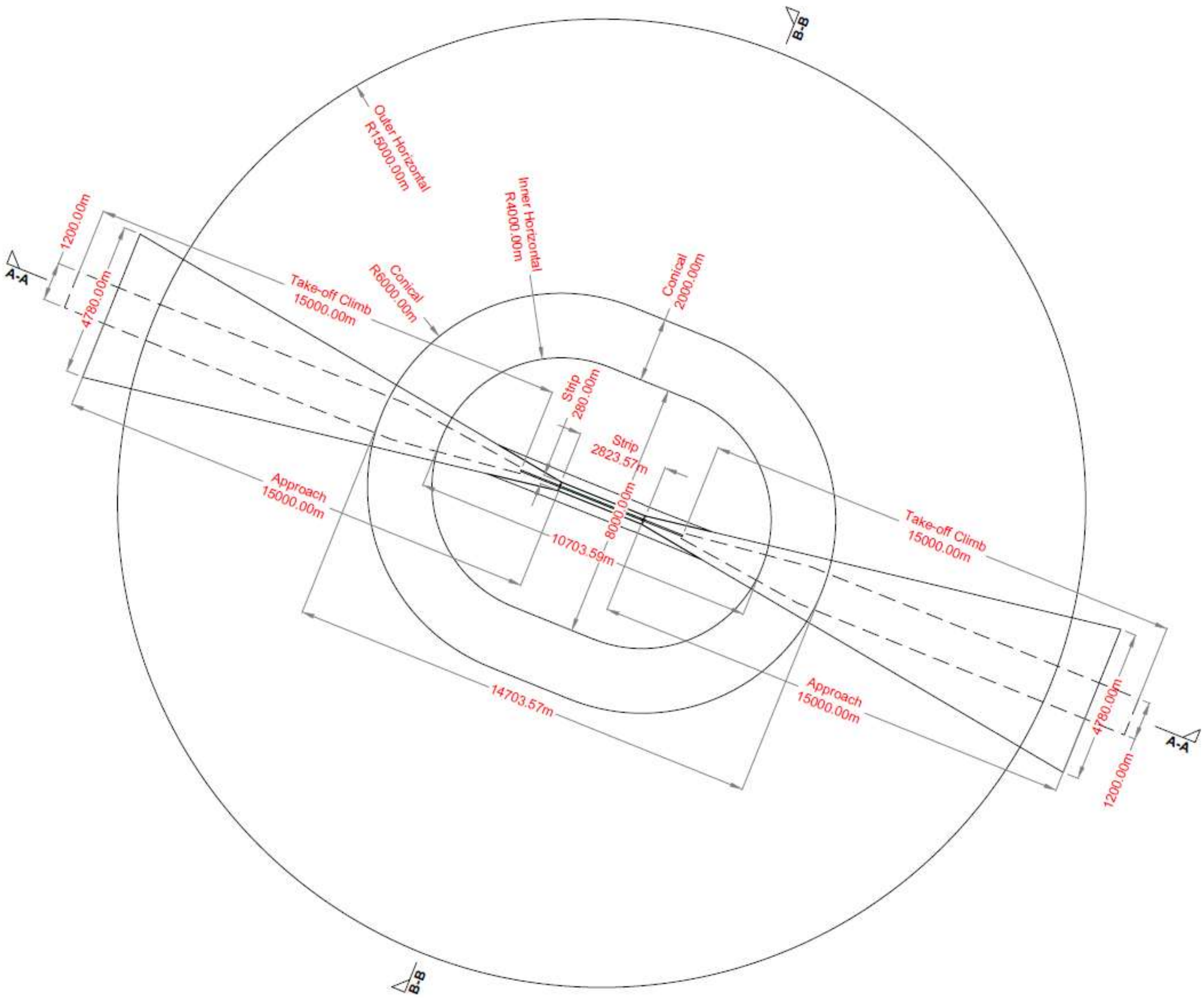
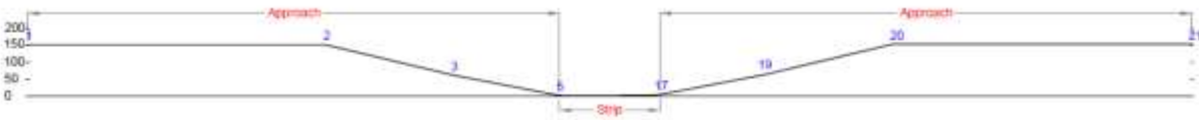


Figure 5.8: Plan of Proposed OLS Model - Existing Scenario

The OLS model as seen in Figure 5.8: Plan of Proposed OLS Model - Existing Scenario, shows the extent of the model with a radius of 15000m which encompasses the Kingston & St. Andrew and Portmore areas.

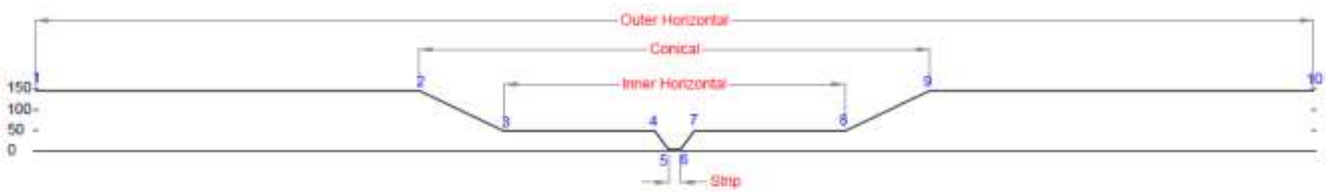
Cross-section data of the OLS model may be seen in Table 5.12 and Table 5.13 which shows the coordinates for the positions of the OLS lines that are intersected by the longitudinal and cross-sections lines. Elevation data may also be seen for the data points of the model along the sections lines.

Table 5.12: OLS Existing Scenario Longitudinal Section Data Points



Section A - A					
Point ID	X	Y	Z	Difference to ARP [m]	Slope [%]
1	757313.9967	649015.6098	152.2800	149.9100	0.00
2	765105.3607	645876.3966	152.2800	149.9100	-2.50
3	768444.5167	644531.0223	62.2800	59.9100	-2.02
4	771199.3204	643421.0869	2.2800	-0.0900	
5	771199.3204	643421.0869	2.8800	0.5100	-0.67
6	771282.7993	643387.4526	2.2800	-0.0900	0.01
7	772508.8075	642893.4827	2.3700	0.0000	0.04
8	773071.9469	642666.5867	2.6100	0.2400	0.08
9	773236.5951	642600.2505	2.7600	0.3900	0.11
10	773429.4221	642522.5587	2.9800	0.6100	0.13
11	773566.3739	642467.3796	3.1700	0.8000	0.99
12	773734.8250	642399.5091	4.9700	2.6000	1.00
13	773762.6480	642388.2990	5.2700	2.9000	0.00
14	773790.4743	642377.0875	5.2700	2.9000	
15	773790.4743	642377.0875	4.9700	2.6000	2.00
16	773804.3891	642371.4811	5.2700	2.9000	2.00
17	773818.3006	642365.8761	5.5700	3.2000	
18	773818.3006	642365.8761	5.2700	2.9000	2.01
19	776573.1043	641255.9407	64.9700	62.6000	2.50
20	779912.2603	639910.5644	154.9700	152.6000	0.00
21	787703.6243	636771.3532	154.9700	152.6000	

Table 5.13: OLS Existing Scenario Cross-section Data Points



Section B - B					
Point ID	X	Y	Z	Difference to ARP [m]	Slope [%]
1	766903.0759	628980.3309	147.3700	145.0000	0.00
2	770266.5168	637328.2215	147.3700	145.0000	-5.00
3	771013.9480	639183.3082	47.3700	45.0000	0.00
4	772338.8875	642471.7412	47.3700	45.0000	-14.30
5	772456.4903	642763.6254	2.3700	0.0000	0.00
6	772561.1307	643023.3376	2.3700	0.0000	14.30
7	772678.7335	643315.2218	47.3700	45.0000	0.00
8	774003.6730	646603.6548	47.3700	45.0000	5.00
9	774751.1042	648458.7415	147.3700	145.0000	0.00
10	778114.5446	656806.6309	147.3700	145.0000	

5.2.4 OLS Proposed Extension Scenario Parameters

The OLS model created for the proposed extension scenario was executed, where the runway length simulated was 3003m in length and 45m wide. The code number and code letter used were 4 and E respectively and the classification and category were precision approach and i respectively. The figures below show the detailed parameters used for defining the OLS model for the given scenario.

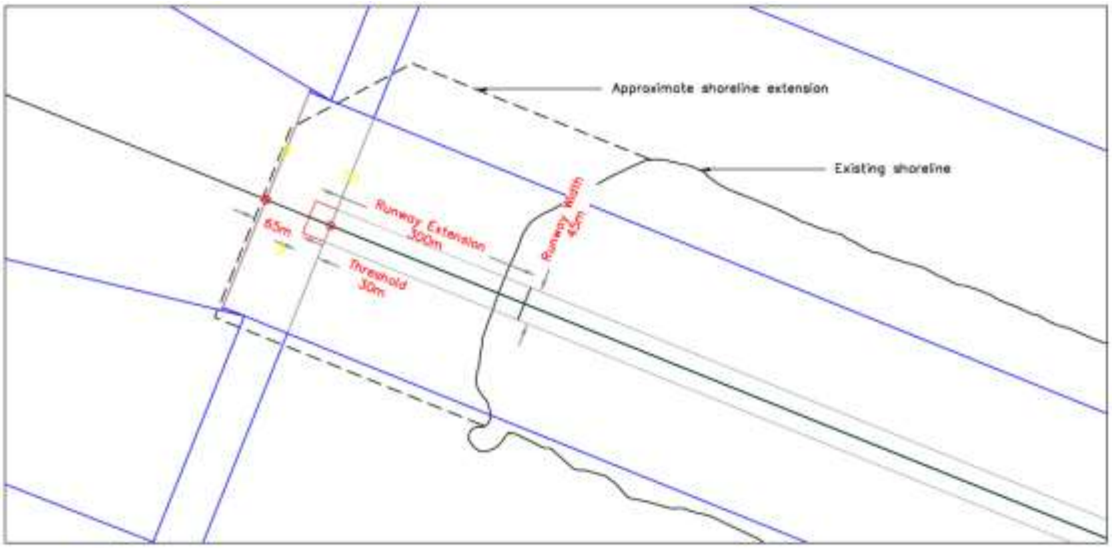


Figure 5.9 Plan of Proposed Runway Extension

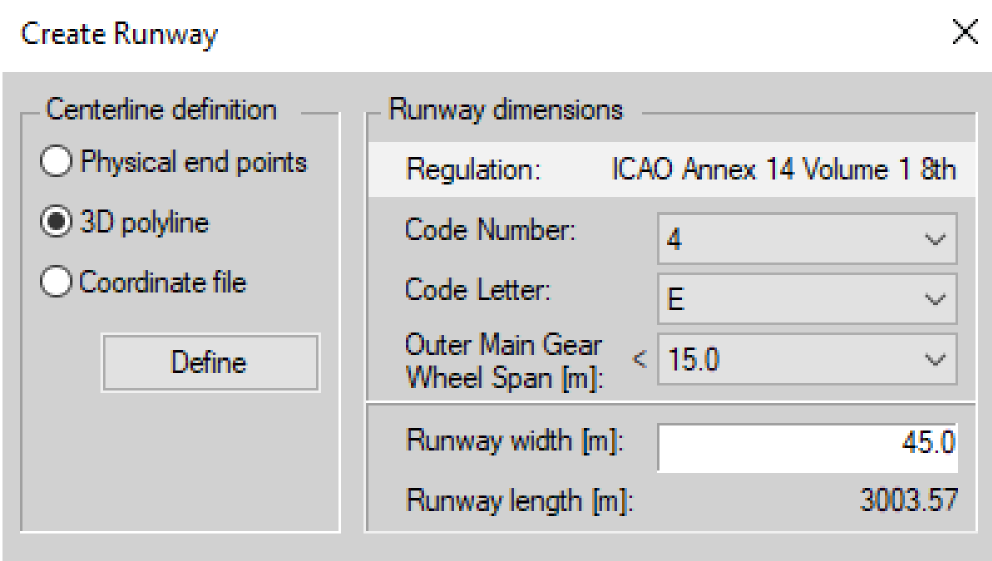
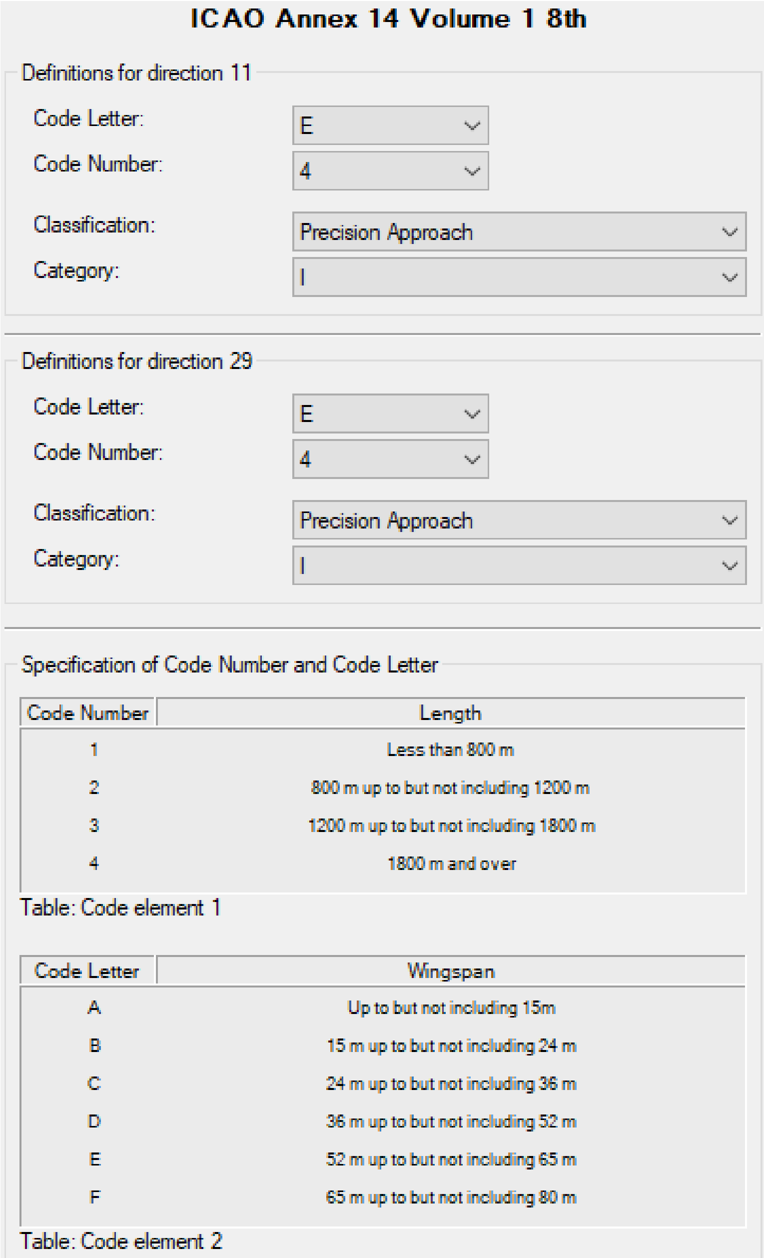


Figure 5.10: SkySafe Runway Definition (Proposed 300m Extension Scenario)

Figure 5.11: SkySafe Runway Details (Proposed 300m Extension Scenario)



ICAO Annex 14 Volume 1 8th

Definitions for direction 11

Code Letter: E

Code Number: 4

Classification: Precision Approach

Category: I

Definitions for direction 29

Code Letter: E

Code Number: 4

Classification: Precision Approach

Category: I

Specification of Code Number and Code Letter

Code Number	Length
1	Less than 800 m
2	800 m up to but not including 1200 m
3	1200 m up to but not including 1800 m
4	1800 m and over

Table: Code element 1

Code Letter	Wingspan
A	Up to but not including 15m
B	15 m up to but not including 24 m
C	24 m up to but not including 36 m
D	36 m up to but not including 52 m
E	52 m up to but not including 65 m
F	65 m up to but not including 80 m

Table: Code element 2

Figure 5.12: SkySafe Runway ICAO Annex 14 Specifications

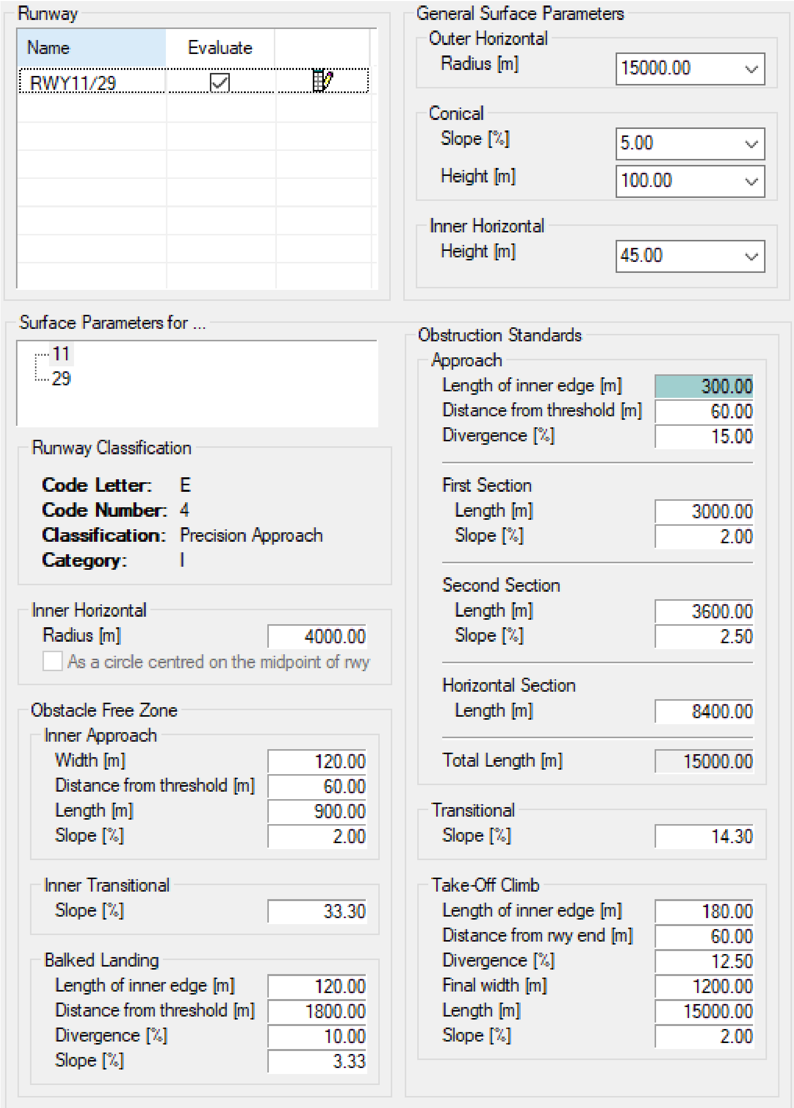


Figure 5.13: SkySafe OLS Properties (Proposed 300m Extension Scenario)

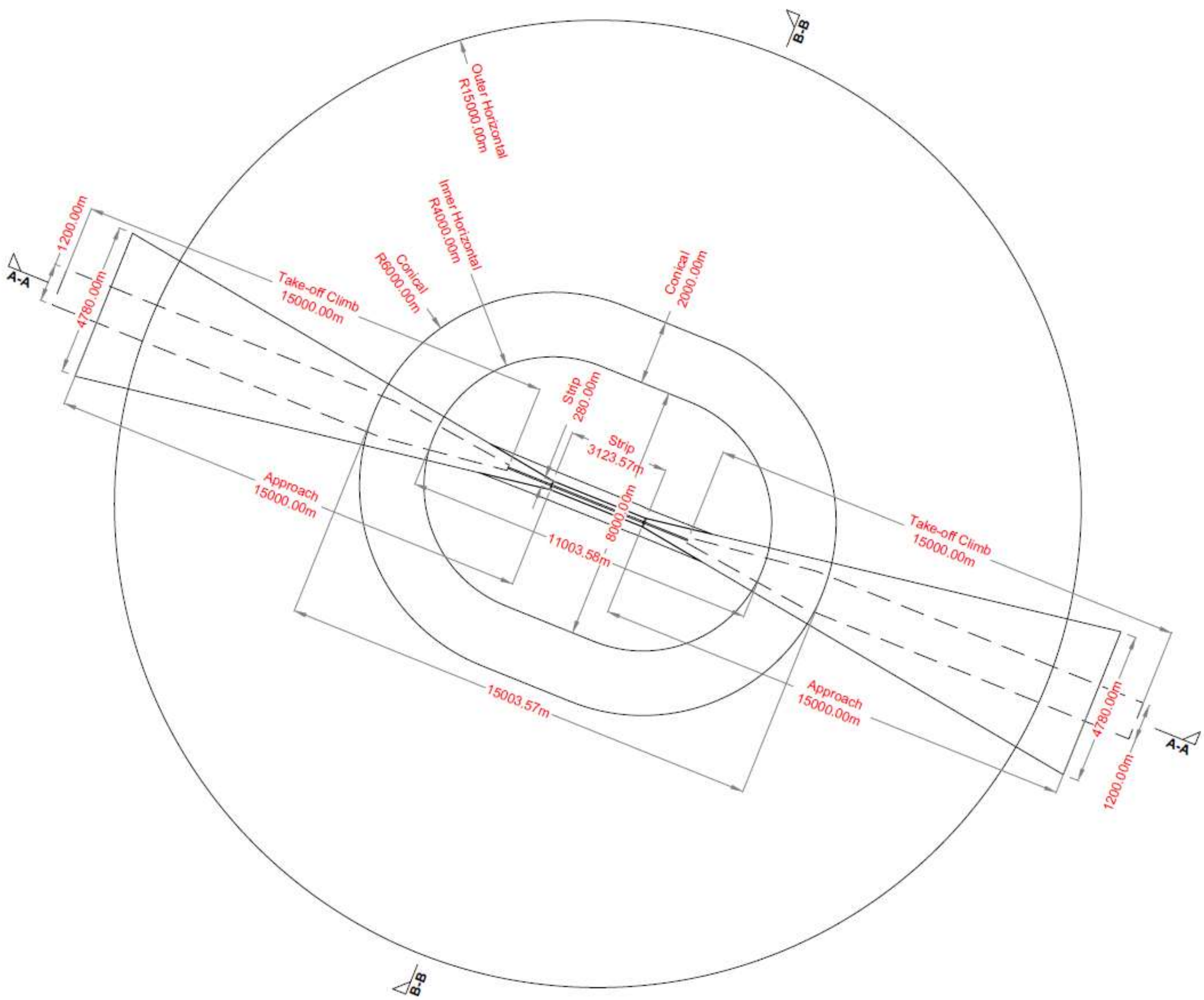
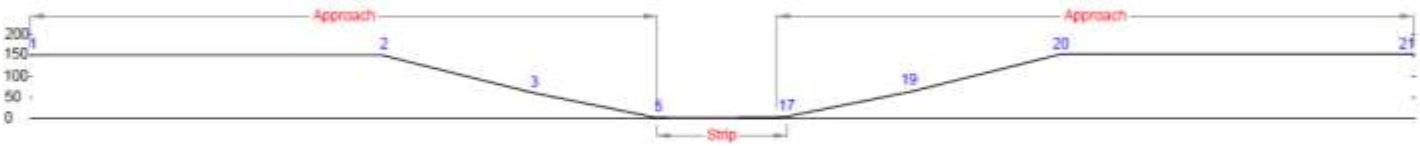


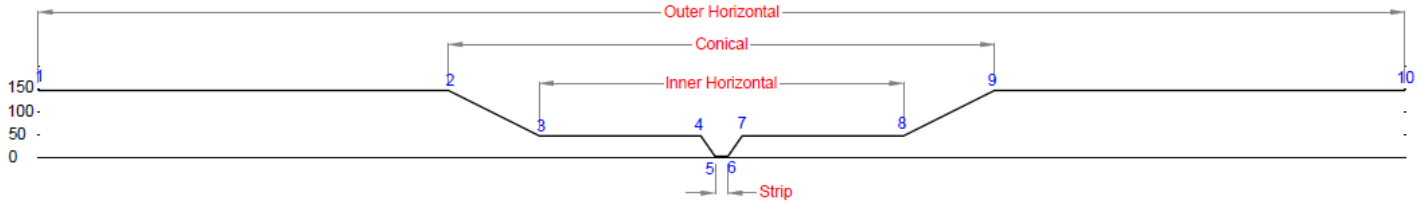
Figure 5.14: Plan of OLS Model for Proposed Runway Scenario

Cross-section data of the OLS model may be seen in Table 5.12 and Table 5.13 which shows the coordinates for the positions of the OLS lines that are intersected by the longitudinal and cross-sections lines. Elevation data may also be seen for the data points of the model along the sections lines.



Section A - A					
Point ID	X	Y	Z	Difference to ARP [m]	Slope [%]
1	757035.7337	649127.7245	152.2800	149.9200	0.00
2	764827.0977	645988.5133	152.2800	149.9200	-2.50
3	768166.2537	644643.1370	62.2800	59.9200	-2.02
4	770921.0574	643533.2016	2.2800	-0.0800	
5	770921.0574	643533.2016	2.8800	0.5200	-0.17
6	771254.9730	643398.6640	2.2800	-0.0800	0.01
7	772369.6760	642949.5400	2.3600	0.0000	0.03
8	773071.9469	642666.5887	2.6100	0.2500	0.08
9	773236.5951	642600.2505	2.7600	0.4000	0.11
10	773429.4221	642522.5587	2.9800	0.6200	0.13
11	773566.3739	642467.3796	3.1700	0.8100	0.99
12	773734.8250	642399.5091	4.9700	2.6100	1.00
13	773762.6480	642388.2990	5.2700	2.9100	0.00
14	773790.4743	642377.0875	5.2700	2.9100	
15	773790.4743	642377.0875	4.9700	2.6100	2.00
16	773804.3891	642371.4811	5.2700	2.9100	2.00
17	773818.3006	642365.8761	5.5700	3.2100	
18	773818.3006	642365.8761	5.2700	2.9100	2.01
19	776573.1043	641255.9407	64.9700	62.6100	2.50
20	779912.2603	639910.5644	154.9700	152.6100	0.00
21	787703.6243	636771.3532	154.9700	152.6100	

Figure 5.15 Section A-A Profile and Data Points through OLS of Proposed Scenario



Section B - B					
Point ID	X	Y	Z	Difference to ARP [m]	Slope [%]
1	766763.9447	629036.3890	147.3600	145.0000	0.00
2	770127.3853	637384.2788	147.3600	145.0000	-5.00
3	770874.8165	639239.3655	47.3600	45.0000	0.00
4	772199.7560	642527.7985	47.3600	45.0000	-14.30
5	772317.3588	642819.6828	2.3600	0.0000	0.00
6	772421.9992	643079.3949	2.3600	0.0000	14.30
7	772539.6020	643371.2792	47.3600	45.0000	0.00
8	773864.5415	646659.7122	47.3600	45.0000	5.00
9	774611.9727	648514.7988	147.3600	145.0000	0.00
10	777975.4134	656862.6890	147.3600	145.0000	

Figure 5.16 Section B-B Profile and Data Points Through OLS of Proposed Runway Scenario

5.2.5 Methodology

The obstacle analysis performed thus far has been done using the existing scenario. The data used for the analysis was the Digital Surface Model (DSM) from the LiDar survey. The DEM is a digital surface that takes into account the elevations of natural and man-made features. The obstacle identified was based on how the different surfaces of the OLS model intersects the DSM.

The DSM could not be used in its entirety as the dataset was large. The DSM data was resampled using a zonal statistic method in ArcGis using the maximum height value found in a 10m by 10m grid of the DSM. Points on a 10m by 10m grid was then extracted so that the terrain/obstacle analysis could be done using the SkySafe add on in Autodesk Civil 3D.

5.2.6 Results and Analysis

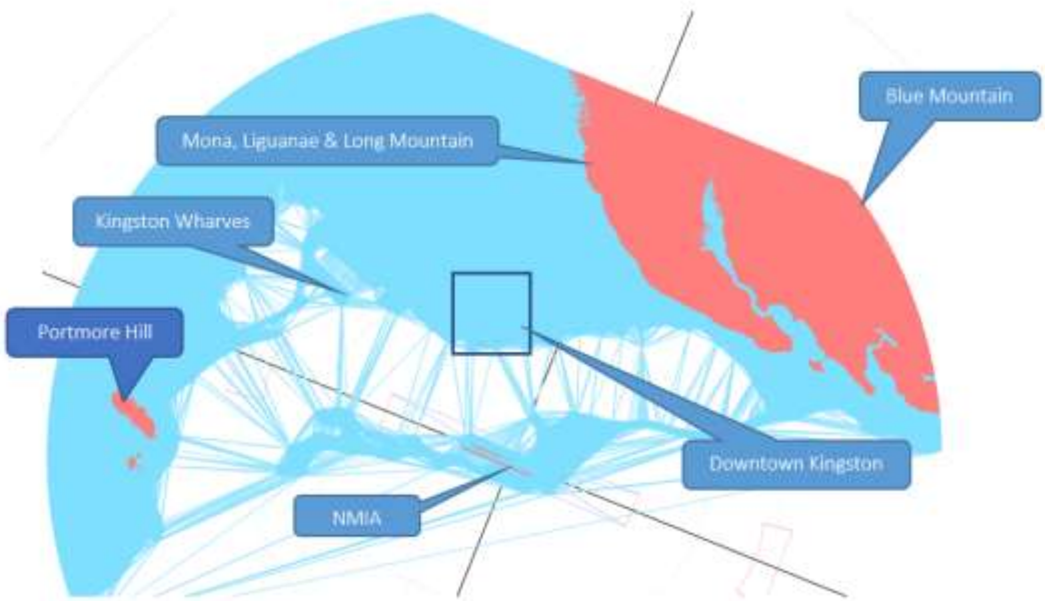


Figure 5.17: Obstacle/Terrain Analysis

The above diagram as seen in Figure 5.17, depicts a tin surface made up of triangular meshes between the 10m by 10m gridded points shown as blue dense lines and the red shaded areas represent possible obstructions. The major terrain obstacles based on the OLS model for the existing runway scenario shows the possible terrain obstacles (natural & man-made features) mostly in the Blue Mountain, Mona, Liguanae, Long Mountain and Portmore hills. Obstacles were also found in the Downtown Kingston, Kingston Wharves and NMIA property. These obstacles were mostly buildings and in the case of the NMIA property was the property fence along the southern edge of the runway. The details of the obstacles found from this visual inspection of the terrain data and the OLS model will be verified in the field as part of the obstacle verification surveys which will then be added to the current OLS and terrain models for further analysis and will be presented in the final obstacle maps. See figures below for a detailed view of the obstacles found.

Figure 5.18: Downtown Kingston Obstacles

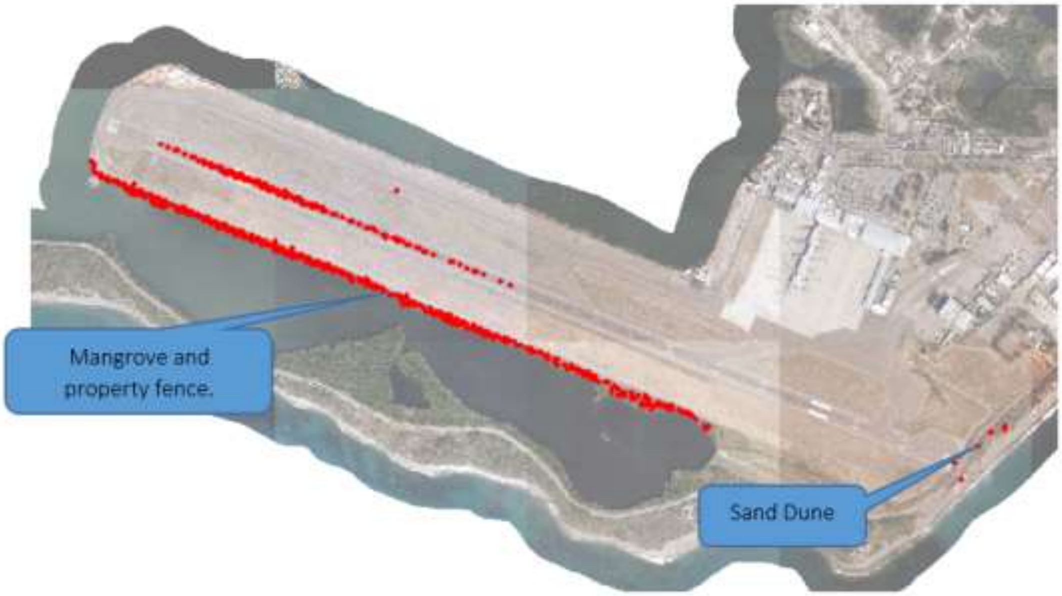


Figure 5.19: NMIA Property Terrain Obstacles

Figure 5.20: Kingston Wharves Obstacle

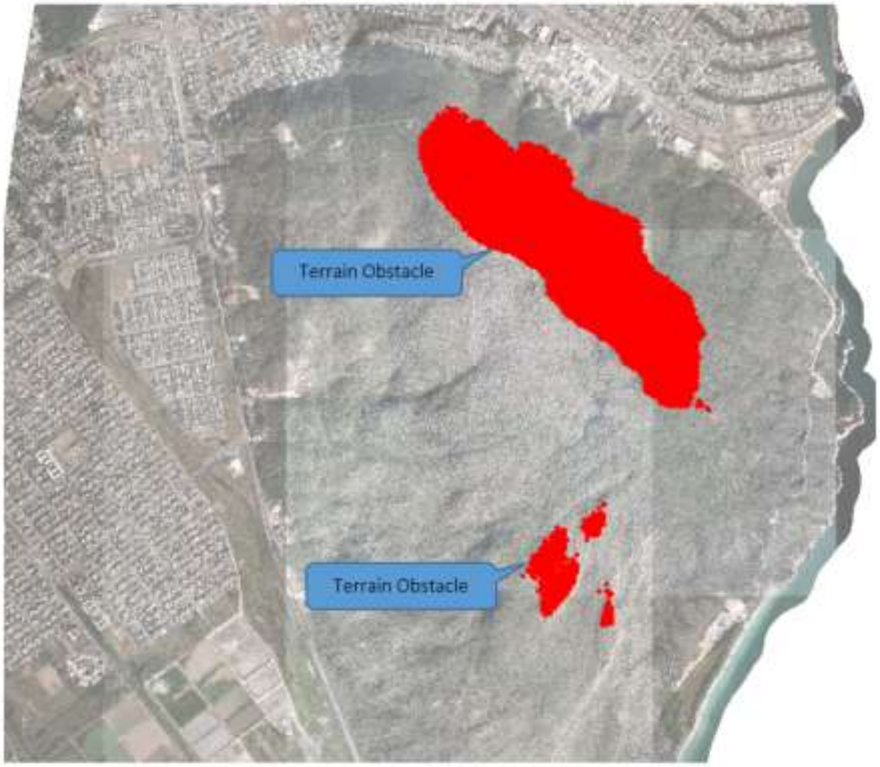


Figure 5.21: Portmore Hill Terrain Obstacle

5.2.7 Summary OLS Definition

The OLS models created were based on two runway scenarios which are, an existing scenario of the runway in its current form and a proposed scenario with a runway extension of 300m to the west. Both models were designed to the ICAO Annex 14, 8th Edition specifications. The OLS models forms as the basis from which terrain and obstacle data maybe evaluated so that obstacles and terrain may be verified as obstacles which penetrate the OLS. The results from the preliminary analysis showed obstacles and terrain obstacles in 6 areas across Kingston and Portmore as seen in Figure 5.17.

5.3 Declination Surveys

5.3.1 Introduction

The Norman Manley International Airport (NMIA) is the main commercial airport serving Kingston and its environs. The Airport accounts for over 1.4 million passenger movements and in excess of 12 million Kilograms of cargo movements per year. It is clear that NMIA is a major contributor to the Jamaican economy and the safety of its employees and clients are paramount.

Declination shows the variation between True North and Magnetic North and changes over time at different rates depending on location and magnetic pull. This survey seeks to determine the declination value as it relates to NMIA runway centerline which may ensure the safe alignment of approaching aircraft while using onboard instrumentation.

5.3.1.1 *Scope of Work*

The surveys carried out are as follows:

1. Determination of the heights of Navigational Aids, Aerodrome Reference Point (ARP)
2. Determination of the runway alignment relative to Magnetic North (Magnetic Bearing).
3. Determination of runway alignment relative to True North.

5.3.2 Survey Methodology

5.3.2.1 *Magnetic Bearing / Compass Observations*

Using a magnetic compass, the magnetic bearing of the runway alignment may be measured and recorded to aid in the calculation of declination of the runway alignment. The equipment used for this survey included: i) 2 Compass Theodolites (Wild T0) and ii) Topcon Hiper II GPS

The first aspect of this survey involved the definition of the center line of the runway. Marks were found at both ends and in the middle of the runway similar to that see in Figure 5.22. These marks were checked and found to define the center line of the runway.

Figure 5.22: Typical survey mark at ends of runway alignment

Two (2) Wild T0 theodolites were temporarily adjusted over the centerline marks found at the ends of the runway thresholds, where each instrument observed the centerline by direct observation to each other over the runway distance of 2.7 km. Observations were done in the early morning so as to eliminate atmospheric effects such as hazing which may introduce errors while making observations. Each instrument observed the runway centerline magnetic bearing for six (6) rounds ensuring that measurements were taken on both face right and left of the instrument. This redundant measurement of observing at 6 rounds from each end of the runway increases the probability of the most probable value (MPV) of the observed magnetic bearing to be closer to the true magnetic bearing of the runway centerline.

Figure 5.23: Wild T0 Instrument Setup at runway 12

5.3.2.2 *Compass Survey Results*

Statistical analysis was done on the raw compass readings for deriving the most probable value (MPV) of the observed bearings. See Table 5.14 and Table 5.15 for statistical results of the compass observations.

Table 5.14: Compass Observations from Runway 30 to Runway 12

Raw Observations					
Direction	**Face**	**D**	**M**	**S**	**D.D**
30-12	**FL**	299	15	40	299.2611
	FR	119	58	50	119.9806
	FL	299	47	20	299.7889
	FR	119	46	10	119.7694
	FL	299	33	40	299.5611
	FR	119	56	50	119.9472
	FL	299	56	50	299.9472
	FR	119	47	10	119.7861

Table 5.15: Compass Observations from Runway 12 to Runway 30

Raw Observations					
Direction	**Face**	**D**	**M**	**S**	**D.D**
12-30	**FR**	300	13	55	300.2319
	FL	120	14	55	120.2486
	FR	300	13	55	300.2319
	FL	120	11	42	120.195
	FR	300	11	50	300.1972
	FL	120	7	55	120.1319
	FR	300	10	40	300.1778
	FL	120	7	40	120.1278

5.3.2.3 *GPS Observations*

The runway alignment observed by GPS was done to acquire the position of the runway alignment relative to True North. The GPS observation method used was static survey where a receiver was used as a based positioned over a known station and with a rover positioned at the runway ends and ARP. The observation time for each point had a minimum observation time of 45mins as the baseline to the known station was relatively short.

Two (2) known marks were established by the United States Geodetic Organization and were used to observe the positions of the three (3) points defining the center line of the runway.

The instrument being used as base was set up on each known station established by the United States Geodetic Organization (MKJPC & MKJPB). Observations for the runway centerline were observed using two know stations as a redundancy measure which increased the confidence of the positions of the observed marks.

Figure 5:5.24 Image of MKJPC known Station

Figure 5.25 Image of Base Station Receiver Setup

The instrument being used as Rover was set up on each point defining the centre line of the runway. (THEAST, THWEST & ARP). Observations were done simultaneously by both Rover and master in static mode for half an hour. This procedure was repeated for each of two (2) known stations

5.3.2.4 *GPS Observation Results*

Using GPS static surveying technique, the following geographic coordinates were computed from the processed and adjusted observed runway data, see Table 5.16. Using Trimble Business Center, the static data was processed to eliminate or minimize residual errors for coordinating the precise locations of the ends of the runway and the airports Aerodrome Reference Point (ARP).

Table 5.16: GPS Observation Geographic Positions

Point ID	Latitude	Longitude
MKJPB	N17°55'50.32829"	W76°46'35.22066"
MKJPC	N17°56'15.96262"	W76°47'41.37110"
THEAST	N17°55'51.95284"	W76°46'32.55598"
ARP	N17°56'08.43188"	W76°47'15.14263"
THWEST	N17°56'24.90969"	W76°47'57.72844"

5.3.3 Results

As previously stated in 5.3.1, Declination shows the variation between True North and Magnetic North. In order to execute the necessary declination values the magnetic bearing of the runway needs to be subtracted from geodetic azimuth of the runway resulting in the declination value of the runway. It should be note that the geodetic azimuth is derived from the orientation of the runway alignment based on the static survey observations. The calculation for the geodetic azimuth was done using Trimble Business Center. Based on the observed compass readings and the geographic coordinates of the runway ends, the calculated declination for the runway alignment (30-12) is 7° 57' 48" West.

Table 5.17 Computational Analysis of Raw Observation Data

Instrument Setup		AVG	Difference	Error			
Dir.	**Face**	**D.D**	**D.D**	**D.D**	**D**	**M**	**S**
12-30	FR	**300.2097**	180.03389	-0.03389	0	-2	-2
	FL	**120.1758**					
Instrument Setup		**AVG**	**Difference**	**Error**			
Dir.	**Face**	**D.D**	**D.D**	**D.D**	**D**	**M**	**S**
30-12	FR	**299.6396**	179.76875	0.23125	0	13	52
	FL	**119.8708**					

Table 5.18 Declination Calculation

Magnetic Bearing M.P.V				
Dir.	**D.D**	**D**	**M**	**S**
30-12	299.9247	299	55	29
12-30	120.0233	120	1	24
Geodetic Azimuth				
Dir.	**D.D**	**D**	**M**	**S**
30-12	292.0142	292	0	51
12-30	112.0069	112	0	25
Declination				
Dir.	**D.D**	**D**	**M**	**S**
30-12	7.910486	7	54	38
12-30	8.016389	8	0	59

Table 5.19 Average Declination Value of NMIA Runway Centerline

Avg Declination			
D.D	**D**	**M**	**S**
7.963438	7	57	48

Magnetic Declination = 7° 57’ 48” West

Figure 5.26: Diagram Showing Magnetic Bearing vs Geodetic Azimuth (True North)

5.3.4 Summary of Declination Survey

Two surveys were done in order to calculate the declination value of NMIA runway centerline. The first survey was done using a magnetic theodolite which resulted in the magnetic bearing of the runway while the second survey was a GNSS Static survey which resulted in the geographic coordinates of the runway center line which is relative to True North. The difference between the results of the two surveys yielded the declination value of the runway centerline and was found to be 7° 57’ 48” West.

5.4 Navigational Aids

The Navigational aids comprises mainly of lighting features on and around the runway. Other navigational features to note are the runway markings, taxiway markings, VOR, air traffic control tower and ARP. The horizontal positions for these features were derives from highly accurate orthomosaic aerial imagery that was flown in January of the year 2020. The vertical elevations were derived from the LiDar survey data. Both vertical and horizontal data meet the national specification of positional accuracy of being within 0.1m accuracy. See below

Figure 5.27: Diagram of Existing Navigational Aids

See appendix for detailed position of navigational aids.

5.5 LIDAR Calibration Report

5.5.1 *Acquisition Parameters and Technologies*:

Kucera International Inc. under contract with CEAC Solutions performed a manned aerial LiDar survey covering designated Area 2C (11026 hectares) surrounding NIMA in support of obstacle and navigational aid identification and analysis work. The aerial LiDar flyover was accomplished on January 24, 25, 26, 28, 29 and 30, 2020 using a Leica ALS80 1 MHz aerial LiDar system (serial no. 8228) operated from Kucera's Piper Navajo Chieftain twin-engine aircraft no. 4102J. A manufacturer calibration report for the ALS80 system is provided in the Appendix. An index to the flight line coverage for each flight day is shown below:

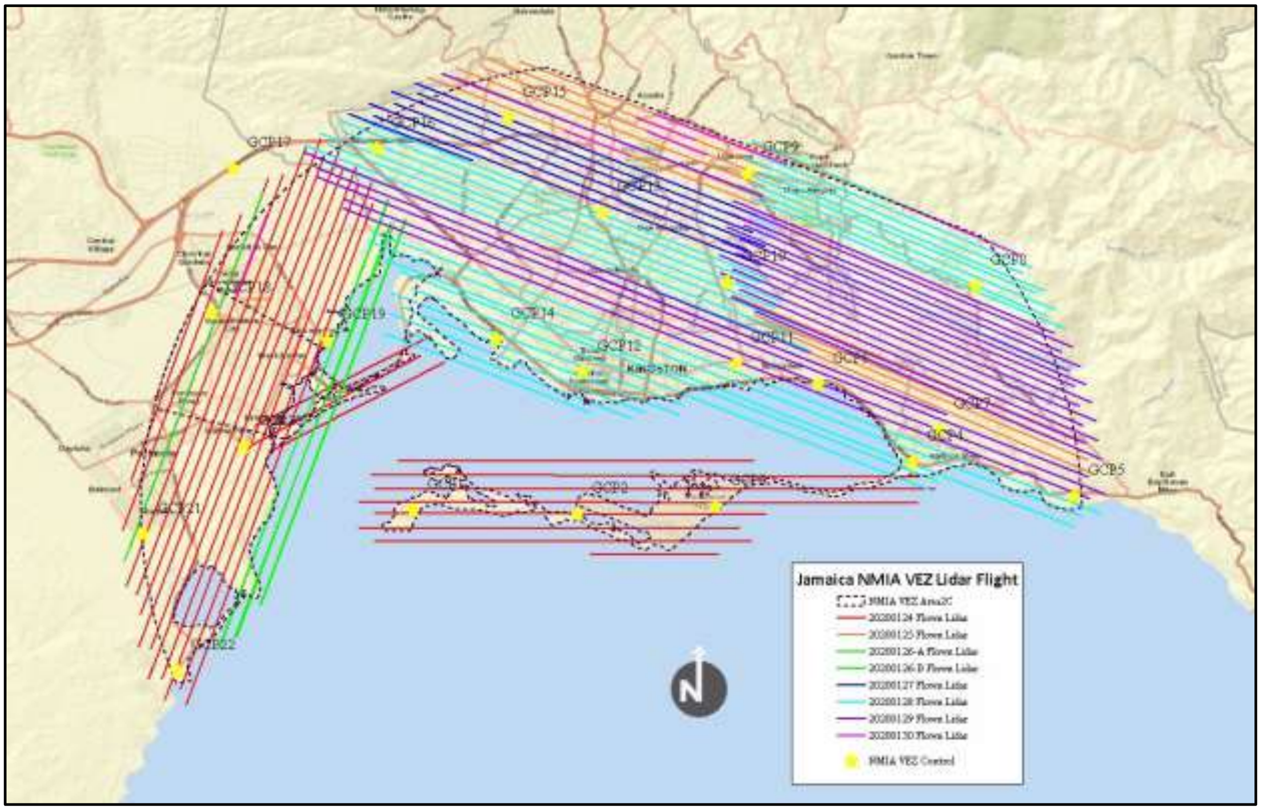


Figure 5.28 Flight lines illustrating data collection missions

Flight and operational settings/parameters within the following ranges were used to maintain 5-10 ppsm LiDar return capture density throughout Area 2C:

Table 5.20 Flight specifications used to maintain 5-10 ppsm LiDAR density

PARAMETER	VALUE	UNIT
Flight altitude	1200-2000	m AGL
Aircraft speed	150	knots
Scan FOV	11 - 40	degrees
Scan Rate	52-71	Hz

Pulse Rate	422-582	KHz
Sidelap/line spacing	30-60% / 900-1100	m
Swath width	365-1000	m
Raw point spacing	0.3 m / 5-10	ppsm

5.5.2 Post-Processing: Calibration, Georeferencing, Accuracy

The captured LiDar return was calibrated, georeferenced and classified using TerraSolid and GeoCue LiDar processing software. The calibration process determined boresight alignment angles from system IMU measurements and capture swath offsets between alternate direction flight strips for adjustment of system shift and drift parameters, with a relative accuracy between adjusted flight swaths within 15 cm being achieved. The calibration process and results were normal with no issues or anomalies encountered. The calibrated LiDar was georeferenced to system-based and TerraPOS PPP-processed airborne GPS/IMU measurements, with final adjustment to measured ground control points distributed through the 2C project area. The primary adjustment datums are JAD2001 vertical, EGM2008 horizontal with meter units. Absolute accuracy of ground return achieved are reported below:

Table 5.21 Summary of ground return absolute accuracy

PARAMETER	VALUE	UNIT
Average dz	+0.004	m
Minimum dz	-0.041	m
Maximum dz	+0.056	m
Average magnitude	0.027	m
Root mean square	0.031	m
Std deviation	0.031	m

The georeferenced return was processed/classified to yield Class 2 ground and Class 1 non-ground return, and first return. The full classified return and first return was provided in ASCII and LAS formats. From the classified return a 1m cell raster ground digital elevation model (DEM) and ground + first return surface elevation model (SEM) were produced and furnished in WGS84 and JAD2001 vertical datums for the obstacle/navigational aid identification/analysis work.

5.6 Recommendations for Future Surveys

Recently introduced aerial LiDar systems such the Leica Terrain Mapper and Optech Galaxy Prime have a higher (2 MHz) maximum pulse rate, terrain tracking capability to maintain high point density in mountainous areas, and greater oblique-looking return - all of which could be used for this survey to achieve greater point density and obstacle + ground feature return. With these systems a return density of 20 ppsm can be time and cost-effectively achieved, which would provide greater feature classification capability and support accurate modeling of the various project area surfaces. For this project a ground return elevation accuracy within 0.1m is readily achievable guided by the specifications summarized in Table 5.20.

6 Climate Change Scenarios and Vulnerability Report

6.1 Background and Scope of Work

As apart a part of the NMIA Various Environmental, Zoning and other Baseline Studies, an assessment was undertaken to analyze the current and future climate change situation at NMIA. Preliminary research indicated that the study area has been vulnerable to hurricane waves, short-term storm events and erosion. It is therefore important to determine the effects that extreme waves and storm surges have on the area to help the agency determine the feasibility of the development. The following are the main objectives of the study:

1. A literature review to capture an understanding of the current situation at NMIA. Studies reviewed focused on NMIA and how the climate affects its environs and operations. This section fulfils the requirements of the Terms of Reference (TOR) which stipulates that previous environmental studies done by NMIA are to be reviewed.
2. A qualitative analysis to examine the relationship between storm surges elevation heights and hurricane intensity and location. Worst case hurricane tracks in modelling storm surge in light of climate change and variability should be considered. It is usual now to consider probabilistic worst-case tracks in planning and historical track in design.
3. Conducting a wave climate study to assess the risks associated with the site under hurricane and storm surges.
4. A combination of global and regional models was used to retrieve; sea level and hurricane predictions. These models generated future climate of the NMIA area under agreed Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP) scenarios.
5. The vulnerability assessment to assess the assets most likely to be affected by storm surge and sea level rise and from perturbations in the climate.

CEAC was commissioned by NMIA to produce a climate change studies report under activity 2.6. The results of the studies conducted is expected to aid in identifying the most suitable floor heights. The scope of works includes but not limited to:

1. Data Collection: Drainage survey at the Airport, Anecdotal survey and Sediment grain size analysis of the beach face and berm at three locations
2. The findings and analysis will be prepared and submitted to the client. To include but not limited to:
    - Description of the environment;
    - Storm Surge and Wave Studies;
    - Shoreline vulnerability (erosion);
3. Vulnerability assessment to identify the vulnerable facilities/ locations at NMIA.

6.2 Data Review and Collation

6.2.1 Historical Databases: storm surge, hurricanes and erosion

6.2.1.1 *Similar Shoreline Projects in the Area*

Studies conducted in the project area indicated that the Palisadoes Shoreline area is prone to flooding from storm surge and over-land flow during storm events. Additionally, wave action has resulted in erosion of the shoreline. Although, sections showing signs of growth. The previous studies in the project area are summarized herein:

6.2.1.1.1 Palisadoes Shoreline Protection Works (2008-2012)

6.2.1.1.1.1 Purpose of study

In 2008 the National Works Agency (NWA) was tasked with the responsibility of designing a method of restoring the stability of the Palisadoes Tombolo with a combination of revetments and dunes.

1. Revetment protection involved: i) 4 to 11 Ton armour stone with a crest elevation of 6.4 meters and ii) a buried revetment for the core of a dune structure.
2. Dune rehabilitation involved: i) dredging a burrow area close to the shore of the Caribbean Sea side of the Palisadoes and ii) using this material to place dunes along the shoreline. Also, to replant and restore as much as possible the native vegetation as a result of the removal of coastal vegetation during the revetments construction along Harbour Side of the Palisadoes. Both were designed to meet the 1 in 100-year return period deep water wave conditions, a project life up to 2050 (37 years), and climate change factors for the SRES A1B or A1 scenario up to the design life.

6.2.1.1.1.2 Long Term Erosion Trends

The historical model indicated a general trend of accretion between 1991 and 2013, except for between 2002 and 2006.The significant erosion observed can be attributed to the passage of Hurricane Charley (August 2004) and Hurricane Ivan (September 2004). Both hurricanes passed to the south of the island with Charley being a category 1 and Ivan category 4 at the time of passing. The coastline is naturally growing, the rate at which it is growing is reduced by the effect of sea level rise. According to the Brunn model the rate of shoreline change for the Palisadoes is 0.21 m/year while the historical analysis determined a rate between 0.2 m/year and 1.4 m/year.

6.2.1.1.1.3 Wave Climate

The extremal analysis results indicated that the 100-year return period event has a wave height of 7.6 m for south eastern waves. Overall, these are relatively large waves with potential for causing severe damage along the shoreline. Their potential resulting near shore climates were investigated using a wave refraction and diffraction model as outlined in the following section.

6.2.1.1.2 NMIA Revetment (2017)

6.2.1.1.2.1 Purpose of study

The Norman Manley International Airport (NMIA) as per its 20 Year Master Plan has aimed to reduce the vulnerability associated with the airport. Historically, the NMIA Airport is vulnerable to hurricane wave attacks, therefore the protection of the associated shoreline is therefore critical to safeguard its contribution to the nation building.

6.2.1.1.2.2 Long Term Erosion Trends

1. Shoreline positions over a number of years were plotted from historical aerial photos (1968 and 1991) and satellite images (from 2010) and compared in order to determine the long-term spatial and temporal erosion trends across the bay. A long-

term trend of **erosion/ shoreline loss of 1.7 to 23.0 metres in the last 42 years**. Global Sea Level rise analysis (using Brunn Rule) indicates that 57% to 100% of this can be explained by sea level rise.

6.2.1.1.2.3 Proposed Shoreline Protection Works

As a result, a revetment was proposed to reduce the vulnerability. The revetment is 1,105 metres long, with 4 to 13 Tonne armour stone and a crest elevation of 6.4 metres above Mean Sea Level which is necessary to resist the 100 Year Return Period wave conditions at the proposed project area of the eastern end of runway for the Norman Manley International Airport.

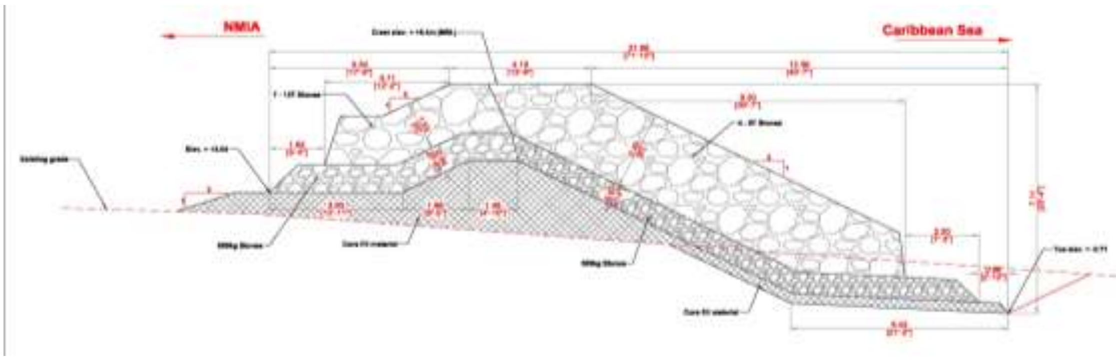
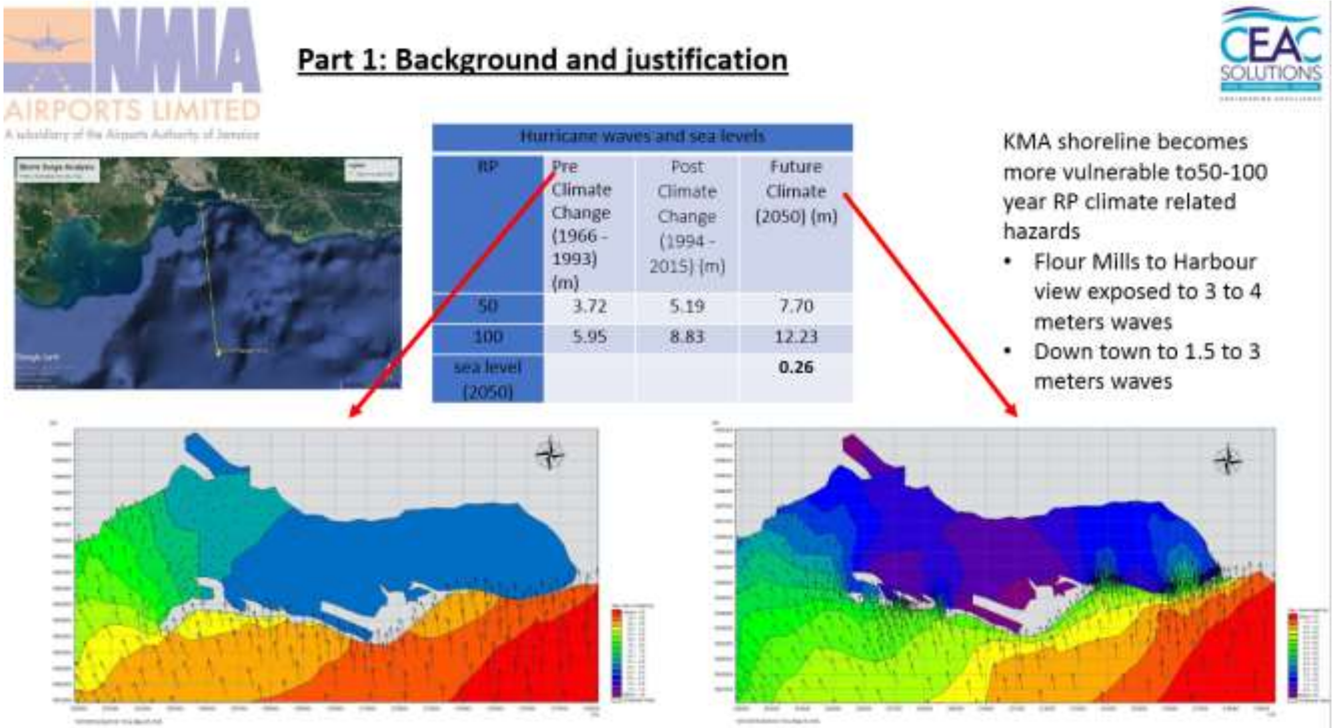


Figure 6.1 NMIA Revetment Proposed

6.2.1.1.3 Global Climate Fund proposal

6.2.1.1.3.1 Purpose of study

Airport Authority of Jamaica (AAJ) in an effort to stabilize the entire Palisadoes shoreline and protect Kingston's shoreline, conceptualized a wide solution to the entire Palisadoes. The proposal aimed to address the vulnerability of the shorelines of Kingston to sea level rise and coastal erosion from Hurricane waves in the future climate



Hurricane waves and sea levels			
RP	Pre Climate Change (1966 - 1993) (m)	Post Climate Change (1994 - 2015) (m)	Future Climate (2050) (m)
50	3.72	5.19	7.70
100	5.95	8.83	12.23
sea level (2050)			**0.26**

Figure 6.2. Vulnerability of Kingston's shoreline in the future climate to sea level rise and increase wave climate intensity

6.2.1.1.3.2 Vulnerability

Kingston's shoreline was determined to be vulnerable to the 100-year RP in the future climate with several breaches to the Palisadoes being anticipated. Three (3) climate change scenarios were simulated to evaluate the shoreline vulnerability of Kingston's shoreline within the harbour. The scenarios are pre-climate change, post climate change and future climate (2050). The Shoreline is moderately susceptible to erosion for both Pre-1993(Scenario 1) and current climate change conditions (Scenario 2), but is highly susceptible to damage for future wave conditions (Scenario 3).

6.2.1.1.3.3 Proposed Solutions

Two solutions were proposed that entailed a mixture of road lifting, sand dunes and revetments. In the section from Port Royal to NMIA: road lifting and sand dunes at +4.5 meters were proposed and in the section between NMIA and Harbour View revetment and dune with crest elevations of 7.0 meters were proposed

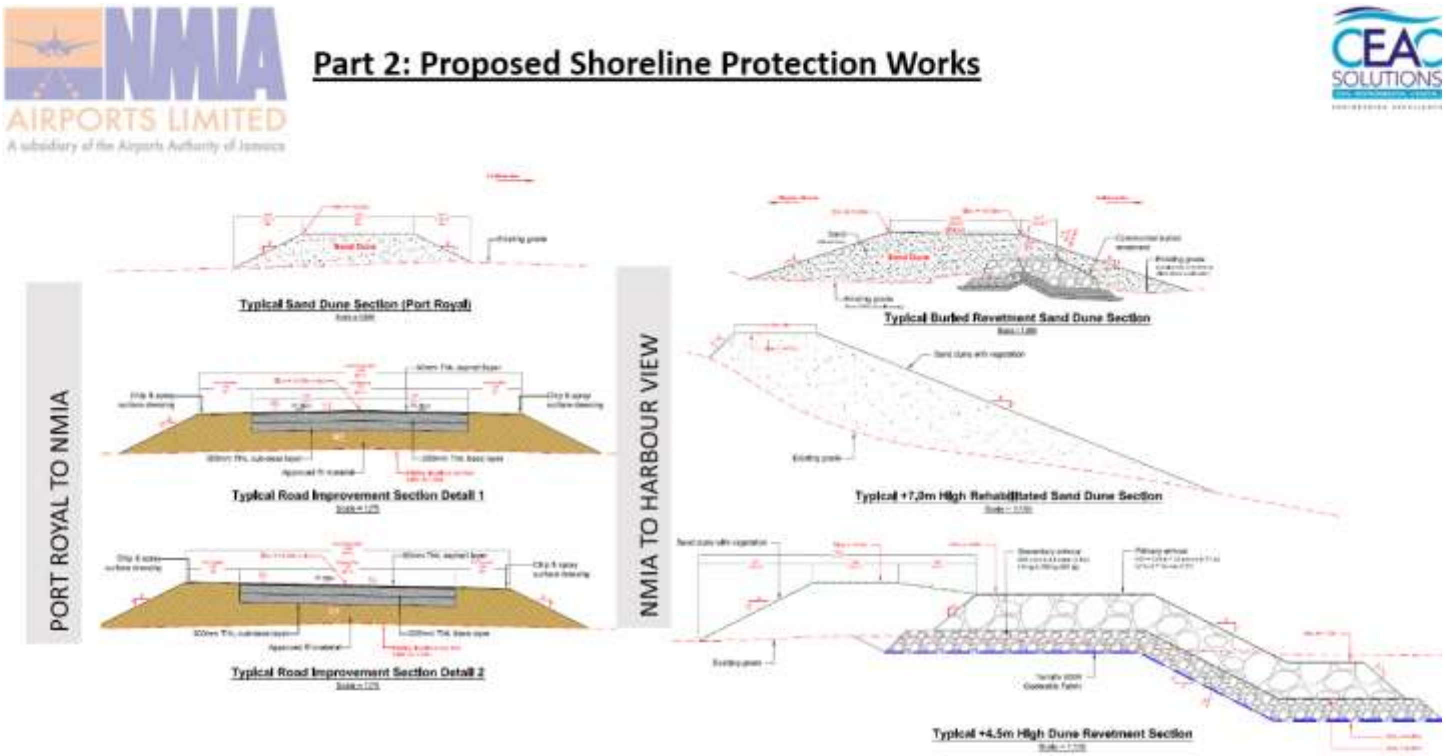


Figure 6.3. Proposed shoreline protection from Port Royal to Harbour View for GCF application

6.2.1.2 *Hazards, Vulnerability and Risk Studies*

6.2.1.2.1 CEAC Vulnerability and Risk Assessment Report for Norman Manley International Airport, 2017

This report was prepared by CEAC Solutions Limited (CEAC) for the Airports Authority of Jamaica (AAJ). Its main purpose was to assess the risks associated with the hazards that would affect the entire length of the project shoreline facing the Caribbean Sea. More focus was however placed along the shoreline adjacent to the end of the runway (Runway 30).

6.2.1.2.2 Background

Both the NMIA as well as the Port Royal Main Road have exhibited signs of vulnerability based on observations and predictions to either coastal erosion, sea level rise (SLR) or storm events. Designs were prepared by the National Works Agency (NWA) as a solution to protect the exposed stretch of shoreline. This design was however not deemed suitable and was revised to meet the criterion of Jamaica Civil Aviation Authority (JCAA) and to have safe limits of overtopping during design storm events.

6.2.1.2.3 Hazard Assessment

Hazard assessment, is executed to identify the hazards that are likely to affect the study area. The assessment yields the nature, frequency and magnitude of hazards as well as spatial occurrence, duration of events and their relationship. The assessment incorporates an anecdotal storm surge survey, a bathymetric survey and numerical storm surge modelling.

6.2.1.2.4 Storm Surge

Storm Surge elevation was analysed under three scenarios; a baseline, a future (2050) and a future + SLR condition, see Table 6.1. Each scenario represents a possible state of the climate that could impact the shoreline. The storm surge was calculated for return periods 5 year to 100 year with result ranging from 0.59 m – 5.19 m, 1.14 m – 5.55 m, 1.26 m – 5.7 m for the baseline, future and future + SLR conditions respectively.

Table 6.1 Predicted Storm surge Elevations (m) for Baseline and with Sea Level Rise

RETURN PERIOD	BASELINE STORM SURGE (m)	FUTURE (2050) (m)	FUTURE (2050) + SLR (m)
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

6.2.1.2.5 Coastal Erosion

Coastal erosion was analysed under two categories; short term and long-term erosion. Short term erosion describes the events that may occur during a short period of time, such as a storm. Long term events are analyzed over a period of years.

The results of the short-term analysis shows 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.
- 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.

The results of the long term analysis indicates that:

- The shoreline from the light house to approximately 450 m east of the runway is eroding at an average rate of 0.14 m to 0.21 m per year.
- The location west of the end of runway is eroding at a rate of 0.1 m to 0.4 m per year.
- The location to the south of the end of runway at a rate of 0.09 m to 0.22 m per year.
- The location east of the end of runway is eroding at a rate of 0.057 m to 0.56 m per year.
- GSLR is estimated to be responsible for approximately 57% to 100% of observed erosion.

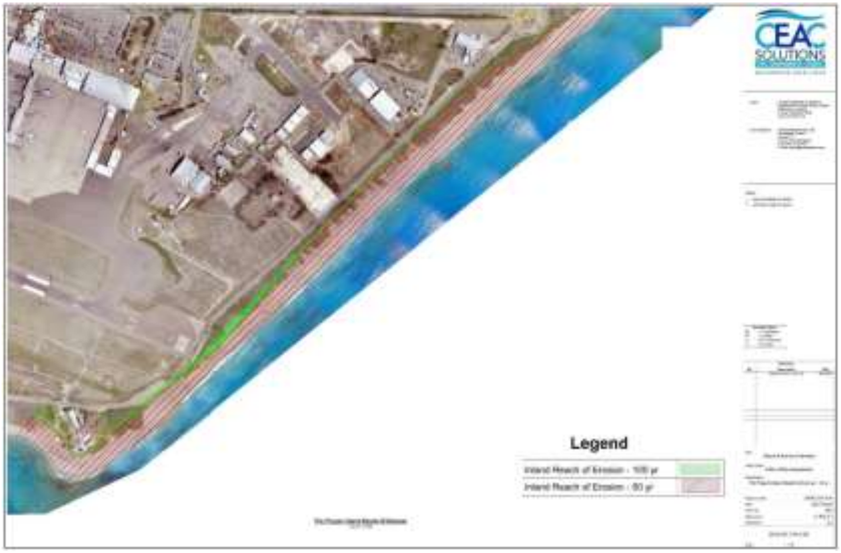


Figure 6.4 Long Term Erosion for the 50- and 100-year storm event

6.2.1.2.6 Exposure Analysis

Exposure analysis defines the interaction between the elements at risk and the hazard's footprint. 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.

NMIA is exposed to storm surge evidently from previous analysis done. The exposure is such that for both baseline and SLR storm surge scenarios the extent of the inundation footprint is 100% for both 50 and 100 year storm events, see Table 6.2. 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 has resulted in the 25-year storm event to produce a predicted inundation footprint of 100% while the 10 year storm event reflects an 85% exposure.

Table 6.2 Number of Buildings Exposed to Storm Surge Hazard

Baseline Storm Surge		
Return Period (Yrs.)	Number of Buildings/Structures	% in Hazard Area
10	88	50%
25	157	89%
50	176	100%
100	176	100%
	Storm Surge with SLR	
10	147	84%
25	176	100%
50	176	100%
100	176	100%

Figure 6.5 Exposure of Airport Assets to 10, 25 and 100 Year Storm Surge Return Period

Along with storm surge NMIA is also vulnerable to wave action of exorbitant heights along the southern shoreline, especially at Runway 30. The Palisadoes stretch is expected to experience wave heights of up to 2.4 m to 3.2 m. Wave heights predicted within the vicinity of Runway 30 will however range from 3.6 m to 4 m. Such waves have the potential to erode the shoreline to extents as seen in Figure 6.6.

Palisadoes Road has historically demonstrated its vulnerability to hazards during the passage of Hurricane Ivan in 2004. The shoreline was deemed to be in a critical state as sediments were deposited within the roadway and parts of the road was inundated rendering the residents of Port Royal stranded. As a result a rock rubble revetment was built along Palisadoes on the Caribbean Sea side. The revetment is comprised of a lower and higher crested design. Although the revetment was designed to reduce the impact of storm surge and wave action it has not been tested by a storm. It is therefore likely that the potential for overtopping, especially at the lower crested end, is possible.

Figure 6.6 Erosion for the 50- and 100-year storm event

6.2.1.2.7 Risk Analysis

The risk analysis was divided into two areas, the direct and indirect losses. Under direct losses storm surge, being the most impactful and of high risk was used to assess the risk associated. The average annualized loss (AAL) was estimated to be J$ 235.1 million while the maximum probable loss for 100-year storm surge is an estimated J$ 8.5 billion. This would cause a serious disruption to the functioning of the airport as well as to the economy, see Table 6.3.

Table 6.3 Storm Surge Risk.

Return Period (Yrs.)	Probability of Annual Exceedance	Maximum Probability Loss (J$)	Average Annualized Loss (J$)
10	0.1	66,840,200	J$ $235,116,603
25	0.04	2,609,051,400	
50	0.02	5,946,321,000	
100	0.01	8,579,307,160	

The risk was also analysed for a direct losses associated with the end of Runway 30. The analysis assessed the potential risk without and with proposed mitigation works to protect Runway 30. The relationship between the two scenarios revealed that there is a potential reduction of 66 % and 80% for the 100 year and 200-year storm events, respectively. Figure 6.7 shows this relationship in a graphical depiction where the blue area is the reduction in risk due to the risk reduction measure, in this case revetments.

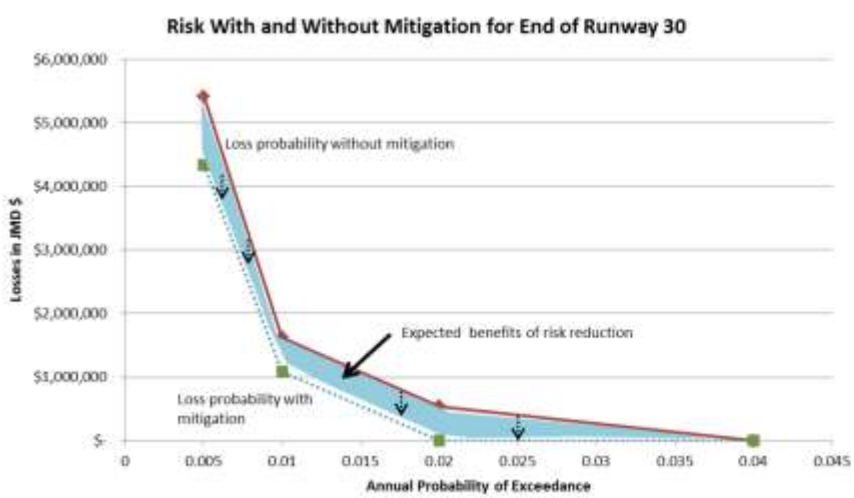


Figure 6.7 Relationship between estimated losses without and with mitigation

The indirect losses, also called functional losses were also assessed in this risk analysis. Functional losses has to do with the interruption of the NMIA. It is calculated by summing the product of average daily budget/sales and downtime with the product of displacement cost/day and displacement time.

Under the assumption that the NMIA lost two days, local 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 is representative of the cumulative economic impact or loss.

6.2.2 Bathymetry and Topographic Data

The approved scope of work for NMIA Hydrodynamic Modelling of Effluent Plume Discharge for the Sewage Treatment Plant, Palisadoes Shoreline Protection and Rehabilitation, NMIA End of Runway Shoreline Protection and Rehabilitation Project and NMIA Wave Climate and Coastal Stabilization called for bathymetric data collection to facilitate the modelling exercise. However, in some instances Bathymetric surveys could not be conducted with the required time period due to rough sea condition, especially on the Caribbean Seaside. Therefore, the bathymetric data for the site was taken from the British Admiralty charts. After analysis of the **existing bathymetric** data at the project site it was deduced that additional data would be needed for the area however the wave climate presents many challenges.

6.2.2.1 *British Admiralty Chart*

The British Admiralty chart No. 465, 459, 456, and 454 were utilized to supplement the detailed bathymetric surveys and for areas nearshore and further offshore. The charts are considered to be a good representation of the areas bathymetry as it is generally updated whenever the survey department conducts surveys in the Harbour and submits the data to the United Kingdom hydrographic office (UKHO).

Data outside of the area was also digitized from the chart to ensure the DEM created was larger than the actual area being modelled, to reduce the possibility of errors introduced by the model boundaries being too close to the active areas. The data was used to create a bathymetric chart of the Bay and a section of the Caribbean Sea on the north coast. See a section of the British Admiralty chart.

6.2.2.2 *CEAC Surveys (2014)*

A bathymetric survey was conducted by CEAC on June 19 and 20th, 2014 at the outfall and dispersion area, using a single beam sonar with autonomous GPS, and it was bench marked to a tide station set up on the shoreline. The surveys were done along predefined gridlines running parallel and perpendicular to the shoreline. Survey lines were set parallel and perpendicular to the shoreline on grid lines with a minimum spacing of 30m, see Figure 6.8 for the survey plan lines.

The project area characterized by depths of 2 to 14 m across the project area. The contours also indicated an area extending to the north-west of the new runway having a (dredged) trench with bottom elevations of -4 to -12m. The outfall pipe extends 42 meters from the shoreline where the diffusers (discharge area) are located within approximately 10-12 meters of water.

Figure 6.8 Survey Lines for the Bathymetric Survey Conducted on June 19 and 20, 2014

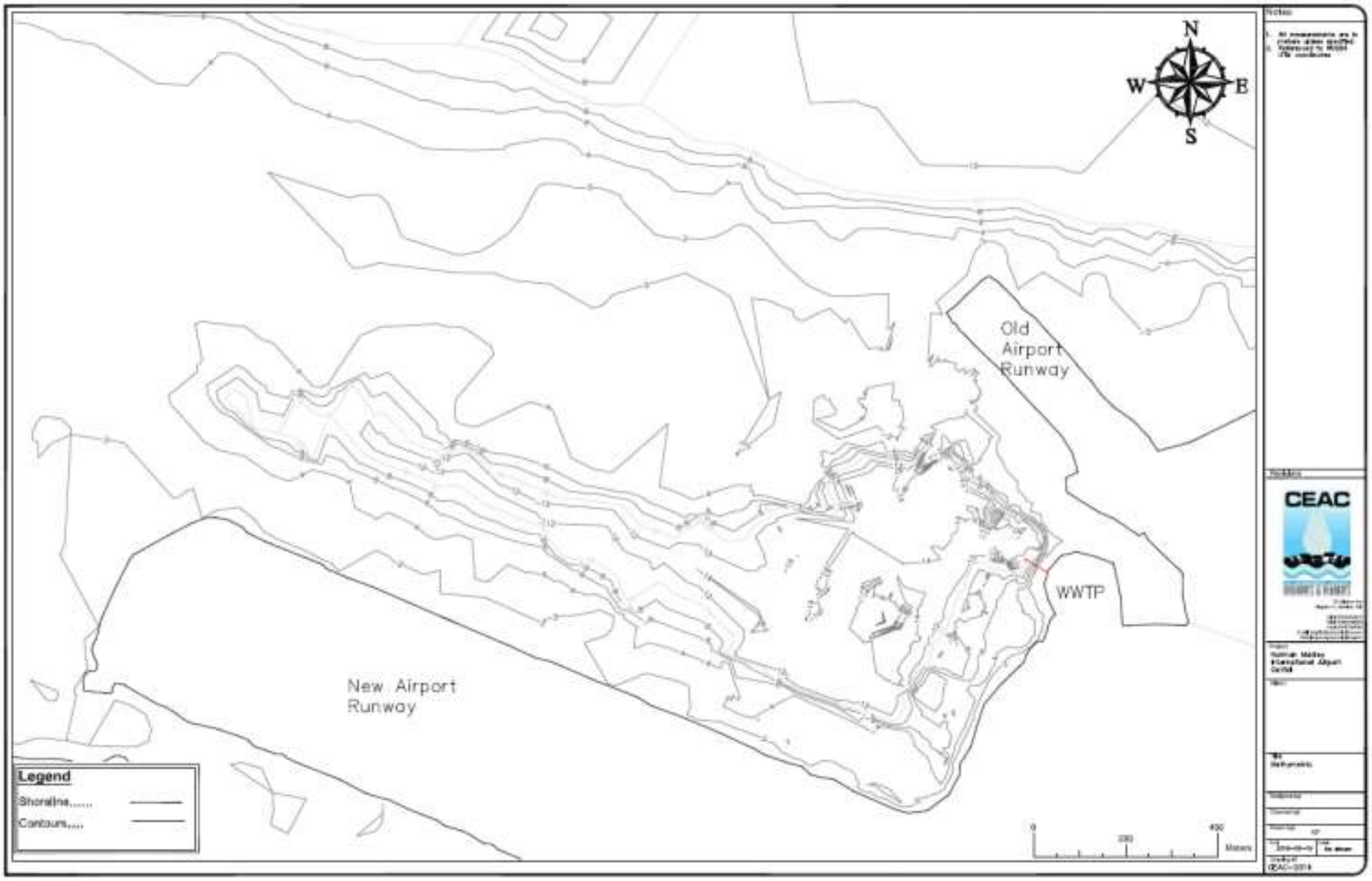


Figure 6.9 Bathymetric survey conducted in 2014

6.2.2.3 *CEAC Surveys (2013)*

A bathymetric survey was conducted by CEAC on November 15th and 20th, 2013 along the Caribbean Sea and harbour side of the Palisadoes. The survey was done to using a Garmin echo sounder along gridlines running parallel and perpendicular to the Caribbean Sea side and harbour side shoreline were followed to collect the bathymetric data. Along the Caribbean Sea side the survey was taken between the NWC treatment plant and the end of the most western low revetment, while the Harbour side survey was taken between Gypsum Quarry and Gun Boat Beach.

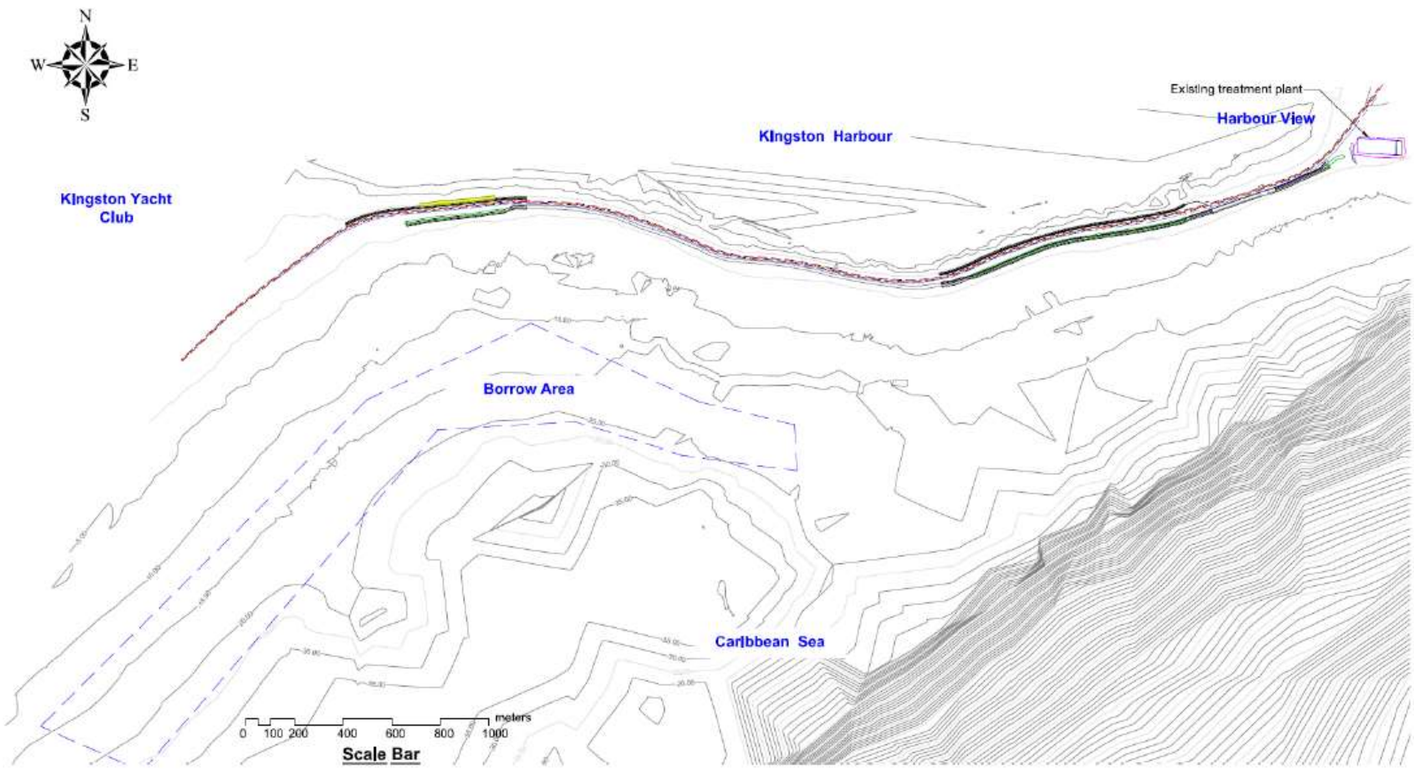


Figure 6.10 Bathymetric chart (2013)

6.2.2.4 *Topographic Surveys (2013)*

As part of the requirements for the NMIA End of Runway Shoreline Protection and Rehabilitation Project in 2013, a topographic survey was required of the dunes for approximately 1,000 metres. The survey was conducted by Gordon and Company Ltd (Commissioned Land Surveyors) from the shoreline (Caribbean Sea) to the road for 1000m stretch of shoreline. The extents of the survey area were offset at 500m to the left and to the right of the end of the runway. See Figure 6.11 below. The survey datum was mean sea level and the projection was JD2001.

The terrain between the shoreline and the road varies from approximately 4.5m to 2m on average when moving from the Queens Warehouse intersection in the north-east to the lighthouse in the south-west. The elevation of the end of the runway is approximately 4.9metres which is almost a metre above the elevation of the dunes. The road elevation within the project area varies from 4.3m in the northeast to 1.1m in the south-west with a sag point at the end of the runway having an average elevation of 0.9m.

Figure 6.11 Topographic survey points along the 1km project area

6.2.2.5 *Topographic Surveys (2017)*

Topographical data for the project area was obtained from an aerial survey conducted during March of 2017. The methodology employed consisted of:

1. Setting out of Twenty (20) ground controls by a commissioned surveyor to reference the aerial survey data to Mean Sea Level (MSL);

2. Conducting the aerial survey of approximately 800 hectares of land at 5 cm accuracy.

Figure 6.12 Ortho-mosaic from aerial survey of NMIA from survey done in March 2020

6.2.3 Grain Size Analysis

6.2.3.1 *Sediment size*

As part of the requirements for the NMIA End of Runway Shoreline Protection and Rehabilitation Project in 2013, a grain size analysis was conducted on the Caribbean Seaside of the project area. Surface sediment samples were recovered from the project area at eight locations along the beach/shoreline. A Global Positioning Point (GPS) waypoint was taken with a *Garmin 530HCx* hand held device at each point to mark the location. See Figure 6.13 below for the sediment sample location points. However, a gap in the data was identified which is no sediment samples were taken inside of the harbour.

Figure 6.13 Sediment sample locations

Grain size analysis of these samples was conducted and the results of this analysis are summarized in Figure 6.14 and Table 6.4.

The grain size analysis was done using the unified classification which is widely used for classification of granular material. The sand sizes varied from coarse sands to gravel based on their mean grain size. Figure 6.14 shows all of the samples are within the coarse range for sand. Three of the samples did not reach the 100% finer as they required sieve sizes larger than the # 4 (4.75mm) sieve. Based on the unified classification system, the descriptions of the samples range from coarse sand to gravel.

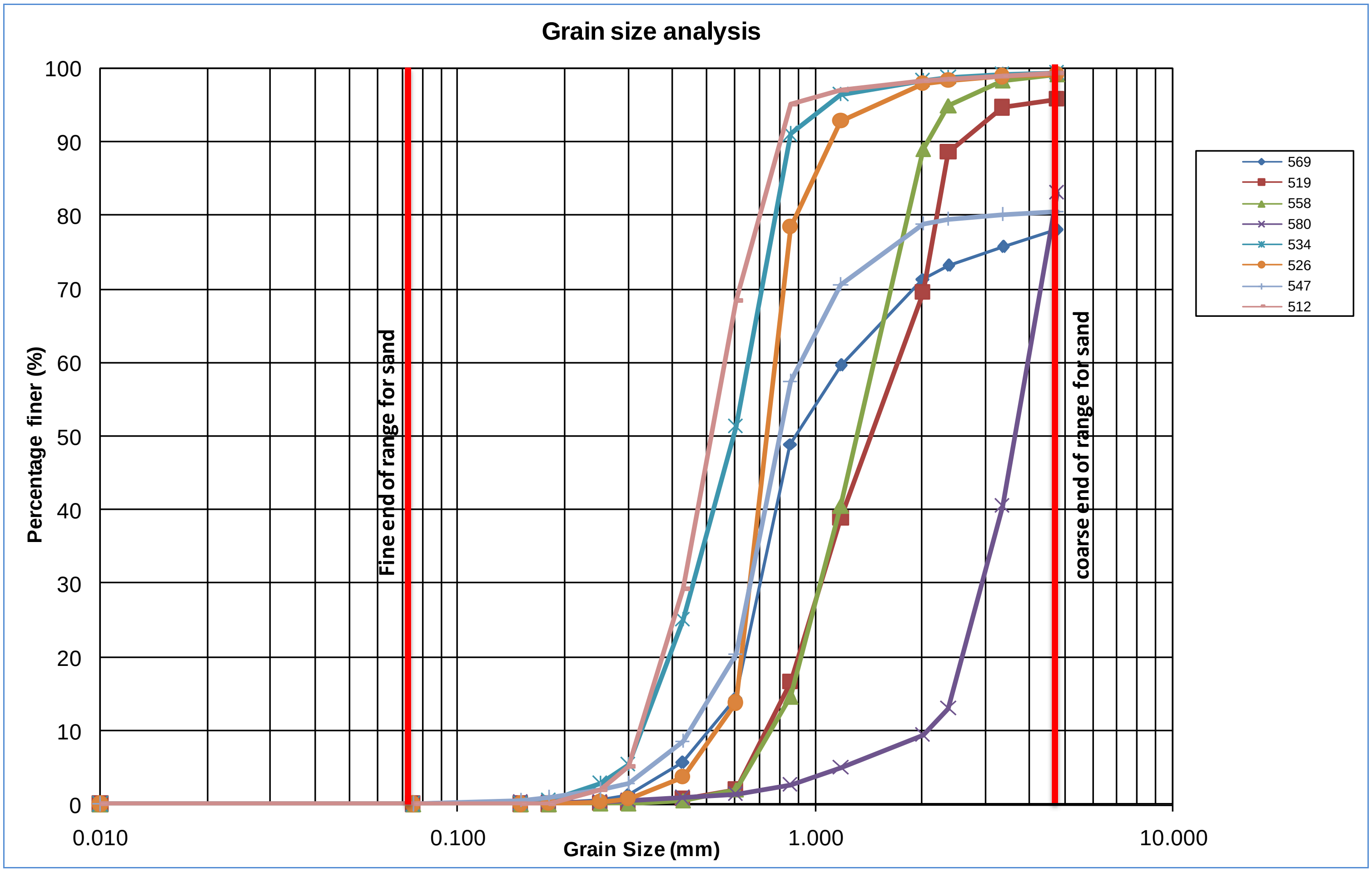


Figure 6.14 Sieve analysis results

Table 6.4 Grain size analysis on beach sand samples east and west of the end of the runway

Sample ID	**569**	**558**	**580**	**534**	**526**	**547**	**512**	**519**
Location (Relative to runway)	**East**	**East**	**East**	**West**	**West**	**West**	**West**	**West**
GRAIN SIZE ANALYSIS RESULTS								
Mean (mm)	0.880	1.339	3.660	0.591	0.740	0.799	0.518	1.477
Mean (phi)	0.184	-0.421	-1.872	0.759	0.435	0.324	0.950	-0.562
Description	coarse sand	very coarse sand	gravel	coarse sand	coarse sand	coarse sand	coarse sand	very coarse sand
Percentage silt	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Percentage >0.06mm and <6.0 mm	78%	99%	83%	100%	99%	81%	99%	96%
Uniformity Coefficient	2.350	1.992	1.940	1.989	1.458	2.047	1.728	2.371
Standard Deviation	-	0.565	-	0.571	0.436	-	0.494	0.739
	extremelely poorly sorted	moderately well sorted	extremelely poorly sorted	moderately well sorted	well sorted	extremelely poorly sorted	well sorted	moderately sorted
Skewness	-	-0.631	-	1.483	1.106	-	1.820	-0.740
	V. strongly positive skewed	strongly negative skewed	V. strongly positive skewed	strongly positive skewed	strongly positive skewed	V. strongly positive skewed	strongly positive skewed	strongly negative skewed
Kurtosis	-	0.894	-	0.950	1.898	-	0.864	0.924
	extremely leptokurtic	platykurtic	extremely leptokurtic	mesokurtic	very leptokurtic	extremely leptokurtic	platykurtic	mesokurtic

6.2.3.2 *Uniformity coefficient*

The uniformity coefficient is a measure of the variation in particle sizes. It is defined as the ratio of the size of particle that has 60 percent of the material finer than itself, to the size of the particle that has 10 percent finer than itself.

The uniformity coefficient is calculated as $U_c = D_{60}/D_{10}$

Where U_c – uniformity coefficient

D_{60} - The grain size, in mm, for which 60% by weight of a soil sample is finer
D_{10} - The grain size, in mm, for which 10% by weight of a soil sample is finer

Within the unified classification system, the sand is well graded if U_c is greater than or equal to 6. All the samples analyzed had uniformity coefficient much less than 6 and are therefore not well graded. The soils can be classified as sorted. This is indicative of wave energy suspending finer particles and removing them offshore and depositing coarser particles on shore.

6.2.3.3 *Standard Deviation*

The Standard deviation is a measure of the degree of sorting of the particles in the sample. A standard deviation of one or less defines a sample that is well sorted while values above one are poorly sorted.

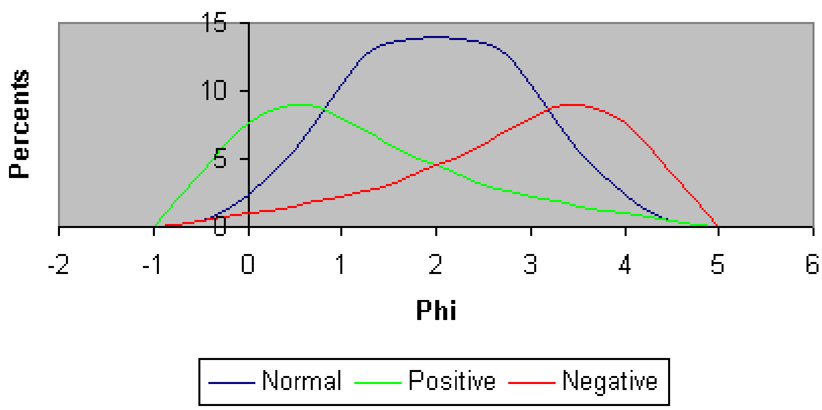
Three of the eight or 37.5 percent of the samples were extremely poorly sorted while the remainder varied from moderately to well sorted. Two of the three extremely poorly sorted samples were to the far west of the end of the runway while the third was the closest to the west of the end of the runway.
This is indicative of increased energy at different point of the shoreline, highlighting the fact wave energy is being focused on different areas of the shoreline.

6.2.3.4 *Skewness*

Skewness describes the shift in the distribution about the normal. The skewness is described by the equation:

$$S = \frac{\phi 84 + \phi 16 - 2(\phi 50)}{2(\phi 84 - \phi 16)} + \frac{\phi 95 + \phi 5 - 2(\phi 50)}{2(\phi 95 - \phi 5)}$$

This formula simply averages the skewness obtained using the 16 phi and 84 phi points with the skewness obtained by using the 5 phi and 95 phi points, both determined by exactly the same principle. This is the best skewness measure to use because it determines the skewness of the "tails" of the curve, not just the central portion, and the "tails" are just where the most critical differences between samples lie. Furthermore, it is geometrically independent of the sorting of the sample.



Symmetrical curves have skewness=0.00; those with excess fine material (a tail to the right) have positive skewness and those with excess coarse material (a tail to the left) have negative skewness. The more the skewness value departs from 0.00, the greater the degree of asymmetry. The following verbal limits on skewness are suggested: for values of skewness:

Values from	To	Mathematically:	Graphically Skewed to the:
+1.00	+0.30	Strongly positive skewed	Very Negative phi values, coarse
+0.30	+0.10	Positive skewed	Negative phi values
+0.10	- 0.10	Near symmetrical	Symmetrical
- 0.10	- 0.30	Negative skewed	Positive phi values
- 0.30	- 1.00	Strongly negative skewed	Very Positive phi values, fine

The results for skewness for the stretch of shoreline can be summarized as follows:

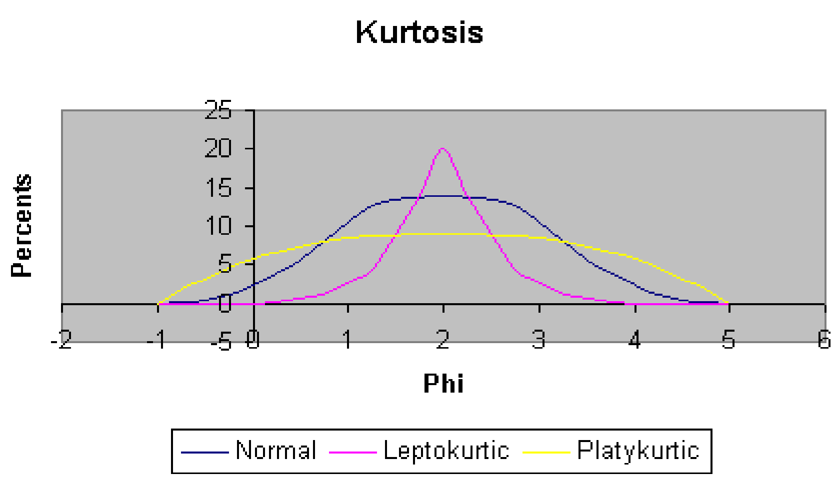
1 Two of the five samples ranged from strong to very strong negative skewness. This is indicative of a coarse tail and an aggressive wave climate at the shoreline that washes out the fines at these locations.

2 Three of the five samples had very strongly positive skewness indicative of locations with moderate wave climates allowing fines to remain on the beach.

6.2.3.5 *Kurtosis*

Kurtosis describes the degree of peakedness or departure from the "normal" frequency or cumulative curve

In the normal probability curve, defined by the Gaussian formula; the phi diameter interval between the 5 phi and 95 phi points should be exactly 2.44 times the phi diameter interval between the 25 phi and 75 phi points. If the sample curve plots as a straight line on probability paper (i.e., if it follows the normal curve), this ratio will be obeyed and we say it has normal kurtosis (1.00). Departure from a straight line will alter this ratio, and kurtosis is the quantitative measure used to describe this departure from normality. It measures the ratio between the sorting in the "tails" of the curve and the sorting in the central portion. If the central portion is better sorted than the tails, the curve is said to be excessively peaked or leptokurtic; if the tails are better sorted than the central portion, the curve is deficiently or flat-peaked and platykurtic.



Strongly platykurtic curves are often bimodal with sub-equal amounts of the two modes; these plot out as a two-peaked frequency curve, with the sag in the middle of the two peaks accounting for its platykurtic character. For normal curves, kurtosis equals 1.00. Leptokurtic curves have a kurtosis over 1.00 (for example a curve with kurtosis=2.00 has exactly twice as large a spread in the tails as it should have, hence it is less well sorted in the tails than in the central portion); and platykurtic have kurtosis under 1.00. Kurtosis involves a ratio of spreads; hence it is a pure number and should not be written with a phi attached. The following verbal limits are suggested for values of kurtosis:

Values from	To	Equal
0.41	0.67	very platykurtic
0.67	0.90	platykurtic
0.90	1.11	mesokurtic
1.10	1.50	leptokurtic
1.50	3.00	very leptokurtic
3.00	∞	extremely leptokurtic

The results for kurtosis for the stretch of shoreline can be summarized as follows:

1. Two of the five samples are platykurtic. This is indicative of a flat top or sediments that are well graded.
2. Three of the five samples are leptokurtic. This is indicative of a flat top or sediments that are well sorted

6.2.4 Sediments and Grain size Analysis (Harbour side)

6.2.4.1 *Sampling*

As mention in section 6.2.3, a gran size analysis has never been conducted for the Harbour side, therefore this sections aims to fill the gap in the data. Sand samples were collected along the shoreline on April 1st, 2020 to determine the representative grain size in order to assess the impacts of the waves on the coastline (beach). Three (3) samples were collected in the project area: i) in the swash zone and ii) at the berm (backshore) at approximately 150 millimetres below the surface to windblown sediments. Samples were collected and analysed to identify the representative grain size and distribution. See Figure 6.15 below for the sand sample locations along the shoreline. However, a limitation was presented in the data collection phase due to areas of the shoreline being inaccessible, therefore causing samples collection to be restricted to the boat house and fire station region.

Figure 6.15 Sediment samples taken along the shoreline in the vicinity of the project site

6.2.4.2 *Results*

A sieve analysis was done using the unified classification system. The sand sizes at the swash zone and berm can be classified as gravel with grain sizes ranging from 2.737 to 4.662 mm. There was no silt content present in either of the samples. Result of the analysis is represented in

Table 6.5.

Table 6.5 Grain Size Analysis Results

Location on beach cross section	Location 1	Location 2	Location 3
Mean Grainsize (mm)	3.472	4.662	2.736
Mean (phi)	-1.796	-2.221	-1.452
Description	gravel	gravel	gravel
Percentage silt	0.00%	0.00%	0.0%
Percentage >0.06mm and <6.0 mm	59%	51%	87%
Uniformity Coefficient	7.337	4.474	2.580
Standard Deviation	0.825	0.462	0.900
	moderately sorted	well sorted	moderately sorted
Skewness	13.484	-4.378	-1.676
	strongly positive skewed	strongly positive skewed	strongly positive skewed
Kurtosis	0.030	-0.218	1.204
	extremely leptokurtic	extremely leptokurtic	leptokurtic

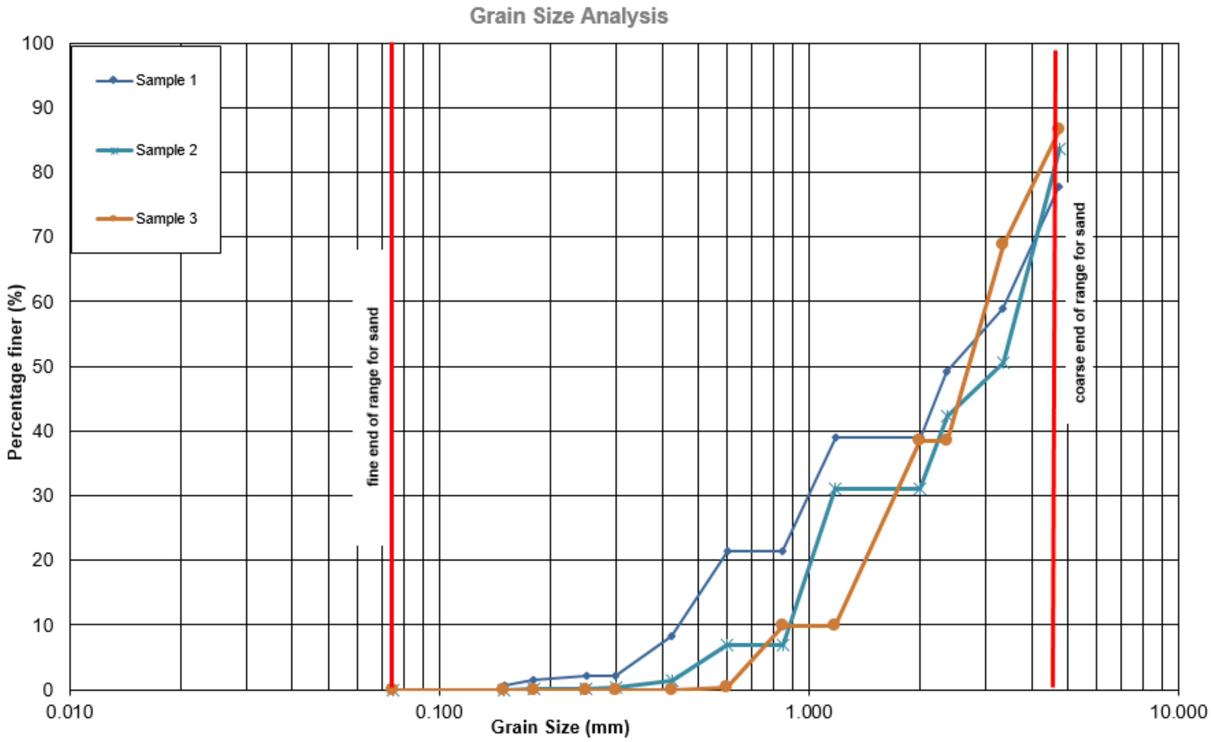


Figure 6.16 Results of Sieve Analysis conducted in the vicinity of the project area

6.2.4.3 *Classification and Wave climate Inference*

The uniformity coefficient (Cu) is a numerical measure of the variation in particle sizes. The samples for location 1 and 2 were classified as being well graded gravel while for location 3 it was classified as poorly graded. The standard deviation measures the degree of sorting of the particles in the sample. Based on the

Table 6.5 above the classification at the location 1 and 3 were moderately sorted and at location 2 was well sorted. This indicates that the beach experiences a wave climate which is not aggressive enough as illustrated by large native sediment sizes at the site. The shoreline had skewness values ranging from -1.676 to 13.484 and is strongly positively skewed. This indicates a long coarse tail of particles and an aggressive wave climate that washes out the finer particles similar to what was indicated by the uniformity coefficient. The sediments found at the site strongly correlated with the type of wave characteristics in a harbour.

6.2.5 Anecdotal Data Collection

6.2.5.1 *Previous*

Anecdotal information on the effects of historical natural hazards were collected to aid in the verification of the models for the area, compile the vulnerability assessment and create mitigation measures in order to reduce the vulnerability at the NMIA. Such evidence was also used to generate an estimate of the return period for actual storm surge versus estimated for verification purposes. The role of anecdotal information in coastal engineering and other scientific research areas has been discussed elsewhere and it is our opinion that the gathering of this information creates a wealth of information to facilitate the management of the storm surge risk.

Interviews were conducted in March of 2017 with available residents and workers in the immediate area with first hand memory of hurricane events. Overall, fifty-eight (58) interviews were conducted with residents having an average age of 53 years and living an average of 35 years in the immediate area. The respondents recalled eight (8) storms, including: Charlie (1951), Allen (1980), Gilbert (1988), Lili (2002), Ivan (2004), Dean (2007), Gustav (2008) and Sandy (2012). Of the respondents, approximately 41.4 percent indicated Hurricane Ivan had storm surges ranging from 0.99 to 3.38 meters in elevation with an average of 1.96 meters. Another 24.1 percent remembered Dean, being the most recent, having storm surge elevations ranging from 1.38 to 2.77 meters with an average elevation of 2.17 meters. The remaining 34.5 percent is shared among the other hurricanes.

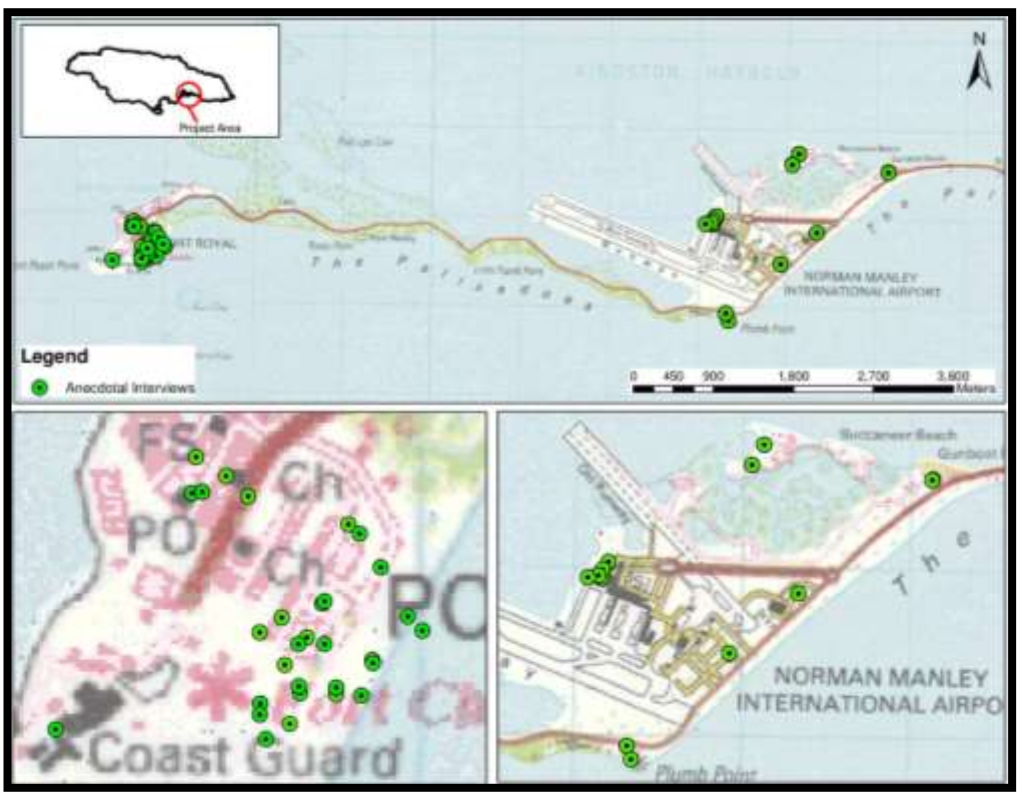


Figure 6.17 Locations in Port Royal and along Palisadoes where anecdotal interviews were conducted.

6.2.5.2 *Anecdotal Survey (2020)*

Interviews were also conducted in May of 2020 with available workers at NMIA using an online survey tool. In total, 16 surveys were completed by workers who have been associated with NMIA for 0- 20 years and over. Overall the respondents recalled three (3) storms, including: Ivan (2004), Dean (2007) and Sandy (2012). Of the respondents, 33.33% indicated that Hurricane Ivan (2004) caused the Main Palisadoes road to be breached. Another 33.33% percent remembered Dean, flooding the east field and the main road being breached. While, the remaining 33.33% percent remembered Sandy (2012) causing beach erosion and pier damage.

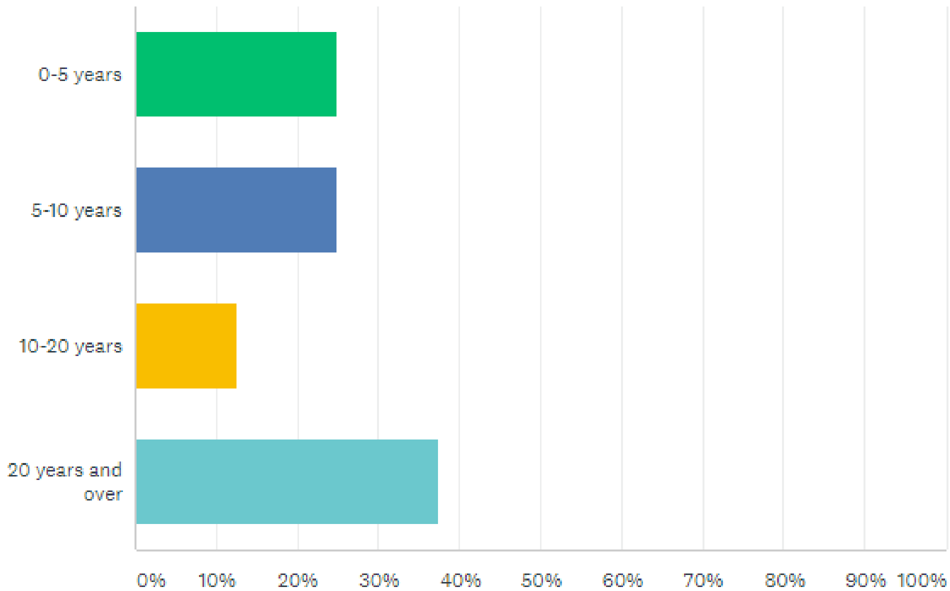


Figure 6.18 Length of time associated with NMIA

6.2.5.2.1 Rain fall/ Flooding Events

All of the respondents stated that both short and intense rain and long and heavy rain induced flooding at the airport. They recalled two (2) flooding events September 25th 2019, with a depth of flooding measure 0.08 m and December 2009 with a depth of 0.05 meters and had a duration of 5 hours. For the recommended mitigation measures for flooding 100% of the respondents suggested cleaning and maintaining of drains, 81.82% suggested drainage improvement, 54.55 % suggested detention ponds and lastly 18.18% suggested repairing the roofs, see Figure 6.19 below.

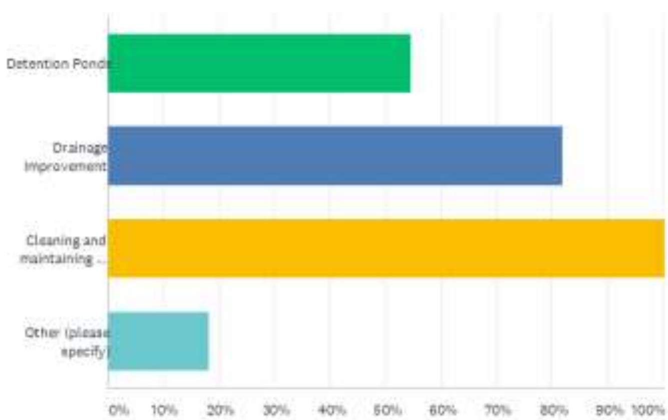


Figure 6.19 Mitigation Measures for flooding

6.2.5.2.2 Coastal Erosion

Thirty-three percent (33%) of the respondents has experience coastal at the airport. For the recommended mitigation measures to combat coastal erosion the 100% of the respondents suggested beach fills, 90% suggested set back measures, and 80 % suggested revamping the revetment.

6.2.5.2.3 Storm surge Events

Thirty-eight percent (38%) of the respondents has experience storm surges at the airport, namely from Hurricane Gilbert which inundated the runway for several days and Ivan (2004). For the recommended mitigation measures for storm surge 71% of the respondents suggested shoreline protection, 71.43% suggested elevation of assets, 28.57 % suggested wet proofing and 14.29% of the respondents suggested relocation and last 57.1% suggested storm water management capacity, see Figure 6.19 below.

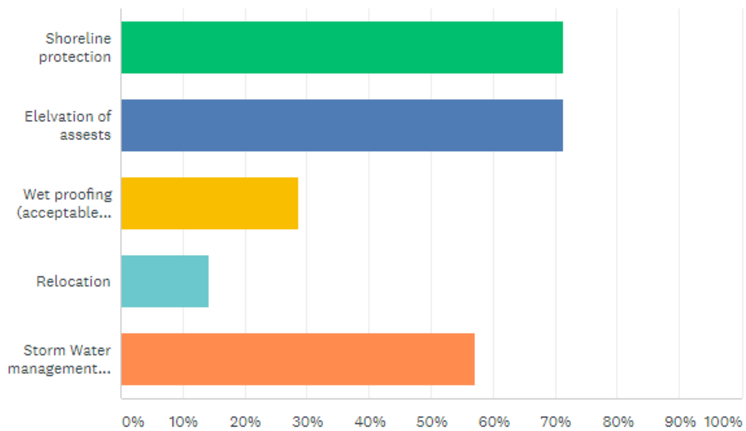


Figure 6.20 Mitigation Measures for storm surge

6.2.6 Summary

The findings from previous data deduced that a gap in the data was identified which is no sediment samples were taken inside of the harbour. Therefore a sediment survey was executed by CEAC Solutions Ltd on the 1st April 2020 to fill the gap in data. Similarly, it was deduced that additional bathymetric data for the project site was needed for the Caribbean Sea side however the wave climate presents many challenges and had to be substituted with chart data. Lastly, an updated anecdotal survey was conducted using an online platform, to compare with the available scientific data to correlate flooding extent/elevation/depth and water surface elevations.

6.3 Climate Change Adaptation (CCA) Technical Advisory Group (TAG)

The Climate Change Adaptation (CCA) Technical Advisory Group (TAG) role in the activity was to provide guidance throughout the duration of the project through the AAJ. The TAG includes technical specialists in the field of climate change adaptation, natural resource management, socio-economic impact assessment, social development and inclusion. The team provided timely input on all technical matters arising from project implementation and provided research directives; ensuring progress towards project outputs. See,Table 6.6 displays the organisation which makeup the TAG team.

Table 6.6 List of organizations that makeup the TAG Team

#	Organizations Involved in TAG
1.	Airports Authority of Jamaica (AAJ)
2.	PAC Kingston Airports Limited (PACKAL)
3.	Bureau of Gender Affairs (BGA)
4.	Caribbean Maritime University (CMU)
5.	Development Bank of Jamaica (DBJ)
6.	Jamaica Civil Aviation Authority (JCAA)
7.	Kingston and St. Andrew Municipal Corporation (KSAMC)
8.	Ministry of Economic Growth and Job Creation (MEGJC)
9.	Ministry of Transport and Mining (MTM)
10.	National Environment and Planning Agency (NEPA)
11.	Tourism Enhancement Fund (TEF)
12.	University of the West Indies (UWI)
13.	Urban Development Corporation (UDC)

Figure 6.21 First TAG Meeting held at Pegasus Hotel

6.4 Climate Change Analysis

6.4.1 Overview and method

This section presents the results from the analyses of simulated data produced by climate models based on likely future projections of carbon dioxide concentration. As such it is necessary to have at least a basic understanding of the process by which the data is generated and the uncertainties involved. In an effort to allow for better understanding and appreciation of the presented data, this section gives a brief overview of the processes involved in generating the data.

6.4.1.1 *Representative Concentration Pathways:*

Future climate projections are based on representative concentration pathways (RCPs). RCPs are factor amalgamated greenhouse gas emission (GHG) scenarios used by the Intergovernmental Panel on Climate Change (IPCC), which categorizes possible future climates of the world. A few of the factors weighed into the scenarios include, energy use, economic activity and land use (IPCC, 2014). RCPs provide a means for researchers and planners to pinpoint the focal areas where climate change instigates heavy socio-economic impacts whilst affording them the ability to ameliorate the requisite policies to combat these possible impacts. There are four (4) defined scenarios namely RCP2.6, 4.5, 6 and 8.5. Each represents a future subjected to a specific radiative forcing value; this as a result of the predicted cumulative GHG emission quantities for each scenario. Figure 6.22 summarize the 4 scenarios and the GHG emission ranges in parts per million (ppm) they represent.

Table 6.7 Description of Representative Concentration Pathway Scenarios (IPCC, 2014)

RCP Scenario/ Radiative Forcing	Description	Likely End of Century Global Mean Surface Temperature Increases
2.6	Low GHG Emissions or neutered impact through social and economic behavioral changes directed towards major mitigation. Denoted by a GHG range ≥ 430 ppm and ≤ 530 ppm.	0.3ºC to 1.7 ºC
4.5	Intermediate mitigation. Denoted by a GHG range ≥ 530 ppm and ≤ 720 ppm.	1.1ºC to 2.6 ºC
6.0	Low intermediate mitigation which falls closer to a business-as-usual behavior. Denoted by a GHG range ≥ 720 ppm and ≤ 1000 ppm.	1.4 ºC to 3.1 ºC
8.5	High GHG Emissions through a business-as-usual behavior or low behavioral change towards GHG mitigation. Denoted by a GHG range > 1000 ppm.	2.6 ºC to 4.8 ºC

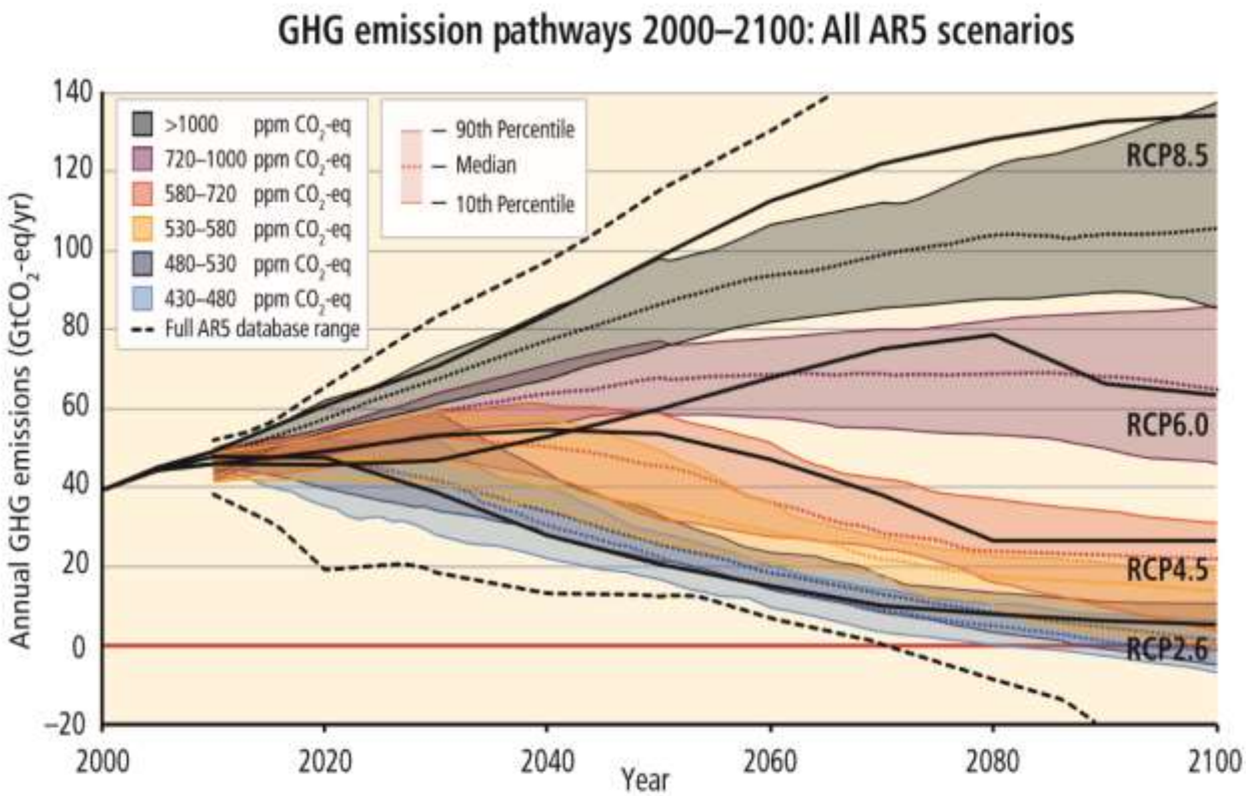


Figure 6.22: Representative Concentration Pathways and their Respective GHG Emission Range (IPCC, 2014)

6.4.1.2 *General Circulation Models:*

In order to project future climates, RCPs are utilized by global climate models (GCMs) along with other parameters to simulate the climate of the future. GCMs use mathematical equations based on conservation laws and physical processes to mimic the behavior of atmospheric motion and their land and ocean interactions. There are numerous GCMs which are run by various organizations around the world. Table 6.8 presents a list of the common GCMs utilized by the IPCC in their assessments. It is to be noted that the skill of each individual GCM varies in performance with some better suited for different regions of the globe. The performance of each is normally determined through statistical validation against observed datasets, see for instance Liu, Xu, & Li (2017), Ahmed, Sachindra, Shahid, Demire, & Chung (2019) and Shi, Wang, Qi, & Chen, (2018). The GCM model utilized for this report is the HadGEM2-ES model from the HadGEM family of models. These models perform reasonably well in the Caribbean region as shown in studies such as Taylor et. al. (2018) and Ryu and Hayhoe (2014).

Table 6.8 List of Commonly used GCMs (Khan, et al., 2018, pp. 5-6)

GCM Name	Developer	Resolution
ACCESS1-0	Commonwealth Scientific and Industrial Research Organisation–Bureau of Meteorology, Australia	1.90 x 1.20
ACCESS1-3		
bcc-csm1-1-m	Beijing Climate Centre, China	2.80 x 2.80
bcc-csm1-1		1.10 x 1.10
BNU-ESM	Beijing Normal University, China	2.80 x 2.80
CanESM2	Canadian Centre for Climate Modelling and Analysis, Canada	2.80 x 2.80

CCSM4	National Centre for Atmospheric Research USA	0.94 x 1.25
CESM1(BGC)		0.94 x 1.25
CMCC-CM	Centro Euro-Mediterraneo sui Cambiamenti Climatici, Italy	0.70 x 0.70
CMCC-CMS		1.90 x 1.90
CNRM-CM5	Centre National de Recherches Météorologiques, Centre, France	1.40 x 1.40
CSIRO-Mk3-6-0	Commonwealth Scientific and Industrial Research Organization, Australia	1.90 x 1.90
EC-EARTH	EC-EARTH consortium published at the Irish Centre for High-End Computing, Netherlands/Ireland	1.10 x 1.10
FGOALS-g2	Institute of Atmospheric Physics, Chinese Academy of Sciences, China	2.80 x 2.80
GFDL-CM3	Geophysical Fluid Dynamics Laboratory, USA	2.50 x 2.00
GFDL-ESM2G		2.50 x 2.00
GFDL-ESM2M		2.50 x 2.00
GISS-E2-R	NASA/GISS (Goddard Institute for Space Studies), USA	2.50 x 2.00
HadGEM2-CC	Met Office Hadley Centre, UK	1.90 x 1.20
HadGEM2-ES		1.90 x 1.20
INMCM4.0	Institute of Numerical Mathematics, Russia	2.00 x 1.50
IPSL-CM5A-LR	Institut Pierre Simon Laplace, France	3.70 x 1.90
IPSL-CM5A-MR		2.50 x 1.30
IPSL-CM5B-LR		3.70 x 1.90
MIROC-ESM-CHEM	The University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, Japan	2.80 x 2.80
MIROC-ESM		2.80 x 2.80
MIROC5		1.40 x 1.40
MPI-ESM-LR	Max Planck Institute for Meteorology, Germany	1.90 x 1.90
MPI-ESM-MR		1.90 x 1.90
MRI-CGCM3	Meteorological Research Institute, Japan	1.10 x 1.10
NorESM1-M	Meteorological Institute, Norway	2.50 x 1.90

6.4.1.3 *Regional Climate Models:*

Data outputted from GCMs is of a coarse resolution, usually greater than 125 km. At coarser/lower resolutions, small islands or even local country scales are generally not represented well or identified at all. See for instance Cantet, Déqué, Palany, & Maridet (2014) and Gao, et al. (2008). In order to have a more accurate representation of smaller regions the output of a GCM can be used as boundary conditions for a regional climate model (RCM), which downscales the GCM to a higher resolution (see Figure 6.23). The higher resolution allows for the study of the influence on dynamics posed by highly variable physical factors; for example topography, land use and land–sea differences, see for instance Filippo (2019) and Wang, et al. (2004). The RCM used to generate results for this study is the International Centre for Theoretical Physics (ICTP) Regional Climate Model (RegCM) V4 (Elguindi, et al., 2011) . RegCM models have been shown to capture the dynamical and land surface processes in the spatial domain of the Caribbean region reasonably well, see for instance Campbell, et al. (2011) and Castro, et al. (2006).

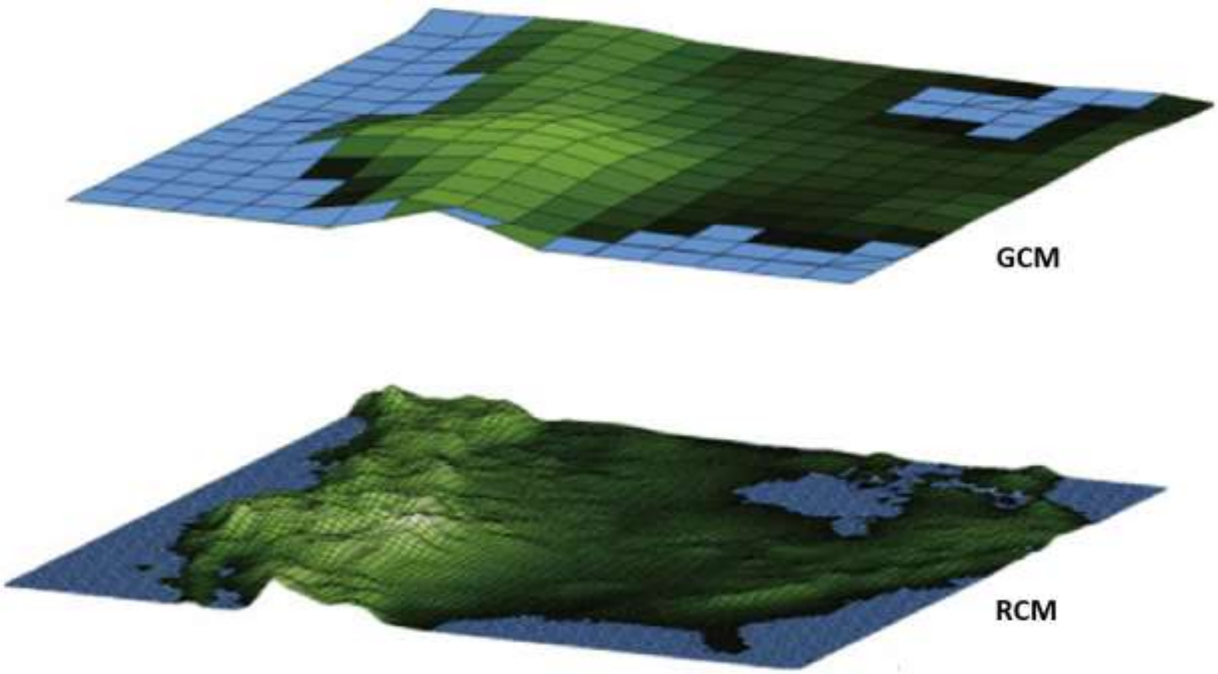


Figure 6.23: Visualization of GCM and RCM Scales (Hannah, 2015)

6.4.1.4 *Data & Methodology*

The data analyzed in this report was HadGEM2-ES simulated data downscaled utilizing RegCM version 4 running at a resolution of 25 kilometres. The modelling is done for both RCP 2.6 (significant mitigation) and RCP 8.5 (business as usual) scenarios. RegCM produces data in gridded form, and as such the data used to represent the Norman Manley International Airport was that of the grid centered on 17.94º N and 76.82º W, see Figure *6.24*. Modelling was done for a 25 year historical baseline period (1980-2004) and then from 2019 through to the end of the century for each of the two RCPs. Model data is therefore not available for the period 2005 to 2018.

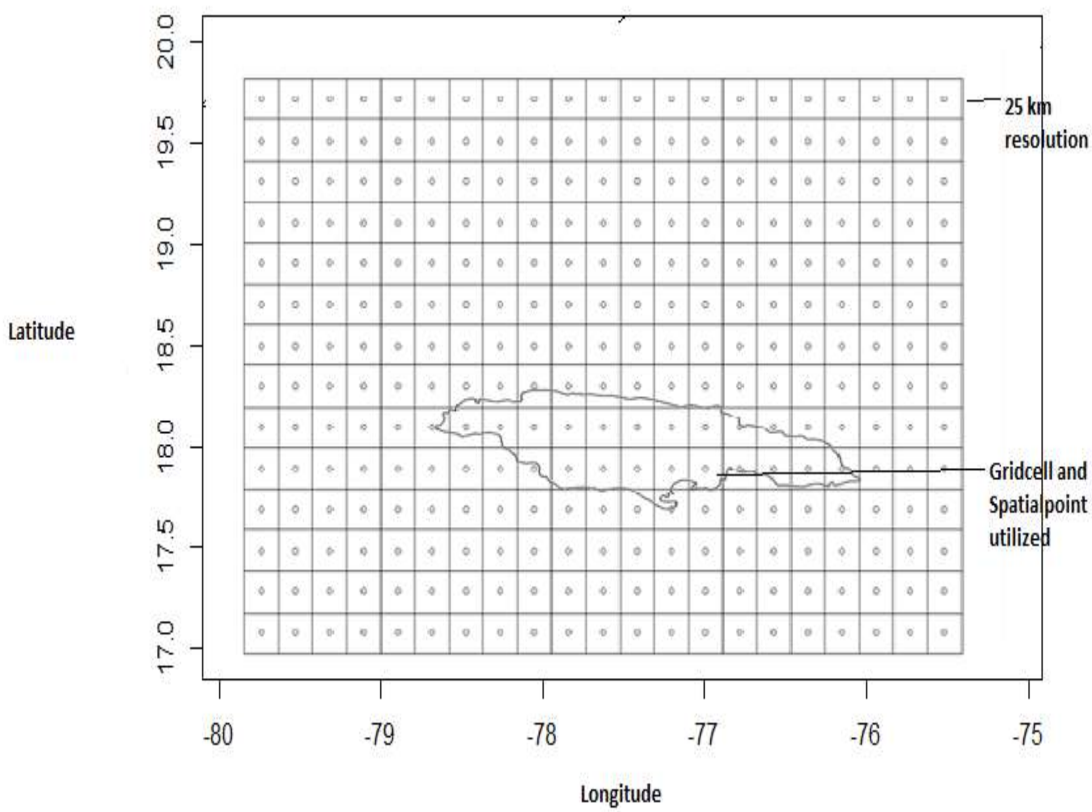


Figure 6.24: Grids Utilized in RegCM Simulations. The grid containing the Norman Manley International Airport is shown.

Anomaly annual time series' are calculated for minimum, mean and maximum air temperature by subtracting the mean average annual values for the 25 years baseline period (1980 to 2004) from the average of each individual year within the periods of analysis. This was done for modelled (RCP 2.6 and RCP 8.5) data through to the end of the century and observed data up to 2019.

Temperature and precipitation monthly climatologies are calculated for three future time slices by averaging over a 25 years period. These climatologies are calculated for periods representing the near term (2019-2043), medium term (2047-2071) and long term (2074-2098) future. The differences between the climatologies of each future period and the baseline period were also determined. Temperature results are presented in terms of absolute differences while precipitation results are presented as a percentage difference from the historical baseline period.

Various climate extremes for both air temperature and precipitation are calculated using the Climpact2 package accessible through the R-Programming language. For more details on the package please see (The Arc Centre of Excellence for Climate System Science, 2016). The extremes considered include daily precipitation (PR), daily maximum temperatures (TX) and daily minimum temperatures (TN).

Table 6.9 Summary of Climate Extremes Utilized (The Arc Centre of Excellence for Climate System Science, 2016)

Extreme Name	Calculation	Units
Amount of Warm Days (TX90p)	Percentage of days when TX > 90th percentile	%
Amount of Warm Nights (TN90p)	Percentage of days when TN > 90th percentile	%
Number of Heavy Rain Days (R10mm)	Number of days when PR >= 10 mm	# of days
Consecutive Dry Days	Maximum number of consecutive dry days (when PR < 1.0 mm)	# of days
Fraction of total wet-day rainfall that comes from very wet days (R95pTOT)	$\frac{100 * \text{Annual sum of daily PR} > \text{95th percentile}}{\text{Sum of daily PR} >= 1.0 \text{ mm}}$	%

6.4.2 Future Climatologies and Trends

6.4.2.1 *Temperature*

Mean Annual Temperatures

Figure 6.25 gives the 10-year running mean (centered on year 5) smoothed anomaly time series for observed and model data for RCP 2.6 and RCP 8.5 mean annual temperatures. The following is noted from the plots:

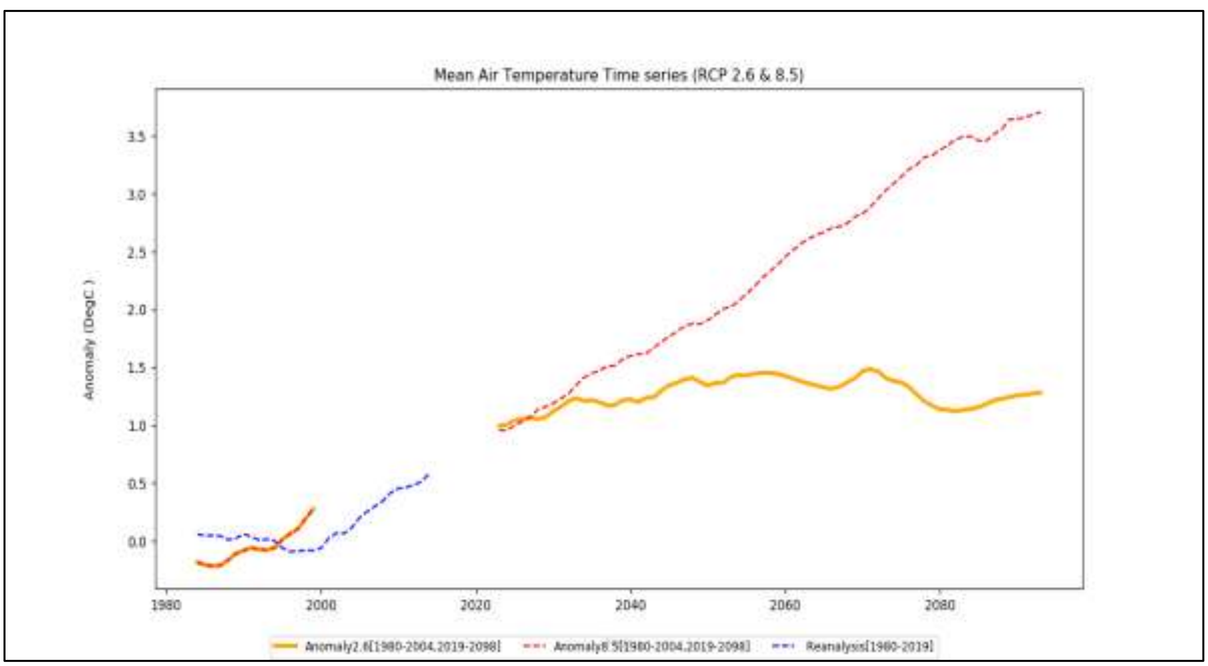


Figure 6.25: 10 Year Running Mean of Air Temperature Anomalies. Observed (blue) and Model Data (orange RCP 2.6 and red RCP 8.5). Anomalies are with respect to the Baseline Period 1980-2004. Units are °C

1. The model data slightly underestimates the observed data in the earlier period of the baseline period. It slightly overestimates it in the latter period. Both indicate an upward trend in surface air temperature for the historical baseline period.
2. Under RCP 2.6 (orange line) future temperatures rise through to mid-century then taper off and remain below 1.5°C with respect to the historical baseline.
3. Under RCP 8.5 plot (red dotted line) temperatures continue to increase at a steady rate of approximately 0.4°C/decade towards the end of century. At the end of the century, temperatures are in excess of 3°C above the historical baseline average. RCP 8.5 is considered a business-as-usual scenario.
4. Under RCP 8.5 the rates of change during the near, medium and long term futures are 0.36°C/decade, 0.48 °C/decade and 0.30 °C/decade respectively.

6.4.2.1.1 Max and Min Temperatures

Figure 6.26 presents the minimum, mean and maximum air temperature climatologies under RCPs 2.6 and 8.5 for baseline (1980-2004), near term (2019-2043), medium term (2047-2071) and long term (2074-2098) futures. Figure 6.26 also shows the differential monthly change relative to the 25-year baseline period (dotted lines). Figure 6.26 gives the data used to create Figure 6.26. The following should be noted from the plots:

1. The known unimodal pattern for air temperature with the highest temperatures in the summer months and lower temperatures in the winter holds in the future for all three defined periods. This is true for all three of the air temperature parameters (mean, maximum and minimum temperatures) and for both RCP 2.6 and 8.5.
2. Under RCP 2.6 temperature increases are marginal between the three future time periods. This is true for all three temperature parameters (mean, maximum and minimum). This is not the case for RCP 8.5 as for all three parameters there is continuous increase for each successive future period.
3. Under both RCP 2.6 and 8.5 increases in future maximum and minimum air temperature display a nearly constant increase across all the 12 months for each future time period. These increases are approximately 1.1°C on average (near term) rising to approximately 1.2°C on average (long term) under RCP 2.6. For RCP 8.5 the increases are approximately 1.3°C on average (near term) rising to approximately 3.5°C on average (long term) See columns 1 and 3 of Figure 6.26.
4. For mean air temperature, increases are not constant across all the 12 months. Larger increases are observed in the winter months (December to February, with the largest increase in December) and smaller increases observed from May through to August. This is true for both RCPs. See column 2 of Figure 6.26.
5. Figure 6.26 present the change factors of the monthly climatologies for mean, maximum and minimum air temperature respectively for all three defined future periods. This for both RCP 2.6 and 8.5.

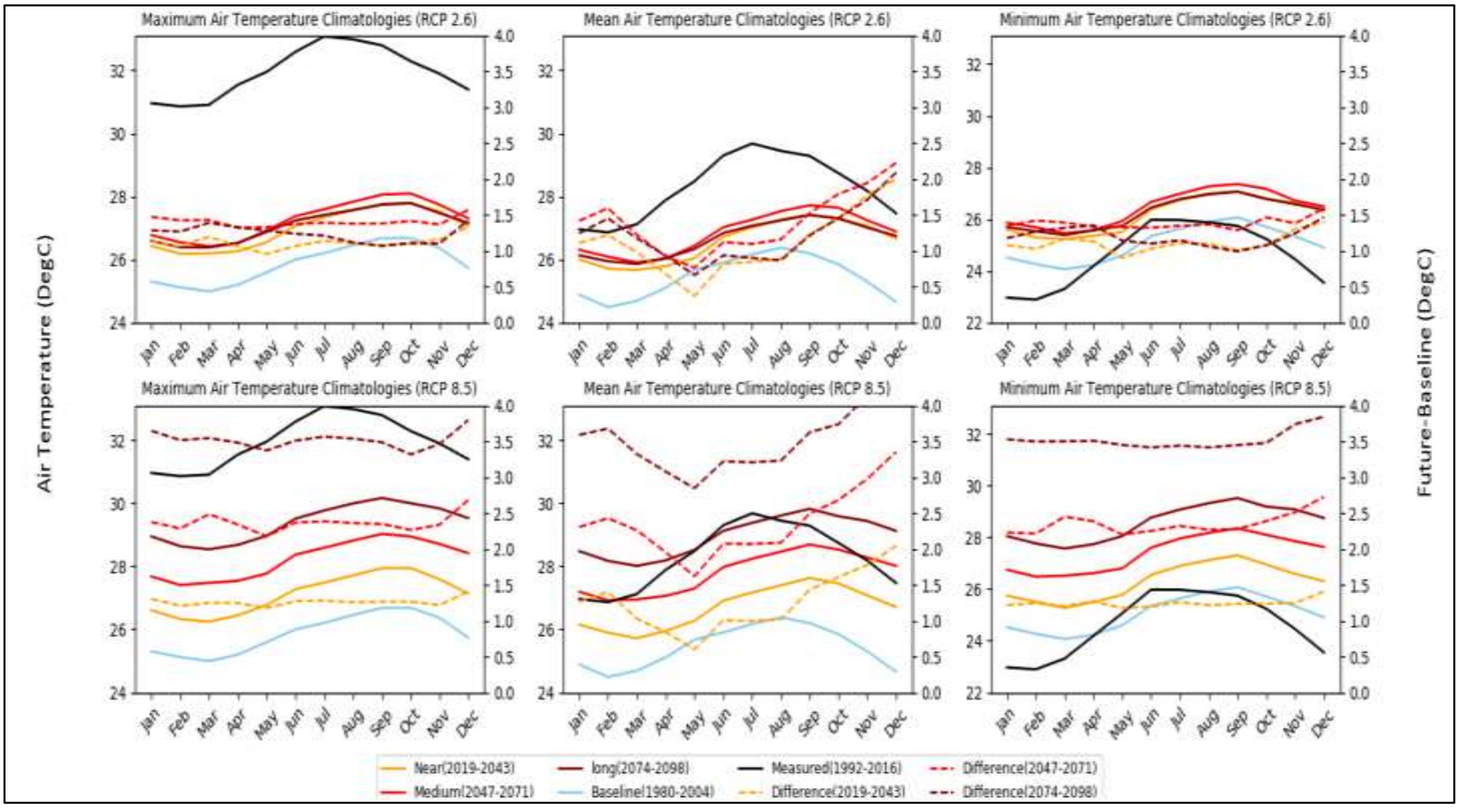


Figure 6.26: Minimum, Mean and Maximum Air Temperature Climatologies based on Model Data. Differences between the Baseline Climatology and that for each Future Time Periods are also shown as dotted lines. Units are ^{o}C.

Table 6.10: Mean Air Temperature Climatologies for RCP 2.6 & 8.5 Along with Projected Change in the Near, Medium and Long Term.

Periods	Scenario	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Model Baseline/°C (1980-2004)		24.9	24.5	24.7	25.1	25.7	25.9	26.2	26.4	26.2	25.9	25.3	24.7
Model Baseline minus Observed / °C		-2.1	-2.4	-2.4	-2.8	-2.8	-3.4	-3.5	-3.1	-3.1	-2.9	-2.9	-2.8
Near Term Change/°C (2019 to 2043)	2.6	1.1	1.2	1.0	0.7	0.4	0.8	0.9	0.9	1.2	1.5	1.8	2.0
	8.5	1.3	1.4	1.0	0.8	0.6	1.0	1.0	1.0	1.4	1.6	1.8	2.1
Medium Term Change/°C (2047-2071)	2.6	1.4	1.6	1.2	0.9	0.8	1.1	1.1	1.2	1.5	1.8	2.0	2.2
	8.5	2.3	2.4	2.3	2.0	1.6	2.1	2.1	2.1	2.5	2.7	3.0	3.4
Long Term Change/°C (2074-2098)	2.6	1.2	1.5	1.2	0.9	0.7	0.9	0.9	0.9	1.2	1.5	1.7	2.1
	8.5	3.6	3.7	3.3	3.1	2.9	3.2	3.2	3.2	3.6	3.7	4.1	4.5

Table 6.11: Same as but for Maximum Temperature

Periods	Scenario	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Model Baseline/°C (1980-2004)		25.3	25.1	25.0	25.2	25.6	26.0	26.2	26.5	26.7	26.7	26.4	25.8
Model Baseline minus Observed / °C		-5.7	-5.7	-5.9	-6.3	-6.4	-6.6	-6.9	-6.5	-6.1	-5.6	-5.5	-5.7
Near Term Change/°C (2019 to 2043)	2.6	1.1	1.1	1.2	1.1	1.0	1.1	1.1	1.1	1.1	1.1	1.2	1.3
	8.5	1.3	1.2	1.3	1.3	1.2	1.3	1.3	1.3	1.3	1.3	1.2	1.4

Medium Term Change/°C (2047-2071)	2.6	1.5	1.4	1.4	1.3	1.3	1.4	1.4	1.4	1.4	1.4	1.4	1.6
	8.5	2.4	2.3	2.5	2.3	2.2	2.4	2.4	2.4	2.4	2.3	2.3	2.7
Long Term Change/°C (2074-2098)	2.6	1.3	1.3	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.1	1.4
	8.5	3.7	3.5	3.5	3.5	3.4	3.5	3.6	3.6	3.5	3.3	3.5	3.8

Table 6.12 Same but for Minimum Temperature

Periods	Scenario	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Model Baseline/°C (1980-2004)		24.5	24.3	24.1	24.2	24.6	25.4	25.6	25.9	26.1	25.7	25.3	24.9
Model Baseline minus Observed / °C		1.5	1.4	0.8	0.0	-0.5	-0.6	-0.3	0.0	0.3	0.5	0.9	1.4
Near Term Change/°C (2019 to 2043)	2.6	1.1	1.0	1.2	1.1	0.9	1.0	1.1	1.1	1.0	1.1	1.3	1.4
	8.5	1.2	1.2	1.2	1.3	1.2	1.2	1.3	1.2	1.2	1.2	1.3	1.4
Medium Term Change/°C (2047-2071)	2.6	1.4	1.4	1.4	1.3	1.3	1.3	1.4	1.4	1.3	1.5	1.4	1.6
	8.5	2.2	2.2	2.5	2.4	2.2	2.3	2.3	2.3	2.3	2.4	2.5	2.7
Long Term Change/°C (2074-2098)	2.6	1.2	1.3	1.3	1.4	1.1	1.1	1.2	1.1	1.0	1.1	1.3	1.5
	8.5	3.5	3.5	3.5	3.5	3.5	3.4	3.4	3.4	3.5	3.5	3.7	3.8

6.4.2.1.2 Extreme Temperatures

Figure 6.27 present the percentage of warm days when maximum temperatures are observed that are greater than the 90th percentile baseline threshold. This was on an annual timescale. The plots were smooth using a 10-year running mean as described in the methodology. The following should be noted from the plots:

I. Under both RCP 2.6 and 8.5, the number of warm days/daily maximum temperatures that fall within the baseline 90th percentile increases significantly. By the mid 2030's more than 80% of the days annually are 'warm' under RCP 2.6. This continues through to the end of the century. Just under 100% of days are warm under RCP 8.5 by mid-century with this continuing through to the end of the century.

II. The RCP 2.6 time series exhibits some inter-annual variability through to the end of the century but the values never fall below 80%.

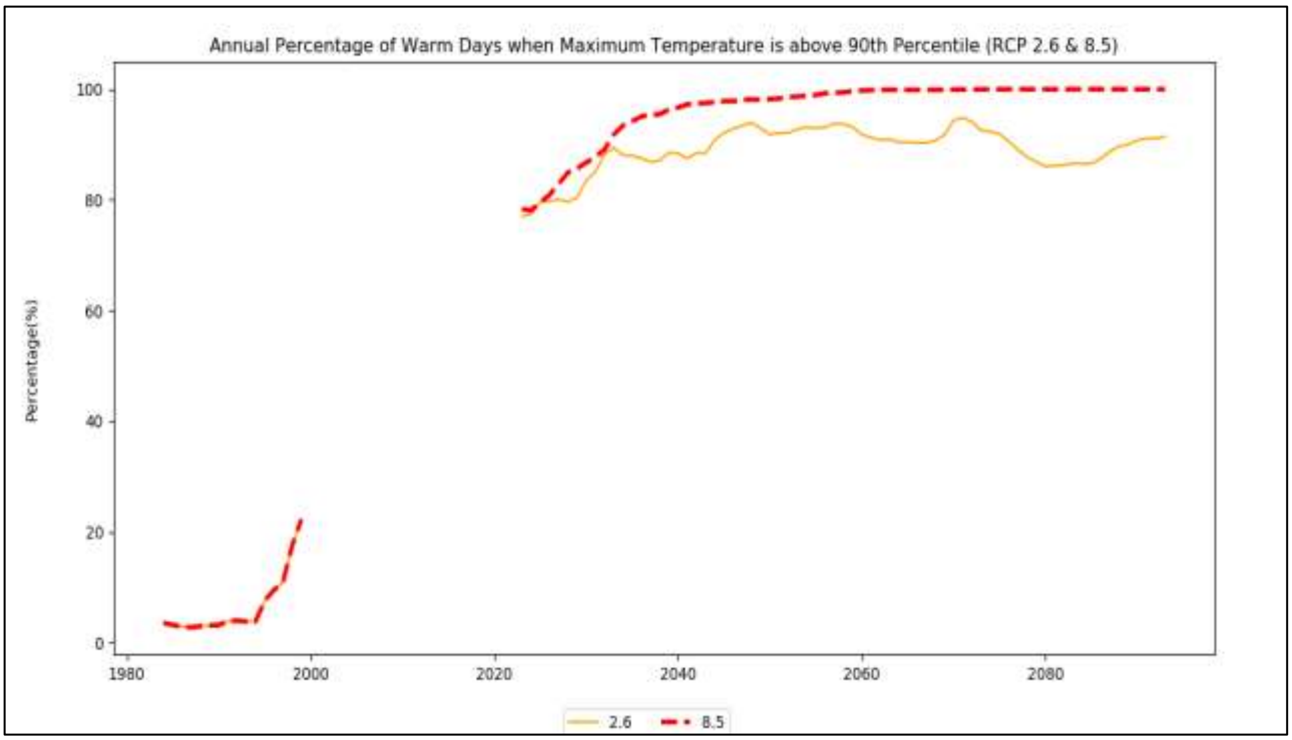


Figure 6.27: Annual Percentage Warm Days based on Maximum Temperatures (>) 90th Percentile in the Baseline Period.

Table 6.13 Percentage of Warm Days when Maximum Temperature Exceed the 90th Percentile

Year	Warm Days (2.6)	Warm Days (8.5)	Year	Warm Days (2.6)	Warm Days (8.5)	Year	Warm Days (2.6)	Warm Days (8.5)
1980	--	--	**2020**	--	--	**2060**	91.8	99.8
1981	--	--	**2021**	--	--	**2061**	91.3	99.8
1982	--	--	**2022**	--	--	**2062**	90.8	99.9
1983	--	--	**2023**	77.0	78.4	**2063**	91.0	99.9
1984	3.6	3.6	**2024**	77.4	78.1	**2064**	90.5	99.9
1985	3.2	3.2	**2025**	79.7	79.6	**2065**	90.4	99.9
1986	2.9	2.9	**2026**	79.8	80.9	**2066**	90.3	99.9
1987	2.8	2.8	**2027**	80.1	82.9	**2067**	90.3	99.9
1988	3.0	3.0	**2028**	79.6	84.9	**2068**	90.7	99.9

1989	3.2	3.2	2029	80.5	85.7	2069	91.8	99.9
1990	3.2	3.2	2030	83.6	86.7	2070	94.4	99.9
1991	3.9	3.9	2031	85.1	87.8	2071	94.9	100.0
1992	4.0	4.0	2032	88.3	89.1	2072	94.1	100.0
1993	3.8	3.8	2033	89.4	91.8	2073	92.5	100.0
1994	3.8	3.8	2034	88.1	93.4	2074	92.4	100.0
1995	7.6	7.6	2035	88.0	94.2	2075	91.9	100.0
1996	9.5	9.5	2036	87.6	95.1	2076	90.6	100.0
1997	11.0	11.0	2037	86.9	95.4	2077	89.1	100.0
1998	17.6	17.6	2038	87.1	95.5	2078	87.7	100.0
1999	22.3	22.3	2039	88.6	96.3	2079	86.9	100.0
2000	--	--	2040	88.4	96.7	2080	86.0	100.0
2001	--	--	2041	87.5	97.3	2081	86.2	100.0
2002	--	--	2042	88.5	97.4	2082	86.3	100.0
2003	--	--	2043	88.5	97.5	2083	86.6	100.0
2004	--	--	2044	90.9	97.7	2084	86.5	100.0
2005	--	--	2045	92.1	97.9	2085	86.6	100.0
2006	--	--	2046	92.9	97.9	2086	87.5	100.0
2007	--	--	2047	93.4	98.1	2087	88.8	100.0
2008	--	--	2048	94.0	98.2	2088	89.7	100.0
2009	--	--	2049	92.9	98.1	2089	90.0	100.0
2010	--	--	2050	91.9	98.2	2090	90.8	100.0
2011	--	--	2051	92.1	98.3	2091	91.1	100.0
2012	--	--	2052	92.1	98.6	2092	91.1	100.0
2013	--	--	2053	92.8	98.7	2093	91.4	100.0
2014	--	--	2054	93.1	98.8	2094	--	--
2015	--	--	2055	93.0	99.0	2095	--	--
2016	--	--	2056	93.1	99.3	2096	--	--
2017	--	--	2057	93.8	99.4	2097	--	--
2018	--	--	2058	93.7	99.4	2098	--	--
2019	--	--	2059	93.2	99.6	--	--	--

Figure 6.28 and Table 6.14 present the percentage of warm nights when minimum temperatures are observed that are greater than the 90th percentile baseline threshold. This was on an annual timescale. The plots were smoothed using a 10 year running mean as described in the methodology. The following should be noted from the plots:

1. Under both RCP 2.6 and 8.5, the percentage of warm nights/daily minimum temperatures that fall within the baseline 90th percentile increases by more than 70% by 2027 under RCP 2.6 and near 100% by 2060 under RCP 8.5.
2. Future projections (2023 and beyond) under RCP 2.6 exhibits inter-annual variability with values hovering around the 80% mark starting in mid-century (2045).

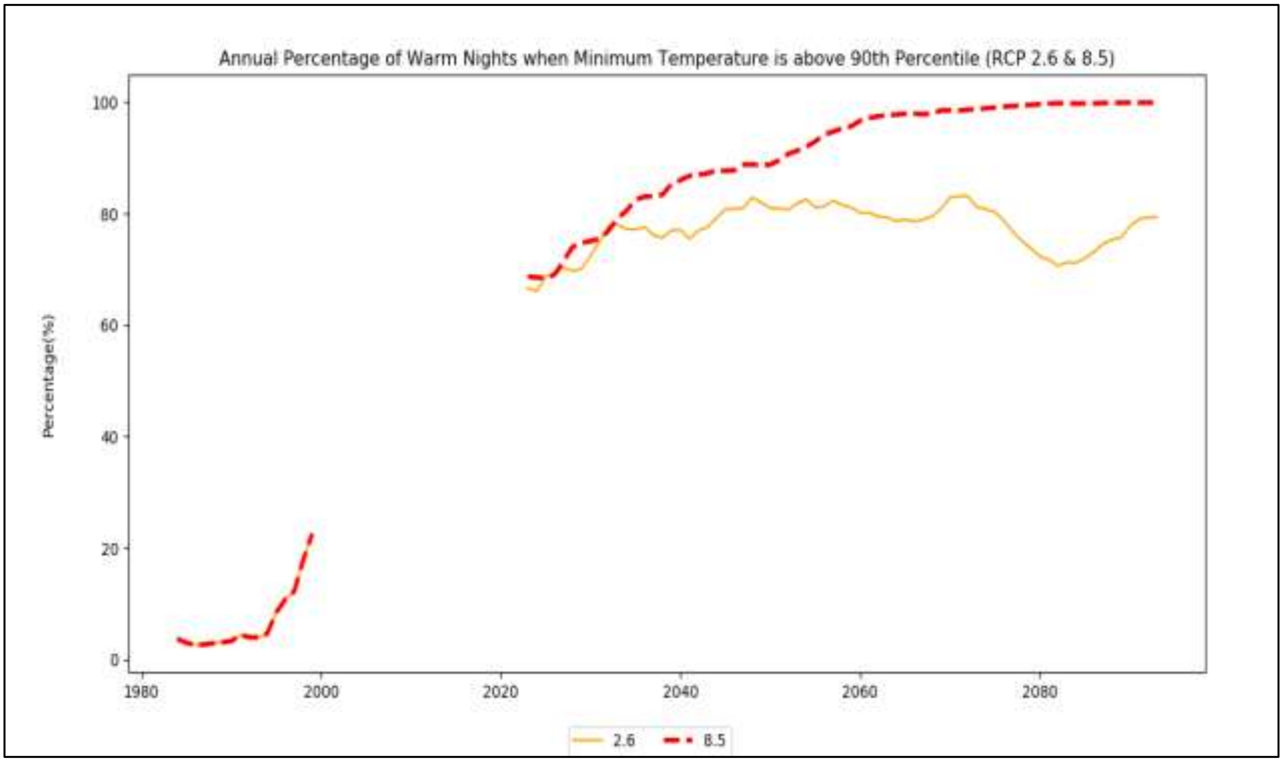


Figure 6.28: Annual Percentage Warm Nights based on Minimum Temperatures (>) 90th Percentile in the Baseline Period

Table 6.14 Percentage of Warm Nights when Minimum Temperature Exceed the 90th Percentile

Year	Warm Nights (2.6)	Warm Nights (8.5)	Year	Warm Nights (2.6)	Warm Nights (8.5)	Year	Warm Nights (2.6)	Warm Nights (8.5)
1980	--	--	2020	--	--	2060	80.1	96.7
1981	--	--	2021	--	--	2061	80.2	97.2
1982	--	--	2022	--	--	2062	79.5	97.4
1983	--	--	2023	66.7	68.7	2063	79.3	97.7
1984	3.7	3.7	2024	66.0	68.6	2064	78.7	97.7
1985	3.1	3.1	2025	68.7	68.4	2065	79.0	97.9
1986	2.7	2.7	2026	69.1	69.1	2066	78.6	97.9
1987	2.7	2.7	2027	70.4	71.6	2067	78.9	97.8
1988	3.0	3.0	2028	69.7	74.0	2068	79.5	97.9
1989	3.2	3.2	2029	70.1	74.7	2069	80.8	98.5
1990	3.4	3.4	2030	72.5	75.1	2070	82.9	98.5
1991	4.4	4.4	2031	75.0	75.5	2071	83.1	98.5
1992	4.0	4.0	2032	77.8	77.0	2072	83.1	98.6
1993	4.0	4.0	2033	78.1	79.2	2073	81.2	98.8
1994	4.7	4.7	2034	77.2	80.5	2074	80.8	98.9
1995	8.5	8.5	2035	77.1	82.5	2075	80.2	99.0
1996	10.8	10.8	2036	77.6	83.0	2076	78.8	99.2
1997	12.2	12.2	2037	76.2	83.1	2077	76.7	99.3
1998	17.8	17.8	2038	75.7	83.4	2078	75.1	99.4
1999	22.6	22.6	2039	77.0	85.3	2079	73.8	99.5
2000	--	--	2040	77.1	86.0	2080	72.3	99.6
2001	--	--	2041	75.5	86.8	2081	71.8	99.7
2002	--	--	2042	77.0	86.9	2082	70.6	99.8
2003	--	--	2043	77.5	87.2	2083	71.3	99.8
2004	--	--	2044	79.2	87.8	2084	71.2	99.7
2005	--	--	2045	80.8	87.7	2085	71.9	99.8
2006	--	--	2046	80.8	87.8	2086	73.1	99.8
2007	--	--	2047	81.0	88.8	2087	74.5	99.8
2008	--	--	2048	82.9	88.8	2088	75.3	99.8
2009	--	--	2049	82.0	88.7	2089	75.7	99.9
2010	--	--	2050	80.9	88.8	2090	77.6	99.9
2011	--	--	2051	80.9	89.6	2091	79.0	99.9
2012	--	--	2052	80.7	90.7	2092	79.3	99.9
2013	--	--	2053	81.8	91.3	2093	79.4	99.9
2014	--	--	2054	82.6	92.0	2094	--	--
2015	--	--	2055	81.1	92.9	2095	--	--
2016	--	--	2056	81.3	94.2	2096	--	--
2017	--	--	2057	82.3	94.7	2097	--	--
2018	--	--	2058	81.5	95.3	2098	--	--
2019	--	--	2059	81.1	95.6	--	--	--

6.4.2.2 *Precipitation*

6.4.2.2.1 Mean Annual Precipitation

Figure 6.29 presents the mean monthly precipitation climatologies for model data for the 25-year baseline period (1980-2004) and the near (2019-2043), medium (2047-2071) and long (2074-2098) term futures. This for both RCP 2.6 and RCP 8.5. Also presented are the future monthly climatological change relative to the baseline as a percentage. This for the three defined future periods. *Figure 6.29* gives the change factors/percentage changes relative to the baseline period for the mean average monthly precipitation. The following are noted:

1. The known bimodal pattern for precipitation with peaks in May and October holds in the future for all three defined periods. This is true for both RCP 2.6 and 8.5, see row 1 of Figure 6.29.
2. Under RCP 2.6 there are slight increases in the rainfall peaks ranging from 6% to 20% over the baseline period. Noticeable is the 20% and greater decrease in precipitation in the months of July and August. See column 1, row 2 of Figure 6.29.
3. Under RCP 8.5 most months exhibit decreases in precipitation with decreases ranging from 20% to 70%. Again the months of July and August have the greatest decrease in precipitation. See column 2 of Figure 6.29.
4. Under RCP 8.5 the greatest decreases are observed in the long term future. See column 2, row 2 Figure 6.29.
5. Table 6.15 presents the change factors of the monthly climatologies for all three defined future periods for both RCP 2.6 and 8.5.

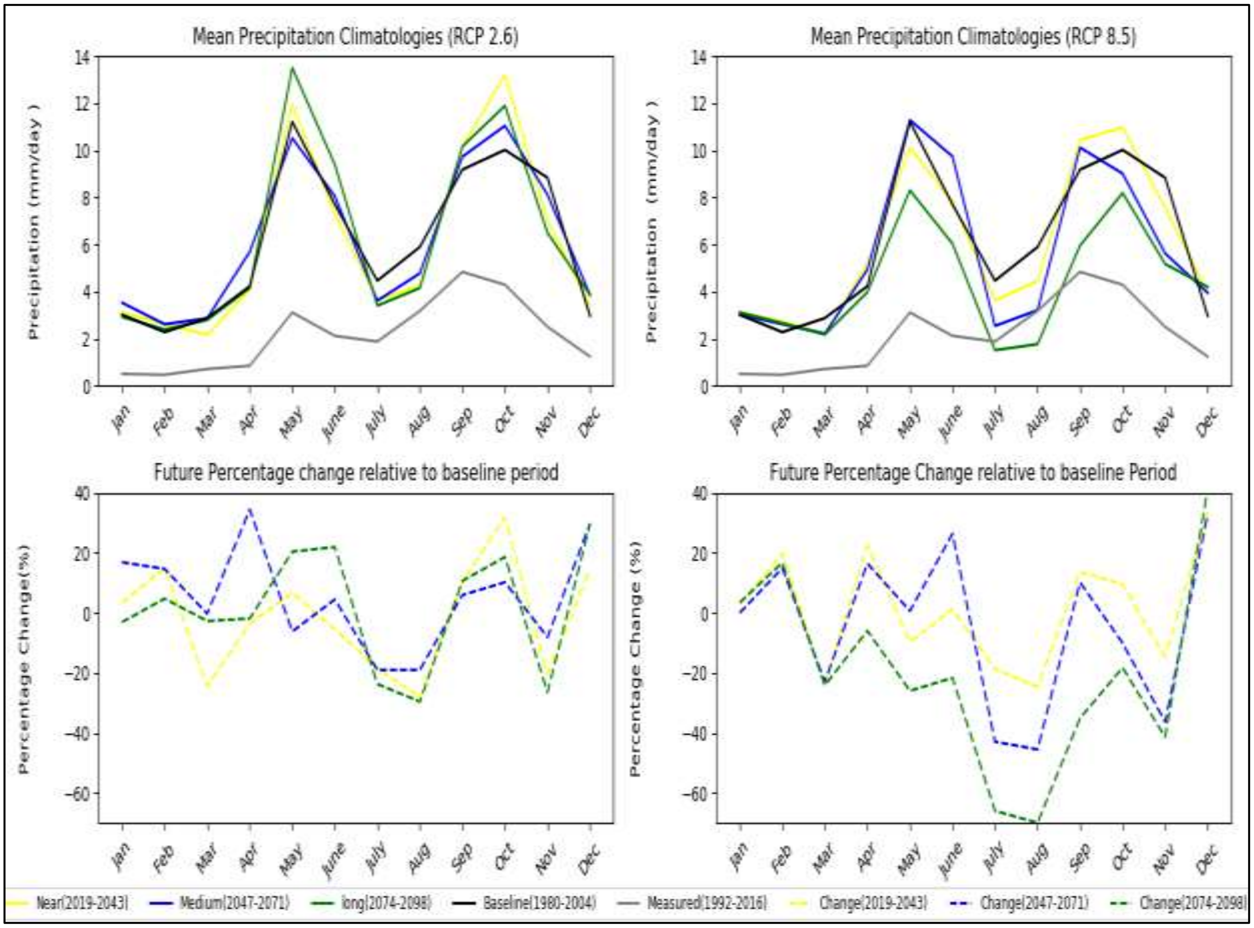


Figure 6.29: Top row: Mean Precipitation Future Climatologies based on Model Data. Bottom row: Percentage Change in Monthly Rainfall for the Three Future Time Periods with respect to the Model Baseline Period.

Table 6.15 Mean Precipitation Baseline Climatologies for RCP 2.6 & 8.5 Along with Projected Change in the Near, Medium and Long Term.

Periods	Scenario	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baseline/mmday^{-1} (1980-2004)		3.0	2.3	2.9	4.2	11.2	7.7	4.5	5.9	9.2	10.0	8.8	3.0
Near Term Change / % (2019 to 2043)	2.6	3.4	15.0	-24.4	-3.6	6.7	-5.5	-18.3	-28.1	10.4	31.9	-20.4	14.6
	8.5	2.8	19.8	-24.1	22.7	-9.7	1.3	-18.7	-24.6	13.6	9.6	-14.7	33.6
Medium Term Change / % (2047-2071)	2.6	16.9	14.7	-0.23	34.5	-6.2	4.5	-19.0	-19.0	6.0	10.2	-8.13	29.9
	8.5	0.0	15.0	-23.0	16.5	0.7	26.4	-42.9	-45.5	10.2	-10.1	-36.3	32.9
Long Term Change / % (2074-2098)	2.6	-3.1	4.8	-2.7	-1.9	20.4	22.0	-23.7	-29.5	10.7	18.7	-26.5	29.7
	8.5	3.4	16.8	-24.1	-5.9	-26.0	-21.6	-66	-69.9	-35.1	-18.2	-41.4	41.2

Extreme Precipitation

Figure 6.30 present the number of days with extreme precipitation events (rainfall events that record more than 10mm of precipitation over 24 hours) observed over the period. This for RCP 2.6 and RCP 8.5. The plots were smoothed using a 10 year running mean as described in the methodology. The following should be noted from the plots:

I. Under RCP 2.6, the number of days with rainfall above 10 mm decreases in the near future relative to the baseline but returns to the baseline levels by mid-century.

II. Under RCP 8.5, at current levels the near term remains similar to the baseline up to mid-century, after which there is a sharp continuous decease toward the end of century. This is consistent with the expected significant drying that is reported in the literature. See for instant Stennett-Brown, Jones, Stephenson, & Taylor (2017).

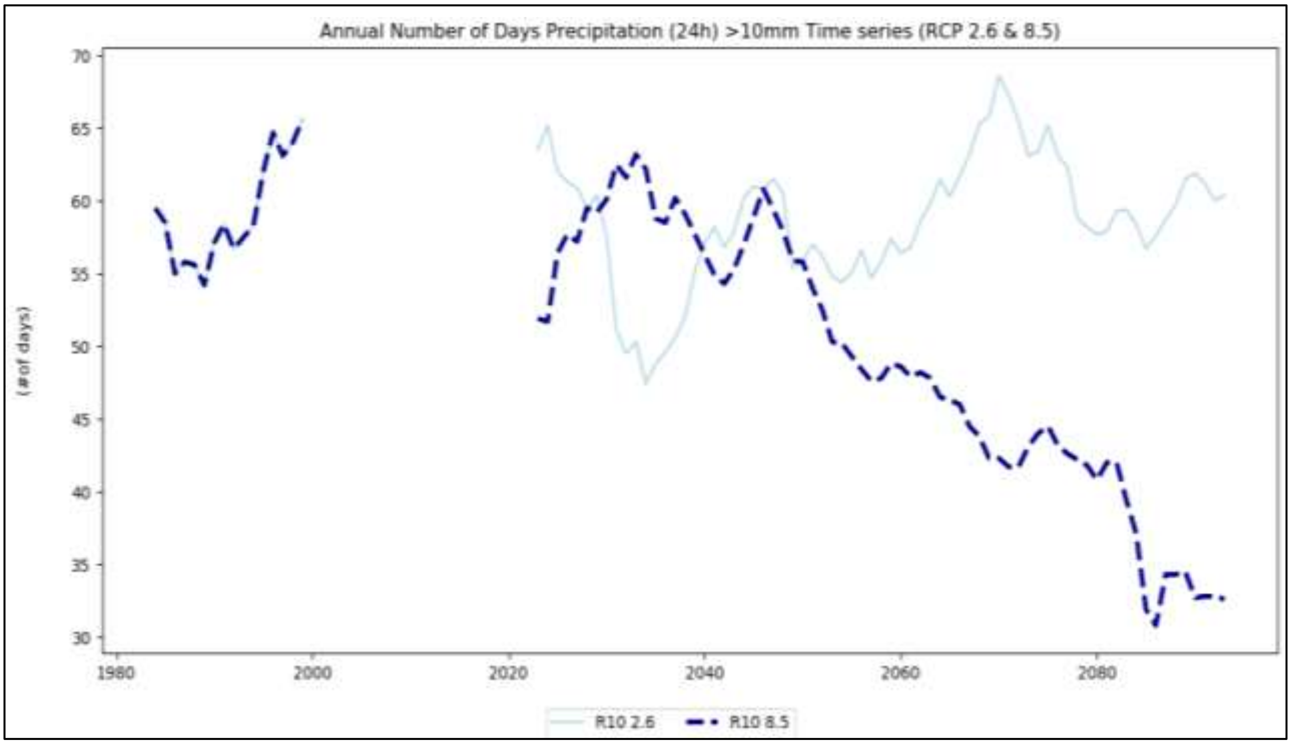


Figure 6.30: Days per year with Extreme 24h Precipitation Events at a (>) 10mm Threshold

Table 6.16 Annual Number of Days Precipitation Exceed 10mm

Year	Number of R10 Days (2.6)	Number of R10 Days (8.5)	Year	Number of R10 Days (2.6)	Number of R10 Days (8.5)	Year	Number of R10 Days (2.6)	Number of R10 Days (8.5)
1980	--	--	2020	--	--	2060	56.4	48.6
1981	--	--	2021	--	--	2061	56.8	47.9
1982	--	--	2022	--	--	2062	58.6	48.2
1983	--	--	2023	63.5	51.9	2063	59.8	47.8
1984	59.5	59.5	2024	65.2	51.7	2064	61.5	46.5
1985	58.5	58.5	2025	62.0	56.4	2065	60.3	46.3
1986	55.0	55.0	2026	61.3	57.7	2066	61.7	46.0
1987	55.8	55.8	2027	60.9	57.2	2067	63.2	44.5
1988	55.6	55.6	2028	59.5	59.5	2068	65.3	43.8
1989	54.2	54.2	2029	60.4	59.2	2069	65.8	42.3
1990	57.1	57.1	2030	57.6	60.1	2070	68.6	42.3
1991	58.4	58.4	2031	51.1	62.5	2071	67.3	41.7
1992	56.7	56.7	2032	49.5	61.6	2072	65.5	41.7
1993	57.5	57.5	2033	50.3	63.2	2073	63.1	43.1
1994	58.3	58.3	2034	47.4	62.2	2074	63.4	44.0
1995	62.0	62.0	2035	48.8	58.8	2075	65.2	44.5
1996	64.7	64.7	2036	49.6	58.5	2076	63.1	43.2
1997	63.1	63.1	2037	50.6	60.2	2077	62.3	42.6
1998	64.0	64.0	2038	52.0	59.1	2078	58.8	42.2
1999	65.6	65.6	2039	55.1	57.7	2079	58.2	41.8
2000	--	--	2040	57.1	56.3	2080	57.7	40.8
2001	--	--	2041	58.2	54.9	2081	57.9	42.0
2002	--	--	2042	56.8	54.3	2082	59.3	42.0
2003	--	--	2043	57.9	55.3	2083	59.4	39.4
2004	--	--	2044	60.2	57.0	2084	58.4	37.1
2005	--	--	2045	61.0	58.9	2085	56.7	31.9
2006	--	--	2046	60.8	60.8	2086	57.6	30.8
2007	--	--	2047	61.5	59.4	2087	58.7	34.3
2008	--	--	2048	60.5	57.9	2088	59.7	34.3
2009	--	--	2049	55.4	55.9	2089	61.5	34.5
2010	--	--	2050	55.9	55.8	2090	61.9	32.7
2011	--	--	2051	57.0	54.0	2091	61.2	32.8
2012	--	--	2052	56.2	52.5	2092	60.0	32.8
2013	--	--	2053	54.8	50.3	2093	60.4	32.6
2014	--	--	2054	54.4	50.2	2094	--	--
2015	--	--	2055	55.1	49.3	2095	--	--
2016	--	--	2056	56.6	48.4	2096	--	--
2017	--	--	2057	54.7	47.6	2097	--	--
2018	--	--	2058	55.8	47.8	2098	--	--
2019	--	--	2059	57.4	48.8	--	--	--

Figure 6.31 present the number of consecutive dry days (CCD); that is the maximum number of consecutive days that recorded precipitation is less than a 1 mm threshold on an annual timescale. This for RCP 2.6 and RCP 8.5. The plots again were smoothed using a 10 year running mean as described in the methodology. The following should be noted from the plots:

1. Under RCP 2.6 dry spells is likely to fluctuate going into the future. The medium term is likely to see a reduction in the number of dry spells while the near and long term futures is likely to see a slight increase in dry spells.
2. Under RCP 8.5 similar fluctuations are likely but now with likely decreases in the near and long term and similar levels to baseline in the medium term.

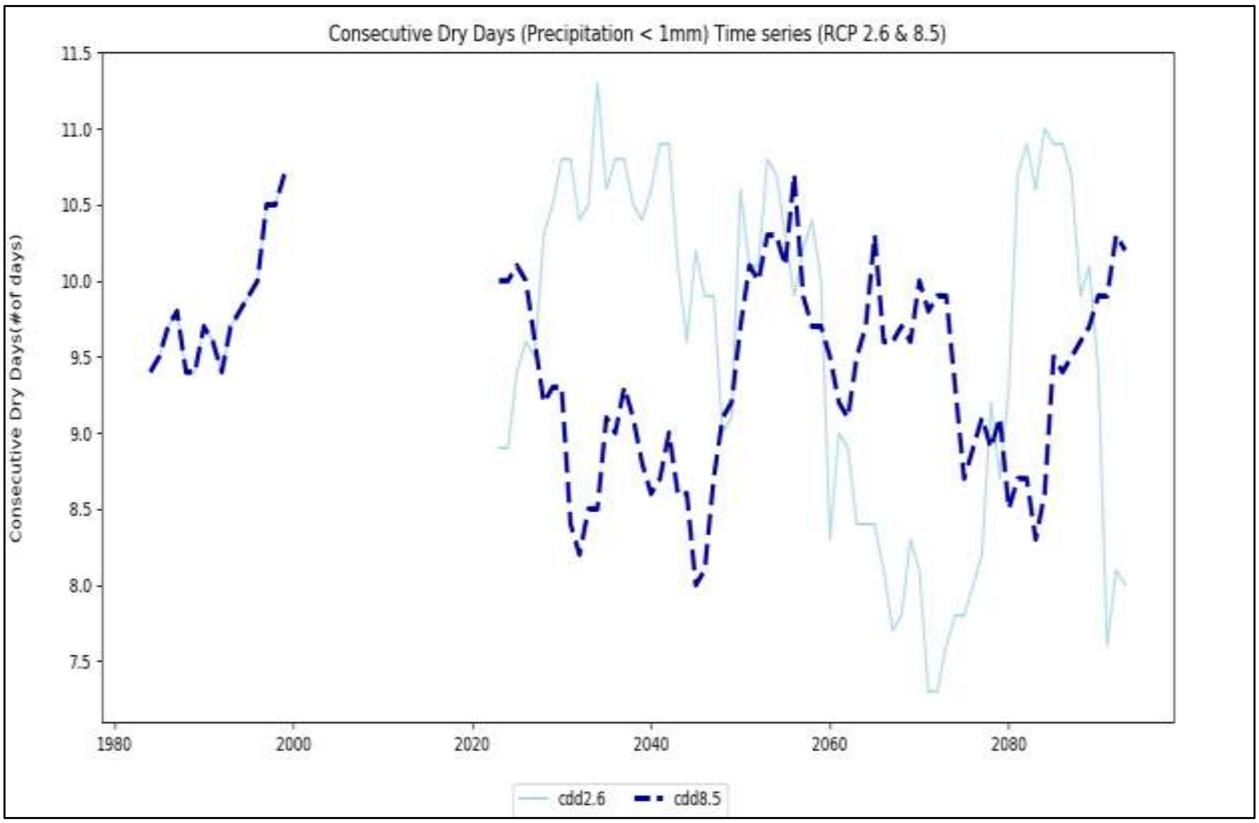


Figure 6.31: Consecutive Dry Days Precipitation Events at a (<) 1mm Threshold

Table 6.17 Number of Consecutive Days when Precipitation is below 1mm

Year	Consecutive Dry Days (2.6)	Consecutive Dry Days (8.5)	Year	Consecutive Dry Days (2.6)	Consecutive Dry Days (8.5)	Year	Consecutive Dry Days (2.6)	Consecutive Dry Days (8.5)
1980	--	--	2020	--	--	2060	8.3	9.5
1981	--	--	2021	--	--	2061	9.0	9.2
1982	--	--	2022	--	--	2062	8.9	9.1
1983	--	--	2023	8.9	10.0	2063	8.4	9.5
1984	9.4	9.4	2024	8.9	10.0	2064	8.4	9.7
1985	9.5	9.5	2025	9.4	10.1	2065	8.4	10.3
1986	9.7	9.7	2026	9.6	10.0	2066	8.1	9.6
1987	9.8	9.8	2027	9.5	9.6	2067	7.7	9.6
1988	9.4	9.4	2028	10.3	9.2	2068	7.8	9.7
1989	9.4	9.4	2029	10.5	9.3	2069	8.3	9.6
1990	9.7	9.7	2030	10.8	9.3	2070	8.1	10.0
1991	9.6	9.6	2031	10.8	8.4	2071	7.3	9.8
1992	9.4	9.4	2032	10.4	8.2	2072	7.3	9.9
1993	9.7	9.7	2033	10.5	8.5	2073	7.6	9.9
1994	9.8	9.8	2034	11.3	8.5	2074	7.8	9.3
1995	9.9	9.9	2035	10.6	9.1	2075	7.8	8.7
1996	10.0	10.0	2036	10.8	9.0	2076	8.0	8.9
1997	10.5	10.5	2037	10.8	9.3	2077	8.2	9.1
1998	10.5	10.5	2038	10.5	9.1	2078	9.2	8.9
1999	10.7	10.7	2039	10.4	8.8	2079	8.7	9.1
2000	--	--	2040	10.6	8.6	2080	9.3	8.5
2001	--	--	2041	10.9	8.7	2081	10.7	8.7
2002	--	--	2042	10.9	9.0	2082	10.9	8.7
2003	--	--	2043	10.1	8.6	2083	10.6	8.3
2004	--	--	2044	9.6	8.6	2084	11.0	8.6
2005	--	--	2045	10.2	8.0	2085	10.9	9.5
2006	--	--	2046	9.9	8.1	2086	10.9	9.4
2007	--	--	2047	9.9	8.7	2087	10.7	9.5
2008	--	--	2048	9.0	9.1	2088	9.9	9.6
2009	--	--	2049	9.1	9.2	2089	10.1	9.7
2010	--	--	2050	10.6	9.7	2090	9.4	9.9
2011	--	--	2051	10.1	10.1	2091	7.6	9.9
2012	--	--	2052	10.1	10.0	2092	8.1	10.3
2013	--	--	2053	10.8	10.3	2093	8.0	10.2
2014	--	--	2054	10.7	10.3	2094	--	--
2015	--	--	2055	10.3	10.1	2095	--	--
2016	--	--	2056	9.9	10.7	2096	--	--
2017	--	--	2057	10.2	9.9	2097	--	--
2018	--	--	2058	10.4	9.7	2098	--	--
2019	--	--	2059	10.0	9.7	--	--	--

Figure 6.32 presents the percentage occurrence of wet days (annual percentage of days with precipitation occurrence greater than the 95th percentile on an annual timescale). The plots again were smoothed using a 10 year running mean as described in the methodology. The following should be noted from the plots:

1. Under RCP 2.6 there is inter-annual variability throughout the period, the percentage of wet days also exhibits a slight positive linear trend going into the future.
2. Under RCP 8.5, there is also inter-annual variability with a slight positive linear trend up to mid-century. There is however a steep falloff (approximately 4% per decade) in the percentage of wet days moving from 2052 towards the end of the century.

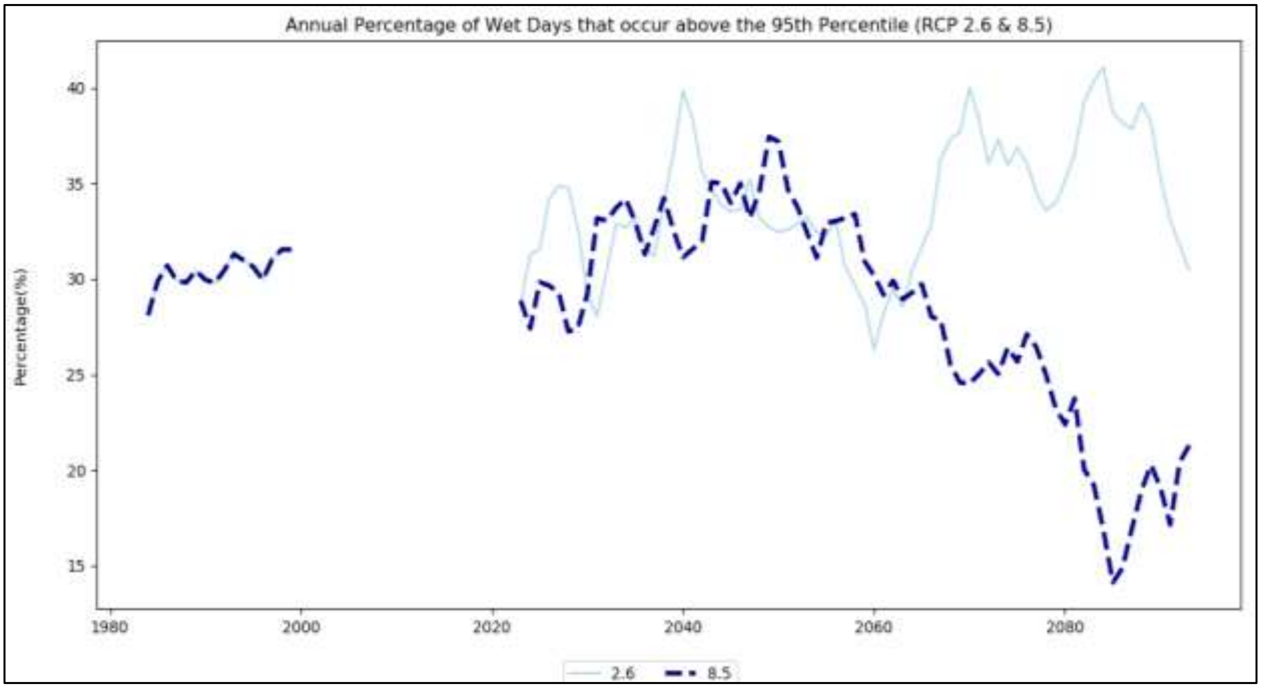


Figure 6.32: Wet Days Percentage Occurrence at a (>) 95th Percentile Threshold

6.4.2.3 *Hurricanes and Sea Level Rise*

This section provides an overview of the likely changes in future sea level rise and hurricane activity based on GCM projections. It is to be noted that the information provided is based on a review of the currently available scholastic literature.

6.4.2.3.1 Sea Level Rise

Rises in localized sea level are based on thermal expansion and salinity as shown in studies such as (Church et al. (2013), Levermann, Griesel, Hofmann, Montoya, & Rahmstorf (2005) and Yin, Schlesinger, & Stouffer (2009), both of which are affected by increases in temperature. An increase in temperature naturally warms the oceans and contributes to salinity by adding fresh water to the ocean through the melting of glaciers and ice sheets, see Table 6.18 extracted from (Climate Studies Group, Mona (CSGM), 2017), gives sea level rise projections for the south coast of Jamaica. It is to be noted that these values are relative to a baseline of 1986 to 2005 utilizing the full ensemble of GCM models under the CMIP project in conjunction with the SimClim 2013 software package. The following should be noted:

1. Under RCP 2.6 sea level rise is likely to be between 0.11 to 0.17m, 0.31 to 0.37 and 0.53 to 0.67m in the near, medium and long term future respectively.
2. Under RCP 6.0 sea level rise is likely to be between 0.11 to 0.17m, 0.31 to 0.39 and 0.58 to 0.80m in the near, medium and long term future respectively.
3. Under RCP 8.5 sea level rise is likely to be between 0.12 to 0.18m, 0.35 to 0.45 and 0.74 to 1.08m in the near, medium and long term future respectively.

Table 6.18 Projected Sea Level Rise for the South Coast of Jamaica.

Sea Level Rise (m) South Coast (-77.157W, 17.142N)								
Centered	2025		2035		2055		End of Century	
Averaged	2020-2029		2030-2039		2050-2059		2080-2100	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
RCP2.6	0.14	0.11 – 0.17	0.20	0.18 – 0.23	0.34	0.31 – 0.37	0.60	0.53 – 0.67
RCP4.5	0.14	0.11 – 0.17	0.20	0.18 – 0.23	0.36	0.32 – 0.40	0.68	0.59 – 0.78
RCP6.0	0.14	0.11 – 0.17	0.20	0.18 – 0.23	0.35	0.31 – 0.39	0.69	0.58 – 0.80
RCP8.5	0.15	0.12 – 0.18	0.22	0.19 – 0.25	0.40	0.35 – 0.45	0.90	0.74 – 1.08

The results provided in the CSGM report are support by other studies including (Kopp, et al., 2014) which projects mean sea level rise around Jamaica to be between 0.7m and 0.9m by the end of the century under RCP 8.5. Their projections are based on a Gaussian process model applied on historical tide gauge data. See Figure 6.33 which is extracted from (Kopp, et al., 2014) which shows projected sea level increases for the globe by the end of century under RCP 8.5.

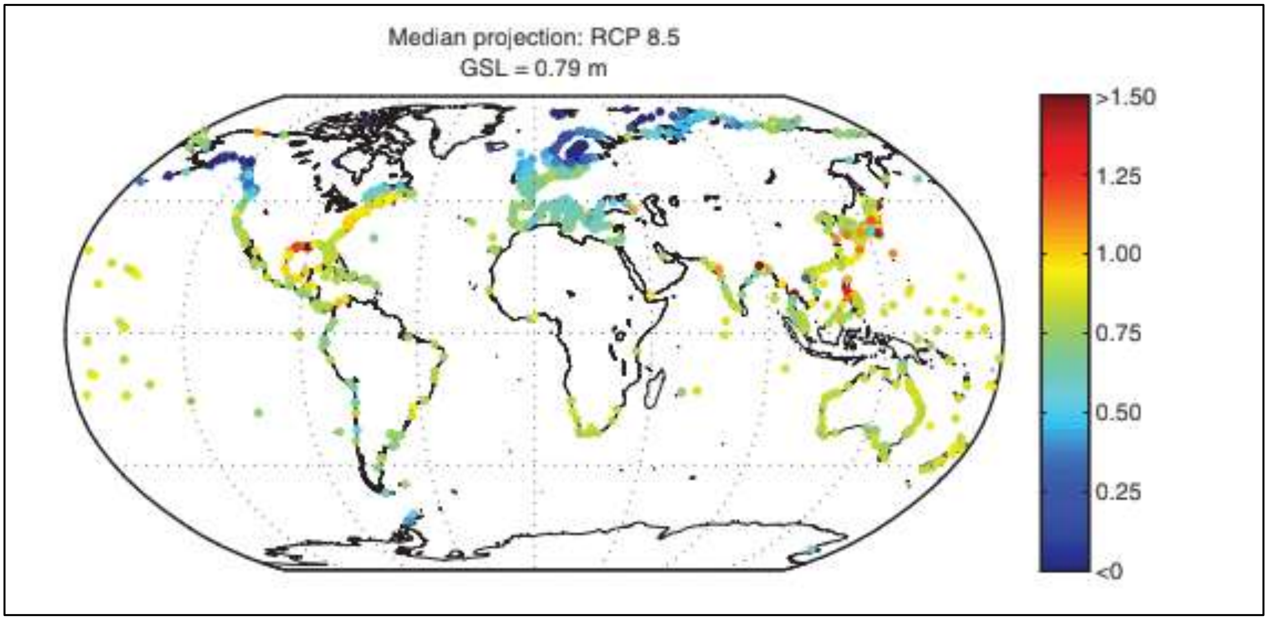


Figure 6.33: Projected end of Century Median Local Sea Level Rise under RCP 8.5 (Kopp, et al., 2014, p. 391)

Additionally, Strauss & Kulp (2018) presented sea level projections using tide gauge readings from Port Royal under the K14 model for RCP 2.6 and 8.5 at the 50th percentile. Their investigation showed that mean sea level increases in the region are likely to be 0.27m (0.30m) and 0.54m (0.82m) by 2050 and 2100 respectively under RCP 2.6 (8.5). Using a 21 mean AOGCM ensemble under RCP 8.5, Carson, et al. (2016) also showed similar projections for sea level rise between 0.7 and 0.8m by the end of the century. See Figure 6.34 which is extracted from Carson, et al. (2016) which shows projected sea level increases for the globe by the end of century under RCP 8.5.

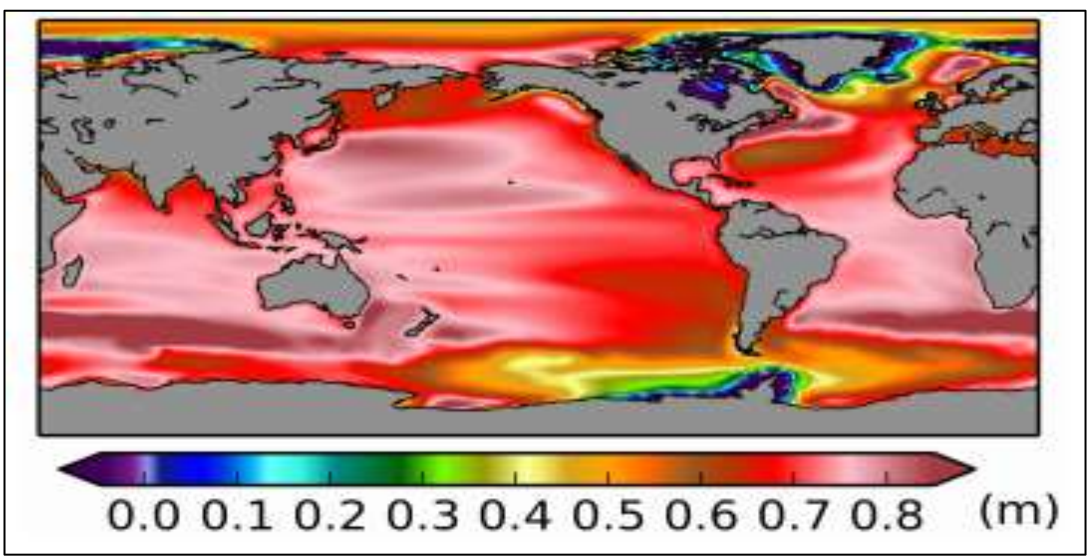


Figure 6.34: Projected Regional/Local Sea Level Mean Change (difference between 2081-2100 and 1986-2005 time periods) under RCP8.5 (Carson, et al., 2016,p.14)

6.4.2.3.2 Hurricane Intensity and Frequency

The majority of the studies available in current literature focus primarily on historic and RCP 4.5 data. Their findings however can be related to the other RCPs, this based on the relationships found. From the available body of literature examined the following changes related to future intensity and frequency of hurricane occurrences are to be noted:

I. The number of hurricanes experienced in a given season is likely to decrease or remain unchanged in the future. Zhang, et al. (2019) for instance found an inversely proportional historical relationship between tropical cyclone frequencies and sea surface temperature (SST). That is tropical cyclone activity decreased with an increase in the warmth of pools in which they form. This is with high confidence (tests of 90-99.9% for the respective pools). As such storms in moderate pools (65th-90th percentile) had decreased by 0.79 storms/decade and in the warm pools (>90th percentile) by 1.08 storms/decade. The suggestion is that with increase in future temperatures there may be reduced overall hurricane frequency in the future. These results are echoed in other reports such as the GSGM 2017 report (Climate Studies Group, Mona (CSGM), 2017), the IPCC 2012 Special Report on Extremes (IPCC, 2012) and (Knutson, et al., 2013).

II. The number of higher category hurricanes are likely to increase in the future. Research including (Bhatia et al., Bender et al., 2018 and Knutson et al., 2013), for instant, showed an increasing trend in major Atlantic hurricanes. Bhatia et al. in their study (Bhatia, Vecchi, Murakami, Underwood, & Kossin, 2018) projected a 72.9 and 135.5 % increase in category 4 and 5 hurricanes respectively by end of century under RCP 4.5. Bender et al. (2010) and Knutson et al. (2013) presented combined category 4 and 5 percentage increases of 100% and 40% respectively. See Figure 6.35 which is extracted from (Bhatia, Vecchi, Murakami, Underwood, & Kossin, 2018) which shows projected hurricane frequency increase as a percentage with respect to 1986 to 2005.

III. Rainfall rates associated with hurricanes are likely to increase in the future. Warmer temperatures are associated with greater convection and thus more moisture in the atmosphere. Knutson et al. (2013) for instance, indicated a likely increase in rainfall rate of between 20% and 33% particularly near the hurricane core.

IV. Wind speeds associated hurricanes are likely to increase in the future. According to (Trepanier, 2020) as temperature increases so does maximum wind speed. See Figure 6.36 extracted from (Trepanier, 2020) which shows the expected rate at which wind speed changes with temperature. For the region on the south coast of Jamaica, this rate is between 2.5 to 3.0 ms^{-1} per °C. This implies an increase from current wind speed by as much as 1.5ms^{-1}, 7.5ms^{-1} and 6.25ms^{-1} in the near, medium- and long-term future respectively.

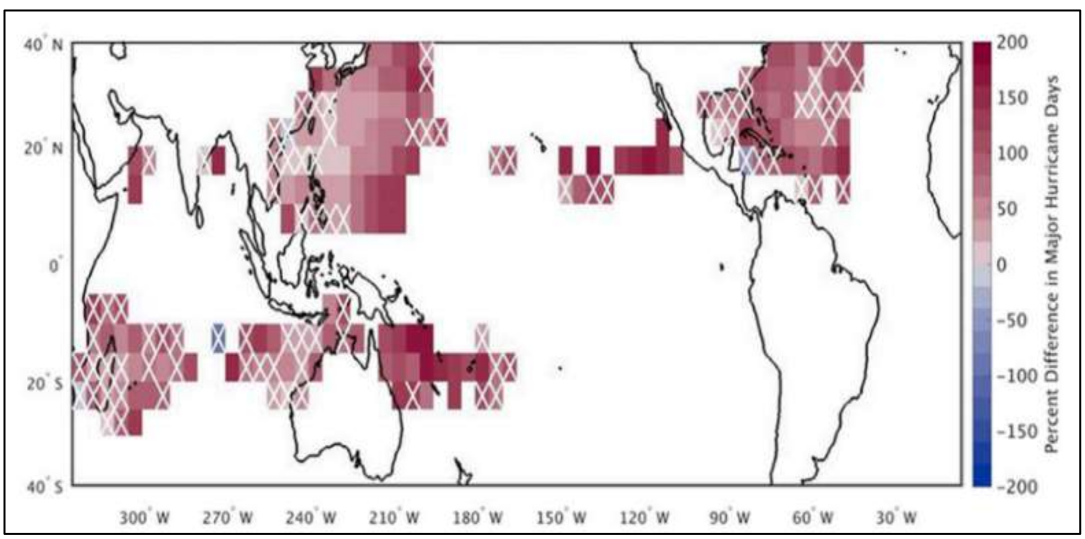


Figure 6.35: Percentage Difference of Major Hurricane Days between 1986-2005 and 2081-2100 by the HiFLOR model. White crosses represent not statistically significant grid boxes (Bhatia,et. al, 2018, p.8298)

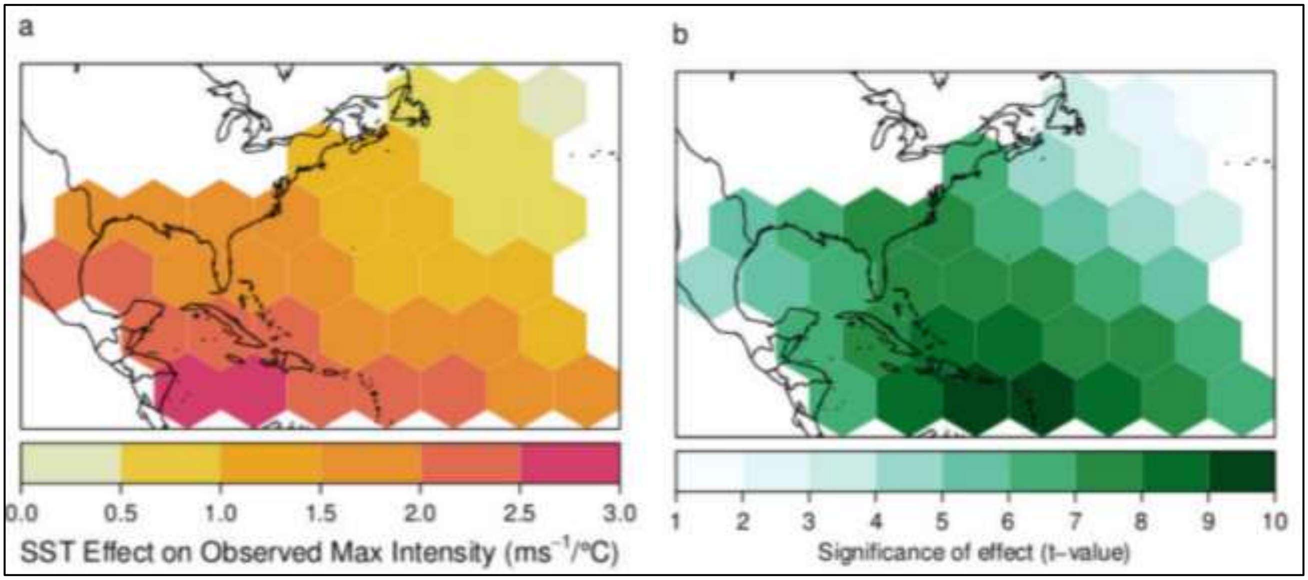


Figure 6.36: (a) Strength of the Local Relationship between the Observed per Event Maximum Wind Intensity and the average ("normal") August–October SST in °C. (b) Significance of the Relationship. (Trepanier, 2020).

6.4.2.4 *Summary*

The variables analyzed include temperature and precipitation (means and extremes), sea level rise and hurricanes. The data analyzed was from the HadGEM2-ES GCM downscaled using the ICTP RegCM version 4. With regards to sea level rise and hurricanes we presented results from recent scholastic studies.

Annual mean temperature is likely to be kept below 1.5°C above preindustrial levels under RCP 2.6, but under RCP 8.5 it is expected to increase at a rate of 0.4°C/decade till the end of century. Temperature climatologies of mean, maximum and minimum temperatures are expected to follow the unimodal pattern in the near, medium and long term future with higher temperature increase being observed in the summer months. This is true for both RCP 2.6 and 8.5. The temperature increases across months are however not uniform. Larger increases are observed in the winter months (December to February, with the largest increase in December) and smaller increases observed from May through to August for both RCPs.

With respect to temperature extremes; the number of warm days/daily maximum temperatures as well as warm nights that fall within the baseline 90th percentile are projected to increase up to as much as 100% under RCP 8.5.

With regards to monthly precipitation climatology, the known bimodal pattern for precipitation with peaks in May and October holds in the future for all three defined periods. The months with the greatest percentage decrease in precipitation across both RCPs are July and August. Under RCP 8.5 there is a decreasing trend in the number of days with rainfall > 10mm and the number of consecutive wet days.

The sea level is expected to increase to as much as 0.67m and 1.08m by the end of the century under RCP 2.6 and RCP 8.5 respectively.

There is expected to be a reduction in the total number of hurricanes in the future, however there is expected to be an increase in the number of major hurricanes. The increase could likely be more than 100% according to the current literature. Rainfall rate and maximum wind speed are also likely to increase in the future.

6.4.3 Climate Change Analysis

6.4.3.1 *Site Specific Trends and Climate-linkages*

The United Nations (2016) stated that climate change is one of the major challenges of our time and adds considerable stress to the environment and by extension our societies. Two of the major effects of this phenomena are the intensification and frequency of tropical cyclones that have heavily impacted the Northern Atlantic region. Climate variability over the North Atlantic is controlled by numerous mechanisms and Chunzai Wang (2017), posited that the top three climate indices that showed high correlations with Rapid Intensification (RI) of tropical cyclones are the June -November El Nino Southern Oscillation (ENSO), Atlantic warm pool (AWP) indices and the January-March North Atlantic oscillation index. Therefore, it is important to understand if, and why, there are observed trends in tropical cyclone intensification rates.

6.4.3.2 *Trends in Extreme Wave Heights*

Trends or non-stationarity in the extreme wave heights were explored for the period 1950 to 2016. The test revealed that a significant trend (increasing) was detected in the extreme wave heights for the period 1950 to 2016 offshore NMIA Airport. The method involved first testing for trends with the Mann Kendal test, then testing for breakpoints at the 5% level. Lastly, testing for the homogeneity of the series to detect breakpoints. The extreme wave climate for the period determined to be homogenous without trend. See *Table 6.19*.

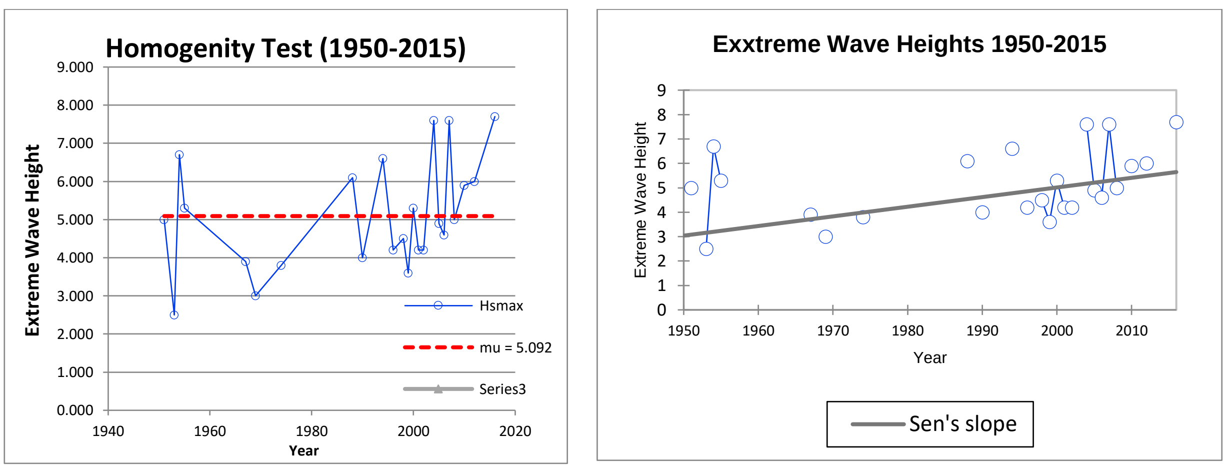


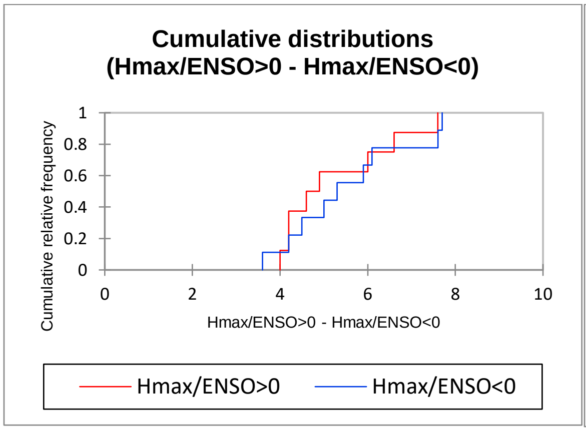
Figure 6.37 Homogeneity test (1950-2015) (A) and extreme wave heights (B)

6.4.3.3 *Climate Associations/linkages*

No significant connections were found between the extreme waves offshore the site and regional climate indices explored. The regional indices explored were: i) Atlantic Multi-decadal Oscillation (AMO), ii) ENSO, iii) Tropical Northern Atlantic (TNA) and iv) Atlantic Warm pool (AWP). The method involved first defining the time series of the regional climate indices and then associating these time series with the extreme wave climate time series. Perturbations of the various climate states were then explored by sorting the extreme waves by various states of the climate as follows:

Table 6.19 Climate state perturbations explored

Cool phase		Warm phase
Cool phase	0 < Annual average AMO > 0	Warm phase
Cool phase/small AWP	0 < AWP > 0	Warm phase/large AWP
Cool phase	0 < TNA > 0	Warm phase



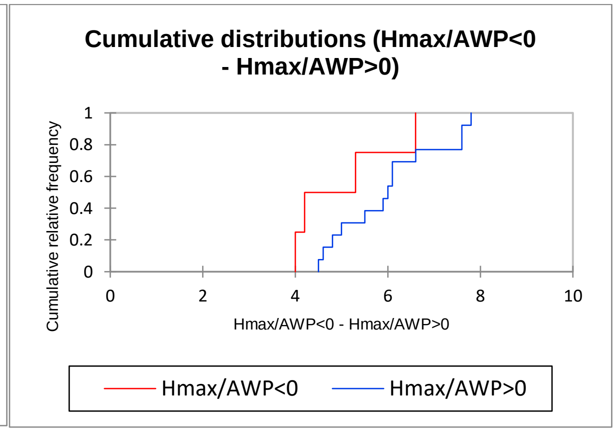


Figure 6.38 KS test for AWP (A) and ENSO (B) versus wave heights

The Kologorov-Smirnov (KS) test indicate that there were no significant climate connections between the extreme wave heights offshore and the regional indices investigated. For instance, with an increase in AWP greater than and less than 0, there was no significant change between the extreme wave heights. The statistical analysis indicate a trend towards higher wave heights with warmers AWP, but this is not at significant levels in the dataset analysed. Therefore, no evidence has been gathered that the climate indices and hurricane wave heights shared any relation within close proximity to the study area. Since both perturbed climate states for the four (4) indices investigated, were statistically similar, it was concluded that no significant climate connections could be determined from the dataset. Recommended regional climate change factors were used for the modelling of the hurricane waves. Please see *Table 6.19*.

6.4.3.4 *Summary*

No site-specific changes (trends or break points) were found in the extreme wave heights. Association with regional climate indices at significant levels were not detected. A conservative approach was adopted to use regional trends. Climate change factors were derived based on the assessments and literature reviewed. The following were incorporated into the design specifically the deep water and nearshore wave climate analysis.

The two-sample Kologorov-Smirnov test proved that there is no trend occurring between the climate indices and extreme wave heights within the study area. Therefore, the regional data set was used to undertake the wave modelling.

Table 6.20 Summary of climate change projections for water levels and hurricane intensities and numbers.

Parameter	Climate Factors (Cf)
Water Level (above existing MSL)	5.8 mm/yr.
Increase in intense hurricanes (cat 4-5)	14%
Decrease in hurricane activity	22%
Increase in number of storms per year	2-8

6.5 Wind and Wave Hindcast

6.5.1 Climate Change Considerations

It was necessary to consider the effect of climate change on the project area. A review of several peer reviewed research papers was conducted in order to inform the approach to applying the climate change variables to each hazard. The hazards included sea level rise, storm intensities and the associated storm surge and wave heights.

6.5.1.1 *Current and Projected Trends for Mean and Extreme Sea Levels*

Global sea levels (GSL's) have risen through the 20th century, and it is expected to accelerate through to the 21st century and beyond because of global warming, but their magnitude remains uncertain. Two main factors contribute to this increase: thermal expansion of sea water due to ocean warming and water mass input from land ice melt and land water reservoirs. A review of D J Rasmussen et al 2018 Environ. Res Lett. Indicates the following:

- Sea level rise (SLR) is increasing the magnitude and intensity of extreme seal levels (ESL's) which will inevitably result in coastal flooding. GSLR rate of increase is heavily dependent of the trajectory of global mean surface temperatures (GMST), however the stabilization of GMST does not imply stabilization of global mean sea level (GMSL).
- A likely range of GMSL above 2000 CE baseline can be projected with medium confidence depending on the temperature stabilization target (1.5 ℃, 2.0 °C, 2.5°C) of warming above pre-industrial levels.
- By 2100, the median GMSL increase for Jamaica and the region is projected to be 58 cm[5] (90% probability of 37 to 93cm) above 2000 CE baseline for the GMST stabilization scenario of 2.5 °C. This projected increase is equivalent to 5.8mm/yr.

The sea levels will be adjusted by 5.8mm/year to account for the changes in sea level at the anticipated end of the project life.

6.5.2 Storm Surge

Hurricane storm surge is an increase in the water levels during the passage of a hurricane. The increases are due to several factors, the major ones include: Inverse barometric pressure, Tides, shoaling, wave setup, wind set up and run-up. Increases in water levels will cause further flooding of the near shore area as well as it will cause more destructive waves to reach closer to the shoreline or further inland. It is crucial to determine the setups that will be generated at the project site in order to assess the vulnerability of the study area.

6.5.2.1 *Procedure*

The approach included searching the National Hurricane Centre (NOAA) database of hurricane track data in the Caribbean Sea that would have passed within 300km of an offshore point. The dataset which dates back to 1886 was utilized to carry out a hind cast, followed by a statistical analysis to determine the hurricane: waves, wind and set-up conditions.

It was necessary to define the deep-water hurricane wave climate at a point offshore the study area at: Latitude: 17.4 degrees North and Longitude: 76.2 degrees West

[5] DJ Rasmussen et al 2018 Environ. Res. Lett.

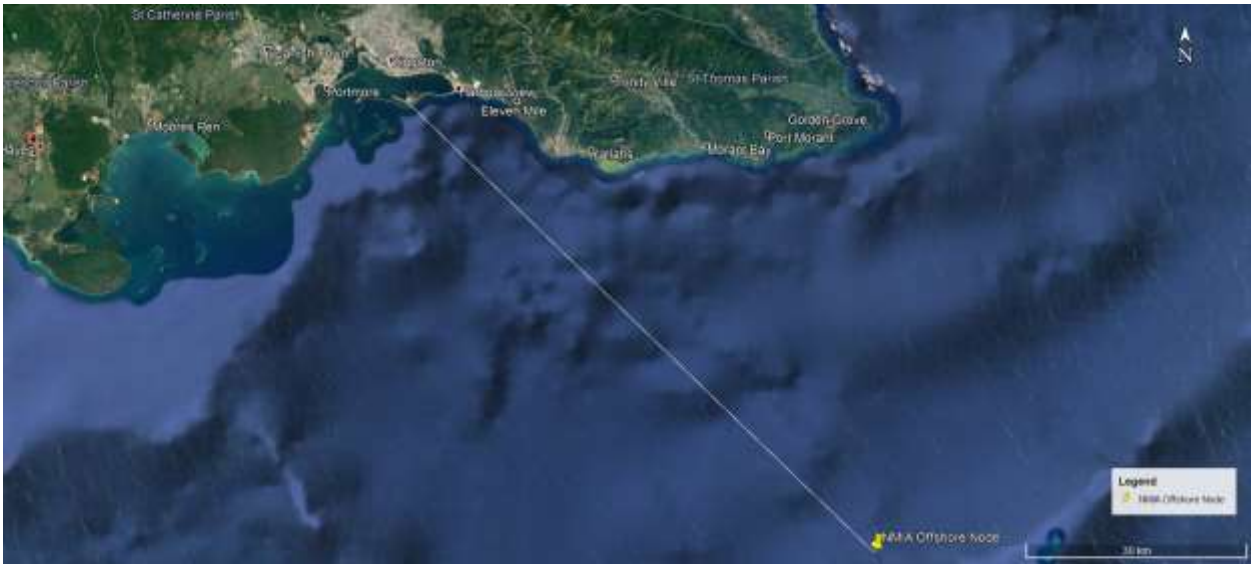


Figure 6.39 Location of the offshore point used for Extremal analysis, showing the track used in the analysis

The following procedure was carried out in order to arrive at the statistical return period surge levels:

1. *Extraction of Storms and Storm Parameters from the historical database.* A historical database of storms was searched for all storms passing within a search radius of 300km radius of the site.
2. Application of the JONSWAP Wind-Wave Model. A wave model was used to determine the wave conditions generated at the site due to the rotating hurricane wind field. This is a widely applied model and has been used for numerous engineering problems. The model computes the wave height from a parametric formulation of the hurricane wind field.
3. *Application of Extremal Statistics.* Here the predicted maximum wave height from each hurricane was arranged in descending order and each assigned an exceedance probability by Weibull's distribution.
4. *A bathymetric profile from deep-water to the site was then defined and each hurricane wave transformed along the profile.* The wave height at the nearshore end of the profile was then extracted from the model and stored in a database. All the returned nearshore values were then subjected to an Extremal Statistical analysis and assigned exceedance.

6.5.2.2 *Occurrences and Directions*

The results of the search from the database for hurricanes that came within the search radius of the site are shown in Extremal analysis results are summarized in the bi-variant. The results of the search clearly indicate the sites overall vulnerability to such systems. In summary:

1. 117 hurricane systems came within 300 kilometers (km) of the project area
2. 8% or 9 of which were classified as catastrophic (Category 5) and
3. 19 were classified as extreme (Category 4)

The bi-variant table analysis indicates that the waves generated offshore the site have approached from all seaward directions possible. However, the most frequent hurricane waves have been noted to come from the southerly direction, more specifically the **south-easterly** direction. In summary, there are:

- 60 (x6 hours) occurrences from the west
- 2 (x6 hours) occurrences from the north-west
- 28 (x6 hours) occurrences from the north

- 42 (x6 hours) occurrences from the north-east
- 52 (x6 hours) occurrences from the east
- **67 (x6 hours) occurrence from the south-east**
- 65 (x6 hours) occurrence from the south
- 62 (x6 hours) occurrence from the south-west

The south west to south-easterly directions are more prevalent for the node considered because of the seaward projection of the eastern part of the island that somewhat buffer the site from remote easterly waves. The site however becomes more exposed as soon as the passing hurricane systems are more south and or west of the island.

6.5.2.3 *Results*

The storm surge data were extracted from 1980- 2016. These years were used because of the introduction of new observing technologies such as satellites which were implemented within this period. Consequently, decreasing in homogeneities and improving the predictions of these storms (Gabriele Villarini, 2011). A total of 17 storms passed within 300km of the site for the period 1980 to 2016 (36 years), where, 10 of the storms were classified as cat 4-5. The annual maximum values of storm surges were then fitted to a Generalized Type III Extreme Value (GEV) distribution to determine the return period storm surge values.

Boot resampling was employed in order to improve the estimates of standard errors and confidence intervals. This was a necessity because the sample size of the dataset, created by the 300 km criteria reduced the original dataset. Approximately 100 samples were generated for the exercise. For all samples generated, the number of elements in each corresponded to the number of elements found in the original data set. The range of sample estimates obtained enabled the model to establish the uncertainty of the mean values estimated. The climate change considerations for future climate scenario included in this exercise predicted that the intensity of category 4 and 5 storm events would increase by 24%.

This process was repeated for three climate change scenarios, Representative Concentrative Pathway (RCP) 2.6, 6 and 8.5 (near, medium- and long-term future). See Table 6.21 below of the results generated from the CEAC Storm surge model.

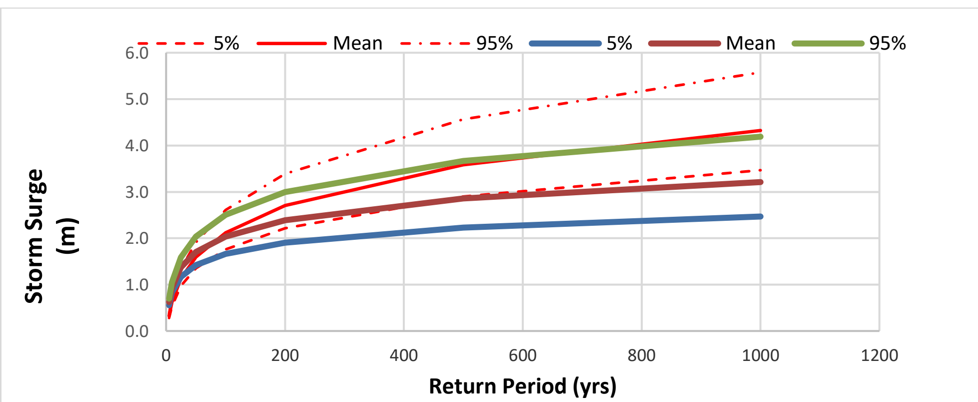


Figure 6.40 Storm Surge elevations for return periods under the predicted current and future climate scenarios (RCP 8.5).

Table 6.21 Summary of storm surge elevations for different return periods and all climate scenarios.

Return Period (Years)	Current climate storm surge elevations (m)	Future climate Storm Surge elevations (m) RCP 2.6	Future climate Strom Surge elevations (m) RCP 6	Future climate Storm Surge elevations (m) RCP 8.5
10	1.1	1.32	1.34	1.41
25	1.8	2.14	2.22	2.22
50	2.4	2.80	2.93	2.94
100	3.0	3.51	3.73	3.79

6.5.3 Deepwater Waves and winds

6.5.3.1 *Results*

Wave and wind information is crucial in order to understand the likely conditions that the proposed project shoreline will be subjected to. This information will be used to adequately design coastal structures to provide maximum protection against the destructive elements that it will encounter.

Both waves and winds were analysed in a similar manner as the storm surges above. The annual maximum values of extreme waves and winds were fitted to a generalized type III extreme value (GEV) distribution to determine the return period wave heights. Bootstrap resampling was employed in order to improve the estimates of standard errors and confidence intervals for given the dataset is only 19 of over 166 years.

The climate change considerations were also included in the exercise. For the future climate scenario the intensity of storm events would increase by 24%. The increase in intensity was applied to all the events that were defined as a category 4 or 5 storm. Similar to the storm surges the climate change scenario as predicted by the model shows an increase in wave heights and wind speeds, see Table 6.22 and

Table 6.24.

This process was repeated for three climate change scenarios, Representative Concentrative Pathway (RCP) 2.6, 6 and 8.5. See Table 6.22 below of the worst case scenario, RCP 8.5.

Table 6.22 Summary of wave heights and periods for different return **periods** and climate scenarios. (RCP 8.5)

Return Period (Years)	Current climate Period (sec)	Current climate Wave Height (m)	Future climate Period (sec)	Future climate Wave Height (m)
10	11.7	6.8	12.0	7.4
25	12.8	8.8	13.1	9.4
50	13.4	10.1	13.8	10.8
100	14.0	11.4	14.3	12.2

Table 6.23 Summary of wave heights for different return periods and all climate scenarios.

Return Period (Years)	Current climate Wave Height (m)	Future climate Wave Height (m) RCP 2.6	Future climate Wave Height (m) RCP 6	Future climate Wave Height (m) RCP 8.5
10	6.8	6.90	7.19	7.4
25	8.8	8.54	9.09	9.4
50	10.1	9.65	10.26	10.8
100	11.4	10.65	11.34	12.2

Table 6.24 Summary of wind speeds for different return periods and climate scenarios (2050)

Return Period (Years)	Future climate Wind speed (m/s) RCP (2.6)	Future climate Wind Speed (m/s) RCP (6.5)	Future climate Wind Speed (m/s) RCP (8.5)
10	40.9	46.6	48.3
25	57.7	67.3	70.6
50	69.6	82.9	87.1
100	82.3	98.1	105.2

The extremal analysis results indicate that for the climate change scenario RCP 8.5(worse case), the 10, 25, 50 and 100-year return period event for current climate scenario are predicted to produce deep water wave height of up to 7.4 m, 9.4 m, 10.8 and 12.2 m respectively. Wind speeds for the same climate scenario (RCP 8.5) for the 10, 25, 50 and 100-year return period event were predicted to be up to 48.3 m/s, 70.6 m/s, 87.1 and 105.2 respectively. Overall, these are relatively large waves and fast wind speeds with potential for causing severe damage along the shoreline. The wave heights and wind speeds were however collected form an offshore point and therefore will undergo some reduction in intensity as they approach the shoreline. Their potential for resulting near shore climates were investigated using a wave refraction and diffraction model as outlined in the sections below.

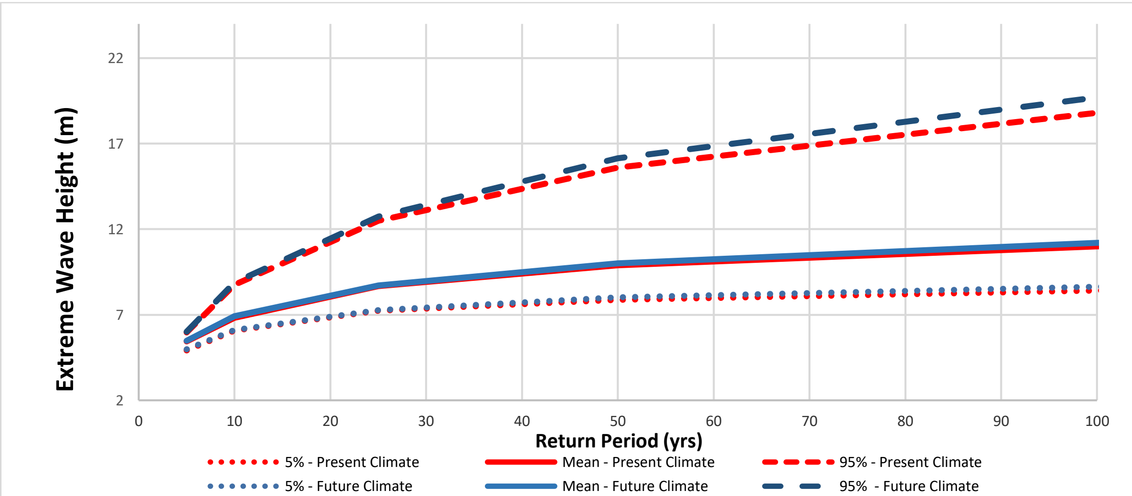


Figure 6.41 Extreme waves elevations for return periods under the predicted current and future climate scenarios (RCP 8.5).

6.5.3.2 *Summary*

Storm surge studies incorporates deep water waves as well as the wind speeds that is used to produces said surges. The data was generated using a statistical analysis to derived return periods. Climate change factors were also used to describe a future climate scenario. Results of this analysis indicated that the wave heights and wind speeds will increase by approximately 24% as seen in Table 6.25. Wave heights under the future climate scenarios for the 50 yr. and 100 yr. return period storm were predicted to be up to 10.8 m and 12.2 m respectively. The results for the offshore storm surge showed that the storm surge elevations 1.41, 2.22, 2.94, 3.79m for the 10, 25, 50 and 100 year return period (RP), see plots below (Figure 6.42). Based on the results considerable damage would occur at the shoreline, therefore a mitigation measures would be needed to lessen the impact of wave energy at the shoreline.

Table 6.25 Change difference between the current and future climate scenarios for different return periods.

Return Period (YRS.)	Change difference between current and future climate
10	19%
25	20%
50	23%
100	27%
Average	22%

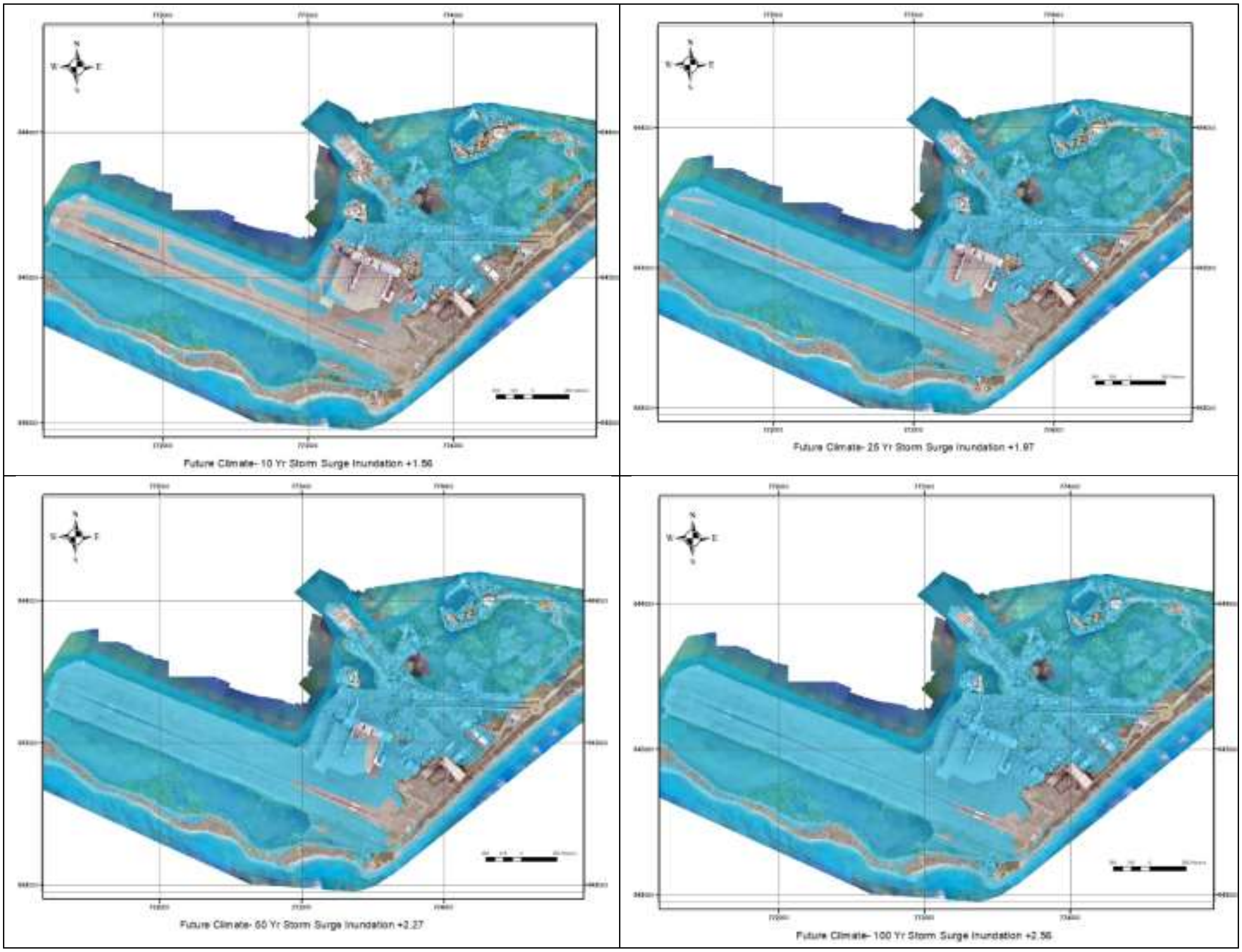


Figure 6.42 Storm surge footprint plots for 10, 25, 50- and 100-Year Return period (RP) RCP 8.5 (2050)

6.6 Nearshore Wave and Storm Surge Climate Analysis

6.6.1 Introduction

6.6.1.1 *Storm Surge Scenarios*

Storm surges are a meteorological phenomenon, mostly wind storms that pose a geophysical risk which abruptly inundated low-lying coastal regions. Over the past decades, the direct impact of such hazards such as storm surges and extreme waves have resulted in grave environmental degradation and socioeconomic disturbances along Jamaica's coast. These hazards are expected to become more severe in the future because of present and projected sea level rise, and more intense hurricanes.

Therefore, this section is aimed at exploring three (3) climate change scenarios, namely RCP2.6, 6 and 8.5 (see) to examine the inundation risk of extreme water levels at NMIA under climate change. The CEAC Storm surge model was used for refitting the recurrence periods of the offshore surge elevations (discussed in Section 6.5.2). These offshore directions were then placed in MIKE 21/3 Coupled Model, to assess the nearshore elevations. Each RCP represents a future subjected to a specific radiative forcing value; this as a result of the predicted cumulative GHG emission quantities for each scenario. The RCPs allows planners to identify the focal areas where climate change instigates heavy socio-economic impacts whilst affording them the ability to upgrade the requisite policies to combat these possible impacts.

6.6.2 Data and Methodology

Data sources are summarized in Table 6.26 including hydrological, geographical, and statistical data.

Table 6.26 Data sources

Data Type	Content	Description	Source
Hydrological Data	Hurricane data	Storm surge in future: 2050 and 2100; RCPs 2.6, 4.5, and 8.5	Emmanuel (2014)
	Astronomical tide	Calculated by harmonic tide models	MIKE DHI
	Sea level rise	Global mean sea-level rise in future: 2050 and 2100; RCPs 2.6, 4.5, and 8.5; two levels (low vs. high) for each RCP.	IPCC (2013)
Statistical data	Storm surge model	Boot strapping (resampling technique)	CEAC Solutions Ltd.

6.6.2.1 *Methodology*

The methodology involves two major subcomponents; Prepare sea level projections over multiple time horizons for each park unit; and estimate potential exposure to storm surge using the MIKE DHI MIKE 21 /3 Integrated Coupled Model:

The general approach taken to complete this assessment is outline below:

1. Prepare storm surge projections for three (3) RCP Scenarios
2. Estimate potential exposure to storm surge using the MIKE DHI MIKE 21 /3 Integrated Coupled Model

6.6.2.1.1 Storm Surge Scenarios

This section provides an overview of the likely changes in future hurricane activity based on GCM projections. It is to be noted that the information provided is based on a review of the currently available scholastic literature, namely Knutson (2014)[6] and Emmanuel (2013)[7] . See climate change scenarios below in Table 6.27.

Table 6.27 Description of Representative Concentration Pathway Scenarios (IPCC, 2014)

RCP Scenario/ Radiative Forcing	Description	Likely End of Century Global Mean Surface Temperature Increases
2.6 (2020-2029)	Low GHG Emissions or neutered impact through social and economic behavioral changes directed towards major mitigation. Denoted by a GHG range ≥ 430 ppm and ≤ 530 ppm.	0.3ºC to 1.7 ºC
6.0 (2055-2059)	Low intermediate mitigation which falls closer to a business-as-usual behavior. Denoted by a GHG range ≥ 720 ppm and ≤ 1000 ppm.	1.4 ºC to 3.1 ºC
8.5 (2080-2100)	High GHG Emissions through a business-as-usual behavior or low behavioral change towards GHG mitigation. Denoted by a GHG range > 1000 ppm.	2.6 ºC to 4.8 ºC

6.6.2.1.2 Objectives and Approach

Deepwater wave data by itself offers limited information on how waves reach the shoreline. It was therefore necessary to determine the nearshore wave climate in order to identify areas of the study area that might be vulnerable to shoreline erosion or direct wave. The approach adopted in order to achieve these objectives was as follows:

- Use the deep-water wave, storm surge setup and hurricane wind data as input for the analysis.
- Determine the hurricane environments along the Harbour side and Caribbean Seaside shoreline.
- Determine the impact of climate change along the Harbour side and Caribbean Seaside Shoreline during hurricane event.
- Prepare a bathymetric database of the project domain for extremal analysis.
- Conduct spatial storm surge and wave transformation analysis within the study area.

6.6.2.1.3 Wave Climate Model: Mike 21/3 Coupled FM Module

The MIKE 21/3 Coupled FM Module suite of computer programs was used to calculate the corresponding distribution of surface water elevation and waves in the area. MIKE 21/3 Coupled Model FM is a truly dynamic modelling system for application within coastal, estuaries and river environments. When using the suite it is possible to simulate the mutual interaction between waves and currents using a dynamic coupling between the Hydrodynamic Module and the Spectral Wave Module.

The two modules are the:

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[6] Knutson, Thomas R., Joseph J. Sirutis, Gabriel A. Vecchi, Stephen Garner, Ming Zhao, Hyeong-Seog Kim, Morris Bender, Robert E. Tuleya, Isaac M. Held, and Gabriele Villarini. "Dynamical downscaling projections of twenty-first-century Atlantic hurricane activity: CMIP3 and CMIP5 model-based scenarios." *Journal of Climate* 26, no. 17 (2013): 6591-6617.

[7] Emanuel, Kerry A. "Downscaling CMIP5 climate models shows increased tropical cyclone activity over the 21st century." *Proceedings of the National Academy of Sciences* 110, no. 30 (2013): 12219-12224

- The hydrodynamic module to calculate the solution for the surface elevation and velocity field at each point in the domain as a function of time with a critical Courant–Friedrichs–Levy (CFL) number.
- The spectral wave module to model the wave propagation and transformation from offshore up to the shoreline was calculated using the spectral wave component

The hydrodynamic model simulates water level variation and flows in response to a variety of forcing functions in lakes, rivers, estuaries and coastal regions. The hydrodynamic module can be used to solve both three-dimensional and two-dimensional problems. The effect facilitates

- Flood and drying
- Momentum dispersion
- Bottom shear stress
- Coriolis force
- Wind shear stress
- Barometric pressure gradients
- Ice coverage
- Tidal potential
- Precipitation/ evaporation
- Wave radiation stresses
- Sources and sinks

The Spectral Waves model simulates the growth, decay and transformation of wind-generated waves and swells in offshore and coastal areas (DHI 2004). MIKE 21 SW includes the following physical phenomena:

- Wave growth by action of wind
- Non-linear wave-wave interaction
- Dissipation due to white capping
- Dissipation due to bottom friction
- Dissipation due to depth-induced wave breaking
- Refraction and shoaling due to depth variations
- Wave-current interaction
- Effect of time-varying water depth and flooding and drying

The discretization of the governing equation in geographical and spectral space is performed using cell-cantered finite volume method. In the geographical domain, an unstructured mesh technique is used. The time integration is performed using a fractional step approach where a multi-sequence explicit method is applied for the propagation of wave action.

6.6.2.1.4 Modelling Approach and Summary Incident Wave Conditions

The output from the storm surge model used for hurricane impact analysis provided us with the incident wave height and period as well as the water setup and wind speeds for the deep-water extremal analysis. These incident wave heights and periods were then used in the Mike 21/3 Coupled Module to generate the surface elevation and nearshore wave climate for existing and proposed shoreline conditions. The spatial patterns of wave breaking and shoaling were noted in relation to the proposed site. Should intense wave focusing be noted, then it would be advisable that this be considered in the design of adequate structural engineering provisions. See Table 6.22,

Table 6.23 and

Table 6.24 for a summary of the setup, incident wave height and wind conditions used for the analysis.

6.6.3 Results

6.6.3.1 *Caribbean Sea Side*

A storm surge analysis was done to observe the rise in the seawater level from the change in meteorological process such as wind and atmospheric pressure, at the shoreline. The storm surge heights were identified from the worst case direction namely: south-easterly (SE) direction, for a 10, 25 50- and 100-year return period storm for all scenarios stated above. The models were simulated using both the current and future climate scenarios to gain a better understanding of the impact the waves on the study area as it relates to climate change. This process was done for each of the climate change scenarios, discussed in Section 6.6.1.1.

See location map below to identify the locations at which results were extracted, Figure 6.43, this was to receive a holistic look at the NMIA. The present climate scenario produced storm surge elevations ranged from 1.72-2.05m for a 50 –year return period at each location; 100-year return period surge elevations approaching the shore ranged from 1.95-2.30m, see Table 6.28 inserted below.

Whereas for the future climate scenarios, the analysis revealed that the surface elevations at the nearshore varied from 2.19, 2.34 and 2.78 m for the 50year RP for all the scenarios (RCP2.6, 6 and 8.5). While for the 100yr RP (Future Climate) the storm surge elevation varied from 2.29, 2.64 and 3.68 m for the all the scenarios respectively (RCP2.6, 6 and 8.5), see Table 6.29. In essence, the NMIA Lighthouse and end of runway 30, were the most vulnerable areas, as the area are low lying.

6.6.3.2 *Harbour Side*

Surges within the harbour are influenced by deep water waves attenuated through the mouth of the harbour and wind. Of the two phenomenon, wind plays the dominant role in wave generation within the harbour especially during a hurricane. These storm surges can cause considerable damage to vulnerable shorelines. As such it was crucial to explore this scenario by simulating the effects that harbour generated surge would have on the study area.

The results indicated that during extreme conditions the existing study area is expected to experience storm surge elevations (present climate 100 year return period) varied from 0.16- 1.05 m from the northern direction (N) under the all future climate scenarios (RCP 2.6, 6, 8.5), see Table 6.31.

Figure 6.43 Location Map indicating the specific points at which results were extracted

Table 6.28 Present climate results from nearshore storm surge model for all locations (Caribbean Sea)

Present climate (Caribbean Sea side)						
	Return Period (yr)	NMIA Roundabout	Sand Dunes Location 1	Sand Dunes Location 3	Sand Dunes Location 3	NMIA Lighthouse
	10	1.02	1.21	1.16	1.23	1.20
	25	2.03	1.94	1.83	1.73	1.65
	50	2.05	2.17	1.95	1.82	1.72
	100	2.10	2.21	2.30	2.10	1.95

Table 6.29 illustrating the future climate results from nearshore storm surge model for all locations (Caribbean Sea)

Scenario 2.6						
	Return Period (yr)	NMIA Roundabout	Sand Dunes Location 1	Sand Dunes Location 3	Sand Dunes Location 3	NMIA Lighthouse
	10	1.12	1.45	1.42	1.25	1.09
	25	1.97	1.85	1.87	2.20	1.49
	50	2.19	2.09	2.16	2.24	1.84

	100	2.29	2.13	2.26	2.5	2.08
Scenario 6						
	Return Period (yr)	NMIA Roundabout	Sand Dunes Location 1	Sand Dunes Location 3	Sand Dunes Location 3	NMIA Lighthouse
	10	1.26	1.60	1.65	1.45	1.35
	25	2.04	1.93	1.82	1.75	1.65
	50	2.34	2.15	2.25	2.23	1.94
	100	2.64	2.58	2.38	2.39	2.43
Scenario 8.5						
	Return Period (yr)	NMIA Roundabout	Sand Dunes Location 1	Sand Dunes Location 3	Sand Dunes Location 3	NMIA Lighthouse
	10	1.87	1.63	1.83	1.59	1..40
	25	2.15	2.05	2.19	1.98	1.75
	50	2.78	2.33	2.25	2.60	2.08
	100	3.3	3.2	3.1	3.68	2.75

Table 6.30 illustrating the present climate results from nearshore storm surge model for all locations (Harbour side)

Present (Harbour side)						
	Return Period (yr)	Southern Mangroves	End of Runway 12	Revetment	Air Traffic Control (ATC)	Northern Runway
	10	0.18	0.27	0.35	0.10	0.35
	25	0.30	0.33	0.28	0.23	0.47
	50	0.41	0.50	0.45	0.24	0.70
	100	0.50	0.54	0.49	0.44	1.04

Table 6.31 illustrating the future climate results from nearshore storm surge model for all locations (Harbour side)

Scenario 2.6 (Harbour side)						
	Return Period (yr)	Southern Mangroves	End of Runway 12	Fire Station	Air Traffic Control (ATC)	Northern Runway
	10	0.22	0.33	0.41	0.15	0.43
	25	0.32	0.40	0.32	0.30	0.52
	50	0.48	0.50	0.45	0.43	0.82
	100	0.53	0.61	0.52	0.54	1.4
Scenario 6.0 (Harbour side)						

	Return Period (yr)	Southern Mangroves	End of Runway 12	Fire Station	Air Traffic Control (ATC)	Northern Runway
	10	0.26	0.33	0.23	0.17	0.33
	25	0.39	0.47	0.42	0.35	0.90
	50	0.54	0.65	0.53	0.55	1.40
	1000	0.63	0.88	1.10	1.60	1.83
Scenario 8.5 (Harbour side)						
	Return Period (yr)	Southern Mangroves	End of Runway 12	Fire Station	Air Traffic Control (ATC)	Northern Runway
	10	0.26	0.40	0.26	0.20	0.36
	25	0.39	0.47	0.54	0.47	0.96
	50	0.54	1.14	1.06	1.20	1.70
	100	0.63	1.53	1.20	1.65	1.86

6.6.4 Summary and Discussion

6.6.4.1 *Harbour Generated Storm Surge*

Results previously discussed may seem daunting but are only used to describe the offshore climate. The waves and wind speeds were then used on the boundaries of the models to simulate and predict the nearshore wave climate. The deep-water waves were only applied to the southern boundary while the wind speeds were applied to the worst-case direction. This approach was executed so as to better simulate the wave generation processes within the harbour, as waves within the harbour are mostly driven by wind. The results of this analysis indicate that waves coming from the north-western direction towards the study area within the harbour are the worst-case scenario. For the 50 yr. and 100 yr. return period storm event wave heights were predicted to be up to 0.43 – 1.86 m under the all future climate scenario (RCP 2.6, 6, 8.5).

6.6.4.2 *Caribbean Sea Side Storm Surge*

After examining the nearshore surface elevation for current and future storms, it was displayed that for the present climate the surface elevation is approximately 0.9 m at the shoreline. While for the 100yr RP (Future Climate) the storm surge elevation varied from 1.7 and 3.7 m for the all the scenarios (RCP2.6, 6 and 8.5). Based on the results, minor- moderate damage would occur at the shoreline from these levels of surface elevation at the shoreline. This is due to the sand dunes that currently situated along the shoreline that act as protection barrier for such surges. Overall, predicted surface elevations for all of the return periods are expected to increase as projected climate change trends ensures.

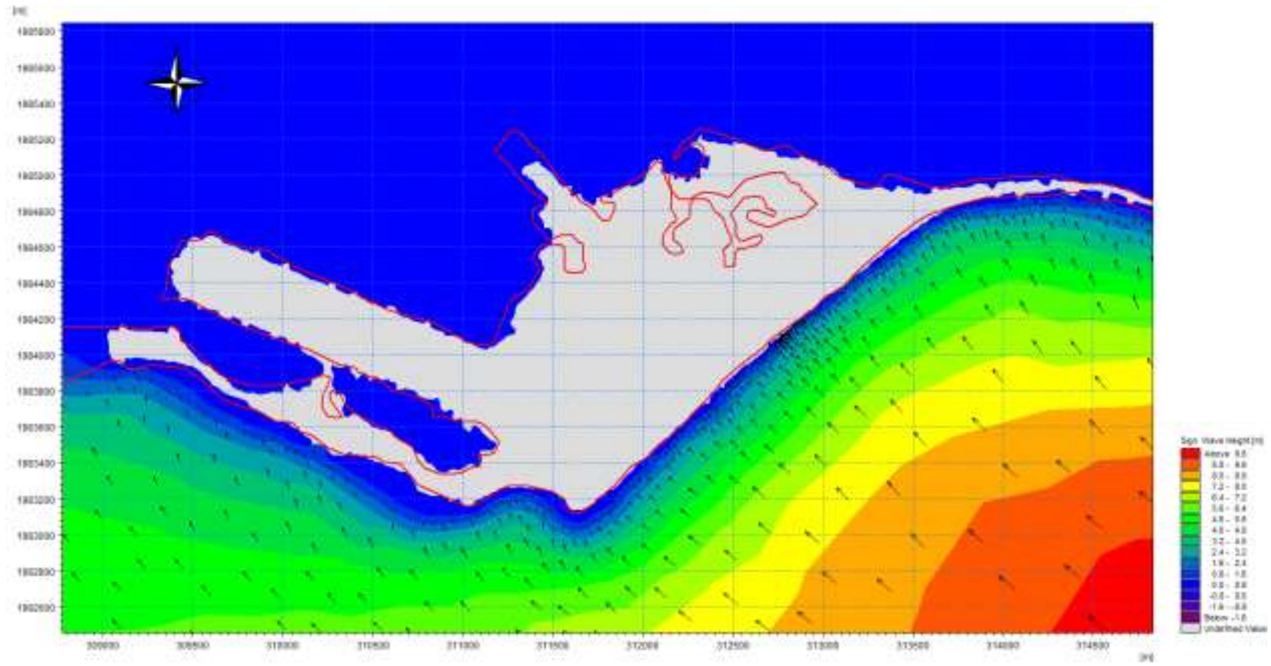
6.7 Nearshore waves

6.7.1 Caribbean Seaside

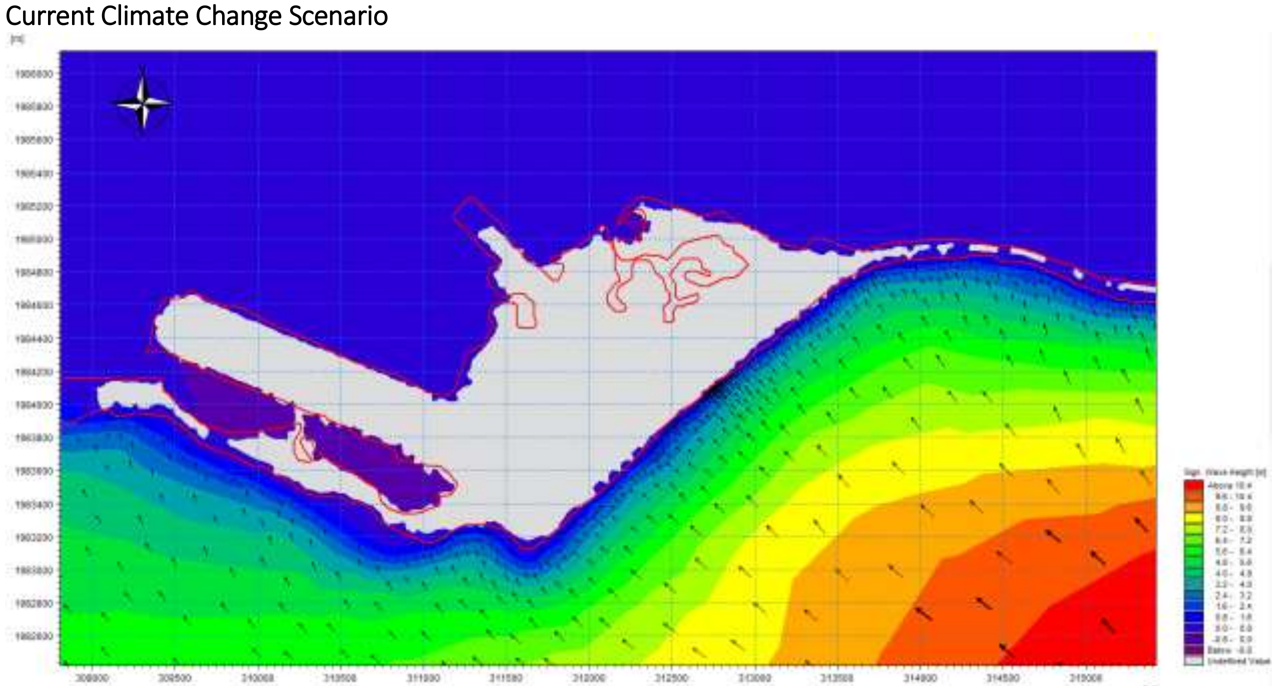
A wave transformation analysis was done to observe how the wave changes as it moves from deep-water to the shoreline. The nearshore wave heights were identified from two dominant directions namely: south-easterly (SE) direction, for a 10, 25 50- and 100-year return period storm (RCP 8.5). The models were simulated using both the current and future climate scenarios (RCP 8.5) to gain a better understanding of the worst case impact the waves on the study area as it relates to climate change.

The present climate scenario produced wave heights ranged from 1.67- 2.37 m for a 50 –year return period and 100-year return period wave heights approaching the shore ranged from 2.43 – 3.47 m.

While for the future climate models, the analysis revealed that the wave heights nearshore ranges from 3.5m to 4.65 m for the 100yr RP (Future Climate) and 1 .9 m to 3.0m for the 50year RP (Future Climate), see Table 6.34. In essence, the end of runway and dune sections of the project area are exposed to wave heights of up to 3.14 to 4.65 meters, see Figure 6.44. This section of shoreline is exposed to more hazardous wave conditions that the Harbour side of the airport.



Current Climate Change Scenario



Future Climate Scenario

Figure 6.44 100 yr. hurricane wave plots coming from the S direction (worst case) under the current and future climate scenarios.

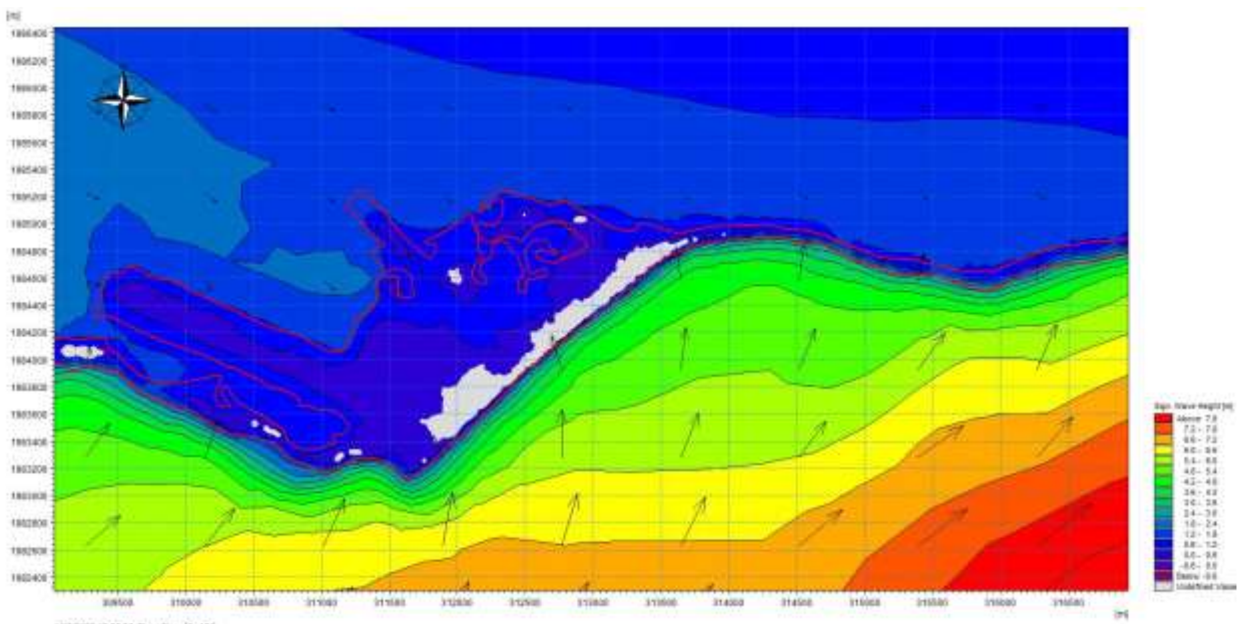
6.7.2 Harbour Generated Waves

Waves within the harbour are influenced by deep water waves attenuated through the mouth of the harbour and wind. Of the two phenomena, wind plays the dominant role in wave generation within the harbour especially during a hurricane. These waves can cause extensive damage to vulnerable shorelines with waves ranging from 0.2 m – 2 m in height, see Figure

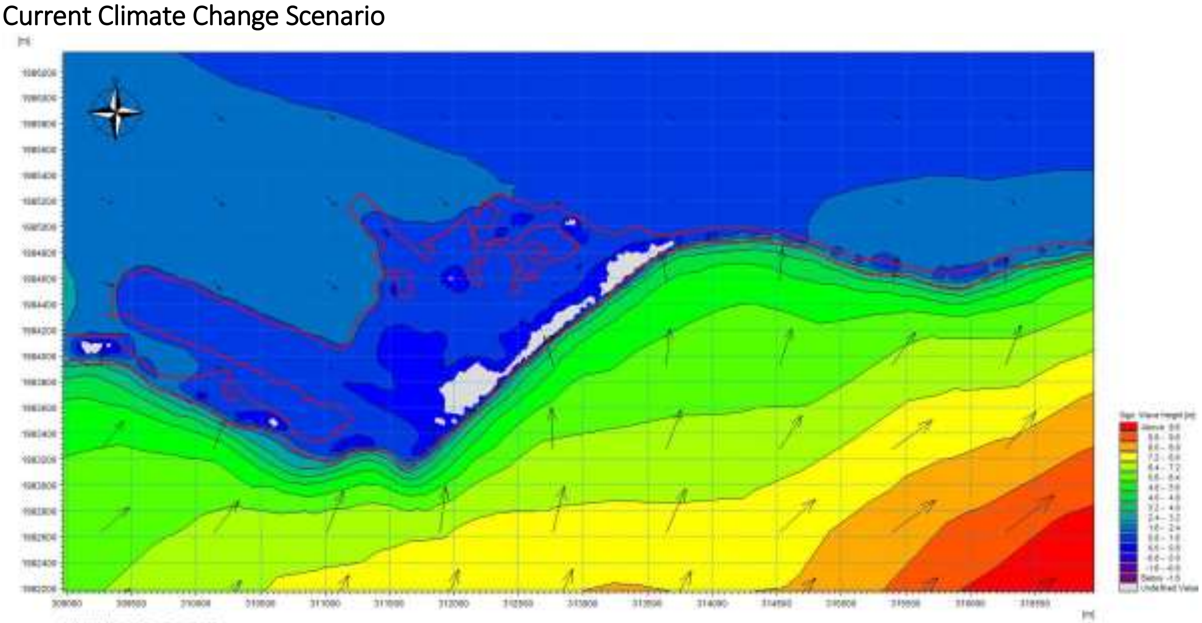
6.45 and Table 6.33. As such it was crucial to explore this scenario by simulating the effects that harbour generated waves would have on the study area.

Two scenarios were simulated to better understand the impact of the waves on the study area as it relates to climate change. These are the current and future climate scenarios. Each scenario will incorporate the expected wave heights for a 10, 25 50- and 100-year return period storm. They were simulated in worse case direction which was considered to be of the most impactful when considering the airport and the runway on the harbour side.

The results indicate that during extreme conditions the existing study area is expected to experience wave heights (100-year return period) of up to 1.36 m from northern (N) direction for the current climate scenario. For the future climate change scenario waves heights (100-year return period) are anticipated to be up to 1.49 m for the same direction mentioned previously.



Current Climate Change Scenario



Future Climate Scenario

Figure 6.45 100 yr. hurricane wave plots coming from the NW direction (worst case) under the current and future climate scenarios in the vicinity of the project site.

Table 6.32 Summary of wave heights arriving at the study area under the current climate scenario.

Return Period (Yrs.)	Northern (m)
10	0.27
25	1.11
50	1.21
100	1.36

Table 6.33 Summary of wave heights arriving at the study area under the future climate scenario.

Return Period (Yrs.)	Northern (m)
10	0.34
25	1.31
50	1.43
100	1.49

6.7.3 Summary Discussion

6.7.3.1 *Caribbean Seaside*

After analyzing nearshore wave heights for current and future storms, it was displayed that the significant wave height is approximately 2.4 m at the shoreline whereas the future climate wave model showed that the wave heights were approximately 3.14 m. The inclusion of climate change has caused a drastic change in the wave heights at the shoreline. The section of the shoreline, which is exposed to more hazardous wave conditions, is within the vicinity of the roundabout while at runway 30 the wave heights were slightly less. Based on the results considerable damage would occur at the shoreline, therefore a mitigation measure is needed to lessen the impact of wave energy at the shoreline. Overall, predicted wave heights for all of the return periods are expected to increase as projected climate change trends ensures.

6.7.3.2 *Nearshore waves from Deep Water*

It was identified that wave heights for current and future storms are approximately 1.36 m at the shoreline whereas the future climate wave model showed that the wave heights were approximately 1.49 m. The inclusion of climate change has caused a drastic change in the wave heights at the shoreline. Overall, predicted wave heights for all of the return periods are expected to increase as projected climate change trends ensures. The section of the shoreline, which is exposed to more hazardous wave conditions, is within the vicinity of the roundabout while at runway 30 the wave heights were slightly less. Based on the results considerable damage would occur at the shoreline, therefore a mitigation measure is needed to lessen the impact of wave energy at the shoreline.

Table 6.34 Summary of hurricane wave heights arriving at the shoreline based on deep water wave transformation modelling of pre climate and future climate.

Wave Heights	Runway 30 (m)	Ministry of Agriculture	Dune Section (m)	Previous NMIA Study
Present Climate				
10 Year RP	0.91	0.96	1.25	
10 Year RP (Future)	0.73	0.87	1.75	0.75-1.0
25 Year RP	1.19	1.23	2.01	
25 Year RP (Future)	1.45	1.93	2.34	1.6-2.0
50 Year RP	1.67	1.96	2.37	
50 Year RP (Future)	1.9	2.24	3.0	2.5-3.0
100 Year RP	2.43	2.81	3.64	
100 Year RP (Future)	3.14	3.31	4.64	3.6-4.0

6.8 Short Term and Long-term Shoreline Erosion

6.8.1 Introduction

It is necessary to determine how the shoreline of the study area will respond to the severe wave climate anticipated. Estimates of how the beach will accrete or erode in response to particular storm events was observed. The adopted approach was to utilize the cross-shore sediment transport model (SBEACH).

6.8.1.1 *Model Description*

SBEACH is an empirically based numerical model for estimating beach and dune erosion due to storm waves and water levels. The magnitude of cross-shore sand transport is related to wave energy dissipation per unit water volume in the main portion of the surf zone. The direction of transport is dependent on deep water wave steepness and sediment fall speed. SBEACH is a short-term storm processes model and is intended for the estimation of beach profile response to storm events. Typical simulation durations are limited to hours in comparison to the exposure times to historical storms.

6.8.1.2 *Input Parameters*

Parameters for the model would include profiles of the project area (2000 m - 3000 m offshore), deep water wave heights, wind speeds and sediment size.

6.8.1.3 *Sediment Size*

The Factual Report[8] done by Geotech Exploration Services Limited for the Airports Authority of Jamaica was reviewed for this analysis. The report contains field and laboratory work done for geotechnical investigations concerning the sub-surface strata in Kingston Harbour within the vicinity of Runway 12. Sixteen boreholes were to be drilled as seen in Figure 6.46. Borehole 1C and 2C were used for this shoreline erosion analysis to determine the sediment size to be used in the simulation, see Table 6.35.

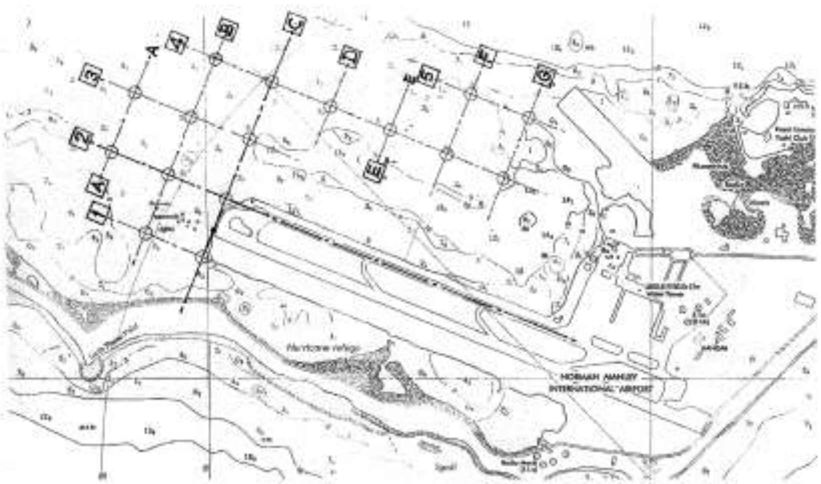


Figure 6.46 Part of Kingston Harbour showing borehole locations. Source: Factual Report, Proposed RESA Extension for NMIA Runway.

Table 6.35 Sediment size used in erosion analysis

Borehole	D50 (mm)
1C	0.36
2C	0.32
Average	0.34

6.8.1.4 *Waves and Wind*

The wave data used in the model corresponds to 10, 25, 50 and 100 year storm events as well as a mean grain size of 0.34 mm. See Table 6.36 and Table 6.37 for input parameters.

Table 6.36 SBEACH input parameters for each storm events under current climate scenario.

Return Period (Yrs.)	Wave Height (m)	Wave Period (m)	Wind Speed (m/s)
10	7.14	11.9	56.85
25	8.94	12.86	80.77
50	10.15	13.45	99.26
100	11.31	13.96	118.06

Table 6.37 SBEACH input parameters for each storm events under future climate scenario.

Return Period (Yrs.)	Wave Height (m)	Wave Period (m)	Wind Speed (m/s)
10	8.43	12.61	67.90
25	10.91	13.79	96.91
50	12.60	14.50	121.63
100	14.19	15.11	149.40

[8] Proposed RESA Extension for NMIA Runway Factual Report. (2008).

6.8.2 Scenarios

SBEACH was used to determine the existing shoreline's response to extreme storm event for 3 directions at the study area point (see Figure 6.47). The directions simulated were the North-Western (NW), Northern (N) and North- Eastern (NE) directions. The current and future climate scenarios was simulated to define the impact of climate change at the study area. Each scenario described the effects of the 10, 25 50 and 100 yr. return period from the different directions previously mentioned.

Figure 6.47 Location of the profile lines used in the erosion model to determine the shoreline response.

6.8.2.1 *Current Climate Scenario*

Results indicate that the shoreline is the most vulnerable to erosion when waves and wind speeds are attenuated along the northern profile. The north-western profile was however observed to experience the least amount of erosion. Along the northern profile the shoreline is expected to experience a maximum vertical erosion of 0.8 m with an inland reach of up to 78 m for the 100 yr. return period. It was also observed that the eroded sediments were displaced seaward resulting in accretion of up to 0.7 m, see Table 6.38 and Figure 6.48.

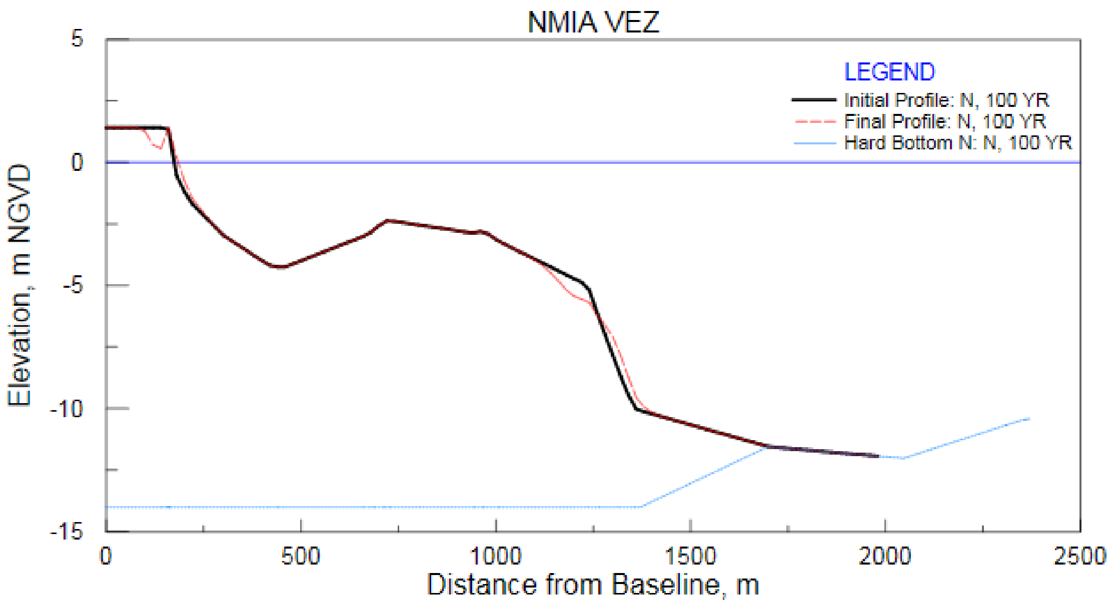


Figure 6.48 Erosion plot for 100 year return period under current climate scenario from the northern direction.

Table 6.38 Summary of results showing the expected (worst case) shoreline erosion under current climate scenario.

Northern Profile			
Return Period	Max Vertical Accretion (m)	Max Vertical Erosion (m)	Inland Reach of Erosion (m)
10	0.6	0.8	73
25	0.7	0.7	72
50	0.6	0.8	83
100	0.7	0.8	78
North-Eastern Profile			
Return Period	Max Vertical Accretion (m)	Max Vertical Erosion (m)	Inland Reach of Erosion (m)
10	0.7	0.9	64
25	0.7	0.7	77
50	0.5	0.8	75
100	0.6	0.7	77
North-Western Profile			
Return Period	Max Vertical Accretion (m)	Max Vertical Erosion (m)	Inland Reach of Erosion (m)
10	0	0	0
25	0.1	0.1	61
50	0.4	0.3	79
100	0.4	0.4	91

6.8.2.2 *Future Climate Scenario.*

Results indicate that the shoreline is the most vulnerable to erosion when waves and wind speeds are attenuated along the northern profile. The north-western profile was however observed to experience the least amount of erosion. Along the northern profile the shoreline is expected to experience a maximum vertical erosion of 0.9 m with an inland reach of up to 79 m for the 100 yr. return period. It was also observed that the eroded sediments were displaced seaward resulting in accretion of up to 0.5 m.

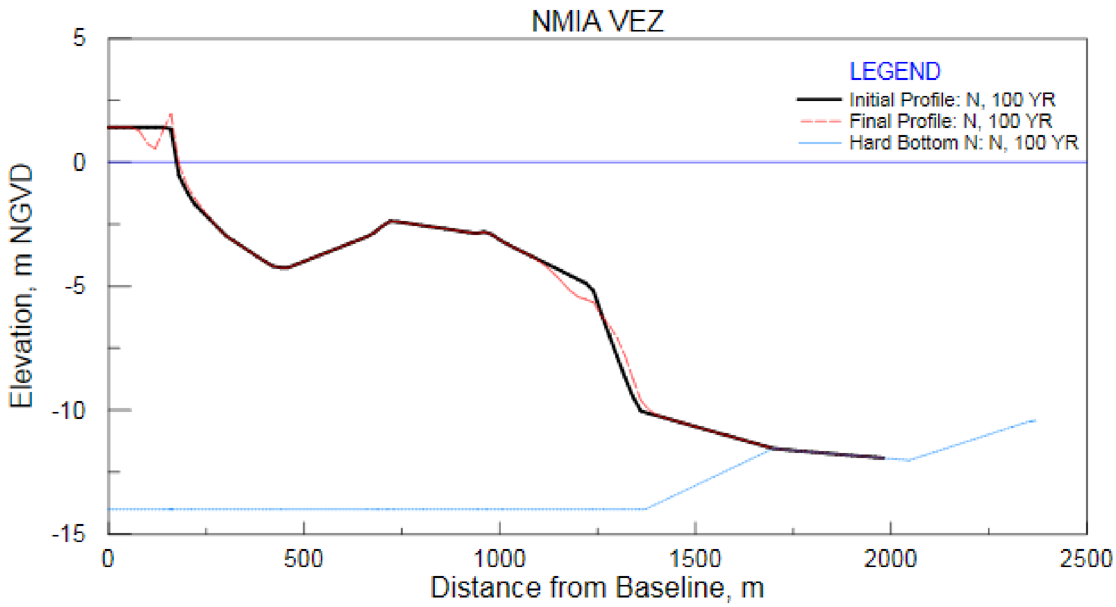


Figure 6.49 Erosion plot for 100 year return period under future climate scenario from the northern direction.

Table 6.39 Summary of results showing the expected (worst case) shoreline erosion under future climate scenario.

Northern Profile			
Return Period	Max Vertical Accretion (m)	Max Vertical Erosion (m)	Inland Reach of Erosion (m)
10	0.7	0.8	74
25	0.7	0.8	78
50	0.7	0.8	80
100	0.5	0.9	79
North-Eastern Profile			
Return Period	Max Vertical Accretion (m)	Max Vertical Erosion (m)	Inland Reach of Erosion (m)
10	0.7	0.8	77
25	0.7	0.8	80
50	0.5	0.7	71
100	0.3	0.3	74
North-Western Profile			
Return Period	Max Vertical Accretion (m)	Max Vertical Erosion (m)	Inland Reach of Erosion (m)
10	0.1	0.1	57
25	0.5	0.5	83
50	0.6	0.6	90
100	0.5	0.7	93

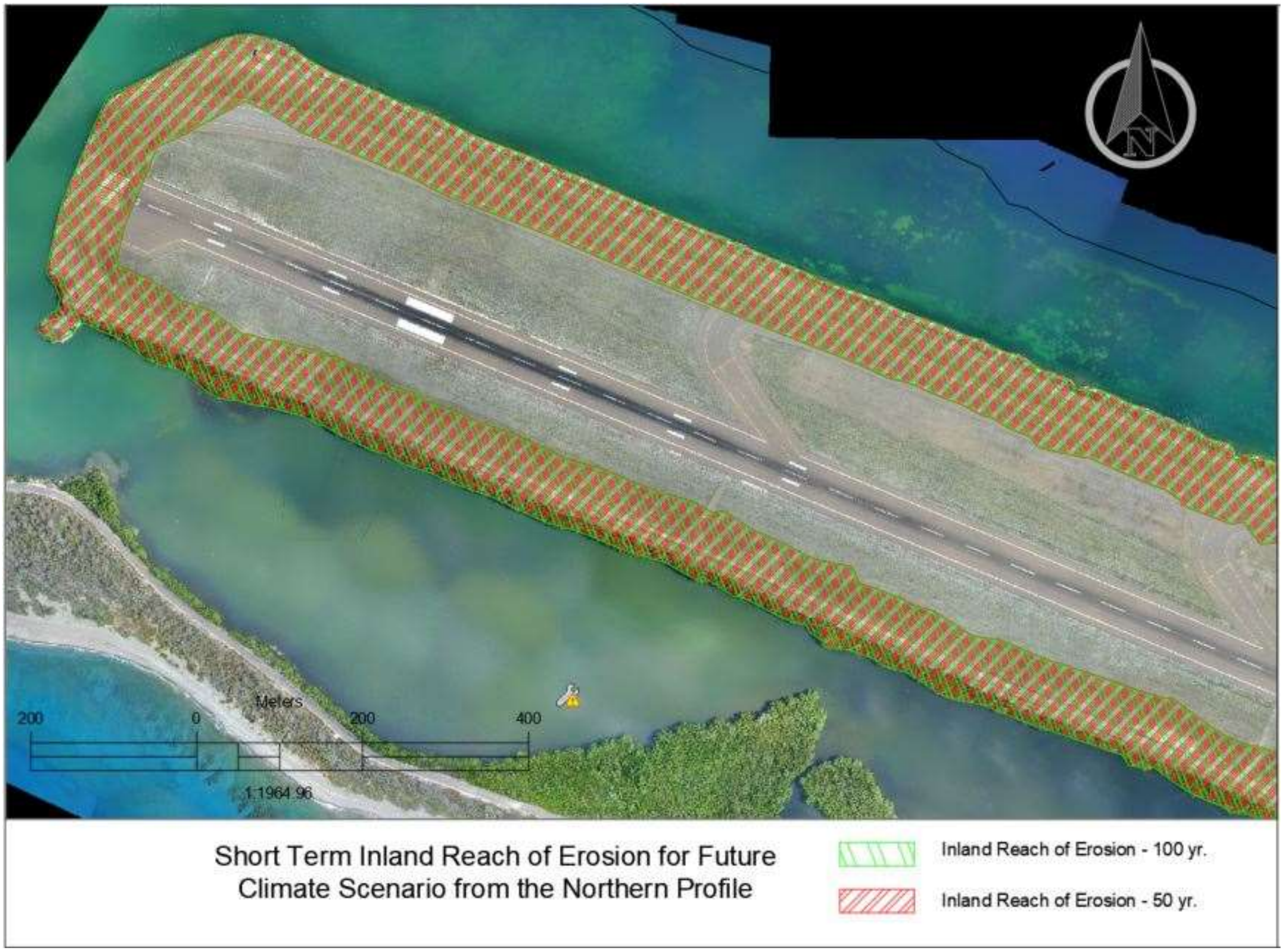


Figure 6.50 Plot of short term inland reach of erosion for future climate

6.8.3 Long Term Shoreline Erosion

Long term shoreline change was determined for the period 2002 to 2020 from baseline shoreline positions located along both the Harbour Side and Caribbean Seaside at the NMIA. The positions for each specific year of analysis were compared in order to determine the spatial and temporal erosion trends. This was important in order to identify the high-risk areas that are erosion hotspots and the long-term threats to the project area from retreating shorelines. This was important in order to identify the actual erosion hotspots that might require stabilization and in order to verify wave transformation modelling.

6.8.3.1 *Methodology*

The overall long-term erosion trend was estimated by:

- Firstly, observation of actual long-term shoreline positions from dated Google earth imagery, as well as observations of aerial imagery that was obtained from an unmanned aerial vehicle flight.
- The rates of accretion and or erosion between the time intervals and the overall time interval were determined using the following relationship:

$$E_y^1 = \frac{D}{N}$$, where

E = the rate of erosion or accretion between two successive intervals (metres per year)

D = the displacement between two intervals (metres)

N = the number of years between two successive intervals (years)

and $E_y^0 = \frac{D_T}{N_T}$, where

E_y^0 = the rate of erosion or accretion from the datum year to the final interval

D_T = the displacement from the datum to the final interval

N_T = the number of years from datum year to final interval

- Sea level rise component was estimated to determine the erosion that was due to chronic global trends versus event-based erosion events (i.e. hurricanes and swell events)

6.8.3.2 *Historical Shorelines*

Figure 6.51 shows the most recent aerial image of the area (2020), over which the current state of the shoreline was inspected. That data was then included in the observations of the shorelines from Google Earth imagery of previous years. Upon examination of the shoreline and comparing it with the other years, it was deduced that there was instances of accretion and erosion was taking place.

Figure 6.51 Historical shoreline changes for project area

6.8.3.3 *Results: Historical Observations*

A summary of the analysis data for both sections, Harbour and Caribbean Seaside, respectively are shown below in Table 6.40. From the analysis we see a general trend of accretion occurring from 2002 to 2020. Plots of the shoreline movement can be seen in Figure 6.52. One can see that over the past 18 years, a maximum around of 0.86 meters of erosion and 0.96 meters of accretion that has occurred along the various sections of the bounded shoreline, based on the observation of historical areal and satellite images of the area.

6.8.3.3.1 *Harbour side (2002 to 2020)*

Both accretion and erosion trends occurred along the harbour side of the project area. The general trend along the shoreline shows at the north-western section of the harbour there was erosion while mainly accretion took place at the southern section of the harbour. In the period from 2002 to 2020, the shoreline accreted at a maximum rate of 0.86 m/yr and eroded at a maximum rate of 0.96 m/yr.

In general, the long-term changes, in the results indicated that the shoreline was eroding mainly at the north-western section, due to the eroding revetment. While for the southern section of the harbour, the accretion was mainly due to the increase in mangroves species. The storm surge modelling highlighted the north-western section prone to greater storm surge inundation levels than that of the south side. This is due to the diffraction that is taking place, as the waves attenuate to the end of the runway 30, therefore decreasing the storm surge levels at the mangroves. From analysis, it has been identified that the shoreline is fairly dynamic at the southern section, while for the north—western section there is need for the revetment to be revamped to reduce the vulnerability along the area.

6.8.3.3.2 Caribbean Sea Side (2002-2020)

From the analysis it was observed that there was a general trend of accretion occurring from 2002 to 2020. Some erosion was observed close to the NMIA Roundabout. In the period from 2002 to 2020, the shoreline accreted at a maximum rate of 0.7 m/yr and eroded at a maximum rate of 0.4 m/yr, see *Table 6.40*.

In general, the long-term changes, in the results indicated that the shoreline was eroding mainly at the north-eastern section, due to the blowout of the dune. While for the western section of the shoreline was accreting mainly due sediment transport direction (east-west). The storm surge modelling highlighted the south-western section prone to greater storm surge inundation levels than that of the north-eastern. This is due to the elevation difference at the locations, the western section is situated in a low-lying area. From analysis, it has been identified that the shoreline is dynamic at the north-eastern section, while for the western section there is need for mitigation measures such as raising the land elevation to reduce the vulnerability along the area.

Table 6.40 the rate of erosion and accretion from 2002-2020 (m).

Assets	Chainage	distance from datum (m)	distance from datum (m)	Observed accretion (erosion) rate (m/year)	Process	Predicted recession (m/year)	Shoreline erosion at 2050 (m)
South mangroves	100	24.9	32.63	0.43	accretion	-0.041	-1.2
South mangroves	200	24.9	32.63	0.43	accretion	-0.041	-1.2
South mangroves	400	22.15	35.75	0.76	accretion	-0.041	-1.2
South mangroves	600	23.5	36.27	0.71	accretion	-0.041	-1.2
South mangroves	800	19.36	31.32	0.66	accretion	-0.041	-1.2
South mangroves	1000	15.92	30.28	0.80	accretion	-0.041	-1.2
South mangroves	1200	22.18	37.34	0.84	accretion	-0.041	-1.2
South mangroves	1400	21.7	31.75	0.56	accretion	-0.041	-1.2
South mangroves	1600	19.04	34.57	0.86	accretion	-0.041	-1.2
South mangroves	1800	46.59	57.28	0.59	accretion	-0.041	-1.2
South mangroves	2000	12.62	22.03	0.52	accretion	-0.041	-1.2
End of Runway 30	2200	59.21	63.6	0.24	accretion	-0.128	-3.8
End of Runway 30	2400	77.89	77.97	0.00	accretion	-0.128	-3.8
End of Runway 30	2600	66.050	65.430	-0.03	erosion	-0.128	-3.8
Revetment	2800	37.32	29.26	-0.45	erosion	-0.128	-13.4
Revetment	3000	31.24	20.36	-0.60	erosion	-0.038	-18.1
Revetment	3200	30.24	19.97	-0.57	erosion	-0.038	-17.1
Revetment	3400	28.49	17.26	-0.62	erosion	-0.038	-18.7
Revetment	3600	28.66	19.73	-0.50	erosion	-0.038	-14.9
Revetment	3800	12.98	15.44	0.14	accretion	-0.038	-1.1
Revetment	4000	25.17	13.23	-0.66	erosion	-0.038	-19.9
Revetment	4200	26.13	14.1	-0.67	erosion	-0.038	-20.1
Revetment	4400	34.12	16.9	-0.96	erosion	-0.038	-28.7
North East Alignment (Fire Station, Control Tower)	4600	30.24	22.12	-0.45	erosion	-0.038	-13.5
North East Alignment (Fire Station, Control Tower)	4800	45.9	31.83	-0.78	erosion	-0.038	-23.5
North East Alignment (Fire Station, Control Tower)	5000	21.12	12.61	-0.47	erosion	-0.038	-14.2

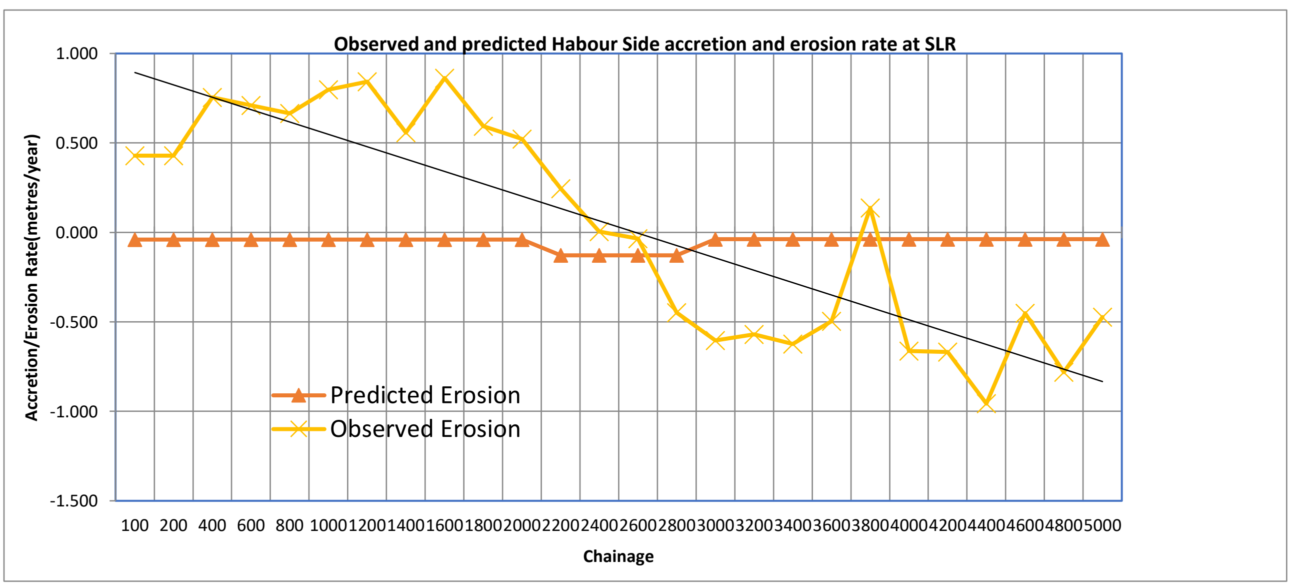


Figure 6.52 Observed and predicted harbour accretion and erosion rate at SLR

Table 6.41 the rate of erosion and accretion from 2002-2020 (m) (Caribbean Sea).

Chainage	distance from datum (m)	distance from datum (m)	Observed accretion (erosion) rate (m/year)	Process	Dune height (m)	Offshore profile, l* (m)	Hs 12hr/yr (m)	depth of offshore limit, h* (m)	Predicted recession (m/year)	Shoreline erosion at 2050 (m)
100	14.99	21.83	0.4	accretion	4.3	120	2	3.2	-0.075	-2.3
200	14.99	21.83	0.4	accretion	5.2	140	2	3.2	-0.078	-2.4
400	40.06	51.8	0.7	accretion	5.3	145	2	3.2	-0.080	-2.4
600	38.85	41.53	0.1	accretion	5.8	100	2	3.2	-0.052	-1.6
800	30.87	34.19	0.2	accretion	6	120	2	3.2	-0.061	-1.8
1000	27.8	24.1	-0.2	erosion	5.35	137	2	3.2	-0.075	-6.2
1200	18	10.53	-0.4	erosion	6.04	110	2	3.2	-0.056	-12.5
1400	15.63	14.62	-0.1	erosion	6.5	120	2	3.2	-0.058	-1.7
1600	11.82	13.96	0.1	accretion	5	100	2	3.2	-0.057	-1.7

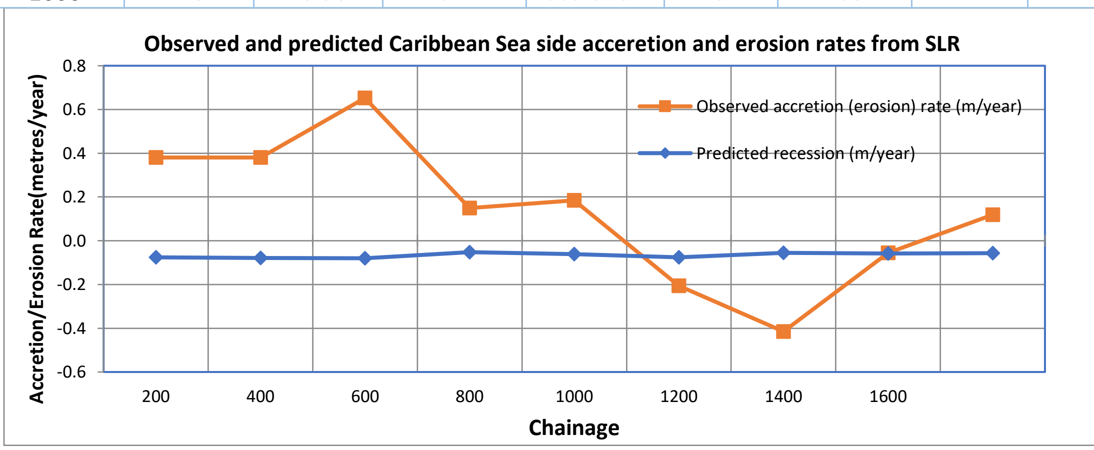


Figure 6.53 Observed and predicted Caribbean Sea side accretion and erosion rates

6.8.3.4 *Relative Impact of Sea Level Rise (SLR) versus Extreme Events*

The Brunn model is perhaps the best-known and most commonly used of the models that relate shoreline retreat to sea level rise. This two-dimensional model assumes an equilibrium profile. Thus, it inherently assumes that the volume of sediment deposited is equal to that eroded from the dunes and that the rise in the nearshore bottom as a result of the deposited sediment is equal to the rise in sea level. The original Brunn model is expressed below in Equation 3 1 and this mathematical relationship was the basis for estimating shoreline retreat within the study area.

Equation 6.1 Bruun Model

$$\Delta y = \frac{\Delta s \cdot l*}{h*}$$

Where:

Δy = Dune line erosion (m)

Δs = Rate of sea level rise (m)

l* = Length of the offshore profile out to a supposed depth, h*, of the limit of material exchange from the beach and the offshore (m)

h* = Depth at offshore limit of l*, to which nearshore sediments exist (as opposed to finer- grained continental shelf sediments) (m)

6.8.3.4.1 Rate of sea level rise, Δs

Inspection of research in this area revealed that global sea level may rise as a result of greenhouse gas-induced global warming at a rate of 4.7 mm/year over the next 100 years. Indeed, there will be regional variation in the sea level rise signal, and for this reason regions may undertake sea-level rise scenario modeling, which takes into account various factors such as land movement and region-specific oceanographic data.

For the purposes of this project, a simple scenario, based on one estimate of sea level rise will be utilized (not taking into account any vertical tectonic movements of the shoreline nor any discernible change in the ocean geodynamic surface). Typically, a mid-range or upper estimate is chosen for such types of scenarios.

6.8.3.4.2 Depth to which nearshore sediments exist, h*

A beach profile has a practical seaward limiting depth, where the wave conditions can no longer change the profile. Sand may move back and forth along this equilibrium profile, but there is no perceptible change in depth. This seaward limiting depth is equivalent to the depth at which nearshore sediments exist (*h**). Hallermeier (Hallermeier, 1981 in Kamphuis, 2000) refers to this depth as the critical or closure depth (d_c), and approximates it using the equation below.

Equation 6.2 Hallermeier estimation of critical or closure depth

$$d_c = 1.6H_{s,12}$$

Where:

$H_{s,12}$ = significant wave height which occurs 12 hrs/yr on average

It was therefore necessary to determine the operational wave climate within the study area between the shoreline and the reefs in order to estimate the critical depth.

The operational/swell wave climate was obtained from a previous in-house study of a nearby site the 12 hour significant wave height was estimated at 2.5m.

6.8.3.4.3 Length of offshore profile, l*

The calculated critical depth (or *h**) was used to estimate the length of the offshore profile. This was done by inspecting each of the profiles cut for the SBEACH modelling and obtaining profile lengths for the corresponding critical depth.

6.8.3.4.4 Calculation and Results

Table 6.40 and shows the calculation of the long term trends expected in 30 years along the Harbour and Caribbean shoreline respectively. As seen in this table, the following input values were incorporated into the Bruun Model to arrive at an estimate for the long-term erosion trend at each of the four (4) profile shoreline positions:

1. Rate of sea-level rise = 4.7 mm/yr.

It should be emphasized here that the results of these calculations are an estimate of the projected shoreline retreat using a simplistic approach with an upper limit of global sea level rise. Indeed, the changes in beach profile over the years may have been impacted by the annual sea level rise as well as operational and storm-induced erosion estimated. This estimation of the sea level rise will assist in the determination of the true impacts that are due to operational and storm induced erosion.

The shoreline along the study area was estimated to retreat at varying rates between 0.04 and 0.13 meters per year as a result of global sea level rise. The shoreline in the vicinity of Runway 12 End has the largest erosion rate of 0.13 m/year.

6.8.3.4.5 Conclusion

It can be concluded for entire project shoreline that the estimated accretion rates have been slowed down due to ongoing erosion, based on the historical overall shoreline accretion trend as well as the projected erosion due to sea level rise. This simply means that in the absence of sea level rise, the accretion rates would have been greater while the opposite for rates of erosion.

With focus on the project area, it is estimated that sea level rise accounts for approximately 1.2- 28.7 m of erosion along the Harbour side. The hot spot area is along the existing revetment. While for the Caribbean Seaside, sea level rise would account for 1.2- 12.5 m of erosion along the harbour side. The most vulnerable area is along the north-eastern section of the shoreline.

6.8.3.4.6 Limitations

Both methods of estimating long term erosion trends have their own limitations. For the Bruun method, estimating long-term erosion trends as result of global sea level rise was not the main focus of this section. Given the anecdotal information in the area, it was important to know how the area is affected by long term and short term weather/climate events.

While for the historical model, the maps obtained were only snapshots at a moment in time that cannot be manipulated to show years or times of interest (such as immediately before and after the hurricanes). Therefore some of the maps may be displaying short term shoreline configurations while others display long term. The accuracy of the rates is therefore subjected to the use of more aerial photos at strategic times which were not available at the time of this study.

Figure 6.54 Long term inland reach of erosion for Future Climate Scenario

6.9 Probabilistic Analysis of Hurricane Intensity and Distance of Hurricane track on storm surge

6.9.1 Background

Jamaica's coast is constantly under environmental pressures from both natural hazards, and climate change related events such as hurricanes, storm surges, and sea level rise. Over the past decades, the direct impact of such hazards have resulted in grave environmental degradation and socioeconomic disturbances along Jamaica's coast. This situation is further exacerbated where dense urban settlements and critical structures are sited in areas deemed susceptible to coastal hazards.

In recent years however, the dynamics of storm surge prediction, hurricane wind field parameterization, and associated storm surge generation factors have been vastly researched by the scientific community. Notwithstanding, there are still key areas of storm surge generation which are poorly understood. The study is therefore aimed at conducting a numerical investigation establishing the relationship between storm size, and distance from coast, on storm surge generation.

6.9.2 Methodology

The methodology involves three major subcomponents; the generation of wind and pressure fields for each hurricane; modelling of wind fields in MIKE 21/3 FM Coupled Model to assess surface elevations at NMIA, and finally; a sensitivity analysis of:

The general approach taken to complete this assessment is outline below:

1. Tropical Cyclone Generator
2. MIKE 21/3 FM Coupled Model
3. Sensitivity Test

6.9.3 Tropical Cyclone Generation

The MIKE Cyclone Generation Tool was used to simulate the wind stress and atmospheric pressure gradients. The Holland B parametric model that was used to generate the wind and pressure field due to it being a well-known strategy to mimic tropical cyclones surges. The input parameters to the model were extracted from the probabilistic tracks generated by CEAC Solutions which were characterized by category 3-5 hurricanes properties. The Saffir Simpson scale was used to categorize the storm wind speed, and central pressures, while the radius to maximum winds and Holland B parameter. The parametric model required six input parameters as follows:

1. Date/Time
2. maximum wind speed,
3. the radius of maximum wind speed
4. neutral pressure
5. central pressure
6. Holland B Parameter

6.9.4 MIKE 21/3 Coupled Model

A MIKE 21/3 Coupled FM model was generated to calculate the corresponding distribution of surface water elevation and waves in the area based on calibrations with historical data and anecdotal information for the Hurricane Ivan (2004) and Sandy (2012). The MIKE 21/3 Coupled Model FM is a truly dynamic modelling system for application within coastal, estuaries and river environments. When using the suite, it is possible to simulate the mutual interaction between waves and currents using a dynamic coupling between the Hydrodynamic Module and the Spectral Wave Module.

6.9.4.1 *Hydrodynamic module*

The Hydrodynamic Module was used to calculate the corresponding distribution of surface water elevation under the influence of the tropical cyclone. A combination of the meteorological and hydrodynamic data is used to create the storm surge model.

6.9.4.2 *Spectral Wave Module*

The spectral wave module tool was utilized to model the significant wave height (Hs), and maximum wave height during the cyclone. This method involved using the time and space-dependent pressure and wind force generated in the previous step are used as an input parameter for both modules.

6.9.5 Sensitivity Test

In order to test the sensitivity of parameters that influenced the storm surge at the study area. A total of seven synthetic hurricane induced storm surge cases were executed to investigate the impacts of increasing the Maximum sustained winds (V_{max}), in the North Atlantic Basin would have on storm surge heights. The V_{max} values were extracted from the Saffir/Simpson hurricane scale. While, the R_{max} and Holland B parameter was calculated using the following equation:

Radius to maximum winds (Rmax)

$$46.4\, e^{-0.0155\, V_{max}} + 0.0169\varphi$$

- Vmax: tangential wind component of the gradient-level maximum wind speed (m/s)
- ϕ : Latitude (degrees)

Holland B Parameter

$$1.38 - 0.00184\Delta p + 0.00309 R_{max}$$

- Δp : Proportional maximum wind speed
- R_(max) : Radius to maximum winds (Rmax)

6.9.5.1 *Simulation of tropical cyclone tracks*

Seven probabilistic hurricane scenarios were modelled, they were as followed:

- **Scenario 1**: A category three (3) hurricane, which ran parallel directly through NMIA.
- **Scenario 2**: A category four (4) hurricane, which ran parallel directly through NMA.
- **Scenario 3**: A category five (5) hurricane, which ran parallel directly through NMIA.
- **Scenario 4**: A category three (3) hurricane, which ran 30 km parallel off NMIA.
- **Scenario 5**: A category four (4) hurricane, which ran 30 km parallel off NMIA.
- **Scenario 6**: A category five (5) hurricane, which ran 30 km parallel off NMIA.

Figure 6.55 Probabilistic Worse Case Tracks

Table 6.42 A summary of the input parameters for the sensitivity models are presented in Table. The Vmax and R_{max} for the simulations represented the intensity of the category of hurricane chosen.

Hurricane Category	Radius to maximum winds (R_{max}) (km)	Maximum Sustained (V_{max}) (mph)	Central Pressure (hPa) (mb)
3	46.0	111-129	945-965
4	43.0	130-156	920 -945
5	41.0	>157	<920

6.9.5.2 *Hurricane Ivan Results*

Two (2) calibration factors were used to minimize the deviation between the observed and computed surge levels and waves. The calibration parameter for the hydrodynamic module included the wind friction. The model initially underestimated the storm surge by 0.2 meter, therefore, the wind friction was increased to accommodate the high wind speeds. This change aided in increasing the surface elevation, even though it was not a drastic increase it aided with the under estimation that was occurring.

The outcome of the storm surge model showed fairly good approximations of the surface elevation generated by Hurricane Ivan. The model results generated a storm surge elevation at Henry Morgan Boulevard, Port Royal, of 1.8 meters, whilst the anecdotal elevation was 2.0 m. Also, at Michelin Ave residents experience storm surge elevations of 1.1 m, whereas, the model generated 1m of surface elevation, see Table 6.43 below:

Table 6.43 Calibration results from model

Area	Water Depth	Height	Water Elevation	Model Results
Henry Morgan Boulevard	0.305	1.786	2.091	1.8
Michelin Ave	0.152	0.975	1.127	1.02

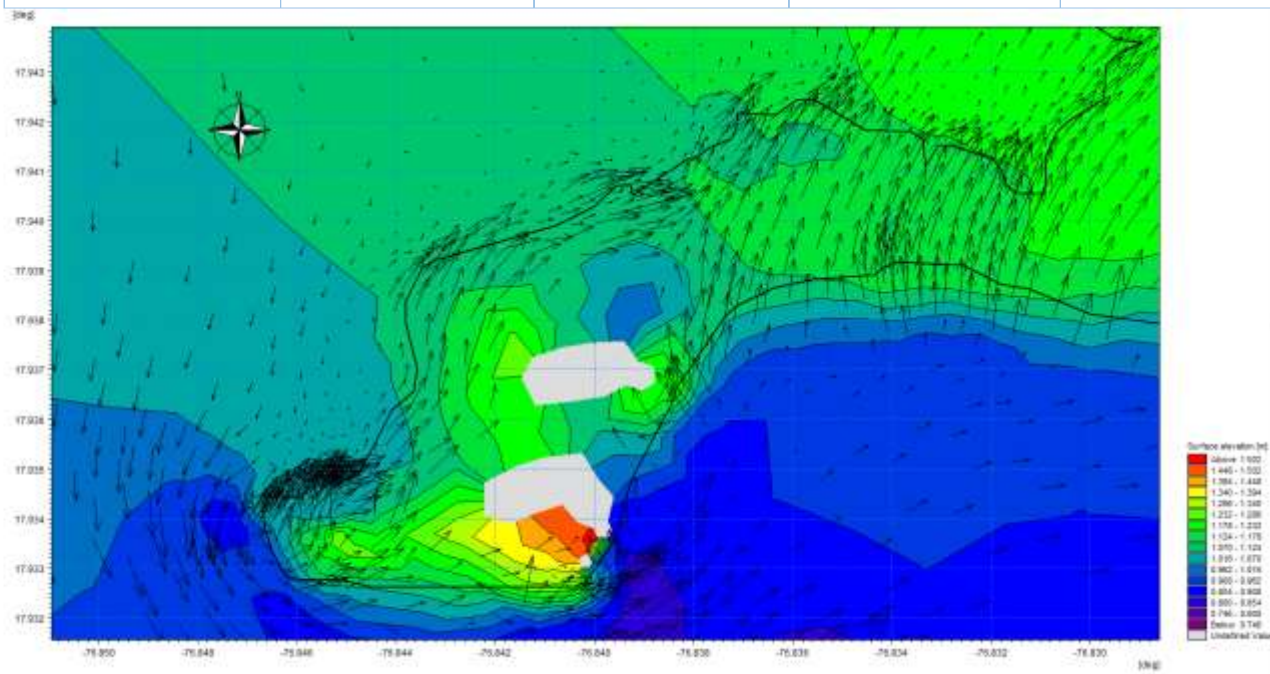


Figure 6.56 Plot of storm surge results generated from Hurricane Ivan (2004)

6.9.6 Results

As seen in Figure 6.57 and Figure 6.58 below, the numerical results indicated there is a strong correlation between wind speeds and storm location on storm surge elevation/generation. Even though the category hurricane is the same (Category 5), change in location caused a drastic reduction in flooding at the site.

Overall, the results indicated that as the probabilistic hurricane increase in intensity, Parallel Directly through NMIA (category 3), Parallel Directly through NMIA (category 4) and Parallel Directly through NMIA (category 5) the surface elevations varied from 1.8, 2.5 and 3.5m respectively. There is an increasing trend which indicates the increase of surge elevation with orientation of hurricane tract and hurricane category. While for the 30 offshore Km hurricane (category 3), 30 offshore KM hurricane (category 4) and 30 offshore KM hurricane (category 5), the surface elevation varied from 0.9, 1.0 and 1.7m respectively. As shown in the *Table 6.44*, the site would be partially inundated by the storm surges during the category 3-5 hurricane events. There is a positive correlation between the two variables being examines, which depicted that with the increase in the category hurricane, the surface elevation would increase. However, it was highlighted that the direct hits produce a higher surface elevation than cyclone which is 30 Km offshore.

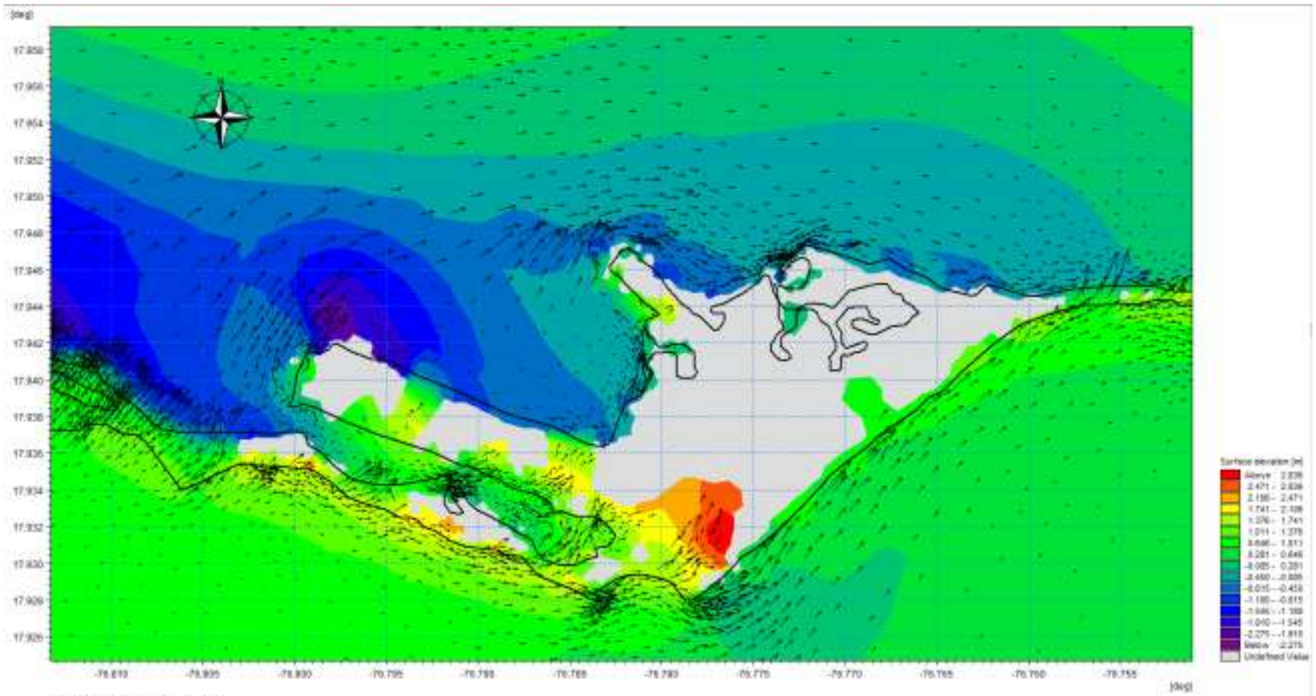


Figure 6.57 Storm surge plots for Direct Parallel hit (Category 5)

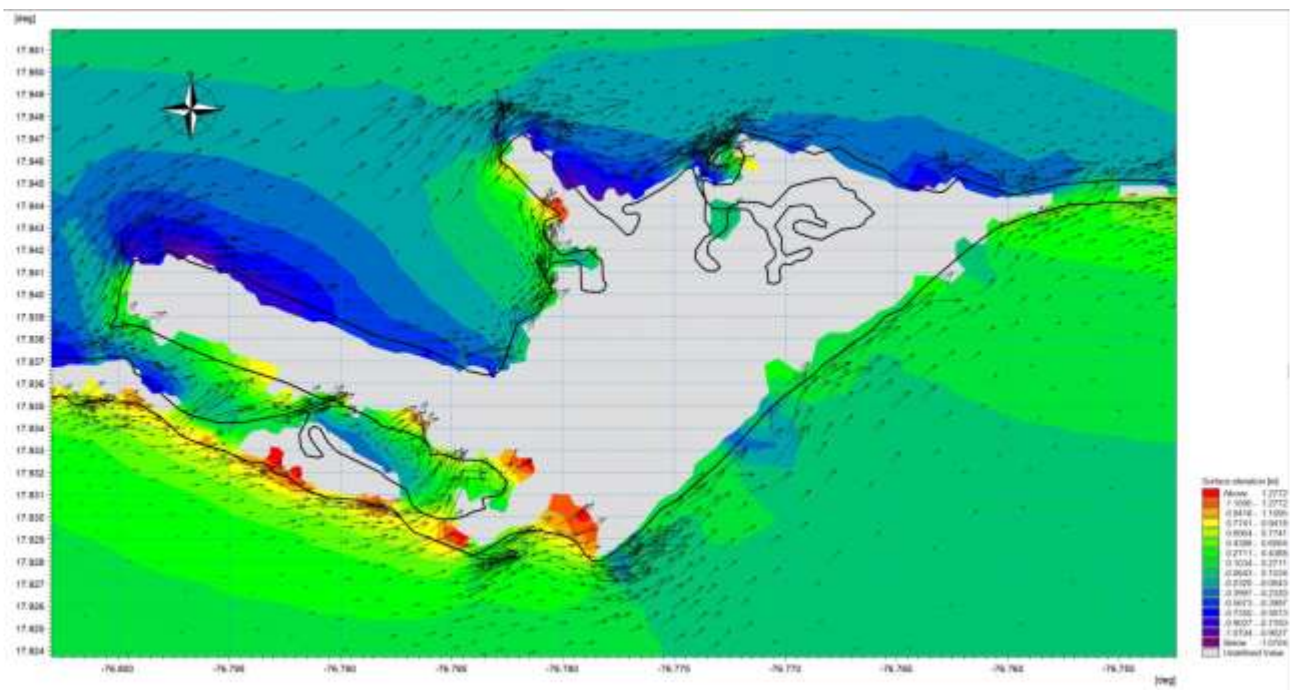


Figure 6.58 Storm surge plots for 30 Km Parallel (Category 5)

Table 6.44 Summary of storm surge inundation at NMIA (m) from probabilistic hurricanes

Location	30 KM offshore (Category 3)	30 KM offshore (Category 4)	30 KM offshore (Category 5)	Parallel Direct Hit (Category 3)	Parallel Direct Hit (Category 4)	Parallel Direct Hit (Category 5)
Surface Elevation	0.8	1.0	1.7	1.8	2.4	3.5

6.9.7 Summary and conclusions

Based on the analysis, it was deduced that the site would be partially inundated based on the elevation of NMIA varying from 0.7 m to 5 m by the storm surge projected for the area in the event of a direct hit from a hurricane. It was estimated that the worst-case scenario storm surge elevations (category 5) would cause a disruption in the operations at the airport. The storm surge inundation levels for a direct hit and 30 KM offshore (Category 5) are **1.7 and 3.5 m** respectively for the parallel directly through NMIA and 30 km parallel off NMIA respectively. The predicted nearshore wave heights for the direct hits (E-W and S-N) are well in excess of the 100-year RP wave height.

A relation between the storm surge elevations and the hurricane categories, this was observed by the increase in storm surge elevation as the category level of the hurricane amplified. This is a key indicator that in the face of disaster that operation would be disrupted, and employees would need to evacuate the area due to the detrimental effects that would transpire with the storm surge elevations. The runway and taxiway have been posed with the greatest risk of inundation, in comparison to the Port Royal Main Road, Ministry of Health Offices and Cargo area which are protected from the sand dunes placed along the shoreline

There is a positive correlation between storm surge height and storm category, location and wind intensity at the site, see **Error! Reference source not found.**. This was observed where the storm surge levels were higher with a parallel direct hit v ersus a hurricane 30km offshore. Therefore, given the location of the Norman Manley International Airport the current risk levels posed by storm surges may be considered as high especially on the runway/taxiway area. The results show that the situation will needs to be addressed if no mitigation measures are implemented the situation may worsen in the future.

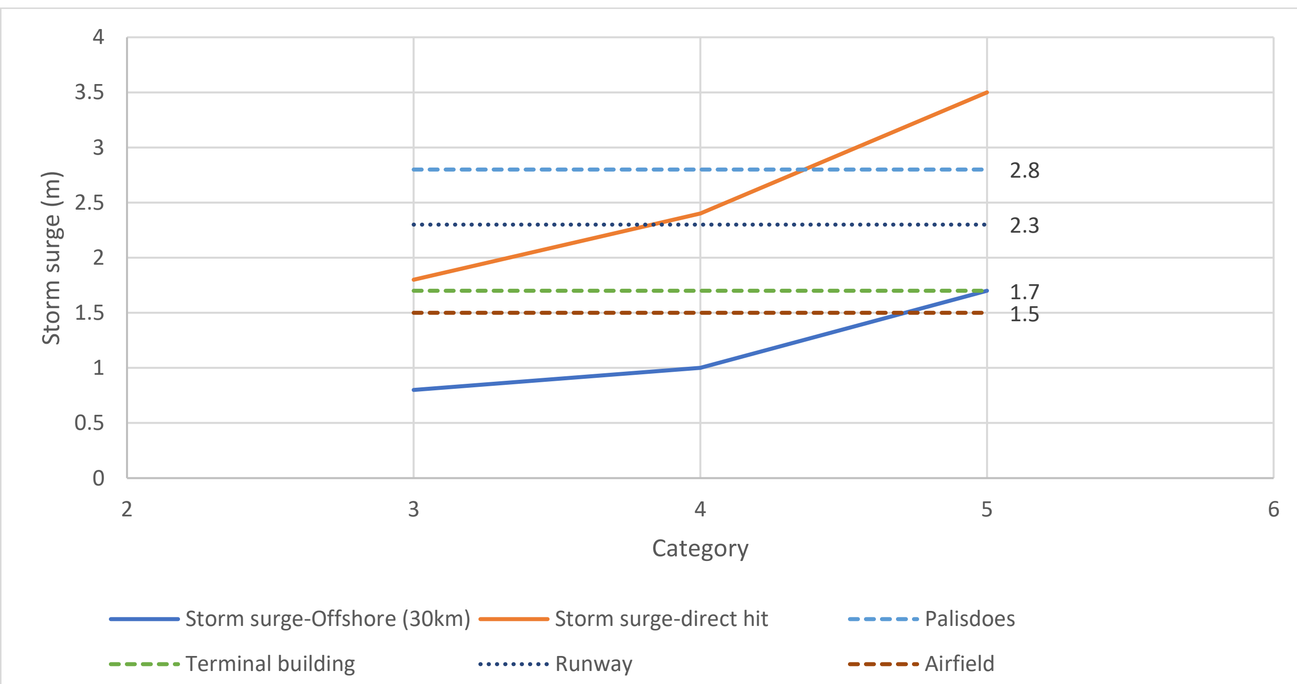


Figure 6.59. Storm surge elevation and representative elevation for selected areas associated with NMIA

6.10 Shoreline Condition Assessment

A Shoreline Protection Condition Assessment was conducted along the project shoreline to gain an appreciation of the effects of the existing climate conditions on the site. The portions of the shoreline that was chosen for the study is approximately 8100 metres in length. There is evidence of previous attempts at protecting the shoreline through the use of hard engineering technique, a revetment, along with soft engineering techniques such as mangroves and sand dunes. The shoreline appears to be relatively unstable especially the north-western corner of runway 12 which illustrated rapid deterioration of the revetment, and the south-eastern area of the beach adjacent to the airport where major blow outs and rills were observed. See aerial imagery in Figure 6.60 below.

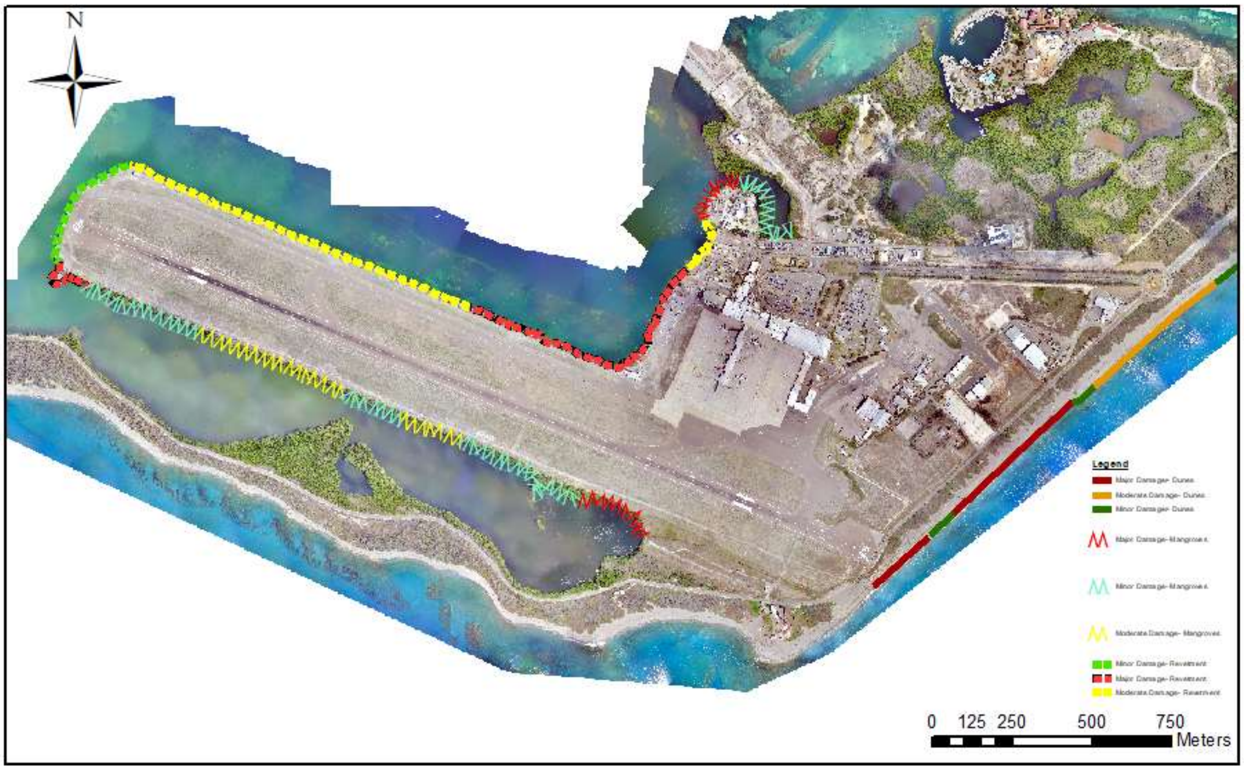


Figure 6.60 Aerial imagery of the section of the NMIA Airport facility showing the shoreline. The sections with the dashed symbology represent the revetment, the zig zag pattern section represents mangroves and the solid lines are the dunes. The red represents portions of the shoreline that needs rehabilitation. The yellow sections represent needs repairs to the shoreline and the green sections shows minor damages.

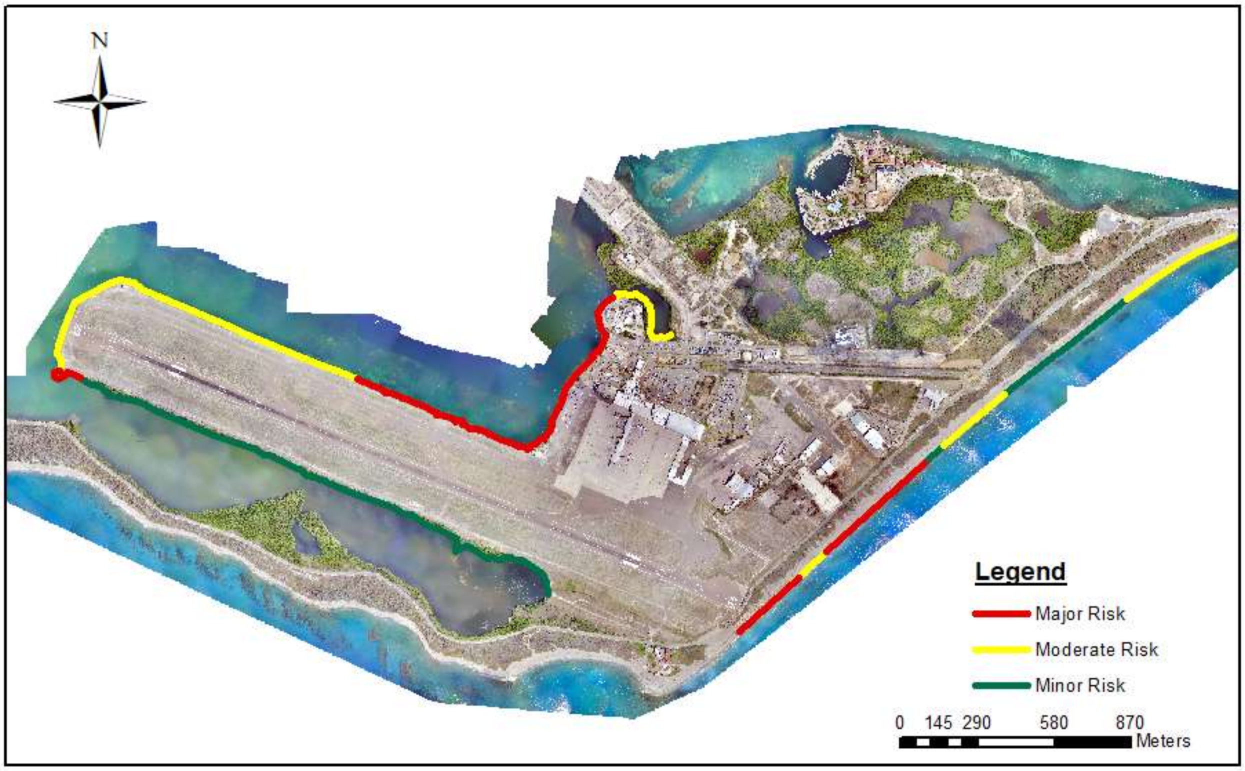


Figure 6.61 Aerial imagery of the section of the NMIA Airport facility showing the shoreline. The sections highlighted in red represents portions of the shoreline that have major damages. The yellow sections represents moderate damage to the shoreline and the green sections shows minor damages.

6.10.1 Methodology and data

The following is a list of items activities that were conducted in order to carry out the shoreline protection condition assessment:

1. Based on an orthomosaic image of the NMIA Airport done from an aerial survey in 2016, the shoreline shapefile was first divided and sampled in 100 meters Chainage to categorize the type of shoreline protection at each given area.
2. The standard damage ratings from descriptions in CIRIA (2007)[9] was used to evaluate the vulnerability and need for rehabilitation or repair. The fragmented shoreline is characterized on a scale of 1–3 (no repairs (1), moderate repairs (2) and rehabilitation (3)). Once the condition of the shoreline protections types is identified, the risk assessment would be determined

Table 6.45 the criteria used to execute the condition assessment

	Revetment	Mangroves	Dunes
No repairs	Slight movement Depressions < ¼ diameter of armour stone Bridging <1/2 diameter	>10 meters width from shoreline to water line	Vegetation width >40 meters and no blow outs

[9] Ciria, Cur. "CETMEF (2007)-The Rock Manual. The Use of Rock in Hydraulic Engineering." Publicação C683 (2007).

Repairs	Some voids with underlayer visible in some sections	Gaps or breaks in canopy that extend from shoreline to water line >5 meters	Blow outs that extend from dune face part way to back of dune
Rehabilitation	Armour fully displaces Loss of under layer is evident.	Width < 10 meters and breaks in canopy > 5 meters	Vegetation width < 40 meters Blow outs that extend from dune face to back of dune

3. Once the areas were identified, the risk assessment was carried out. The risk assessment was then broken down into three components: the vulnerability/condition of the shoreline (previously described), the hazard assessment and the exposure. The risk assessment utilized the following conceptual equation:

Equation 6.3. Conceptual risk assessment formula for each length (i) of the shoreline.

$$\text{Risk} = \text{Condition score}_i \times \text{Hazard score}_i \times \text{Exposure score}_i$$

a) The hazard assessment seeks to understand the nature, frequency, magnitude and spatial occurrence of hazards. The assessment was executed by CEAC Solutions from the 50-year return period, using nearshore wave models driven by perturbed wave and wind climates of the future. Magnitude and frequency of hazards across the three different shorelines were determined from a ranking scale (Table 6.46).
b) The exposure analysis was executed using 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. Similarly, exposures were rated on a scale of 1 to 3 based on the perceived importance and value of the assets associated with the stretch of shoreline. For example, the runway and fuel farm were given a high exposure rating (3) and the open fields and perimeter road a low rating (1).
c) This final step combines the results of the condition, hazard and exposure assessment; and determines the level of risk that occurs as a result of the hazard.

Table 6.46 Hazard rating scale for response of revetment, mangrove and dune shoreline systems based on wave heights (m) at toe of system

Hazard score	Revetment	Mangroves	Dune
Low (1)	< 1	< 1.5	< 1.5
Medium (1)	1-2	1.5-4	1.5-3
High (1)	3	>4	> 3

The assessment developed was based on the usage of both existing local and global available data sources, as well as, data collected specifically for the project area.

Table 6.47 Data used for the coastal vulnerability assessment

Variable	Data Source	Data Period
Shoreline Shapefile	Assets of PIOJ	-
Topography/Terrain	Aerial Map of NMIA	2016
Significant wave height	MIKE Wave Model Simulation	2020

6.10.2 Key Findings

This section provides a summary of the condition and risk assessment at the NMIA Shoreline, see Table 6.48 and

Table 6.49 shows summary of the findings for both the protection condition and risk assessment.

6.10.3 Revetment

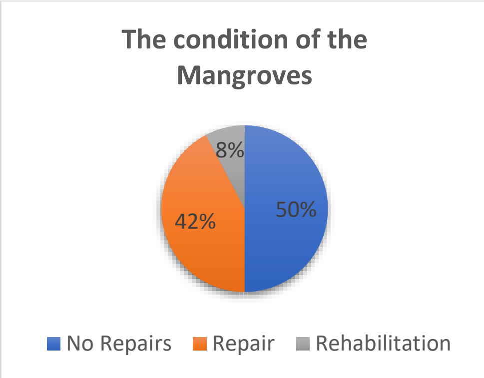
The condition assessment substantiated that the revetment is in poor condition. The results showed that 36% of the revetment needs rehabilitation, 49% is in need of repairs, and 15% has recorded minor damages. The revetment's ability to resist the load from extreme winds and wave action would be seriously compromised in a hurricane event. The existing revetment appears to have reached its physical life span, as in many areas the rocks were observed to have been completely displaced and the filter layers completely exposed to the elements. From the risk assessment carried out, it revealed that 64% of the revetment is at moderate risk while the remaining 36% is exposed to major risk.

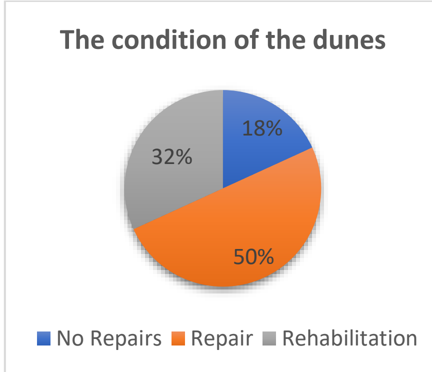
6.10.3.1 *Dune*

Coastal dunes are formed at the interface between the sea and land. This soft engineering technique aids in preventing coastal retreat and protect rom coastal flooding. It was determined that for the Palisadoes the dunes are greatly influenced by the local climatic and soil conditions, particularly in the distribution of coastal plant species (Thompson, 1997). The general condition assessment substantiated that the dune is in moderate condition. The results showed that 32% of the revetment which have less than 40 metres width of vegetation and blowouts needs rehabilitation, while 50% is in need of repairs, while 18% has minor damages. The risk assessment also reflected that 46% of the revetment is at moderate risk, 46% is exposed to major risk and the remaining 8% is exposed to minor risk. However, from previous studies done by CEAC Solution Limited, it was observed that even though the dunes have the blowouts' and rills, from a coastal protection perspective the dunes in their present form are providing a very positive outcome.

6.10.3.2 *Mangroves*

Mangroves are among the most effective natural forms of coastal protection found in the world. Their complex root systems and physical structure are able to absorb wave energy and reduce wave heights from storm surge. It was noted that an increase in mangroves width can minimize not only wave heights and inundation depths but can also reduce currents and hydraulic activity. However, it was recognized that coastal mangroves could be destroyed from tsunami type wave heights exceeding 4 meters. The general condition assessment and the subsequent detailed investigation further substantiated that the mangroves are in fairly good condition. Currently, 9% of the mangroves needs rehabilitation, 43% is in need of repairs, while 48% has experienced minor damages, see Figure 6.62 below. The risk assessment carried out depicted that 46% of the mangroves is at minor risk, 46% of the mangroves is at moderate risk and the remaining 8% is exposed to major risk.





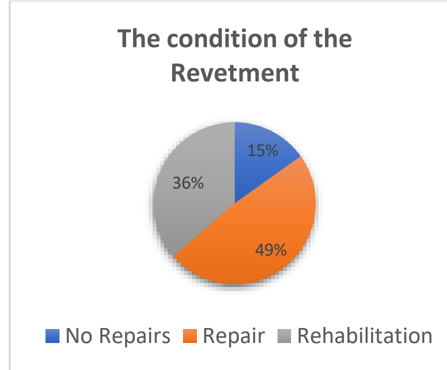


Figure 6.62 A Pie chart for the condition of the Mangroves (A), Revetment (B) and Dunes (C)

Table 6.48 Summary Table of the condition assessment

	Mangroves	Revetment	Dunes
No Repairs	13	5	4
Repair	11	16	11
Rehabilitation	2	12	7
Total	26	33	22

Table 6.49 Summary table of the risk assessment

	Mangroves	Revetment	Dunes
Minor Risk	12	0	1
Moderate Risk	12	21	14
Major Risk	2	12	7
Total	26	33	22

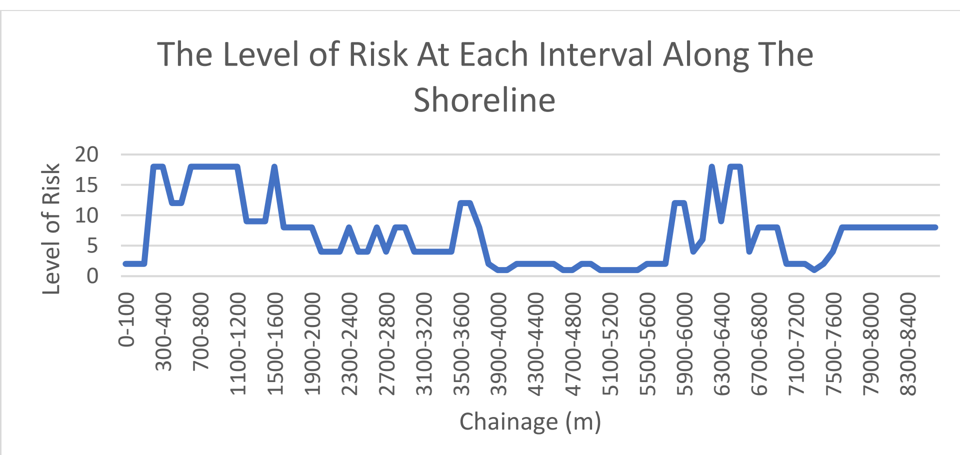


Figure 6.63 The level of risk at each given interval

6.10.4 Conclusion

The data shows that given the location of the Norman Manley International Airport the current risk levels posed by extreme waves may be considered as high. The results show that the situation will need to be addressed if no mitigation measures are implemented the situation may worsen in the future.

1. Caribbean Sea future climate for the 10 to 100-year RP waves with 2050 SLR. It would be convenient at this point to consider some mitigation options such as:
    a. No dune rehabilitation for Palisadoes or Runway 30 with 2050 SLR
    b. Dune nourishment on Palisadoes with 2050 SLR
    c. Dune and revetment at end of runway 30 with 2050 SLR
2. Inner harbour/runway revetment/shoreline for the 50 to 100-year RP wind-generated waves. It would be convenient at this point to consider some mitigation options such as:
    a. No-revetment scenario with 2050 SLR
    b. Dune and revetment at end of runway 30 with 2050 SLR
    c.

Asset components	Natural hazard and climate Drivers	Vulnerability assessment method
Runway, taxiways and aprons Offices-Tenants Operations: ARFF, Fuel farm	Wave heights and SLR	1. Determine area affected by erosion for RP 10 to 100 year for present and future climate scenarios and create erosion hazard map. 2. Value assets affected, including paved areas, dunes and potentially buildings. 3. Define damage curve for cases were erosion encroaches on to asset 4. Determine damage by applying erosion hazard map to vulnerability curve

6.11 Vulnerability Assessment

6.11.1 Background

The aim of the vulnerability assessment is to identify the assets, facilities and locations that are highly expose to hazards such as storm surge and sea level rise along the entire length of the project shoreline. As climate change is on the brink of us, prioritization is critical to mitigating impacts of sea level rise and storm surge (SLR/SS) to the most vulnerable assets. The vulnerability assessment methodology, including how vulnerability and risk were measured, was included in the Deliverable one (1) Report.

6.11.1.1 *Sea level rise*

The University of the West Indies Climate Studies Group Mona (CSGM) projected sea level rise for the south coast of Jamaica utilizing the full ensemble of GCM models under the CMIP project in conjunction with the SimClim 2013 software package(See results below Table 6.50). The SLR assessment was conducted using RCP 2.6, 6.0 and 8.5 (2055) scenarios as it represents a range of cases regarding the concentration of Greenhouse gases (GHGs) in the atmosphere associated with future global development patterns to the end of the century. See Table 6.50 below.

Table 6.50 Projected Sea Level Rise for the South Coast of Jamaica.

Sea Level Rise (m) South Coast (-77.157W, 17.142N)								
Centered	2025		2035		2055		End of Century	
Averaged	2020-2029		2030-2039		2050-2059		2080-2100	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
RCP2.6	0.14	0.11 – 0.17	0.20	0.18 – 0.23	0.34	0.31 – 0.37	0.60	0.53 – 0.67
RCP4.5	0.14	0.11 – 0.17	0.20	0.18 – 0.23	0.36	0.32 – 0.40	0.68	0.59 – 0.78
RCP6.0	0.14	0.11 – 0.17	0.20	0.18 – 0.23	0.35	0.31 – 0.39	0.69	0.58 – 0.80
RCP8.5	0.15	0.12 – 0.18	0.22	0.19 – 0.25	0.40	0.35 – 0.45	0.90	0.74 – 1.08

6.11.1.2 *Storm Surge*

The extent and depth of flooding was informed by the 2050 storm surge scenarios was generated from the CEAC Storm surge model (section 6.5.2). The results indicated that the storm surge height under RCP 8.5 is 3.79m which represents a future increase of 24% in category 3-5 hurricanes. This data in conjunction with the asset map aided in identifying all the vulnerable locations at the project site.

6.11.2 Results

The vulnerability assessment revealed that it is important for the storm surge data to be accurate as the relationship between mapping scales and estimation of storm surge flooding depth is complex. It is vital to note that there are still many unknowns relative to potential damages caused by SLR/SS. Damages tend to increase with longer duration of flooding which could occur if the pumps and drainage systems are not functioning to their expected capacity during and after a storm.

The geological and topographical characteristics of the NMIA is such that it increases the susceptibility of the site to coastal flooding from storm surge. The analysis shows that for all return periods the land and buildings at the NMIA are highly exposed to varying degrees of flooding as a result of storm surge hazard. All the scenarios, depicted that more than 80% of the airport land and facilities are inundated. With exceptions of the area south the Old Air Jamaica Hanger. Figure 6.64-Figure 6.68 shows the estimated storm surge and sea level rise inundation levels at NMIA (RCP 2.6, 6 and 8.5), where the dark blue sections depicts area of "High criticality" (SLR+SS), the lighter blue shows areas of "Moderate criticality" (SS Only) and the lightest blue on the map depicts "Low Critically" (No Hazard). This can have large scale impact such as interruptions to flight schedules as well as business operations at the airport.

Table 6.51 illustrates a vulnerability matrix for various airport components at the NMIA. The matrix utilizes a weighted value in order to measure the vulnerability of the NMIA airport infrastructure to the combined impacts of sea level rise and storm surge (using the climate change scenario RCP 8.5).

The table depicts the vulnerability levels of the assets at NMIA, where "Serious Impact" is displayed in red and "Trivial/Minor Impact" is displayed in green. It was deduced that storm surge poses a greater threat to the infrastructure and other critical assets than that of sea level rise. However, it should be noted that if these two hazard coincide, the impact would be much greater.

Table 6.51 Results of vulnerability matrix (RCP 8.5)

	Airport Components	Exposure metric	Sea Level	Storm surge	Weighted Value
1	**Infrastructure**				
1.1	Roads and parking				
1.11	Internal road network (airside and landside)	length	4	6	5.00
1.12	Parking lots	area	4	6	5.00
1.13	Drainage system	length	4	6	5.00
1.2	Access to airport			6	
1.21	Palisadoes	length	2	6	4.00
1.3	Runway, taxiways and aprons				
1.31	Runway (including southern edge)	area	2	6	4.00
1.32	Taxiway (including northern edge)	area	2	6	4.00
1.33	Apron	area	2	6	4.00
1.34	R12 end	length and area	2	6	4.00
1.35	R30 end	length and area	2	4	3.00
2	**Buildings**				
2.1	Terminals	number and ground floor area	1	6	3.50
2.2	Offices-AAJ/PACKAL	number and ground floor area	1	6	3.50
2.3	Offices-Tenants	number and ground floor area	1	6	3.50
3	**Operations**				
3.1	ARFF, Fuel farm	number of tanks and buildings	2	6	4.00
3.2	Lighting and navigation aids		2	6	4.00
3.21	Approach lights	number	4	6	5.00
3.22	NAVAIDS	number	2	6	4.00
3.23	ATC Tower	number	2	4	3.00
3.3	HVAC - Terminal building	number of units	2	2	2.00
3.4	Water and waste water system		2	6	4.00
3.41	Water storage	number	4	6	5.00
3.42	WWTP	number	2	6	4.00

6.11.2.1 *Preliminary Vulnerability Criticality Assessment*

The level of risk that climate change poses to a specific component of the airport system would be multiplied by the occurrence probability of the climate change by its impact on the airport component. Table 6.52 represents the possible levels of risk that a climate change can pose to an airport element. The scale ranges from 1 to 12 and are spread among four categories going from "Null" to "High" risk. Finally, the result of the methodology of evaluation of the vulnerability to climate change will be summarized in a risk matrix as shown in Table 6.52. The value contained in each cell of the table then represents the vulnerability of the associated airport component on the concerned climate change.

Table 6.52 Vulnerability levels of airport components of climate change

		Impacts			
		Trivial	Minor	Serious	Catastrophic
Probability of occurrence	>100 years	Low (3)	Medium (6)	High (9)	High (12)
	5-100 years	Null (2)	Low (4)	Medium (6)	High (8)
	<5 years	Null (1)	Null (2)	Low (3)	Low (4)

Table 6.53 Prioritization list of vulnerable facilities in order of criticality

	Airport Components	Weighted Value
3.41	Water storage	5.00
1.12	Parking lots	5.00
1.11	Internal road network (airside and landside)	5.00
1.13	Drainage system	5.00
3.21	Approach lights	5.00
3.42	WWTP	4.00
3.4	Water and waste water system	4.00
1.32	Taxiway (including northern edge)	4.00
1.31	Runway (including southern edge)	4.00
1.34	R12 end	4.00
1.21	Palisadoes	4.00
3.22	NAVAIDS	4.00
3.2	Lighting and navigation aids	4.00
3.1	ARFF, Fuel farm	4.00
1.33	Apron	4.00
2.1	Terminals	3.50
2.3	Offices-Tenants	3.50
2.2	Offices-AAJ/PACKAL	3.50
1.35	R30 end	3.00
3.23	ATC Tower	3.00
3.3	HVAC - Terminal building	2.00

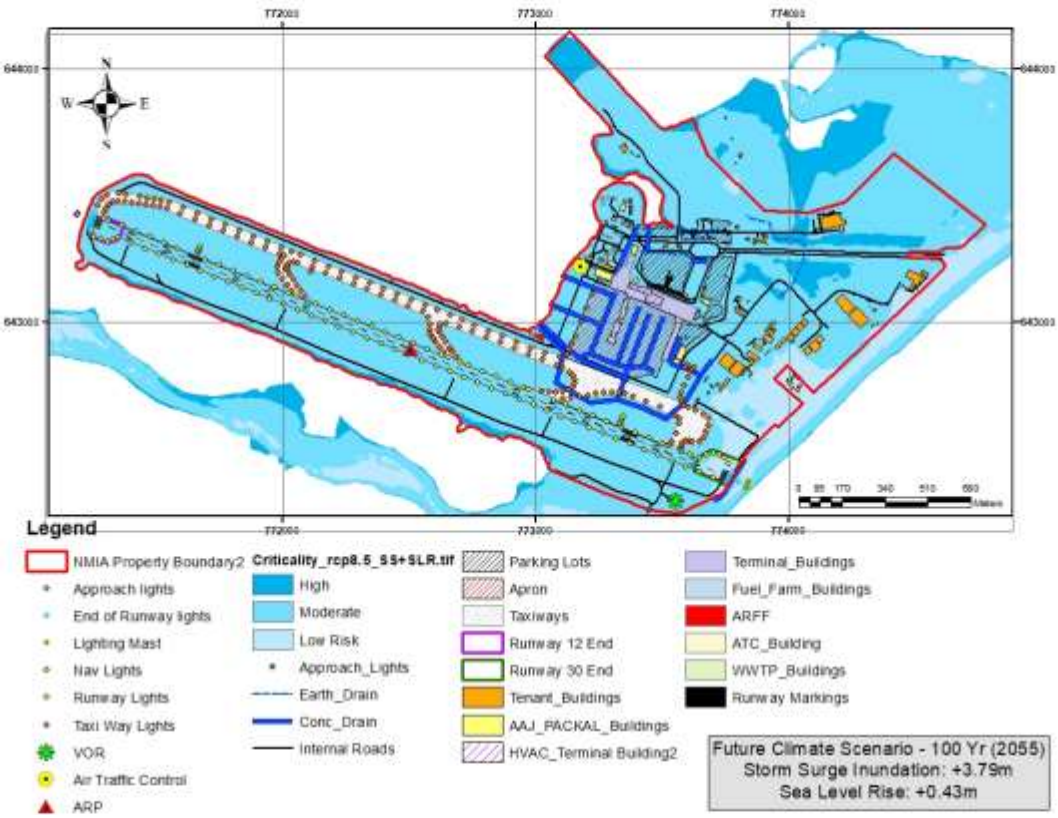


Figure 6.64 Assets Map under storm surge and sea level rise (RCP 8.5)

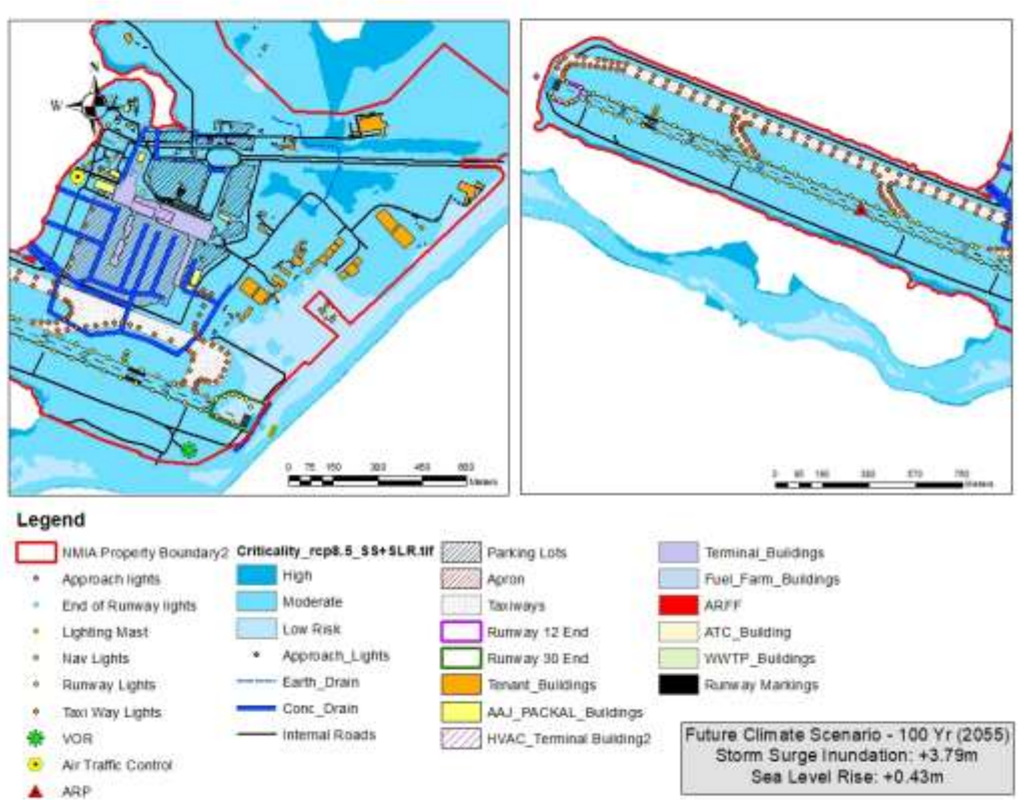


Figure 6.65 Assets Map under storm surge and sea level rise (RCP 8.5) (zoom in)

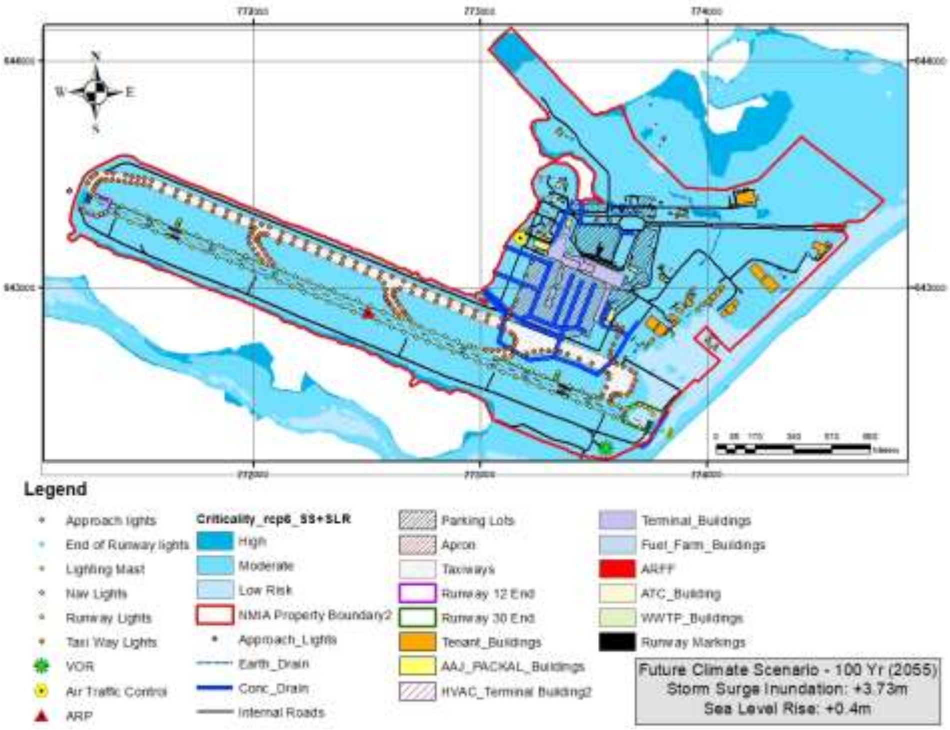


Figure 6.66 Assets Map under storm surge and sea level rise (RCP 6)

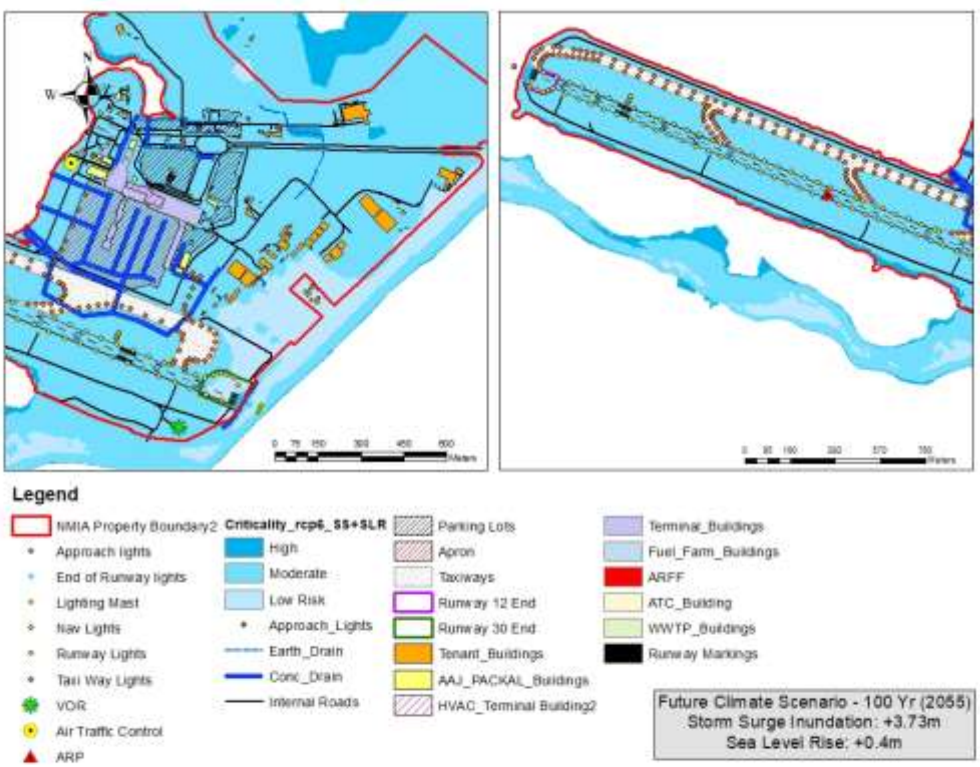


Figure 6.67 Assets Map under storm surge and sea level rise (RCP 6) (Zoom in)

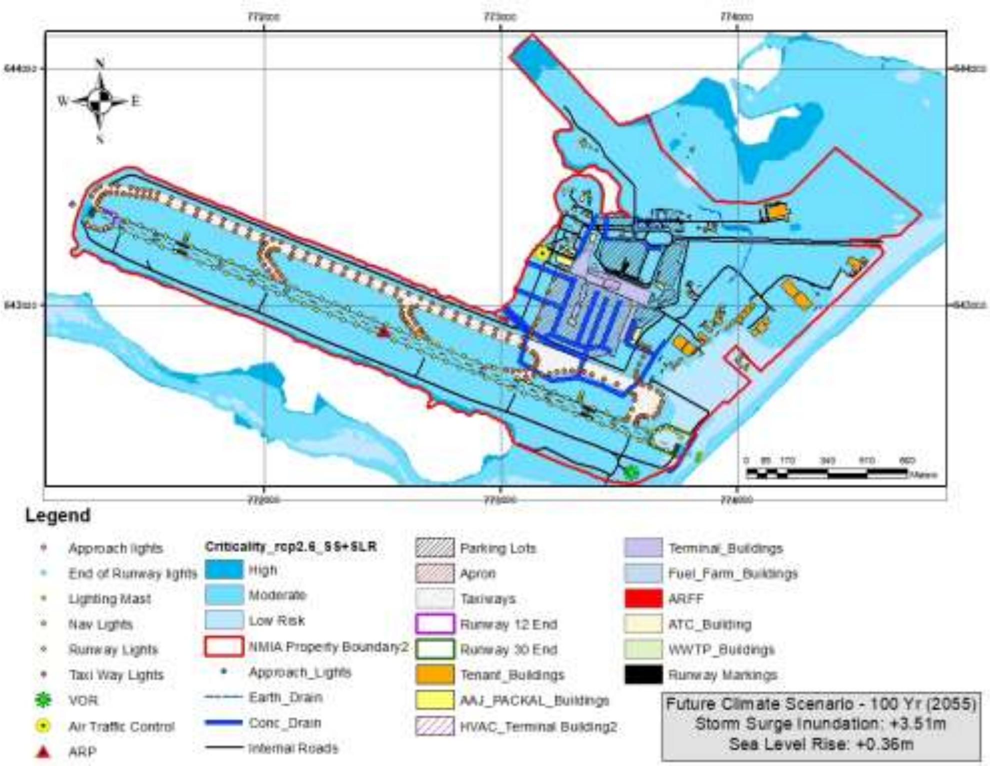


Figure 6.68 Assets Map under storm surge and sea level rise (RCP 2.6)

6.11.3 Conclusion

Norman Manley International Airport is moderately vulnerable to storm surge and this will increase when sea level rise is factored in. More than 80% of the airport will be affected by storm surge with exception of the area south of the Old Air Jamaica Hanger, which has an elevation of 5m. Therefore, a need for a mitigation plan would be need to be in place in order to reduce the vulnerability of the project to hazards. As, the disruption of operations at NMIA would have a multiplier effect on other businesses, a continuity of operations plan should be considered a strategic imperative for the airport.

6.12 Conclusion

Climate Change Study

This section reports on the results of an analysis of the future climate of Norman Manley International Airport. The variables analyzed include temperature and precipitation (means and extremes), sea level rise and hurricanes. The data analyzed was from the HadGEM2-ES GCM downscaled using the ICTP RegCM version 4. With regards to sea level rise and hurricanes we presented results from recent scholastic studies.

Annual mean temperature is likely to be kept below 1.5°C above preindustrial levels under RCP 2.6, but under RCP 8.5 it is expected to increase at a rate of 0.4°C/decade till the end of century. Temperature climatologies of mean, maximum and minimum temperatures are expected to follow the unimodal pattern in the near, medium and long term future with higher temperature increase being observed in the summer months. This is true for both RCP 2.6 and 8.5. The temperature increases across months are however not uniform. Larger increases are observed in the winter months (December to February, with the largest increase in December) and smaller increases observed from May through to August for both RCPs.

With respect to temperature extremes; the number of warm days/daily maximum temperatures as well as warm nights that fall within the baseline 90th percentile are projected to increase up to as much as 100% under RCP 8.5.

With regards to monthly precipitation climatology, the known bimodal pattern for precipitation with peaks in May and October holds in the future for all three defined periods. The months with the greatest percentage decrease in precipitation across both RCPs are July and August. Under RCP 8.5 there is a decreasing trend in the number of days with rainfall > 10mm and the number of consecutive wet days.

The sea level is expected to increase to as much as 0.67m and 1.08m by the end of the century under RCP 2.6 and RCP 8.5 respectively.

There is expected to be a reduction in the total number of hurricanes in the future, however there is expected to be an increase in the number of major hurricanes. The increase could likely be more than 100% according to the current literature. Rainfall rate and maximum wind speed are also likely to increase in the future.

Climate Linkage

No site-specific changes (trends or break points) were found in the extreme wave heights. Association with regional climate indices at significant levels were not detected. A conservative approach was adopted to use regional trends. Climate change factors were derived based on the assessments and literature reviewed. The following were incorporated into the design specifically the deep water and nearshore wave climate analysis.

The two-sample Kologorov-Smirnov test proved that there is no trend occurring between the climate indices and extreme wave heights within the study area. Therefore, the regional data set was used to undertake the wave modelling.

Table 6.54 Summary of climate change projections for water levels and hurricane intensities and numbers.

Parameter	Climate Factors (Cf)
Water Level (above existing MSL)	5.8 mm/yr.
Increase in intense hurricanes (cat 4-5)	14%
Decrease in hurricane activity	22%
Increase in number of storms per year	2-8

Extreme Waves Analysis

Storm surge studies incorporates deep water waves as well as the wind speeds that is used to produces said surges. The data was generated using a statistical analysis to derived return periods. Climate change factors were also used to describe a future climate scenario. Results of this analysis indicated that the wave heights and wind speeds will increase by approximately 24% as seen in Table 6.25. Wave heights under the present climate scenarios for the 50 yr. and 100 yr. return period storm were predicted to be up to 10.8 m and 12.2 m respectively. Wind speeds for the 50 yr. and 100 yr. return period events under present climate scenario were predicated to be up to 69.6 m/s and 105.2 m/s respectively. The results for the offshore storm surge showed that the storm surge elevations 1.41, 2.22, 2.94, 3.79m for the 10, 25, 50 and 100 year return period (RP), see plots below (Figure 6.42). Based on the results considerable damage would occur at the shoreline, therefore a mitigation measures would be needed to lessen the impact of wave energy at the shoreline.

Table 6.55 Change difference between the current and future climate scenarios for different return periods.

Return Period (YRS.)	Change difference between current and future climate
10	19%
25	20%
50	23%
100	27%
Average	22%

Storm Surge (Nearshore)

Harbour Generated Storm Surge

Results previously discussed may seem daunting but are only used to describe the offshore climate. The waves and wind speeds were then used on the boundaries of the models to simulate and predict the nearshore wave climate. The deep water waves were only applied to the southern boundary while the wind speeds were applied to the worst case direction. This approach was executed so as to better simulate the wave generation processes within the harbour, as waves within the harbour are mostly driven by wind. The results of this analysis indicate that waves coming from the north-western direction towards the study area within the harbour are the worst case scenario. For the 50 yr. and 100 yr. return period storm event wave heights were predicted to be up to 0.43 – 1.86 m under the all future climate scenario (RCP 2.6, 6, 8.5).

Caribbean Sea Side Storm Surge

After examining the nearshore surface elevation for current and future storms, it was displayed that for the present climate the surface elevation is approximately 0.9 m at the shoreline. While for the 100yr RP (Future Climate) the storm surge elevation varied from 0.89 and 1.7 m for the all the scenarios (RCP2.6, 6 and 8.5). Based on the results, minor- moderate damage would occur at the shoreline from these levels of surface elevation at the shoreline. This is due to the sand dunes that currently situated along the shoreline that act as protection barrier for such surges. Overall, predicted surface elevations for all of the return periods are expected to increase as projected climate change trends ensures.

Long Term Shoreline Erosion

It can be concluded for entire project shoreline that the estimated accretion rates have been slowed down due to ongoing erosion, based on the historical overall shoreline accretion trend as well as the projected erosion due to sea level rise. This simply means that in the absence of sea level rise, the accretion rates would have been greater while the opposite for rates of erosion.

With focus on the project area, it is estimated that sea level rise accounts for approximately 1.2- 28.7 m of erosion along the Harbour side. The hot spot area is along the existing revetment. While for the Caribbean Seaside, sea level rise would account for 1.2- 12.5 m of erosion along the harbour side. The most vulnerable area is along the north-eastern section of the shoreline.

Probabilistic Hurricanes

After analysis of the data shows there is a positive correlation between the surge height and the storm location and wind intensity at the site. This was observed where the storm surge levels were higher with a parallel direct hit versus a hurricane 30km offshore. Therefore, given the location of the Norman Manley International Airport the current risk levels posed by storm surges may be considered as high especially on the runway/taxiway area. The results show that the situation will needs to be addressed if no mitigation measures are implemented the situation may worsen in the future.

Shoreline Condition Assessment

The data shows that given the location of the Norman Manley International Airport the current risk levels posed by extreme waves may be considered as high. The results show that the situation will needs to be addressed if no mitigation measures are implemented the situation may worsen in the future.

- Caribbean Sea future climate for the 10 to 100-year RP waves with 2050 SLR. It would be convenient at this point to consider some mitigation options such as:
    a) No dune rehabilitation for Palisadoes or Runway 30 with 2050 SLR
    b) Dune nourishment on Palisadoes with 2050 SLR
    c) Dune and revetment at end of runway 30 with 2050 SLR
- Inner harbour/runway revetment/shoreline for the 50 to 100-year RP wind-generated waves. It would be convenient at this point to consider some mitigation options such as:
    a) No-revetment scenario with 2050 SLR
    b) Dune and revetment at end of runway 30 with 2050 SLR

Asset components	Natural hazard and climate Drivers	Vulnerability assessment method
Runway, taxiways and aprons Offices-Tenants Operations: ARFF, Fuel farm	Wave heights and SLR	1. Determine area affected by erosion for RP 10 to 100 year for present and future climate scenarios and create erosion hazard map. 2. Value assets affected, including paved areas, dunes and potentially buildings. 3. Define damage curve for cases were erosion encroaches on to asset 4. Determine damage by applying erosion hazard map to vulnerability curve

Vulnerability Assessment

From the data it was deduced that the location of the Norman Manley International Airport causes the level of vulnerability posed by storm surge to be moderate and will increase when sea level rise is factored in. More than 80% of the airport will be affected by storm surge with exception of the area south of the Old Air Jamaica Hanger, which has an elevation of 5m. Therefore, mitigation plan should be put in place in order to reduce the vulnerability of the project to hazards. As, the disruption of operations at NMIA would have a multiplier effect on other businesses, a continuity of operations plan should be considered a strategic imperative for the airport.

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8 Appendix

8.1 Appendix 1

8.1.1 Data Dictionary:

```
"NMIA Asset Collector", Dictionary, "Data dictionary developed for NMIA Assets"
"Terminal_Buildings", area, "Civil Structures - Buildings", 1, seconds, 1, Code
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  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required, Label2
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  "Dimensions", text, 100, normal, required
  "Condition", menu, normal, required
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    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Pictures", filename, normal, required
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    "Glass",[GLASS]
    "Metal",[MTL]
    "Wood",[WD]

"Support_Buildings", area, "Civil Structures - Buildings", 1, seconds, 1, Code
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  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required, Label2
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    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
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    "Glass",[GLASS]
    "Metal",[MTL]
    "Wood",[WD]

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    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
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    "Glass",[GLASS]
    "Metal",[MTL]
    "Wood",[WD]


"Roadways", line, "Civil Structures - Roads and Perimeters", 1, seconds, 1, Code
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  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
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    "Fair",[3]
    "Poor",[2]
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    "Asphalt-paved",[ASP]
    "Earth-paved",[EAR]
    "Gravel-paved",[GVL]

"Perimeter_fence_gate", line, "Civil Structures - Roads and Perimeters", 1, seconds, 1, Code
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  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
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    "Fair",[3]
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    "Metal",[MTL]
    "Steel",[STL]
    "Wire",[WIRE]
    "Wood",[WD]

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    "Fair",[3]
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    "Metal",[MTL]
    "Steel",[STL]

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  "Dimensions", text, 100, normal, required
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    "Metal",[MTL]
    "Steel",[STL]

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      "Glass",[GLASS]
      "Metal",[MTL]
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      "Good",[4]
      "Fair",[3]
      "Poor",[2]
      "Failed",[1]
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      "Metal",[MTL]
      "Steel",[STL]

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    "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
    "Condition", menu, normal, required
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      "Fair",[3]
      "Poor",[2]
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    "Manufacturer", text, 100, normal, required, Label2

  "Taxiway_Lights", point, "Electrical - Airfield Lights", 1, seconds, 1, Code
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    "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
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      "Poor",[2]
      "Failed",[1]
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  "Approach_Lights", point, "Electrical - Airfield Lights", 1, seconds, 1, Code
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    "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
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    "Failed",[1]
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  "Secondary Voltage", text, 100, normal, required
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    "Metal",[MTL]
    "Wood",[WD]
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    "Failed",[1]
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  "Serial Number", text, 100, normal, normal
  "Photograph", filename, normal, required

"Electric_Poles_Light", point, "Electrical - Distribution System", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Type", menu, required, "Material used in construction", required
    "Concrete",[CONC]
    "Metal",[MTL]
    "Wood",[WD]
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Pictures", filename, normal, required
  "Operating Voltage", text, 100, normal, required
  "Single or Three phas", text, 100, normal, required
  "Phase connection", text, 100, normal, required
  "Serial Number", text, 100, normal, required
  "Photograph", filename, normal, required
  "Number of fixtures", numeric, 0, 0, 0, 0, normal, required, Label1
  "Fixture Wattage type", text, 100, normal, required, Label2

"4kV_WestSubstation", area, "Electrical - Distribution System", 1, seconds, 1, Code
```

```
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Pictures", filename, normal, required
  "kVa rating", text, 100, normal, required, Label1
  "Primary Voltage", text, 100, normal, required, Label2
  "Secondary Voltage", text, 100, normal, required
  "Single or Three phas", text, 100, normal, required
  "Phase connection", text, 100, normal, required
  "Photograph", filename, normal, required

"Sewage_Manholes", point, "Mechanical - Wastewater Infrastructure", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Dimensions", text, 100, normal, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Depth", numeric, 0, 0, 0, 0, normal, required
  "Pipe Specifications", text, 100, required, "Number; Size of pipes", required
  "Pictures", filename, normal, required

"Wstewtr_Potable_Pipe", line, "Mechanical - Wastewater Infrastructure", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Diameter", numeric, 2, 0.00, 0.00, 0.00, normal, required, Label1
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Invert Level", text, 100, normal, required, Label2
  "Crown Level", text, 100, normal, required
  "Material", menu, normal, "Material used in construction", required
    "Concrete",[CONC]
    "Metal",[MTL]
    "Steel",[STL]
    "Plastic",[PVC]
    "Asbestos Cement",[AC]
  "Thickness", text, 100, normal, required

"Wstewtr_Lift_Station", point, "Mechanical - Wastewater Infrastructure", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Pictures", filename, normal, required
  "kVa rating", text, 100, normal, required
  "Primary Voltage", text, 100, normal, required
  "Secondary Voltage", text, 100, normal, required
  "Single or Three phas", text, 100, normal, required
  "Phase connection", text, 100, normal, required
  "Manufacturer", text, 100, normal, required
  "Serial Number", text, 100, normal, normal
  "Date Manufactured", text, 100, normal, required
```

```
  "Photograph", filename, normal, required

"Potable_Water_Valves", point, "Mechanical- Potable Water Infrastructure", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Photograph", filename, normal, required
  "Manufacturer", text, 100, required, required
  "Dimensions", text, 100, normal, required
  "Specs Material", menu, normal, required, Label1
    "Gate Valves",[GV]
    "Globe Valve",[GBV]
    "Plug Valve",[PLV]
    "Diaphragm Valve",[DIAPH]
    "Ball Valve",[BALL]
    "Butterfly Valve",[BFV]
    "Needle Valve",[NV]
    "Check Valve",[CV]
    "Pressure Relief Valv",[PRV]
    "Control Valves",[COV]

"HVAC_Water_Valves", point, "Mechanical - HVAC Infrastructure", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Photograph", filename, normal, required
  "Manufacturer", text, 100, normal, required
  "Dimensions", text, 100, normal, required
  "Specs Material", menu, normal, required
    "Gate Valves",[GV]
    "Globe Valve",[GBV]
    "Plug Valve",[PLV]
    "Diaphragm Valve",[DIAPH]
    "Ball Valve",[BALL]
    "Butterfly Valve",[BFV]
    "Needle Valve",[NV]
    "Check Valve",[CV]
    "Pressure Relief Valv",[PRV]
    "Control Valves",[COV]

"Storm_Water_Manholes", point, "Mechanical - Storm Water Infrastructure", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Dimensions", text, 100, normal, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Invert Level", text, 100, normal, required
  "Crown Level", text, 100, normal, required
  "Pipe Specifications", text, 100, normal, "Number; Size of pipes", required
  "Pictures", filename, normal, required
```

```
"Undrgrnd_Storm_Pipes", line, "Mechanical - Storm Water Infrastructure", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Depth", numeric, 0, 0, 0, 0, normal, required
  "Material", menu, normal, "Material used in construction", required
    "Concrete",[CONC]
    "Metal",[MTL]
    "Steel",[STL]
    "Plastic",[PVC]
    "Asbestos Cement",[AC]
  "Diameter", numeric, 2, 0.00, 0.00, 0.00, normal, required

"Stormwtr_Pump_Statio", point, "Mechanical - Storm Water Infrastructure", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Pictures", filename, normal, required
  "kVa rating", text, 100, normal, required
  "Primary Voltage", text, 100, normal, required
  "Secondary Voltage", text, 100, normal, required
  "Single or Three phas", text, 100, normal, required
  "Phase connection", text, 100, normal, required
  "Manufacturer", text, 100, normal, required
  "Serial Number", text, 100, normal, normal
  "Date Manufactured", text, 100, normal, required
  "Photograph", filename, normal, required

"Apron_Contamin_Wells", point, "Environmental - Wells", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Dimensions", text, 100, normal, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Depth", numeric, 0, 0, 0, 0, normal, required
  "Pipe Specifications", text, 100, required, "Number; Size of pipes", required
  "Conduit Specs", text, 100, normal, normal
  "Pictures", filename, normal, required

"Oil_Water_Separators", area, "Environmental - O/W Separators", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Dimensions", text, 100, normal, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Depth", numeric, 0, 0, 0, 0, normal, required
  "Pipe Specifications", text, 100, required, "Number; Size of pipes", required
  "Conduit Specs", text, 100, normal, normal
  "Pictures", filename, normal, required
```

```
"Storm_Water_Drains", line, "Environmental - Drains", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Dimensions", text, 100, normal, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Depth", numeric, 0, 0, 0, 0, normal, required
  "Pictures", filename, normal, required
  "Material", menu, normal, "Material used in construction", required
    "Concrete",[CONC]
    "Brick",[BRK]
    "Earth-line",[ERTH]

"Vegetation_points", point, "Natural Features - Terrestrial", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Description", text, 100, required, required
  "Pictures", filename, normal, required

"Vegetation_polyline", line, "Natural Features - Terrestrial", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Description", text, 100, required, required
  "Pictures", filename, normal, required

"Water_Features", point, "Naturall Features - Hydrological", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Dimensions", text, 100, normal, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Area", numeric, 2, 0.00, 0.00, 0.00, normal, required, Label1
  "Description", text, 100, required, required
  "Pictures", filename, normal, required

"Runway", area, "Airside Facilities - Airside Areas", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Dimensions", text, 100, normal, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Specifications", text, 100, required, "Refers to type,color,voltage or current ", required
```

```
"Taxiways", area, "Airside Facilities - Airside Areas", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Dimensions", text, 100, normal, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Specifications", text, 100, required, "Refers to type,color,voltage or current ", required

"Ramp", area, "Airside Facilities - Airside Areas", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Dimensions", text, 100, normal, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Specifications", text, 100, required, "Refers to type,color,voltage or current ", required

"Aircraft_Stands", area, "Airside Facilities - Airside Areas", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Dimensions", text, 100, normal, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Specifications", text, 100, required, "Refers to type,color,voltage or current ", required

"PAPI", point, "Airside Facilities - Navigation Aids", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Dimensions", text, 100, normal, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Specifications", text, 100, required, "Refers to type,color,voltage or current ", required
  "Pictures", filename, normal, required
  "Material", menu, normal, "Material used in construction", required
    "Concrete",[CONC]
    "Glass",[GLASS]
    "Metal",[MTL]
    "Steel",[STL]

"DVOR", point, "Airside Facilities - Navigation Aids", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Dimensions", text, 100, normal, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Specifications", text, 100, required, "Refers to type,color,voltage or current ", required
```

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  "Pictures", filename, normal, required
  "Material", menu, normal, "Material used in construction", required
    "Concrete",[CONC]
    "Glass",[GLASS]
    "Metal",[MTL]
    "Steel",[STL]

"ILS", point, "Airside Facilities - Navigation Aids", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Dimensions", text, 100, normal, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Specifications", text, 100, required, "Refers to type,color,voltage or current ", required
  "Pictures", filename, normal, required
  "Material", menu, normal, "Material used in construction", required
    "Concrete",[CONC]
    "Glass",[GLASS]
    "Metal",[MTL]
    "Steel",[STL]

"Windsocks", point, "Airside Facilities - Navigation Aids", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Dimensions", text, 100, normal, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Specifications", text, 100, required, "Refers to type,color,voltage or current ", required
  "Pictures", filename, normal, required
  "Material", menu, normal, "Material used in construction", required
    "Concrete",[CONC]
    "Glass",[GLASS]
    "Metal",[MTL]
    "Steel",[STL]

"AWOS", point, "Airside Facilities - Navigation Aids", 1, seconds, 1, Code
  "X1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Y1", numeric, 6, 0.000000, 0.000000, 0.000000, required, required
  "Dimensions", text, 100, normal, required
  "Condition", menu, normal, required
    "Excellent",[5]
    "Good",[4]
    "Fair",[3]
    "Poor",[2]
    "Failed",[1]
  "Specifications", text, 100, required, "Refers to type,color,voltage or current ", required
  "Pictures", filename, normal, required
  "Material", menu, normal, "Material used in construction", required, Label1
    "Concrete",[CONC]
    "Glass",[GLASS]
    "Metal",[MTL]
    "Steel",[STL]
```

Table 8.1: Summary of the Identified Gaps

Subcategory	*Existing data*	*Gaps*	
		Missing Attributes	*Spatial Gaps*
Air Traffic Control Buildings	• Latitude/Longitude Coordinates • Description • Conditions • Construction Material • Pictures	• Dimension	
Support Buildings	• Latitude/Longitude Coordinates • Description • Conditions Construction Material • Pictures	• Dimension	DM – Data misalignment GV – Vector Geometry Misrepresentation
Terminal Buildings	• Latitude/Longitude Coordinates • Description • Conditions Construction Material • Pictures	• Dimension	DM – Data misalignment
Roadways	• Latitude/Longitude Coordinates	• Description • Dimension • Conditions • Construction Material • Pictures	FC – Feature Discontinuity DM – Data misalignment
Perimeter fencing and gates	• Latitude/Longitude Coordinates	• Description • Dimension • Conditions • Construction Material • Pictures	AB – Complete Absence FC – Feature Discontinuity OI – Observed on Imagery
Cell Towers	• Latitude/Longitude Coordinates • Description • Conditions • Construction Material	• Dimension • Pictures	
Substations		• Latitude/Longitude Coordinates • Description • Dimension • Conditions • Construction Material	AB – Complete Absence
Electrical Manholes	• Latitude/Longitude Coordinates	• Dimension • Condition • Depth • Pictures	AB – Complete Absence FC – Feature Discontinuity
Light Masts – Airside	• Latitude/Longitude Coordinates • Condition • Description • Construction Material	• Dimension • Pictures	
Light Masts – Landside	• Latitude/Longitude Coordinates • Condition • Description • Construction Material	• Dimension • Pictures	AB – Complete Absence
Runway Lights	• Latitude/Longitude Coordinates • Conditions • Specifications	• Manufacturer • Pictures	
Taxiway Lights	• Latitude/Longitude Coordinates • Conditions • Specifications	• Manufacturer • Pictures	
Approach Lights	• Latitude/Longitude Coordinates • Conditions	• Manufacturer • Pictures	

	• Specifications		
Airfield Directional Signs	• Latitude/Longitude Coordinates • Conditions • Specifications	• Manufacturer • Pictures	
Runway Markings		• Latitude/Longitude Coordinates • Dimensions • Conditions • Specifications • Pictures	OI – Observed on Imagery
Taxiway Markings		• Latitude/Longitude Coordinates • Dimensions • Conditions • Specifications • Pictures	OI – Observed on Imagery
Ramp Markings		• Latitude/Longitude Coordinates • Dimensions • Conditions • Specifications • Pictures	AB – Complete Absence
Electrical Poles	• Latitude/Longitude Coordinates • Type • Condition	• Height • Serial Number • Pictures	
Distribution Transformers		• Latitude/Longitude Coordinates • Condition • kVa rating • Primary Voltage • Secondary Voltage • Single or Three phase • Phase connection • Impedance • Manufacturer • PCB Content • Serial Number • Date Manufactured • Pictures	AB – Complete Absence
4,000 V West Substation Runway Distribution System	• Latitude/Longitude Coordinates • Condition • Pictures	• kVa rating • Primary Voltage • Secondary Voltage • Single or Three phase • Phase connection	
24,000 V Main Distribution System Substation	• Latitude/Longitude Coordinates • Condition • Pictures	• kVa rating • Primary Voltage • Secondary Voltage • Single or Three phase • Phase connection	
Overhead Electrical Cables	• Latitude/Longitude Coordinates	• Type of conductor • Amount of Conductors • Cross-sectional Area • Condition • Route • Impedance • Manufacturer • Operating Voltage • Single or Three phase • Phase connection	AB – Complete Absence DE – Exists on design plan

Underground Electrical Cables	• Latitude/Longitude Coordinates	• Type of conductor • Amount of Conductors • Cross-sectional Area • Condition • Type of Insulation • Depth • Impedance • Manufacturer	
Sewage Manholes	• Latitude/Longitude Coordinates	• Dimensions • Depth • Condition • Pipe Specifications • Pictures	AB – Complete Absence FC – Feature Discontinuity
Underground Wastewater and Potable Water Pipes	• Latitude/Longitude Coordinates	• Diameter • Condition • Invert Level • Crown Level • Construction Material • Thickness	AB – Complete Absence FC – Feature Discontinuity
Potable Water Valves	• Latitude/Longitude Coordinates • Condition • Type • Pictures	• Manufacturer • Dimensions/Size	
HVAC Chilled Water Valves	• Latitude/Longitude Coordinates • Conditions • Type • Pictures	• Manufacturer • Dimensions/Size	
Storm Water Manholes		• Latitude/Longitude Coordinates • Dimension • Condition • Invert Level • Crown Level • Pipe specifications • Pictures	MA – Misattributed data
Underground Storm Water Pipelines	• Latitude/Longitude Coordinates	• Depth • Condition • Construction Material • Diameter	AB – Complete Absence FC – Feature Discontinuity
Storm Water Pump Stations		• Latitude/Longitude Coordinates • Condition • kVa rating • Primary Voltage • Secondary Voltage • Single or Three phase • Delta • Manufacturer • Serial Number • Date Manufactured • Pictures	AB – Complete Absence
Wastewater Lift Station	• Latitude/Longitude Coordinates	• kVa rating • Primary Voltage • Secondary Voltage • Single or Three phase • Delta • Manufacturer • Serial Number • Date Manufactured	

		• Pictures	
Storm Water Drains (open)	• Latitude/Longitude Coordinates • Condition • Construction Material	• Dimensions • Depth • Pictures	AB – Complete Absence
Vegetation (points)	• Latitude/Longitude Coordinates • Condition • Description	• Pictures	
Vegetation (polylines)	• Latitude/Longitude Coordinates • Description	• Condition • Pictures	AB – Complete Absence DE – Exists on design plan FC – Feature Discontinuity GV – Vector Geometry Misrepresentation
Water Features	• Latitude/Longitude Coordinates • Description • Condition	• Dimensions • Area • Pictures	DE – Exists on design plan

8.1.2 Noise Calibration

Brüel & Kjær
North America Inc.

The Bruel and Kjaer Calibration Laboratory
3079 Premiere Parkway Suite 120
Duluth, GA 30097
Telephone: 770-209-6907
Fax: 770-447-4033
Web site address: http://www.bksv.com

ACCREDITED

Calibration Certificate # 1568.01

CERTIFICATE OF CALIBRATION No.: CAS-416103-L3Y8P3-403 Page 1 of 2

CALIBRATION OF:

Calibrator:	Brüel & Kjær	Type 4231 IEC Class: 1		Serial No.:	3018640

CUSTOMER:

CL Environmental
20 Windsor Avenue
5 Kingston Jamaica

CALIBRATION CONDITIONS:

Environment conditions:	Air temperature:	23.4	°C
	Air pressure:	98.698	kPa
	Relative Humidity:	32	%RH

SPECIFICATIONS:

This document certifies that the acoustic calibrator as listed under "Type" has been calibrated and unless otherwise indicated under "Final Data", meets acceptance criteria as prescribed by the referenced Procedure. Statements of compliance, where applicable, are based on calibration results falling within specified criteria with no reduction by the uncertainty of the measurements. The calibration of the listed transducer was accomplished using a test system which conforms to the requirements of ISO/IEC 17025, ANSI/NCSL Z540-1, and guidelines of ISO 10012-1. For "as received" and "final" data, see the attached page(s). Items marked with one asterisk (*) are not covered by the scope of the current A2LA accreditation. This Certificate and attached data pages shall not be reproduced, except in full, without written approval of the Bruel and Kjaer Calibration Laboratory-Duluth, GA. Results relate only to the items tested. The transducer has been calibrated using Measurement Standards with values traceable to the National Institute of Standards and Technology, National Measurement Institutes or derived from natural physical constants. The acoustic calibrator has been calibrated in accordance with the requirements as specified in IEC60942.

PROCEDURE:

The measurements have been performed with the assistance of Brüel & Kjær acoustic calibrator calibration application Software version 2.3.4 Type 7794 using calibration procedure 4231 Complete

RESULTS:

[X] "As Received" Data: Within Acceptance Criteria [ ] "As Received" Data: Outside Acceptance Criteria
[X] "Final" Data : Within Acceptance Criteria [ ] "Final" Data : Outside Acceptance Criteria

The reported expanded uncertainty is based on the standard uncertainty multiplied by a coverage factor $k = 2$, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with EA-4/02from elements originating from the standards, calibration method, effect of environmental conditions and any short time contribution from the calibrator under calibration.

Date of Calibration: November 4, 2019 Certificate issued: November 4, 2019

Meshaun Hobbs
Calibration Technician

Quality Representative

Figure 8.1 Bruel & Kjaer 4231 Noise Calibration Certificate

Brüel & Kjær
North America Inc.

CERTIFICATE OF CALIBRATION

No.: CAS-416103-L3Y8P3-403

Type: 4231 Serial No.: 3018640 Page 2 of 2

Sound Pressure Levels

All stated values are valid at environmental reference conditions

Nominal Level [dB]	Accept Limit Lower [dB]	Accept Limit Upper [dB]	Measured Level [dB]	Measurement Uncertainty [dB]
94	93.80	94.20	93.98	0.12
114	113.80	114.20	113.97	0.12

Frequency

Nominal Frequency [Hz]	Accept Limit Lower [Hz]	Accept Limit Upper [Hz]	Measured Frequency [Hz]	Measurement Uncertainty [Hz]
1000	999.00	1001.00	999.97	0.10

Total Distortion*

Distortion mode: [X] TD* [ ] THD*

Calibration Level [dB]*	Accept Limit [%]*	Measured Distortion [%]*	Measurement Uncertainty [%]*
94	1.00	0.55	0.13
114	1.00	0.33	0.13

Environmental Reference Conditions:

Pressure: 101.3 kPa, Temperature: 23 °C, Relative Humidity: 50%

Instrument List

Type	Description	Serial no	Cal. date	Due date	Calibrated by	Trace number
3560	PULSE Analyzer	2723320	2019-10-17	2020-10-31	JCA	CAS-413598-Q8W9Z2-101
9545	Transfer Microphone	3	2019-10-16	2020-10-31	MH	CAS-413598-Q8W9Z2-401
4228	Reference Sound Source	1610502	2019-04-05	2021-04-30	W.Shipman	CAS-375162-C8J4Z3-705

During the calibration the calibrator has been loaded by the load volume of the Transfer Microphone. The load volumes for a number of different types of Transfer Microphones are listed in the table below.
For Brüel & Kjær Pistonphones types 4220 and 4228 the result of the SPL calibration has been corrected to be valid for a load volume of 1333 mm^3. For all other types the result is valid with the actual load volume.

Transfer Microphone Type	Fulfils standard IEC 61094-1 LS	Fulfils standard IEC 61094-4 WS	Load Volume 1" (1/2" mic including DP-0776)	Load Volume 1/2"
4180	yes	yes	1126 mm^3	43 mm^3
4192	-	yes	1273 mm^3	190 mm^3
9545	-	-	1333 mm^3	-

Condition "As Received":

Good

Comments

Figure 8.2 Bruel & Kjaer 4231 Noise Calibration Certificate

8.1.3 NMIA Aircraft Movement Data

Table 8.2 NMIA Aircraft arrival and departure dates and times during noise assessment

Direction	Airline_Code	Date	Flight_Number	Actual_Time	Equipment	Departure To	Runway
DEPARTING	NORTHERN AIR CARGO	03/13/2020	8039	0:20	B763	KMIA	12
ARRIVING	AMERICAN AIRLINES	03/13/2020	1082	0:21	B738		12
ARRIVING	AMERIJET	03/13/2020	849	0:29	B763		12
ARRIVING	DELTA AIRLINES	03/13/2020	383	0:34	B738		12
DEPARTING	PRIVATE	03/13/2020	BILL	0:49	C25B	MDJB	12
DEPARTING	AMERIJET	03/13/2020	848	1:23	B763	MNMG	12
DEPARTING	CARIBBEAN AIRLINES	03/13/2020	017	1:28	B738	KJFK	12
DEPARTING	JAMAICA DEFENCE FORCE	03/13/2020	FREE	2:20	HELI	UPC	12
ARRIVING	JET BLUE	03/13/2020	2959	5:16	A320		12
ARRIVING	JET BLUE	03/13/2020	659	6:28	A321		12
DEPARTING	JET BLUE	03/13/2020	2860	6:34	A320	KJFK	12
DEPARTING	JET BLUE	03/13/2020	960	8:04	A321	KJFK	12
ARRIVING	CARIBBEAN AIRLINES	03/13/2020	016	10:35	B738		12
DEPARTING	AMERICAN AIRLINES	03/13/2020	2370	11:01	B738	KMIA	12
DEPARTING	DELTA AIRLINES	03/13/2020	2843	12:29	B738	KJFK	12
ARRIVING	JET BLUE	03/13/2020	1675	12:35	A320		12
ARRIVING	JET BLUE	03/13/2020	559	12:38	A321		12
ARRIVING	WORLD ATLANTIC AIRLINES	03/13/2020	620	12:58	MD83		12
DEPARTING	JAMAICA DEFENCE FORCE	03/13/2020	FREE	13:24	DA40	ZZZZ	12

DEPARTING	WORLD ATLANTIC AIRLINES	03/13/2020	620	13:58	MD83	MKJS	12
DEPARTING	JET BLUE	03/13/2020	1676	14:01	A320	KFLL	12
ARRIVING	JAMAICA DEFENCE FORCE	03/13/2020	FREE	14:07	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/13/2020	FREE	14:07	DA40	CCTS	12
DEPARTING	AIR TURKS AND CAICUS	03/13/2020	613	14:10	E120	MUCU	12
DEPARTING	INTERISLAND AIRWAYS	03/13/2020	251	14:13	E145	MBPV	12
ARRIVING	JAMAICA DEFENCE FORCE	03/13/2020	FREE	14:14	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/13/2020	FREE	14:15	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/13/2020	FREE	14:21	DA40		12
DEPARTING	JET BLUE	03/13/2020	560	14:25	A321	KJFK	12
ARRIVING	JAMAICA DEFENCE FORCE	03/13/2020	FREE	14:36	DA40		12
ARRIVING	JAMAICA DEFENCE FORCE	03/13/2020	FREE	14:39	HELI		12
ARRIVING	DELTA	03/13/2020	2841	14:41	B738		12
DEPARTING	PRIVATE	03/13/2020	BILL	14:48	PRM1	KTMB	12
DEPARTING	JDF	03/13/2020	free	14:52	DA40	CCTS	12
ARRIVING	JDF	03/13/2020	free	14:58	DA40		12
DEPARTING	JDF	03/13/2020	free	14:59	DA40	CCTS	12
DEPARTING	JDF	03/13/2020	free	15:06	DA40	CCTS	12
ARRIVING	JDF	03/13/2020	free	15:07	DA40		12
DEPARTING	JDF	03/13/2020	free	15:13	DA40	CCTS	12
ARRIVING	JDF	03/13/2020	free	15:14	DA40		12

DEPARTING	JDF	03/13/2020	free	15:21	DA40	CCTS	12
ARRIVING	JDF	03/13/2020	free	15:22	DA40		12
DEPARTING	JDF	03/13/2020	free	15:27	DA40	CCTS	12
ARRIVING	JDF	03/13/2020	free	15:28	DA40		12
ARRIVING	PRIVATE	03/13/2020	BILL	15:41	C56X		12
DEPARTING	JDF	03/13/2020	free	15:43	DA40	CCTS	12
ARRIVING	JDF	03/13/2020	free	15:44	DA40		12
ARRIVING	CARIBBEAN AIRLINES	03/13/2020	414	15:46	B738		12
ARRIVING	SPIRIT AIRLINES	03/13/2020	723	15:49	A320		12
ARRIVING	JDF	03/13/2020	free	15:58	DA40		12
ARRIVING	MILITARY	03/13/2020	free	16:05	HELI		12
DEPARTING	PRIVATE	03/13/2020	BILL	16:09	C56X	MKJS	12
DEPARTING	JAMAICA DEFENCE FORCE	03/13/2020	FREE	16:12	HELI	UPC	12
ARRIVING	PRIVATE	03/13/2020	BILL	16:14	C421		12
ARRIVING	AMERICAN AIRLINES	03/13/2020	1589	16:24	B738		12
DEPARTING	DELTA	03/13/2020	321	16:38	B738	KATL	12
ARRIVING	FEDERAL EXPRESS	03/13/2020	8126	16:46	ATR42		12
DEPARTING	CARIBBEAN AIRLINES	03/13/2020	414	16:52	B738	MYNN	12
DEPARTING	SPIRIT AIRLINES	03/13/2020	702	17:05	A320	KFLL	12
ARRIVING	IBC	03/13/2020	965	17:31	SW4		12
ARRIVING	AMERICAN AIRLINES	03/13/2020	1400	17:36	B738		12

ARRIVING	CUBANA AIRLINES	03/13/2020	6084	17:39	YK42		12
ARRIVING	WESTJET AIRLINES	03/13/2020	2600	17:42	B737		12
DEPARTING	FEDERAL EXPRESS	03/13/2020	8126	17:43	ATR42	MKJS	12
DEPARTING	JAMAICA DEFENCE FORCE	03/13/2020	FREE	17:53	DA42	MKJS	12
DEPARTING	AMERICAN AIRLINES	03/13/2020	1545	17:56	B738	KMIA	12
DEPARTING	JDF	03/13/2020	free	18:22	DA40	MKJS	12
ARRIVING	PRIVATE	03/13/2020	BILL	18:24	C560		12
DEPARTING	IBC	03/13/2020	510	18:33	SW4	MKJS	12
DEPARTING	PRIVATE	03/13/2020	BILL	18:50	C421	MPMG	12
DEPARTING	CARIBBEAN AIRLINES	03/13/2020	033	18:53	B738	KFLL	12
DEPARTING	CUBANA AIRLINES	03/13/2020	6085	18:56	YK42	MUCU	12
DEPARTING	WESTJET AIRLINES	03/13/2020	2601	18:59	B737	CYYZ	12
DEPARTING	AMERICAN AIRLINES	03/13/2020	1548	19:03	B738	KMIA	12
ARRIVING	MILITARY	03/13/2020	free	19:27	DA42		12
DEPARTING	PRIVATE	03/13/2020	BILL	19:29	C560	MYNN	12
ARRIVING	JDF	03/13/2020	FREE	20:06	DA40		12
DEPARTING	CARIBBEAN AIRLINES	03/13/2020	455	20:10	B738	TBPB	12
ARRIVING	ISLAND WAYS	03/13/2020	408	20:23	E120		30
ARRIVING	JET BLUE	03/13/2020	875	21:05	A320		12
ARRIVING	IBC	03/13/2020	509	21:09	SW4		12
ARRIVING	CARIBBEAN AIRLINES	03/13/2020	415	21:12	B738		12

ARRIVING	PRIVATE	03/13/2020	BILL	21:20	GLF4		12
ARRIVING	PRIVATE	03/13/2020	BILL	21:22	PRM1		12
ARRIVING	AIR TURKS AND CAICUS	03/13/2020	250	21:28	E145		12
ARRIVING	AIR CANADA	03/13/2020	1802	21:47	A321		12
ARRIVING	BRITISH AIRWAYS	03/13/2020	2263	21:51	B772		12
ARRIVING	LYNDEN AIR CARGO	03/13/2020	2039	21:53	C130		12
ARRIVING	JDF	03/13/2020	free	21:57	DA40		12
DEPARTING	JDF	03/13/2020	FREE	21:58	DA40	CCTS	12
DEPARTING	PRIVATE	03/13/2020	BILL	22:00	PRM1	MKTP	12
ARRIVING	FEDERAL EXPRESS	03/13/2020	7126	22:06	ATR42		12
ARRIVING	JDF	03/13/2020	free	22:07	DA40		12
DEPARTING	JDF	03/13/2020	FREE	22:08	DA40	CCTS	12
ARRIVING	JDF	03/13/2020	free	22:14	DA40		12
DEPARTING	JDF	03/13/2020	FREE	22:15	DA40	CCTS	12
DEPARTING	IBC	03/13/2020	964	22:24	SW4	KMIA	12
ARRIVING	JDF	03/13/2020	free	22:26	DA40		12
DEPARTING	JDF	03/13/2020	FREE	22:27	DA40	CCTS	12
DEPARTING	JET BLUE	03/13/2020	876	22:31	A320	KFLL	30
DEPARTING	CARIBBEAN AIRLINES	03/13/2020	415	22:35	B738	TTPP	12
ARRIVING	JDF	03/13/2020	free	22:38	DA40		12
DEPARTING	FEDERAL EXPRESS	03/13/2020	7126	22:46	ATR42	KMIA	30

DEPARTING	AIR CANADA	03/13/2020	1803	23:11	A321	CYZX	12
ARRIVING	CARIBBEAN AIRLINES	03/13/2020	036	23:26	B738		12
ARRIVING	CAYMAN AIRWAYS	03/13/2020	606	23:31	B733		12
ARRIVING	AMERICAN AIRLINES	03/14/2020	1082	0:15	B738		12
ARRIVING	DELTA AIRLINES	03/14/2020	383	0:26	B737-800		12
DEPARTING	CAYMAN AIRWAYS	03/14/2020	607	0:32	B733	MWCR	30
DEPARTING	BRITISH AIRWAYS	03/14/2020	25k	0:47	B772	EGKK	12
ARRIVING	PRIVATE	03/14/2020	BILL	0:49	H25B		12
DEPARTING	CARIBBEAN AIRLINES	03/14/2020	017	1:24	B738	KJFK	12
DEPARTING	PRIVATE	03/14/2020	BILL	1:48	H25B	TNCA	12
ARRIVING	CARIBBEAN AIRLINES	03/14/2020	454	2:26	B738		30
ARRIVING	JET BLUE	03/14/2020	2959	5:19	A320		12
ARRIVING	PRIVATE	03/14/2020	BILL	5:38	B738		12
ARRIVING	JET BLUE	03/14/2020	659	6:44	A321		12
DEPARTING	JET BLUE	03/14/2020	BILL	6:47	A320	KJFK	12
DEPARTING	PRIVATE	03/14/2020	BILL	7:12	B738	SLCB	12
DEPARTING	JET BLUE	03/14/2020	960	8:20	A321	KJFK	30
ARRIVING	CARIBBEAN AIRLINES	03/14/2020	016	10:37	B738		12
DEPARTING	LYNDEN AIR CARGO	03/14/2020	2039	10:45	C130	TVSA	12
DEPARTING	AMERICAN AIRLINES	03/14/2020	2370	11:06	B738	KMIA	30
ARRIVING	PRIVATE	03/14/2020	BILL	11:17	PC12		12

ARRIVING	JET BLUE	03/14/2020	559	12:20	A321		12
ARRIVING	JET BLUE	03/14/2020	1675	12:32	A320		12
DEPARTING	DELTA AIRLINES	03/14/2020	2843	12:40	B737-800	KJFK	12
DEPARTING	PRIVATE	03/14/2020	BILL	12:43	PC12	KTMB	12
ARRIVING	CAYMAN AIRWAYS	03/14/2020	600	12:58	B738		12
DEPARTING	JET BLUE	03/14/2020	1676	13:49	A320	KFLL	30
DEPARTING	AIR TURKS AND CAICUS	03/14/2020	251	13:59	E145	MBPV	12
DEPARTING	ISLAND WAYS	03/14/2020	407	14:11	E120	MDSD	12
ARRIVING	DELTA AIRLINES	03/14/2020	2841	14:19	B738		12
DEPARTING	JET BLUE	03/14/2020	560	14:21	A321	KJFK	12
DEPARTING	CARIBBEAN AIRLINES	03/14/2020	009	14:31	B738	MWCR	30
ARRIVING	SPIRIT AIRLINES	03/14/2020	723	16:03	A320		12
DEPARTING	PRIVATE	03/14/2020	BILL	16:12	GLF4	KSLC	12
DEPARTING	DELTA AIRLINES	03/14/2020	321	16:27	B738	KATL	12
DEPARTING	MILITARY	03/14/2020	free	16:40	DA40	MKJP	12
ARRIVING	AMERICAN AIRLINES	03/14/2020	1589	16:42	B738		12
ARRIVING	MILITARY	03/14/2020	free	16:46	DA40		12
DEPARTING	SPIRIT AIRLINES	03/14/2020	702	17:06	A320	KFLL	12
ARRIVING	CARIBBEAN AIRLINES	03/14/2020	008	17:24	B738		12
ARRIVING	AMERICAN AIRLINES	03/14/2020	1400	17:31	B738		12
DEPARTING	AMERICAN AIRLINES	03/14/2020	1545	17:46	B738	KMIA	12

ARRIVING	CARIBBEAN AIRLINES	03/14/2020	456	17:56	B738		12
ARRIVING	WESTJET AIRLINES	03/14/2020	2600	18:06	B737		12
ARRIVING	PRIVATE	03/14/2020	BILL	18:11	E55P		12
ARRIVING	COPA AIRLINES	03/14/2020	418	18:29	E190		12
DEPARTING	PRIVATE	03/14/2020	BILL	18:55	E55P	KHOU	12
DEPARTING	AMERICAN AIRLINES	03/14/2020	1548	19:01	B738	KMIA	12
DEPARTING	JAMAICA DEFENCE FORCE	03/14/2020	FREE	19:04	DA42	MKJS	12
DEPARTING	WESTJET AIRLINES	03/14/2020	2601	19:07	B737	CYYZ	12
DEPARTING	CARIBBEAN AIRLINES	03/14/2020	033	19:21	B738	KFLL	12
DEPARTING	CARIBBEAN AIRLINES	03/14/2020	457	19:24	B738	TNCM	12
ARRIVING	ROYAL AIR FORCE	03/14/2020	2888	20:01	A332		12
DEPARTING	COPA AIRLINES	03/14/2020	417	20:12	E190	MPTO	12
ARRIVING	JET BLUE	03/14/2020	875	21:04	A320		12
ARRIVING	JDF	03/14/2020	FREE	21:49	DA40		12
DEPARTING	JET BLUE	03/14/2020	876	22:22	A320	KFLL	12
ARRIVING	INTERISLAND AIRWAYS	03/14/2020	250	22:55	E145		12
ARRIVING	AIR TURKS AND CAICUS	03/14/2020	617	23:00	E145		12
ARRIVING	CARIBBEAN AIRLINES	03/14/2020	36	23:56	B738		12
DEPARTING	ROYAL AIR FORCE	03/15/2020	free	0:19	A332	MZBZ	12
ARRIVING	AMERICAN AIRLINES	03/15/2020	1082	0:24	B738		12
ARRIVING	DELAT CONNECTION	03/15/2020	383	0:48	B738		12

DEPARTING	INTERISLAND AIRWAYS	03/15/2020	618	1:05	E145	MUHA	30
DEPARTING	CARIBBEAN AIRLINES	03/15/2020	017	1:30	B738	KJFK	30
ARRIVING	JET BLUE	03/15/2020	2959	5:08	A320		12
ARRIVING	JET BLUE	03/15/2020	659	6:33	A321		12
DEPARTING	JET BLUE	03/15/2020	2860	6:47	A320	KJFK	30
DEPARTING	JET BLUE	03/15/2020	960	8:28	A321	KJFK	30
ARRIVING	CARIBBEAN AIRLINES	03/15/2020	016	10:16	B737		12
DEPARTING	AMERICAN AIRLINES	03/15/2020	2370	11:14	B738	KMIA	30
ARRIVING	JET BLUE	03/15/2020	559	12:32	A321		12
ARRIVING	JET BLUE	03/15/2020	1675	12:40	A320		12
DEPARTING	DELAT CONNECTION	03/15/2020	2843	12:42	B738	KJFK	30
DEPARTING	CARIBBEAN AIRLINES	03/15/2020	079	13:52	B737	CYYZ	30
DEPARTING	JET BLUE	03/15/2020	1676	13:54	A320	KFLL	30
DEPARTING	AIR TURKS AND CAICUS	03/15/2020	251	14:04	E145	MBPV	12
DEPARTING	JET BLUE	03/15/2020	560	14:19	A321	KJFK	30
ARRIVING	PRIVATE	03/15/2020	BILL	14:40	C25B		12
ARRIVING	DELTA	03/15/2020	2841	14:43	B738		12
ARRIVING	CARIBBEAN AIRLINES	03/15/2020	414	14:46	B738		12
DEPARTING	PRIVATE	03/15/2020	BILL	14:53	C525	KFLL	12
ARRIVING	SPIRIT AIRLINES	03/15/2020	723	16:03	A320		12
DEPARTING	CARIBBEAN AIRLINES	03/15/2020	414	16:11	B738	MYNN	12

ARRIVING	PRIVATE	03/15/2020	BILL	16:23	PC12		12
DEPARTING	DELTA	03/15/2020	321	16:35	B738	KATL	12
ARRIVING	AMERICAN AIRLINES	03/15/2020	1589	16:36	B738		12
DEPARTING	PRIVATE	03/15/2020	BILL	16:59	C25B	MDJB	12
DEPARTING	PRIVATE	03/15/2020	BILL	17:00	PC12	MKTP	12
DEPARTING	SPIRIT AIRLINES	03/15/2020	702	17:06	A320	KFLL	30
ARRIVING	AMERICAN AIRLINES	03/15/2020	1400	17:44	B738		12
ARRIVING	JET BLUE	03/15/2020	2600	17:46	B737		12
DEPARTING	CARIBBEAN AIRLINES	03/15/2020	033	18:46	B738	KFLL	30
DEPARTING	AMERICAN AIRLINES	03/15/2020	1548	19:06	B738	KMIA	30
DEPARTING	JET BLUE	03/15/2020	2601	19:12	B737	CYYZ	12
DEPARTING	AMERICAN AIRLINES	03/15/2020	1545	19:29	B738	KMIA	30
ARRIVING	CARIBBEAN AIRLINES	03/15/2020	415	20:12	B738		12
DEPARTING	CARIBBEAN AIRLINES	03/15/2020	415	21:13	B738	TTPP	12
ARRIVING	PRIVATE	03/15/2020	BILL	21:37	C56X		12
ARRIVING	AIR TURKS AND CAICUS	03/15/2020	250	21:41	E145		12
DEPARTING	PRIVATE	03/15/2020	BILL	22:17	C56X	MKTP	30
ARRIVING	PRIVATE	03/15/2020	BILL	22:37	C525		12
ARRIVING	JET BLUE	03/15/2020	875	22:47	A320		12
ARRIVING	CAYMAN AIRWAYS	03/15/2020	606	23:26	B738		12
ARRIVING	CARIBBEAN AIRLINES	03/15/2020	036	23:33	B738		12

ARRIVING	CARIBBEAN AIRLINES	03/15/2020	078	23:48	B737		12
DEPARTING	JET BLUE	03/16/2020	876	0:01	A320	KFLL	12
ARRIVING	AMERICAN AIRLINES	03/16/2020	1082	0:26	B738		30
ARRIVING	DELTA AIRLINES	03/16/2020	383	0:45	B738		30
DEPARTING	CAYMAN AIRWAYS	03/16/2020	607	0:48	B738	MWCR	30
DEPARTING	CARIBBEAN AIRLINES	03/16/2020	017	1:30	B738	KJFK	30
ARRIVING	JET BLUE	03/16/2020	2959	5:02	A320		12
DEPARTING	JET BLUE	03/16/2020	2860	6:37	A320	KJFK	12
ARRIVING	CARIBBEAN AIRLINES	03/16/2020	016	10:23	B738		12
DEPARTING	AMERICAN AIRLINES	03/16/2020	2370	11:03	B738	KMIA	30
ARRIVING	PRIVATE	03/16/2020	BILL	11:09	PC12		12
DEPARTING	PRIVATE	03/16/2020	BILL	12:05	PC12	KTMB	30
ARRIVING	JET BLUE	03/16/2020	559	12:20	A321		12
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	12:28	DA40	S/W	30
DEPARTING	DELTA AIRLINES	03/16/2020	2843	12:36	B738	KJFK	12
ARRIVING	JET BLUE	03/16/2020	1675	12:40	A320		12
ARRIVING	CAYMAN AIRWAYS	03/16/2020	620	13:07	B738		12
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	13:27	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	13:27	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	13:33	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	13:33	DA40		12

ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	13:40	DA40		12
ARRIVING	NORTHERN AIR CARGO	03/16/2020	8040	13:43	B763		12
DEPARTING	AIR TURKS AND CAICUS	03/16/2020	251	13:50	E145	MBPV	12
DEPARTING	JET BLUE	03/16/2020	1676	13:53	A320	KFLL	30
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	13:56	DA42	S/W	30
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	14:03	DA40	S/W	30
DEPARTING	CAYMAN AIRWAYS	03/16/2020	621	14:06	B733	MKJS	30
DEPARTING	JET BLUE	03/16/2020	560	14:29	A321	KJFK	30
ARRIVING	DELTA AIRLINES	03/16/2020	2841	14:36	B738		12
DEPARTING	MILITARY	03/16/2020	free	14:39	DA40	ZZZZ	12
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	14:56	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	14:57	DA40	CCTS	12
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	15:00	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	15:00	DA42		12
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	15:03	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	15:04	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	15:05	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	15:06	DA42	CCTS	12
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	15:11	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	15:11	DA40		12

DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	15:12	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	15:12	DA42		12
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	15:15	DA40		12
ARRIVING	FEDERAL EXPRESS	03/16/2020	8126	15:22	ATR42		12
DEPARTING	NORTHERN AIR CARGO	03/16/2020	8040	15:28	B763	MKJS	30
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	15:31	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	15:58	DA42	S/W	12
ARRIVING	SPIRIT AIRLINES	03/16/2020	723	16:05	A320		12
ARRIVING	AMERICAN AIRLINES	03/16/2020	1589	16:27	B738		12
ARRIVING	IBC	03/16/2020	965	16:28	SW4		12
ARRIVING	PRIVATE	03/16/2020	BILL	16:30	C500		12
DEPARTING	DELTA AIRLINES	03/16/2020	321	16:32	B738	KATL	12
ARRIVING	CARIBBEAN AIRLINES	03/16/2020	458	16:41	B737		12
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	16:46	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	16:47	DA42	CCTS	12
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	16:51	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	16:51	DA42		12
DEPARTING	FEDERAL EXPRESS	03/16/2020	8126	16:56	ATR42	MKJS	12
ARRIVING	PRIVATE	03/16/2020	BILL	17:04	PC12		12
DEPARTING	SPIRIT AIRLINES	03/16/2020	702	17:06	A320	KFLL	12

ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	17:08	DA42		12
ARRIVING	WESTJET AIRLINES	03/16/2020	2600	17:21	B737		12
DEPARTING	PRIVATE	03/16/2020	BILL	17:35	PC12	MKTP	30
ARRIVING	AMERICAN AIRLINES	03/16/2020	1400	17:48	B738		12
DEPARTING	IBC	03/16/2020	510	18:02	SW4	MKJS	12
DEPARTING	AMERICAN AIRLINES	03/16/2020	1545	18:07	B738	KMIA	12
ARRIVING	PRIVATE	03/16/2020	6084	18:16	AT45		12
ARRIVING	MILITARY	03/16/2020	free	18:22	DA40		12
ARRIVING	COPA AIRLINES	03/16/2020	418	18:37	E190		12
ARRIVING	PRIVATE	03/16/2020	BILL	18:48	ASTR		12
DEPARTING	WESTJET AIRLINES	03/16/2020	2601	18:57	B737	CYYZ	30
DEPARTING	AMERICAN AIRLINES	03/16/2020	1548	19:05	B738	KMIA	30
DEPARTING	CARIBBEAN AIRLINES	03/16/2020	459	19:24	B737	TAPA	12
DEPARTING	CARIBBEAN AIRLINES	03/16/2020	456	19:43	B737	TBPB	12
DEPARTING	CUBANA AIRLINES	03/16/2020	6085	19:53	YK42	MUCU	12
ARRIVING	AMERIJET	03/16/2020	816	20:01	B763		12
DEPARTING	PRIVATE	03/16/2020	BILL	20:07	C500	SVBM	12
DEPARTING	PRIVATE	03/16/2020	BILL	20:19	ASTR	KOPF	12
DEPARTING	COPA AIRLINES	03/16/2020	417	20:23	E190	MPTO	12
ARRIVING	IBC	03/16/2020	509	20:48	SW4		12
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	20:54	DA40	CCTS	30

DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	21:10	DA40	CCTS	12
ARRIVING	JET BLUE	03/16/2020	875	21:11	A320		12
DEPARTING	AMERIJET	03/16/2020	816	21:20	B763	TNCC	30
ARRIVING	AIR CANADA	03/16/2020	1802	21:22	A321		12
ARRIVING	FEDERAL EXPRESS	03/16/2020	7126	21:34	ATR42		12
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	21:51	DA40		30
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	21:52	DA40	CCTS	30
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	21:54	DA40	CCTS	30
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	21:54	DA40		30
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	21:59	DA40	CCTS	30
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	21:59	DA40		30
ARRIVING	BRITISH AIRWAYS	03/16/2020	2263	22:05	B772		30
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	22:08	DA40	CCTS	30
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	22:08	DA40		30
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	22:11	DA42	CCTS	30
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	22:15	DA40		30
DEPARTING	IBC	03/16/2020	964	22:20	SW4	KMIA	30
DEPARTING	JET BLUE	03/16/2020	876	22:26	A320	KFLL	30
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	22:28	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	22:28	DA40		12

DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	22:31	DA40	CCTS	30
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	22:35	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	22:35	DA40		12
DEPARTING	AIR CANADA	03/16/2020	1803	22:38	A321	CYYZ	30
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	22:42	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	22:42	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	22:45	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	22:45	DA40		12
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	22:49	DA42		30
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	22:49	DA42	CCTS	30
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	22:52	DA40		12
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	22:56	DA42		30
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	22:56	DA42	CCTS	30
DEPARTING	FEDERAL EXPRESS	03/16/2020	7126	23:00	ATR42	KMIA	30
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	23:03	DA42		30
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	23:03	DA42	CCTS	30
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	23:10	DA42		30
DEPARTING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	23:10	DA42	CCTS	30
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	23:22	DA40		30
ARRIVING	JAMAICA DEFENCE FORCE	03/16/2020	FREE	23:25	DA42		30

DEPARTING	JDF	03/17/2020	free	0:19	DA40	ZZZZ	12
ARRIVING	AMERICAN AIRLINES	03/17/2020	1082	0:26	B738		12
ARRIVING	INTERISLAND AIRWAYS	03/17/2020	250	0:38	E120		12
ARRIVING	DELTA	03/17/2020	383	1:28	B738		12
DEPARTING	CARIBBEAN AIRLINES	03/17/2020	017	1:44	B738	KJFK	12
DEPARTING	INTERISLAND AIRWAYS	03/17/2020	604	1:44	E120	MKJS	12
ARRIVING	JDF	03/17/2020	free	1:49	DA40		12
DEPARTING	JDF	03/17/2020	free	1:49	DA40	CCTS	12
DEPARTING	BRITISH AIRWAYS	03/17/2020	25k	1:53	B772	EGKK	12
ARRIVING	JDF	03/17/2020	free	1:56	DA40		12
DEPARTING	JDF	03/17/2020	free	1:56	DA40	CCTS	12
ARRIVING	CARIBBEAN AIRLINES	03/17/2020	454	2:07	B737		12
ARRIVING	JDF	03/17/2020	free	2:09	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	4:00	B350	ZZZZ	12
ARRIVING	JET BLUE	03/17/2020	2959	6:02	A320		12
ARRIVING	JET BLUE	03/17/2020	659	6:29	A321		12
DEPARTING	JET BLUE	03/17/2020	2860	7:16	A320	KJFK	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	7:29	B350		12
DEPARTING	JET BLUE	03/17/2020	960	8:03	A321	KJFK	12
ARRIVING	CARIBBEAN AIRLINES	03/17/2020	016	10:59	B738		12
DEPARTING	AMERICAN AIRLINES	03/17/2020	2370	11:08	B738	KMIA	12

ARRIVING	JET BLUE	03/17/2020	559	12:36	A321		12
ARRIVING	JET BLUE	03/17/2020	1675	12:39	A320		12
DEPARTING	DELTA	03/17/2020	2843	12:41	B738	KJFK	12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	12:52	DA40	S/W	12
ARRIVING	CAYMAN AIRWAYS	03/17/2020	600	12:53	B733		12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	13:32	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	13:32	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	13:38	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	13:38	DA40	CCTS	12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	13:42	DA42	S/W	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	13:44	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	13:44	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	13:50	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	13:51	DA40	CCTS	12
DEPARTING	JET BLUE	03/17/2020	1676	13:55	A320	KFLL	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	13:57	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	13:58	DA40	CCTS	12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	14:04	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	14:05	DA40		12
DEPARTING	JET BLUE	03/17/2020	560	14:18	A321	KJFK	12

ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	14:19	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	14:19	DA40	S/W	12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	14:20	DA40	CCTS	12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	14:24	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	14:26	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	14:26	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	14:30	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	14:30	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	14:32	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	14:32	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	14:37	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	14:37	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	14:39	DA40		12
ARRIVING	CARIBBEAN AIRLINES	03/17/2020	414	14:43	B737		12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	`	14:44	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	14:45	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	14:52	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	14:53	DA42	CCTS	12
ARRIVING	AIR TURKS AND CAICUS	03/17/2020	601	14:55	E120		12
ARRIVING	PRIVATE	03/17/2020	BILL	15:01	PRM1		12

DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	15:04	B350	L/C	12
ARRIVING	PRIVATE	03/17/2020	BILL	15:13	C25B		12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	15:16	DA40		12
ARRIVING	DELTA AIRLINES	03/17/2020	2841	15:24	B738		12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	15:26	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	15:26	DA42	S/W	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	15:35	DA40		12
ARRIVING	JDF	03/17/2020	free	15:36	HELI		12
DEPARTING	AIR TURKS AND CAICUS	03/17/2020	251	15:37	E120	MBPV	12
DEPARTING	CAYMAN AIRWAYS	03/17/2020	601	15:42	B733	MWCR	12
ARRIVING	FEDERAL EXPRESS	03/17/2020	8126	15:44	ATR42		12
DEPARTING	PRIVATE	03/17/2020	BILL	15:48	PRM1	MYNN	12
DEPARTING	CARIBBEAN AIRLINES	03/17/2020	414	15:56	B737	TTPP	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	15:59	DA42		12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	16:15	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	16:16	DA42	CCTS	12
ARRIVING	AMERICAN AIRLINES	03/17/2020	1589	16:20	B738		12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	16:22	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	16:22	DA42	CCTS	12
ARRIVING	PRIVATE	03/17/2020	BILL	16:25	LJ35		12

ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	16:27	DA42		12
DEPARTING	FEDERAL EXPRESS	03/17/2020	8126	16:28	ATR42	MKJS	12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	16:28	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	16:35	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	16:35	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	16:38	DA42		12
DEPARTING	DELTA AIRLINES	03/17/2020	321	16:42	B738	KATL	12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	16:47	DA40	L/C	12
DEPARTING	PRIVATE	03/17/2020	BILL	17:08	C25B	MDJB	12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	17:25	DA42	L/C	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	17:25	DA40		12
DEPARTING	JDF	03/17/2020	FREE	17:27	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	17:35	DA40		12
DEPARTING	JDF	03/17/2020	FREE	17:35	DA40	CCTS	12
ARRIVING	AMERICAN AIRLINES	03/17/2020	1400	17:42	B738		12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	17:44	DA40		12
DEPARTING	JDF	03/17/2020	FREE	17:45	DA40	CCTS	12
ARRIVING	MERLIN EXPRESS	03/17/2020	505	17:46	SF340		12
ARRIVING	IBC	03/17/2020	965	17:49	SW4		12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	17:52	DA40		12

DEPARTING	AMERICAN AIRLINES	03/17/2020	1545	17:52	B738	KMIA	12
DEPARTING	JDF	03/17/2020	FREE	17:53	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	18:08	DA40		12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	18:13	DA42		12
DEPARTING	JDF	03/17/2020	FREE	18:14	DA40	CCTS	12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	18:24	DA40	S/W	12
ARRIVING	JDF	03/17/2020	FREE	18:27	DA40		12
DEPARTING	JDF	03/17/2020	FREE	18:31	DA40	CCTS	12
ARRIVING	JDF	03/17/2020	FREE	18:31	DA40		12
ARRIVING	JDF	03/17/2020	FREE	18:40	DA40		12
DEPARTING	IBC	03/17/2020	510	18:44	SW4	MKJS	12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	18:50	DA42	S/W	12
DEPARTING	CARIBBEAN AIRLINES	03/17/2020	033	18:51	B737	KFLL	12
ARRIVING	PRIVATE	03/17/2020	BILL	18:56	PRM1		12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	18:58	B350		12
DEPARTING	AMERICAN AIRLINES	03/17/2020	1548	19:00	B738	KMIA	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	19:04	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	19:05	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	19:12	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	19:13	DA40	CCTS	12
DEPARTING	PRIVATE	03/17/2020	BILL	19:16	PRM1	MKTP	12

ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	19:20	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	19:21	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	19:28	DA40		12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	19:29	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	19:30	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	19:34	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	19:35	DA42	CCTS	12
ARRIVING	CARIBBEAN AIRLINES	03/17/2020	415	19:43	B737		12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	19:45	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	19:46	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	19:51	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	19:51	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	19:59	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/17/2020	FREE	20:23	HELI	UPC	12
ARRIVING	JET BLUE	03/17/2020	875	21:03	A320		12
DEPARTING	CARIBBEAN AIRLINES	03/17/2020	415	21:13	B737	TTPP	12
ARRIVING	AIR CANADA	03/17/2020	1802	21:58	A321		12
ARRIVING	FEDERAL EXPRESS	03/17/2020	7126	22:20	ATR42		12
DEPARTING	JET BLUE	03/17/2020	876	22:22	A320	KFLL	30
DEPARTING	MERLIN EXPRESS	03/17/2020	964	22:37	SF340	KMIA	30

DEPARTING	FEDERAL EXPRESS	03/17/2020	7126	22:55	ATR42	KMIA	12
ARRIVING	ISLAND WAYS	03/17/2020	250	23:00	E120		30
DEPARTING	AIR CANADA	03/17/2020	1803	23:04	A321	CYYZ	30
ARRIVING	CARIBBEAN AIRLINES	03/17/2020	036	23:44	B737		12
ARRIVING	AMERICAN AIRLINES	03/18/2020	1082	0:17	B738		12
ARRIVING	DELTA AIRLINES	03/18/2020	383	0:39	B738		12
DEPARTING	PRIVATE	03/18/2020	BILL	1:09	LJ35	KFXE	12
DEPARTING	CARIBBEAN AIRLINES	03/18/2020	017	1:34	B737	KJFK	12
ARRIVING	JET BLUE	03/18/2020	2959	4:54	A320		12
DEPARTING	JET BLUE	03/18/2020	2860	6:38	A320	KJFK	12
ARRIVING	JET BLUE	03/18/2020	659	6:39	A321		12
DEPARTING	JET BLUE	03/18/2020	960	8:06	A321	KJFK	12
ARRIVING	CARIBBEAN AIRLINES	03/18/2020	016	10:39	B738		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	12:13	DA40	S/W	12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	12:17	DA42	S/W	12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	12:21	DA42		12
ARRIVING	JET BLUE	03/18/2020	559	12:33	A321		12
DEPARTING	DELTA AIRLINES	03/18/2020	2843	12:36	B738	KJFK	12
ARRIVING	JET BLUE	03/18/2020	1675	12:44	A320		12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	12:56	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	12:57	DA40	CCTS	12

ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	12:57	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	13:03	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	13:03	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	13:05	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	13:05	DA42		12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	13:10	DA40		12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	13:12	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	13:13	DA42	CCTS	12
ARRIVING	JDF	03/18/2020	free	13:16	HELI		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	13:30	DA40	CCTS	12
DEPARTING	AIR TURKS AND CAICUS	03/18/2020	251	13:44	E120	MBPV	12
DEPARTING	JET BLUE	03/18/2020	1676	13:49	A320	KFLL	12
DEPARTING	JET BLUE	03/18/2020	560	14:08	A321	KJFK	12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	14:15	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	14:16	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	14:21	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	14:21	DA40	CCTS	12
ARRIVING	DELTA	03/18/2020	2841	14:34	B738		12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	14:38	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	15:21	DA42	S/W	12

ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	16:00	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	16:00	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	16:05	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	16:05	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	16:09	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	16:09	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	16:13	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	16:13	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	16:18	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	16:18	DA42	CCTS	12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	16:21	DA40	S/W	12
ARRIVING	AMERICAN AIRLINES	03/18/2020	1589	16:28	B738		12
ARRIVING	CARIBBEAN AIRLINES	03/18/2020	456	16:30	B738		12
ARRIVING	MILITARY	03/18/2020	bill	16:32	C130		12
ARRIVING	FEDERAL EXPRESS	03/18/2020	8126	16:37	ATR42		12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	16:40	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	16:40	DA42	CCTS	12
DEPARTING	DELTA	03/18/2020	321	16:43	B738	KATL	12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	16:46	DA42		12
DEPARTING	MILITARY	03/18/2020	20	16:53	DA40	CCTS	12

ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	17:05	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	17:05	DA40	CCTS	12
DEPARTING	FEDERAL EXPRESS	03/18/2020	8126	17:28	ATR42	MKJS	12
ARRIVING	IBC	03/18/2020	965	17:28	SW4		12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	17:40	DA40		12
DEPARTING	JDF	03/18/2020	free	17:42	HELI	UPC	12
DEPARTING	AMERICAN AIRLINES	03/18/2020	1545	17:52	B738	KMIA	12
ARRIVING	MILITARY	03/18/2020	20	17:56	DA40		12
DEPARTING	MILITARY	03/18/2020	20	17:56	DA40	CCTS	12
ARRIVING	MILITARY	03/18/2020	20	18:03	DA40		12
ARRIVING	AIR CANADA	03/18/2020	1802	18:04	A321		12
DEPARTING	MILITARY	03/18/2020	67	18:07	C130	MUGM	12
DEPARTING	MILITARY	03/18/2020	21	18:33	DA42	CCTS	12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	18:53	DA40	MKTP	12
DEPARTING	AMERICAN AIRLINES	03/18/2020	1548	19:01	B738	KMIA	12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	19:02	DA40	S/W	12
ARRIVING	MILITARY	03/18/2020	21	19:02	DA42		12
DEPARTING	AIR CANADA	03/18/2020	1803	19:07	A321	CYYZ	12
DEPARTING	CARIBBEAN AIRLINES	03/18/2020	457	19:11	B738	TNCM	12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	19:24	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	19:24	DA40	CCTS	12

ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	19:25	HELI		12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	19:29	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	19:29	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	19:36	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	19:36	DA40	CCTS	12
DEPARTING	IBC	03/18/2020	510	19:38	SW4	MKJS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	19:42	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	19:42	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	19:44	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	19:45	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	19:48	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	19:48	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	19:51	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	19:51	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	19:52	DA40		12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	19:57	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	19:57	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	20:05	DA40		12
ARRIVING	JET BLUE	03/18/2020	875	21:07	A320		12
ARRIVING	IBC	03/18/2020	504	21:29	SW4		12

ARRIVING	FEDERAL EXPRESS	03/18/2020	7126	21:48	ATR42		12
DEPARTING	IBC	03/18/2020	964	22:07	SW4	KMIA	12
DEPARTING	JET BLUE	03/18/2020	876	22:17	A320	KFLL	12
ARRIVING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	22:23	HELI		12
DEPARTING	FEDERAL EXPRESS	03/18/2020	7126	22:27	ATR42	KMIA	12
DEPARTING	JAMAICA DEFENCE FORCE	03/18/2020	FREE	22:28	HELI	UPC	12
ARRIVING	BRITISH AIRWAYS	03/18/2020	2263	22:36	B772		12
ARRIVING	AIR TURKS AND CAICUS	03/18/2020	250	23:05	E145		30
ARRIVING	AMERIJET	03/18/2020	839	23:25	B763		30
ARRIVING	INTERISLAND AIRWAYS	03/19/2020	617	0:08	E145		12
ARRIVING	DELTA AIRLINES	03/19/2020	383	0:42	B738		12
DEPARTING	AMERIJET	03/19/2020	383	0:49	B763	MNMG	12
DEPARTING	BRITISH AIRWAYS	03/19/2020	25k	1:09	B772	EGKK	12
DEPARTING	CARIBBEAN AIRLINES	03/19/2020	017	1:40	B738	KJFK	12
ARRIVING	JDF	03/19/2020	free	3:46	B350		12
ARRIVING	JET BLUE	03/19/2020	2959	5:02	A320		12
DEPARTING	JET BLUE	03/19/2020	2860	6:38	A320	KJFK	12
ARRIVING	JET BLUE	03/19/2020	659	6:39	A321		12
DEPARTING	JET BLUE	03/19/2020	960	8:15	A321	KJFK	12
ARRIVING	CARIBBEAN AIRLINES	03/19/2020	016	10:30	B738		12
DEPARTING	MILITARY	03/19/2020	free	12:26	DA40	ZZZZ	12

ARRIVING	JET BLUE	03/19/2020	1675	12:31	A320		12
DEPARTING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	12:34	DA40	ZZZZ	12
ARRIVING	JET BLUE	03/19/2020	559	12:41	A321		12
ARRIVING	MILITARY	03/19/2020	free	13:03	DA40		12
DEPARTING	MILITARY	03/19/2020	free	13:09	DA40	ZZZZ	12
ARRIVING	WORLD ATLANTIC AIRLINES	03/19/2020	600	13:12	MD83		12
ARRIVING	MILITARY	03/19/2020	free	13:15	DA40		12
DEPARTING	MILITARY	03/19/2020	free	13:16	DA40	ZZZZ	12
ARRIVING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	13:18	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	13:19	DA40	ZZZZ	12
DEPARTING	MILITARY	03/19/2020	free	13:23	DA40	ZZZZ	12
ARRIVING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	13:25	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	13:26	DA40	ZZZZ	12
ARRIVING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	13:30	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	13:31	DA40	ZZZZ	12
DEPARTING	MILITARY	03/19/2020	free	13:32	DA40	ZZZZ	12
ARRIVING	MILITARY	03/19/2020	free	13:37	DA40		12
DEPARTING	MILITARY	03/19/2020	free	13:38	DA40	ZZZZ	12
ARRIVING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	13:40	DA40		12
ARRIVING	MILITARY	03/19/2020	free	13:43	DA40		12

DEPARTING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	13:56	HELI	ZZZZ	12
DEPARTING	JET BLUE	03/19/2020	1676	13:59	A320	KFLL	12
DEPARTING	AIR TURKS AND CAICUS	03/19/2020	251	14:01	E145	MBPV	12
DEPARTING	JET BLUE	03/19/2020	560	14:16	A321	KJFK	12
DEPARTING	WORLD ATLANTIC AIRLINES	03/19/2020	601	14:27	MD83	MWCR	12
DEPARTING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	15:14	DA40	S/W	12
ARRIVING	PRIVATE	03/19/2020	BILL	15:30	BE19		12
ARRIVING	FEDERAL EXPRESS	03/19/2020	8126	15:59	ATR42		12
ARRIVING	SPIRIT AIRLINES	03/19/2020	723	16:02	A320		12
ARRIVING	CARIBBEAN AIRLINES	03/19/2020	723	16:02	B738		12
ARRIVING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	16:03	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	16:09	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	16:15	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	16:15	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	16:22	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	16:22	DA40	CCTS	12
ARRIVING	AMERICAN AIRLINES	03/19/2020	1589	16:25	B737-800		12
ARRIVING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	16:27	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	16:27	DA40	CCTS	12
DEPARTING	DELTA AIRLINES	03/19/2020	321	16:31	B738	KATL	12

ARRIVING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	16:34	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	16:34	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	16:41	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	16:41	DA40	CCTS	12
DEPARTING	FEDERAL EXPRESS	03/19/2020	8126	16:45	ATR42	MKJS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	16:48	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	16:48	DA40	CCTS	12
DEPARTING	PRIVATE	03/19/2020	BILL	17:13	BE19	MBPV	12
ARRIVING	IBC	03/19/2020	965	17:14	SW4		12
DEPARTING	SPIRIT AIRLINES	03/19/2020	702	17:20	A320	KFLL	12
ARRIVING	AMERICAN AIRLINES	03/19/2020	1400	17:35	B738		12
DEPARTING	AMERICAN AIRLINES	03/19/2020	1545	17:52	B737-800	KMIA	12
ARRIVING	CUBANA AIRLINES	03/19/2020	6050	18:00	YK42		12
ARRIVING	COPA AIRLINES	03/19/2020	418	18:32	B738		12
DEPARTING	AMERICAN AIRLINES	03/19/2020	1548	18:47	B738	KMIA	12
DEPARTING	CARIBBEAN AIRLINES	03/19/2020	033	18:53	B738	KFLL	12
ARRIVING	CARIBBEAN AIRLINES	03/19/2020	459	19:06	B738		12
DEPARTING	CUBANA AIRLINES	03/19/2020	6051	19:09	YK42	MUCM	12
DEPARTING	IBC	03/19/2020	510	19:38	SW4	MKJS	12
DEPARTING	COPA AIRLINES	03/19/2020	417	20:26	B738	MPTO	12
ARRIVING	JET BLUE	03/19/2020	875	21:01	A320		12

ARRIVING	AIR CANADA	03/19/2020	14802	21:09	A321		12
ARRIVING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	21:23	HELI		12
DEPARTING	JAMAICA DEFENCE FORCE	03/19/2020	FREE	21:23	HELI	UPC	12
ARRIVING	FEDERAL EXPRESS	03/19/2020	7126	21:34	ATR42		12
ARRIVING	INTERISLAND AIRWAYS	03/19/2020	250	21:36	E120		12
ARRIVING	IBC	03/19/2020	509	21:37	SW4		12
DEPARTING	IBC	03/19/2020	964	22:12	SW4	KMIA	12
DEPARTING	JET BLUE	03/19/2020	876	22:18	A320	KFLL	12
DEPARTING	AIR CANADA	03/19/2020	1803	22:39	A321	CYYZ	12
ARRIVING	NORTHERN AIR CARGO	03/19/2020	8038	23:03	B763		12
ARRIVING	AMERIJET	03/19/2020	849	23:13	B763		12
DEPARTING	JDF	03/19/2020	free	23:46	B350	ZZZZ	12
ARRIVING	CARIBBEAN AIRLINES	03/19/2020	036	23:46	B738		12
DEPARTING	AMERIJET	03/20/2020	848	0:04	B763	MNMG	12
DEPARTING	NORTHERN AIR CARGO	03/20/2020	8039	1:08	B763	KMIA	12
ARRIVING	DELTA	03/20/2020	383	1:24	B738		12
DEPARTING	CARIBBEAN AIRLINES	03/20/2020	017	1:28	B738	KJFK	12
ARRIVING	JET BLUE	03/20/2020	2959	5:01	A320		12
ARRIVING	JET BLUE	03/20/2020	659	6:25	A321		12
DEPARTING	JET BLUE	03/20/2020	2860	6:41	A320	KJFK	12
ARRIVING	JAMAICA DEFENCE FORCE	03/20/2020	FREE	7:22	B350		12

DEPARTING	JET BLUE	03/20/2020	960	8:16	A321	KJFK	12
ARRIVING	CARIBBEAN AIRLINES	03/20/2020	016	10:20	B738		12
DEPARTING	JDF	03/20/2020	free	12:21	DA40	ZZZZ	12
ARRIVING	JET BLUE	03/20/2020	559	12:32	A321		12
DEPARTING	JDF	03/20/2020	bill	12:36	DA40	ZZZZ	12
ARRIVING	JET BLUE	03/20/2020	1675	12:40	A320		12
DEPARTING	JDF	03/20/2020	free	12:43	DA40	ZZZZ	12
ARRIVING	JDF	03/20/2020	bill	13:20	DA40		12
ARRIVING	WORLD ATLANTIC AIRLINES	03/20/2020	620	13:32	MD83		12
ARRIVING	JDF	03/20/2020	23	13:36	DA40		12
DEPARTING	INTERISLAND AIRWAYS	03/20/2020	251	13:46	E120	MBPV	12
ARRIVING	JDF	03/20/2020	bill	13:48	DA40		12
DEPARTING	JET BLUE	03/20/2020	1676	13:51	A320	KFLL	12
DEPARTING	JET BLUE	03/20/2020	560	14:16	A321	KJFK	12
DEPARTING	WORLD ATLANTIC AIRLINES	03/20/2020	620	14:49	MD83	MKJS	12
ARRIVING	CARIBBEAN AIRLINES	03/20/2020	414	14:54	B738		12
DEPARTING	JDF	03/20/2020	free	15:05	DA40	CCTS	12
DEPARTING	JAMAICA DEFENCE FORCE	03/20/2020	FREE	15:07	DA42	MKJP	12
DEPARTING	JAMAICA DEFENCE FORCE	03/20/2020	FREE	15:13	DA42	MKJP	12
ARRIVING	SPIRIT AIRLINES	03/20/2020	723	15:30	A320		12
DEPARTING	JDF	03/20/2020	free	15:51	DA40	MKJP	12

ARRIVING	JDF	03/20/2020	free	15:52	DA40		12
ARRIVING	JDF	03/20/2020	bill	15:56	HELI		12
ARRIVING	JAMAICA DEFENCE FORCE	03/20/2020	FREE	15:57	DA42		12
ARRIVING	CARIBBEAN AIRLINES	03/20/2020	414	16:14	B738		12
ARRIVING	AMERICAN AIRLINES	03/20/2020	1589	16:32	B738		12
ARRIVING	FEDERAL EXPRESS	03/20/2020	8126	16:36	ATR42		12
DEPARTING	DELTA	03/20/2020	321	16:38	B738	KATL	12
DEPARTING	JDF	03/20/2020	free	16:40	DA40	MKJP	12
DEPARTING	MILITARY	03/20/2020	free	16:50	DA42	MKJP	12
ARRIVING	JAMAICA DEFENCE FORCE	03/20/2020	FREE	16:54	DA42		12
ARRIVING	JDF	03/20/2020	free	17:01	DA40		12
DEPARTING	SPIRIT AIRLINES	03/20/2020	702	17:03	A320	KFLL	12
ARRIVING	MILITARY	03/20/2020	free	17:03	DA42		12
DEPARTING	FEDERAL EXPRESS	03/20/2020	8126	17:23	ATR42	KMIA	12
ARRIVING	IBC	03/20/2020	965	18:00	SW4		12
ARRIVING	CUBANA AIRLINES	03/20/2020	6084	18:03	YK42		12
ARRIVING	WESTJET AIRLINES	03/20/2020	2600	18:08	B737		12
DEPARTING	JAMAICA DEFENCE FORCE	03/20/2020	FREE	18:29	DA40	MKJP	12
ARRIVING	PRIVATE	03/20/2020	BILL	18:43	LJ35		12
DEPARTING	AMERICAN AIRLINES	03/20/2020	1548	18:55	B738	KMIA	12
ARRIVING	JAMAICA DEFENCE FORCE	03/20/2020	FREE	19:09	DA40		12

DEPARTING	WESTJET AIRLINES	03/20/2020	2601	19:14	B737	CYYZ	12
DEPARTING	CUBANA AIRLINES	03/20/2020	6085	19:30	YK42	MUCU	12
ARRIVING	PRIVATE	03/20/2020	BILL	20:12	E145		12
ARRIVING	CARIBBEAN AIRLINES	03/20/2020	415	20:15	B738		12
DEPARTING	JDF	03/20/2020	free	20:22	HELI	UPC	12
DEPARTING	PRIVATE	03/20/2020	BILL	20:43	LJ35	KFXE	12
DEPARTING	PRIVATE	03/20/2020	BILL	21:07	E145	TFFF	12
ARRIVING	JET BLUE	03/20/2020	875	21:10	A320		12
ARRIVING	AIR CANADA	03/20/2020	1802	21:22	A321		12
ARRIVING	FEDERAL EXPRESS	03/20/2020	7126	21:30	ATR42		12
DEPARTING	IBC	03/20/2020	964	22:00	SW4	KMIA	12
ARRIVING	BRITISH AIRWAYS	03/20/2020	2263	22:07	B772		30
DEPARTING	FEDERAL EXPRESS	03/20/2020	7126	22:16	ATR42	KMIA	30
DEPARTING	JET BLUE	03/20/2020	876	22:26	A320	KFLL	12
DEPARTING	CARIBBEAN AIRLINES	03/20/2020	415	22:29	B738	TBPB	30
DEPARTING	AIR CANADA	03/20/2020	1803	22:45	A321	CYYZ	30
ARRIVING	CAYMAN AIRWAYS	03/20/2020	606	23:42	B738		12
DEPARTING	BRITISH AIRWAYS	03/21/2020	25K	0:45	B772	EGKK	12
ARRIVING	DELTA AIRLINES	03/21/2020	383	0:47	B738		12
DEPARTING	CAYMAN AIRWAYS	03/21/2020	607	1:05	B738	MWCR	12
DEPARTING	CARIBBEAN AIRLINES	03/21/2020	017	1:40	B738	KJFK	12

ARRIVING	PRIVATE	03/21/2020	BILL	3:33	GLEX		12
DEPARTING	JAMAICA DEFENCE FORCE	03/21/2020	FREE	4:20	B350	S/W	12
ARRIVING	JET BLUE	03/21/2020	2959	5:03	A320		12
ARRIVING	JET BLUE	03/21/2020	659	6:32	A321		12
DEPARTING	JET BLUE	03/21/2020	2860	6:35	A320	KJFK	12
ARRIVING	JAMAICA DEFENCE FORCE	03/21/2020	FREE	6:51	B350		12
DEPARTING	JET BLUE	03/21/2020	960	8:14	A321	KJFK	12
ARRIVING	CARIBBEAN AIRLINES	03/21/2020	016	10:42	B738		12
ARRIVING	JET BLUE	03/21/2020	559	12:23	A321		12
ARRIVING	JET BLUE	03/21/2020	1675	12:27	A320		12
DEPARTING	CARIBBEAN AIRLINES	03/21/2020	7033	13:09	B738	KFLL	12
ARRIVING	WORLD ATLANTIC AIRLINES	03/21/2020	600	13:32	MD83		12
DEPARTING	JET BLUE	03/21/2020	1676	13:52	A320	KFLL	12
DEPARTING	JAMAICA DEFENCE FORCE	03/21/2020	FREE	13:54	DA42	S/W	12
DEPARTING	JET BLUE	03/21/2020	560	14:19	A321	KJFK	12
DEPARTING	CARIBBEAN AIRLINES	03/21/2020	009	14:30	B738	MWCR	12
DEPARTING	WORLD ATLANTIC AIRLINES	03/21/2020	601	14:48	MD83	MWCR	12
ARRIVING	MILITARY	03/21/2020	free	15:07	DA42		12
ARRIVING	PRIVATE	03/21/2020	BILL	15:09	PRM1		12
DEPARTING	JAMAICA DEFENCE FORCE	03/21/2020	FREE	15:22	DA42	S/W	12
ARRIVING	JAMAICA DEFENCE FORCE	03/21/2020	FREE	15:28	DA42		12

ARRIVING	CARIBBEAN AIRLINES	03/21/2020	7010	15:50	B738		12
ARRIVING	SPIRIT AIRLINES	03/21/2020	723	15:53	A320		12
DEPARTING	PRIVATE	03/21/2020	BILL	15:55	PRM1	MYNN	12
DEPARTING	JAMAICA DEFENCE FORCE	03/21/2020	FREE	15:58	DA42	S/W	12
DEPARTING	DELTA AIRLINES	03/21/2020	321	16:30	B738	KATL	12
ARRIVING	AMERICAN AIRLINES	03/21/2020	1589	16:36	B738		12
ARRIVING	JAMAICA DEFENCE FORCE	03/21/2020	FREE	16:39	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/21/2020	FREE	16:39	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/21/2020	FREE	16:43	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/21/2020	FREE	16:44	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/21/2020	FREE	16:54	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/21/2020	FREE	16:54	DA42	CCTS	12
ARRIVING	PRIVATE	03/21/2020	BILL	16:57	E145		12
ARRIVING	JAMAICA DEFENCE FORCE	03/21/2020	FREE	17:00	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/21/2020	FREE	17:00	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/21/2020	FREE	17:07	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/21/2020	FREE	17:07	DA42	CCTS	12
DEPARTING	SPIRIT AIRLINES	03/21/2020	702	17:11	A320	KFLL	12
ARRIVING	JAMAICA DEFENCE FORCE	03/21/2020	FREE	17:21	DA42		12
ARRIVING	WESTJET AIRLINES	03/21/2020	2600	17:29	B737		12

ARRIVING	CARIBBEAN AIRLINES	03/21/2020	008	17:34	B737		12
ARRIVING	CARIBBEAN AIRLINES	03/21/2020	456	17:47	B738		12
DEPARTING	AMERICAN AIRLINES	03/21/2020	1545	17:57	B738	KMIA	12
ARRIVING	CARIBBEAN AIRLINES	03/21/2020	3036	18:02	B738		12
DEPARTING	PRIVATE	03/21/2020	BILL	18:05	E145	MGGT	12
ARRIVING	CUBANA AIRLINES	03/21/2020	9256	18:29	IL96		12
DEPARTING	WESTJET AIRLINES	03/21/2020	2601	19:04	B737	CYYZ	12
DEPARTING	CARIBBEAN AIRLINES	03/21/2020	7015	19:18	B738	TTPP	12
DEPARTING	CARIBBEAN AIRLINES	03/21/2020	7017	19:28	B738	TTPP	12
DEPARTING	CARIBBEAN AIRLINES	03/21/2020	457	19:36	B738	TNCM	12
ARRIVING	PRIVATE	03/21/2020	BILL	19:43	GLF4		12
ARRIVING	PRIVATE	03/21/2020	BILL	19:47	C56X		12
DEPARTING	CARIBBEAN AIRLINES	03/21/2020	7019	19:50	B738	TTPP	12
DEPARTING	CUBANA AIRLINES	03/21/2020	9257	20:35	IL96	MUHA	12
DEPARTING	PRIVATE	03/21/2020	BILL	20:37	GLF4	KTEB	12
ARRIVING	BAHAMAS AIR	03/21/2020	905	20:42	B737		12
DEPARTING	PRIVATE	03/21/2020	BILL	20:51	C56X	MYNN	12
ARRIVING	PRIVATE	03/21/2020	BILL	20:52	PRM1		12
ARRIVING	AIR TURKS AND CAICUS	03/21/2020	250	20:59	E145		12
ARRIVING	JET BLUE	03/21/2020	875	21:01	A320		12
DEPARTING	PRIVATE	03/21/2020	BILL	21:12	PRM1	MKTP	12

DEPARTING	AIR TURKS AND CAICUS	03/21/2020	618	22:02	E145	MUHA	12
ARRIVING	PRIVATE	03/21/2020	BILL	22:07	B407		12
DEPARTING	PRIVATE	03/21/2020	BILL	22:28	GLEX	KLAX	12
DEPARTING	JET BLUE	03/21/2020	876	22:36	A320	KFLL	12
DEPARTING	PRIVATE	03/21/2020	BILL	22:40	B407	MKTP	12
DEPARTING	BAHAMAS AIR	03/21/2020	906	22:54	B737	MYNN	12
ARRIVING	DELTA AIRLINES	03/22/2020	383	1:14	B738		12
ARRIVING	AIR TURKS AND CAICUS	03/22/2020	617	1:21	E145		12
DEPARTING	JAMAICA DEFENCE FORCE	03/22/2020	FREE	2:17	B350	MKJP	30
ARRIVING	CAYMAN AIRWAYS	03/22/2020	3606	3:13	B738		12
ARRIVING	PRIVATE	03/22/2020	BILL	3:27	LJ45		12
ARRIVING	PRIVATE	03/22/2020	BILL	3:40	GALX		12
DEPARTING	CAYMAN AIRWAYS	03/22/2020	3607	4:10	B738	MWCR	30
ARRIVING	JAMAICA DEFENCE FORCE	03/22/2020	FREE	5:22	B350		12
ARRIVING	JAMAICA DEFENCE FORCE	03/22/2020	FREE	7:15	B350		12
ARRIVING	JET BLUE	03/22/2020	6125	13:11	A321		12
DEPARTING	JET BLUE	03/22/2020	560	14:10	A321	KJFK	30
ARRIVING	SPIRIT AIRLINES	03/22/2020	723	15:43	A320		12
DEPARTING	AIR TURKS AND CAICUS	03/22/2020	251	15:46	E145	MBPV	12
ARRIVING	PRIVATE	03/22/2020	BILL	15:47	B407		12
DEPARTING	PRIVATE	03/22/2020	BILL	15:51	B407	ZZZZ	12

DEPARTING	PRIVATE	03/22/2020	BILL	15:56	LJ45	MKTP	12
DEPARTING	DELTA AIRLINES	03/22/2020	321	16:49	B738	KATL	12
ARRIVING	JDF	03/22/2020	free	16:58	DA40		12
DEPARTING	JDF	03/22/2020	FREE	16:58	DA40	CCTS	12
ARRIVING	JDF	03/22/2020	free	17:04	DA40		12
DEPARTING	JDF	03/22/2020	free	17:05	DA40	CCTS	12
DEPARTING	SPIRIT AIRLINES	03/22/2020	702	17:07	A320	KFLL	30
ARRIVING	JDF	03/22/2020	free	17:11	DA40		12
DEPARTING	JDF	03/22/2020	free	17:12	DA40	CCTS	12
ARRIVING	JDF	03/22/2020	free	17:26	DA40		12
ARRIVING	WESTJET AIRLINES	03/22/2020	2600	17:47	B737		12
ARRIVING	AMERICAN AIRLINES	03/22/2020	9686	18:04	B737-800		12
DEPARTING	AMERICAN AIRLINES	03/22/2020	1548	19:02	B737-800	KMIA	12
ARRIVING	JET BLUE	03/22/2020	6175	20:54	A320		12
ARRIVING	BRITISH AIRWAYS	03/22/2020	2263	21:52	B772		12
DEPARTING	JET BLUE	03/22/2020	876	22:19	A320	KFLL	12
DEPARTING	BRITISH AIRWAYS	03/23/2020	25k	0:52	B772	EGKK	12
DEPARTING	PRIVATE	03/23/2020	BILL	0:56	GALX	KHOU	12
ARRIVING	JET BLUE	03/23/2020	6125	12:34	A321		12
ARRIVING	JET BLUE	03/23/2020	6175	12:37	A320		12
ARRIVING	NORTHERN AIR CARGO	03/23/2020	8040	13:48	B763		12

DEPARTING	JET BLUE	03/23/2020	1676	14:00	A320	KFLL	30
DEPARTING	JAMAICA DEFENCE FORCE	03/23/2020	FREE	14:10	DA42	S/W	12
DEPARTING	JET BLUE	03/23/2020	560	14:19	A321	KJFK	12
ARRIVING	FEDERAL EXPRESS	03/23/2020	8126	14:52	ATR42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/23/2020	FREE	14:57	DA42	CCTS	12
DEPARTING	JAMAICA DEFENCE FORCE	03/23/2020	FREE	14:58	DA40	S/W	12
DEPARTING	JAMAICA DEFENCE FORCE	03/23/2020	FREE	15:00	DA42	S/W	12
DEPARTING	JAMAICA DEFENCE FORCE	03/23/2020	FREE	15:22	DA42	S/W	12
ARRIVING	JAMAICA DEFENCE FORCE	03/23/2020	FREE	15:28	DA42		12
ARRIVING	IBC	03/23/2020	965	15:29	SW4		12
DEPARTING	NORTHERN AIR CARGO	03/23/2020	8040	15:34	B763	MKJS	12
ARRIVING	SPIRIT AIRLINES	03/23/2020	723	15:35	A320		12
DEPARTING	FEDERAL EXPRESS	03/23/2020	8126	16:00	ATR42	MKJS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/23/2020	FREE	16:11	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/23/2020	FREE	16:12	DA42	CCTS	12
DEPARTING	JAMAICA DEFENCE FORCE	03/23/2020	FREE	16:22	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/23/2020	FREE	16:30	DA42		12
DEPARTING	IBC	03/23/2020	510	16:36	SW4	MKJS	12
DEPARTING	SPIRIT AIRLINES	03/23/2020	702	16:59	A320	KFLL	12
ARRIVING	JAMAICA DEFENCE FORCE	03/23/2020	FREE	17:03	DA42		12

ARRIVING	WESTJET AIRLINES	03/23/2020	2600	18:14	B737		12
ARRIVING	MERLIN EXPRESS	03/23/2020	730	18:17	SF340		12
DEPARTING	JAMAICA DEFENCE FORCE	03/23/2020	FREE	18:49	DA42	S/W	12
ARRIVING	AMERIJET	03/23/2020	814	18:51	B763		12
ARRIVING	AMERICAN AIRLINES	03/23/2020	9690	18:55	B738		12
DEPARTING	WESTJET AIRLINES	03/23/2020	2601	19:04	B737	CYYZ	12
ARRIVING	JAMAICA DEFENCE FORCE	03/23/2020	FREE	19:32	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/23/2020	FREE	19:33	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/23/2020	FREE	19:38	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/23/2020	FREE	19:38	DA42	CCTS	12
DEPARTING	AMERICAN AIRLINES	03/23/2020	1548	19:46	B738	KMIA	12
ARRIVING	JAMAICA DEFENCE FORCE	03/23/2020	FREE	19:48	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/23/2020	FREE	19:48	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/23/2020	FREE	19:52	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/23/2020	FREE	19:52	DA42	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/23/2020	FREE	19:56	DA42		12
DEPARTING	AMERIJET	03/23/2020	814	20:04	B763	KMIA	12
ARRIVING	CUBANA AIRLINES	03/23/2020	6084	20:46	YK42		12
ARRIVING	AIR CANADA	03/23/2020	7105	21:20	A321		12
ARRIVING	FEDERAL EXPRESS	03/23/2020	7126	21:31	ATR42		12

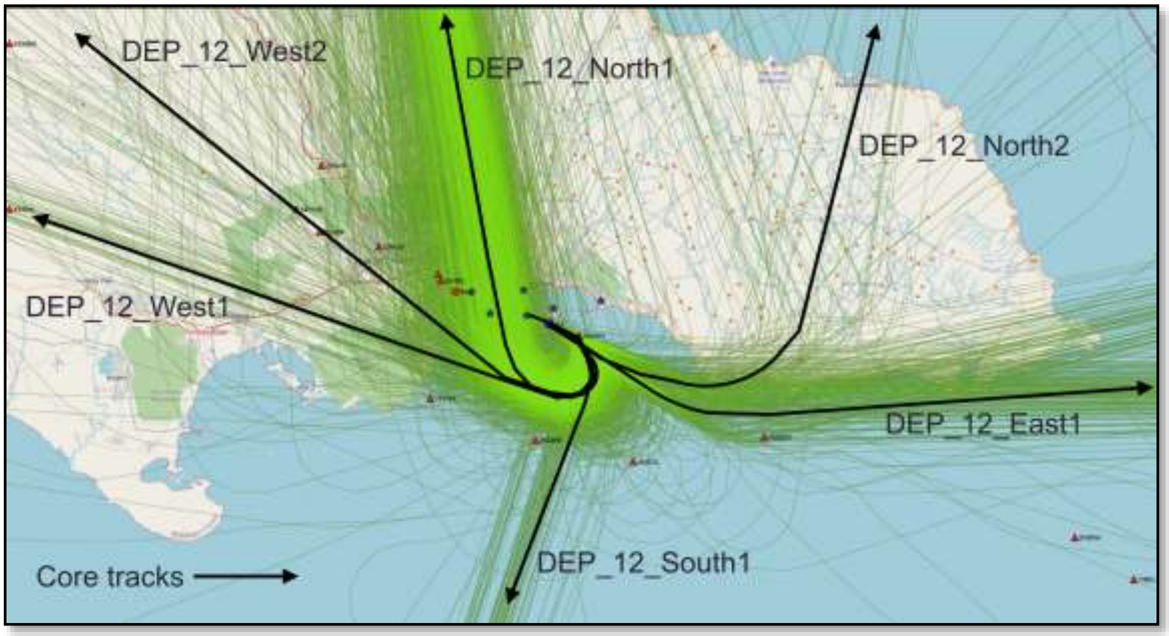
DEPARTING	MERLIN EXPRESS	03/23/2020	964	21:59	SF340	KMIA	12
DEPARTING	CUBANA AIRLINES	03/23/2020	6085	22:16	YK42	MUCU	12
DEPARTING	FEDERAL EXPRESS	03/23/2020	7126	22:25	ATR42	KMIA	12
DEPARTING	AIR CANADA	03/23/2020	1803	22:45	A321	CYYZ	12
ARRIVING	BRITISH AIRWAYS	03/23/2020	2263	22:53	B772		12
DEPARTING	BRITISH AIRWAYS	03/24/2020	25k	1:07	B772	EGKK	12
ARRIVING	PRIVATE	03/24/2020	BILL	1:46	C560		12
DEPARTING	PRIVATE	03/24/2020	BILL	2:14	C560	MYNN	12
ARRIVING	JDF	03/24/2020	FREE	11:22	B350		12
DEPARTING	JDF	03/24/2020	free	11:22	B350	ZZZZ	12
ARRIVING	JET BLUE	03/24/2020	6125	12:33	A321		12
ARRIVING	JET BLUE	03/24/2020	6157	13:23	A320		12
DEPARTING	MILITARY	03/24/2020	free	14:14	DA42	CCTS	12
DEPARTING	JAMAICA DEFENCE FORCE	03/24/2020	FREE	14:16	DA40	ZZZZ	12
ARRIVING	MILITARY	03/24/2020	FREE	14:19	DA42		12
DEPARTING	MILITARY	03/24/2020	free	14:19	DA42	CCTS	12
ARRIVING	MILITARY	03/24/2020	FREE	14:24	DA42		12
DEPARTING	MILITARY	03/24/2020	free	14:25	DA42	CCTS	12
ARRIVING	MILITARY	03/24/2020	FREE	14:30	DA42		12
DEPARTING	MILITARY	03/24/2020	free	14:31	DA42	CCTS	12
DEPARTING	JET BLUE	03/24/2020	1676	14:33	A320	KFLL	12

ARRIVING	JDF	03/24/2020	FREE	14:36	B350		12
DEPARTING	JET BLUE	03/24/2020	560	14:38	A321	KJFK	12
ARRIVING	MILITARY	03/24/2020	FREE	14:41	DA42		12
DEPARTING	MILITARY	03/24/2020	free	14:41	DA42	CCTS	12
ARRIVING	MILITARY	03/24/2020	free	14:45	DA42		12
DEPARTING	MILITARY	03/24/2020	free	14:45	DA42	CCTS	12
ARRIVING	MILITARY	03/24/2020	free	14:51	DA42		12
DEPARTING	MILITARY	03/24/2020	free	14:51	DA42	CCTS	12
ARRIVING	MILITARY	03/24/2020	free	14:56	DA42		12
DEPARTING	MILITARY	03/24/2020	free	14:56	DA42	ZZZZ	12
ARRIVING	JAMAICA DEFENCE FORCE	03/24/2020	FREE	15:00	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/24/2020	FREE	15:01	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/24/2020	FREE	15:07	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/24/2020	FREE	15:07	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/24/2020	FREE	15:15	DA40		12
DEPARTING	JAMAICA DEFENCE FORCE	03/24/2020	FREE	15:16	DA40	CCTS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/24/2020	FREE	15:22	DA40		12
DEPARTING	MILITARY	03/24/2020	free	15:31	DA42	CCTS	12
ARRIVING	MILITARY	03/24/2020	FREE	15:31	DA42		12
ARRIVING	MILITARY	03/24/2020	free	15:36	DA42		12
DEPARTING	MILITARY	03/24/2020	free	15:37	DA42	CCTS	12

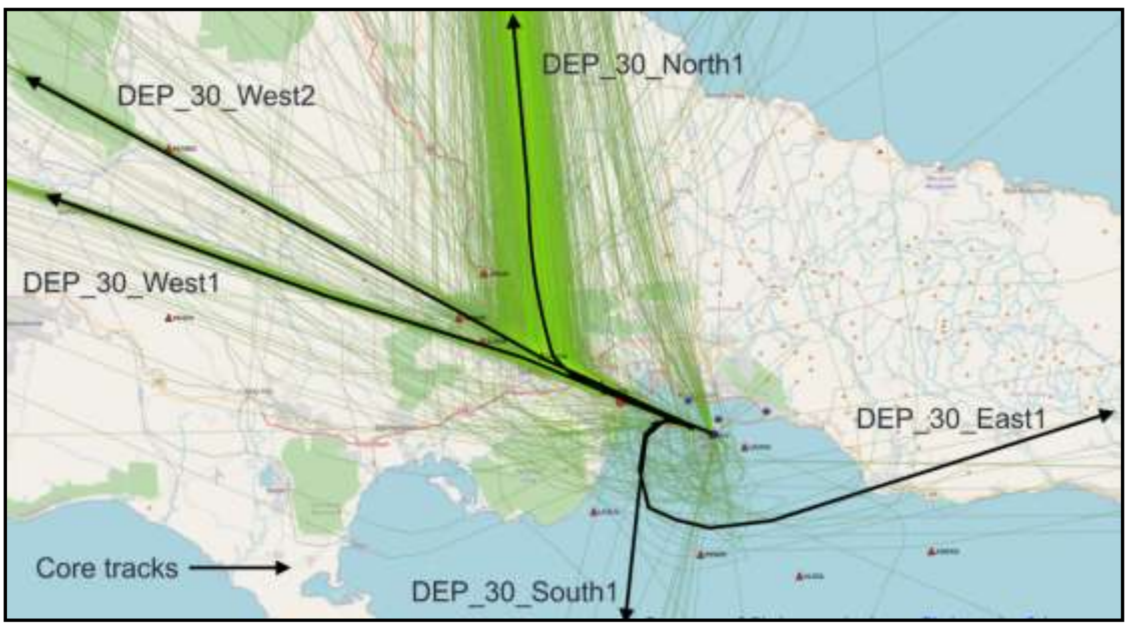
ARRIVING	MILITARY	03/24/2020	free	15:43	DA42		12
DEPARTING	MILITARY	03/24/2020	free	16:00	DA42	CCTS	12
ARRIVING	MILITARY	03/24/2020	FREE	16:05	DA42		12
DEPARTING	MILITARY	03/24/2020	free	16:05	DA42	CCTS	12
ARRIVING	MILITARY	03/24/2020	FREE	16:11	DA42		12
DEPARTING	MILITARY	03/24/2020	free	16:11	DA42	CCTS	12
ARRIVING	MILITARY	03/24/2020	FREE	16:17	DA42		12
DEPARTING	MILITARY	03/24/2020	free	16:18	DA42	CCTS	12
ARRIVING	FEDERAL EXPRESS	03/24/2020	8126	16:26	ATR42		12
ARRIVING	PRIVATE	03/24/2020	BILL	17:00	PA34		12
DEPARTING	FEDERAL EXPRESS	03/24/2020	8126	17:02	ATR42	MKJS	12
ARRIVING	DELTA AIRLINES	03/24/2020	8784	17:29	B739		12
ARRIVING	AMERICAN AIRLINES	03/24/2020	9685	17:37	B738		12
ARRIVING	IBC	03/24/2020	965	17:53	SW4		12
DEPARTING	JAMAICA DEFENCE FORCE	03/24/2020	FREE	18:06	DA42	S/W	12
DEPARTING	PRIVATE	03/24/2020	BILL	18:23	PA34	MTPP	12
DEPARTING	AMERICAN AIRLINES	03/24/2020	1548	18:55	B738	KMIA	12
DEPARTING	IBC	03/24/2020	510	19:29	SW4	MKJS	12
ARRIVING	JAMAICA DEFENCE FORCE	03/24/2020	FREE	19:36	HELI		12
ARRIVING	JAMAICA DEFENCE FORCE	03/24/2020	FREE	19:37	DA42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/24/2020	FREE	19:42	HELI	UPC	12

ARRIVING	JAMAICA DEFENCE FORCE	03/24/2020	FREE	19:52	HELI		12
DEPARTING	JAMAICA DEFENCE FORCE	03/24/2020	FREE	19:54	HELI	ZZZZ	12
DEPARTING	DELTA AIRLINES	03/24/2020	8785	19:58	B739	KATL	12
ARRIVING	JAMAICA DEFENCE FORCE	03/24/2020	FREE	20:50	HELI		12
DEPARTING	JAMAICA DEFENCE FORCE	03/24/2020	FREE	21:00	HELI	UPC	12
ARRIVING	AIR CANADA	03/24/2020	7105	21:15	A321		12
ARRIVING	IBC	03/24/2020	504	21:29	SW4		12
ARRIVING	FEDERAL EXPRESS	03/24/2020	7126	21:33	ATR42		12
DEPARTING	JAMAICA DEFENCE FORCE	03/24/2020	FREE	22:02	B350	ZZZZ	12
DEPARTING	FEDERAL EXPRESS	03/24/2020	7126	22:08	ATR42	KMIA	12
DEPARTING	IBC	03/24/2020	964	22:15	SW4	KMIA	12
DEPARTING	AIR CANADA	03/24/2020	1803	22:40	A321	CYYZ	12
ARRIVING	JAMAICA DEFENCE FORCE	03/24/2020	FREE	23:30	B350		12

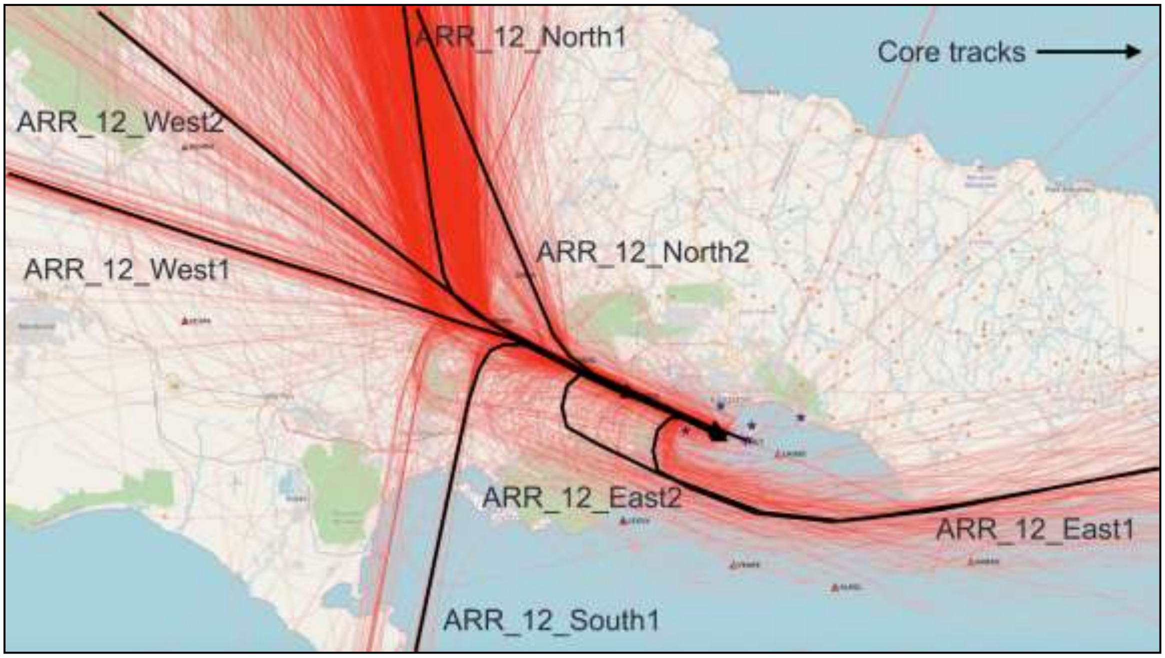
8.1.4 Departure and Arrival Core Tracks Modeled



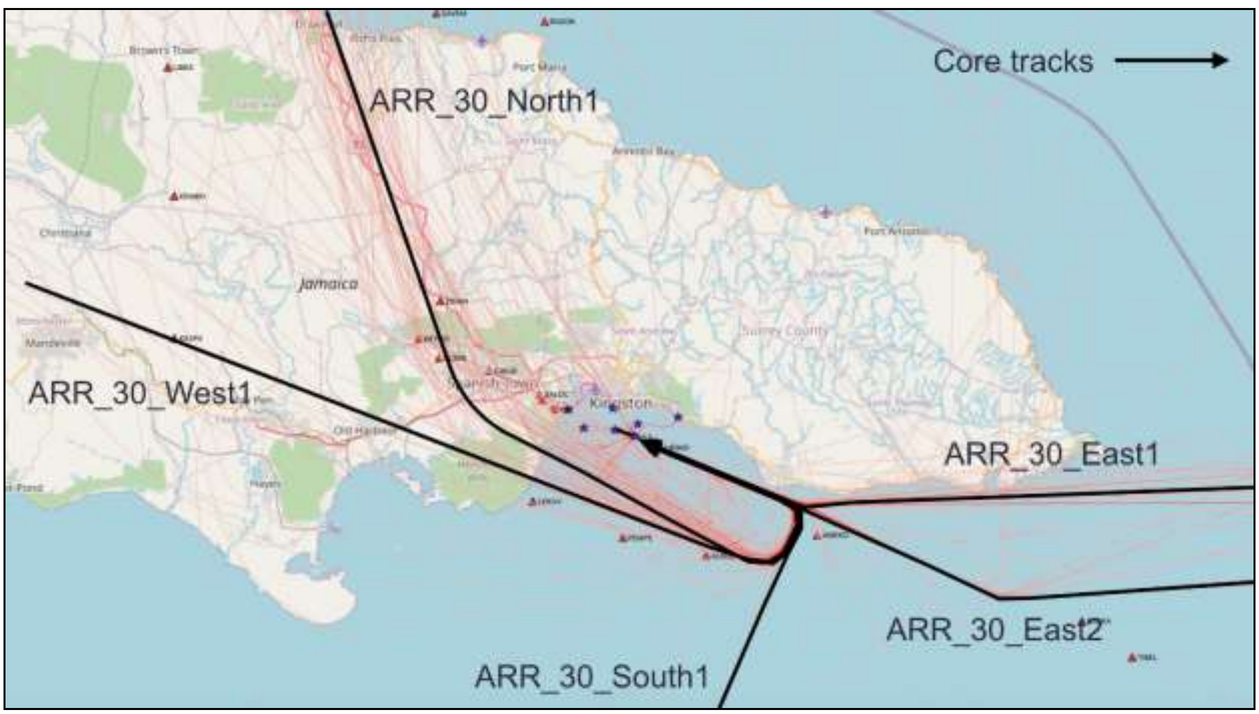
Runway 12 Departure Tracks and Core Departure Tracks Modeled in AEDT 3c. Source of Map: OpenStreet. Source of Flight Track Data: FlightAware.



Runway 30 Departure Tracks and Core Departure Tracks Modeled in AEDT 3c. Source of Map: OpenStreet. Source of Flight Track Data: FlightAware.

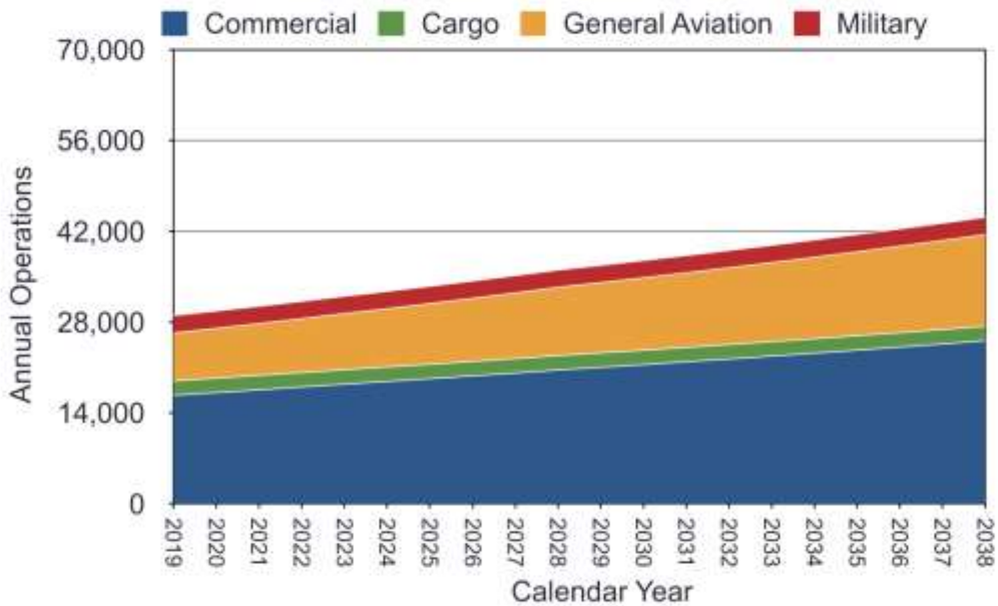


Runway 12 Arrival Tracks and Core Arrival Tracks Modeled in AEDT 3c. Source of Map: OpenStreet. Source of Flight Track Data: FlightAware.

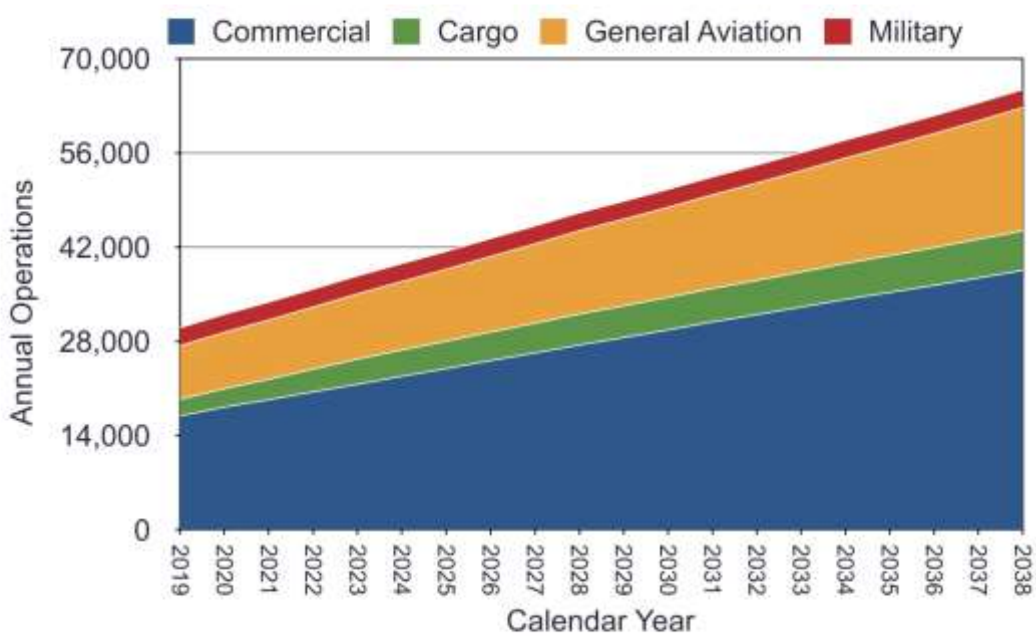


Runway 30 Arrival Tracks and Core Arrival Tracks Modeled in AEDT 3c. Source of Map: OpenStreet. Source of Flight Track Data: FlightAware.

8.1.5 NMIA Master Plan Projections



Norman Manley International Airport Aviation Forecast: Base High Scenario. Source of Data: NMIA 2013 Master Plan.



Norman Manley International Airport Aviation Forecast: Vision 2030 Scenario. Source of Data: NMIA 2013 Master Plan.

8.1.6 Summary of Noise Meter Events Duration and Number of Events Daily

Summary of Noise Meter Events at Runway 12.

Date	Number of Noise Events	Average Duration of Noise Events (s)	LAeq (dBA)	L_{DN} (dBA)
'12-Mar-2020'	73	20.44	76.74	66.97
'13-Mar-2020'	67	23.27	76.85	70.31
'14-Mar-2020'	44	20.91	77.47	64.57
'15-Mar-2020'	36	18.69	77.83	62.81
'16-Mar-2020'	66	19.00	75.98	66.33
'17-Mar-2020'	40	19.28	75.95	62.45
'18-Mar-2020'	51	19.37	75.90	63.60
'19-Mar-2020'	46	19.07	76.72	64.01
'20-Mar-2020'	48	18.90	76.23	63.93
'21-Mar-2020'	50	18.88	76.27	61.72
'22-Mar-2020'	16	18.94	77.94	57.59
'23-Mar-2020'	37	18.97	75.80	59.84
'24-Mar-2020'	27	18.04	74.60	58.17

Summary of Noise Meter Events at Runway 30 Threshold.

Date	Number of Noise Events	Average Duration of Noise Events (s)	LAeq (dBA)	L_{DN} (dBA)
'12-Mar-2020'	45	20.82	90.15	63.14
'13-Mar-2020'	66	23.02	88.37	67.08
'14-Mar-2020'	31	20.77	91.05	62.96
'15-Mar-2020'	29	20.24	90.29	61.80
'16-Mar-2020'	47	19.62	88.92	63.59
'17-Mar-2020'	39	19.03	90.22	63.75
'18-Mar-2020'	39	19.69	88.67	63.39
'19-Mar-2020'	41	19.68	90.24	64.48
'20-Mar-2020'	45	20.18	87.54	63.75
'21-Mar-2020'	32	19.84	89.98	63.62
'22-Mar-2020'	8	18.88	90.55	61.86
'23-Mar-2020'	15	18.40	92.26	61.46
'24-Mar-2020'	6	19.00	95.00	60.55

Summary of Noise Meter Events at Morgans Harbour.

Date	Number of Noise Events	Average Duration of Noise Events (s)	LAeq (dBA)	L_{DN} (dBA)
'14-Mar-2020'	14	24.57	62.17	54.4
'16-Mar-2020'	44	26.50	64.35	56.43
'17-Mar-2020'	12	18.75	59.42	55.21
'18-Mar-2020'	11	24.00	62.39	54.96

'19-Mar-2020'	16	22.63	63.27	55.73
'20-Mar-2020'	20	19.80	62.50	53.84
'21-Mar-2020'	15	16.87	61.42	53.97
'22-Mar-2020'	39	15.36	63.27	55.41

Summary of Noise Meter Events at Newport East.

Date	Number of Noise Events	Average Duration of Noise Events (s)	LAeq (dBA)	L_{DN} (dBA)
'12-Mar-2020'	122	26.93	63.12	60.82
'13-Mar-2020'	84	19.90	62.45	59.93
'14-Mar-2020'	64	29.47	64.52	57.37
'15-Mar-2020'	115	24.62	61.69	59.02
'16-Mar-2020'	141	29.87	63.84	60.55
'17-Mar-2020'	119	47.59	63.49	60.69
'18-Mar-2020'	66	18.30	62.53	59.85
'19-Mar-2020'	166	16.29	63.80	57.66
'20-Mar-2020'	19	18.11	61.97	57.81
'21-Mar-2020'	44	18.41	62.93	56.68
'22-Mar-2020'	29	22.24	60.40	56.1
'23-Mar-2020'	91	17.04	61.91	59.45
'24-Mar-2020'	64	44.75	61.86	58.71
'25-Mar-2020'	15	21.60	64.31	59.47

Summary of Noise Meter Events at Port Henderson.

Date	Number of Noise Events	Average Duration of Noise Events (s)	LAeq (dBA)	L_{DN} (dBA)
'12-Mar-2020'	129	19.29	63.23	60.24
'13-Mar-2020'	114	20.82	64.23	60.10
'14-Mar-2020'	104	19.68	63.99	60.29
'15-Mar-2020'	99	19.92	62.44	59.89
'16-Mar-2020'	117	20.03	63.01	59.70
'20-Mar-2020'	97	20.70	64.30	59.94

Summary of Noise Meter Events at Caribbean Maritime University (CMU).

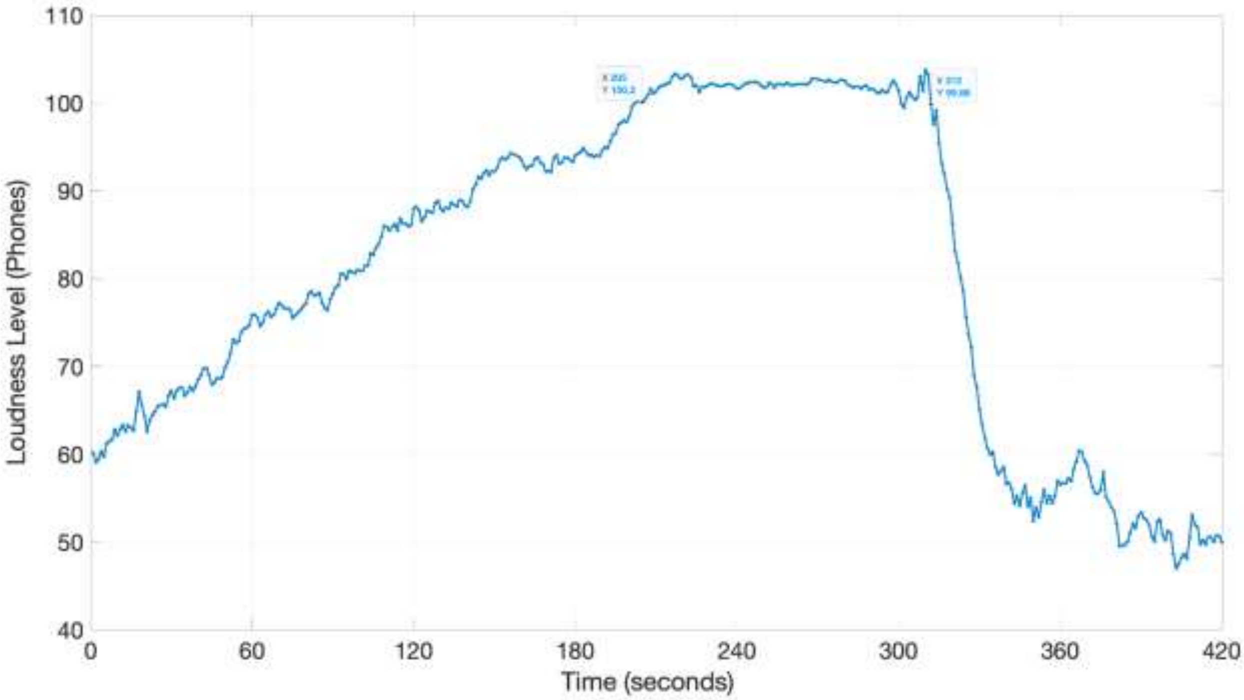
Date	Number of Noise Events	Average Duration of Noise Events (s)	LAeq (dBA)	L_{DN} (dBA)
'12-Mar-2020'	396	163.88	45.33	55.43
'13-Mar-2020'	723	60.06	46.33	53.33
'14-Mar-2020'	643	28.75	45.26	54.58
'15-Mar-2020'	565	30.43	45.76	48.89
'16-Mar-2020'	359	56.50	46.07	51.21
'17-Mar-2020'	38	26.16	45.84	48.75
'17-Mar-2020'	386	56.39	43.52	52.80
'18-Mar-2020'	537	43.63	44.76	51.60
'19-Mar-2020'	887	48.28	44.65	49.46
'20-Mar-2020'	889	40.91	45.12	48.48
'21-Mar-2020'	897	44.16	45.80	52.08
'22-Mar-2020'	1364	29.34	44.59	49.81
'23-Mar-2020'	746	74.58	44.70	49.51
'24-Mar-2020'	785	45.23	44.44	48.95
'25-Mar-2020'	520	32.85	45.10	46.11

Summary of Noise Meter Events at Martello Harbour View.

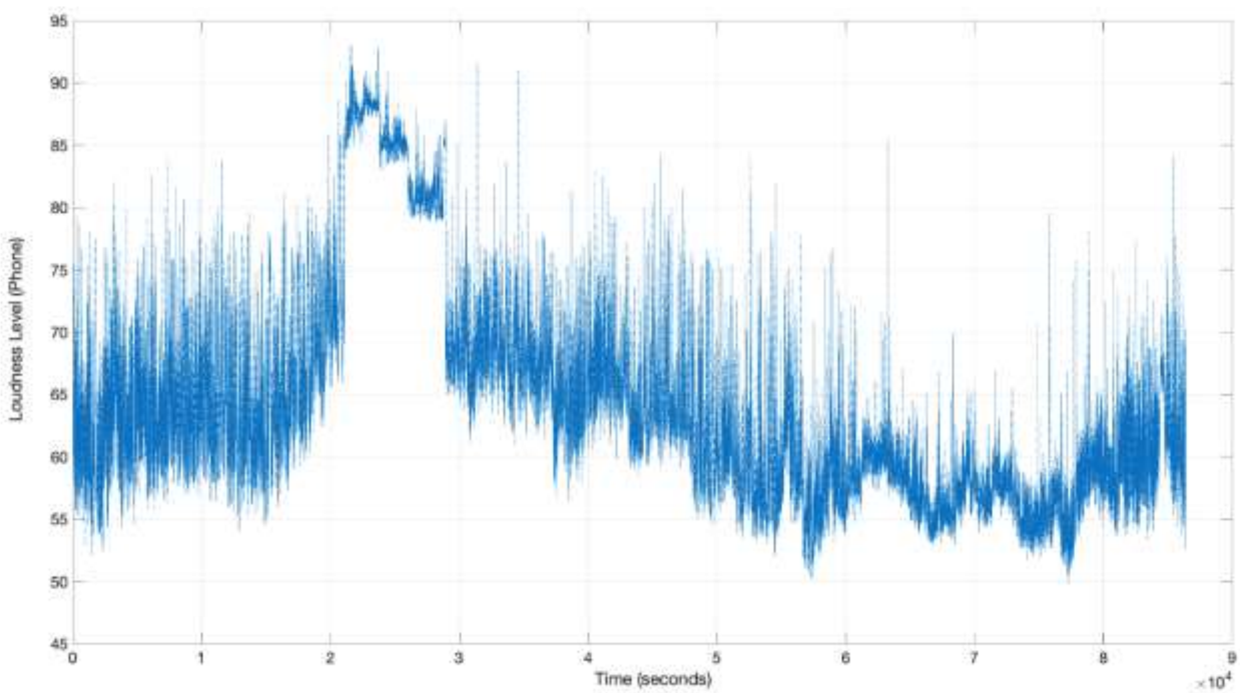
Date	Number of Noise Events	Average Duration of Noise Events (s)	LAeq (dBA)	L_{DN} (dBA)
'12-Mar-2020'	1073	17.83	54.74	55.76
'13-Mar-2020'	882	17.08	54.32	54.86
'14-Mar-2020'	768	17.21	54.66	54.02
'15-Mar-2020'	488	16.16	53.18	52.93

'16-Mar-2020'	792	16.16	53.52	53.97
'17-Mar-2020'	754	16.29	53.95	54.82
'18-Mar-2020'	624	16.19	53.85	52.98
'19-Mar-2020'	465	33.58	53.69	57.76
'20-Mar-2020'	625	19.10	53.95	54.53
'21-Mar-2020'	544	16.19	53.59	52.91
'22-Mar-2020'	512	16.87	53.13	53.36
'23-Mar-2020'	713	17.64	53.89	54.17
'24-Mar-2020'	499	16.20	54.14	52.79

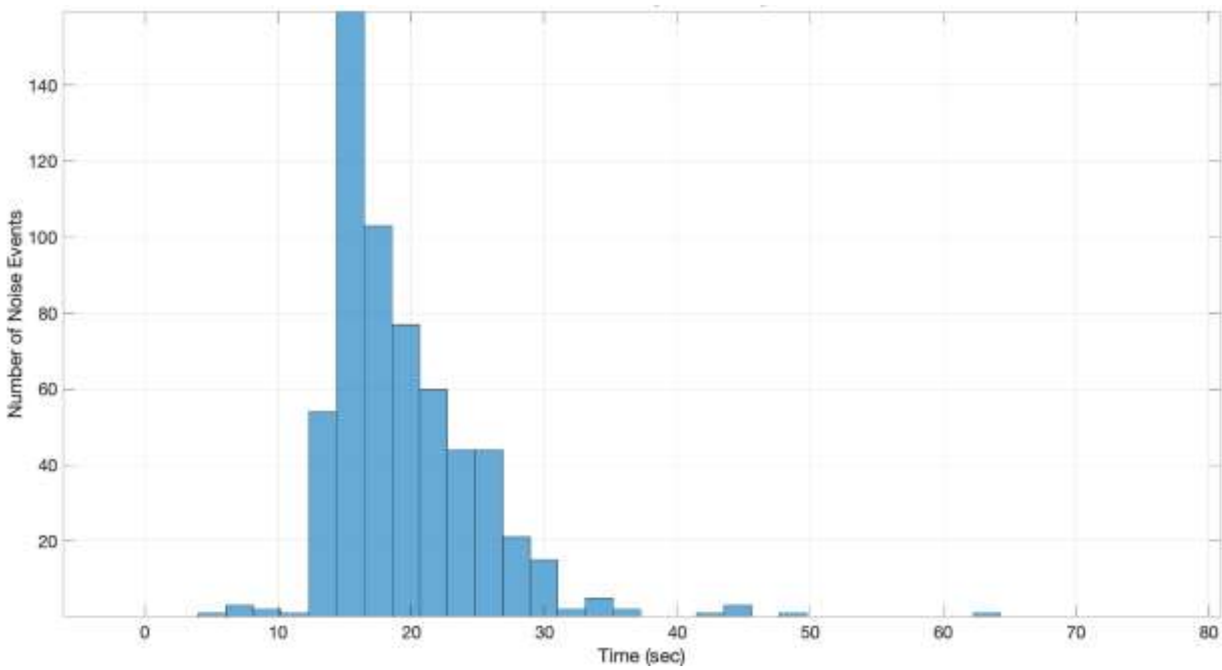
8.1.7 Supporting Plots to Verify Engine Runups and Duration of Noise Events Near Runway Thresholds



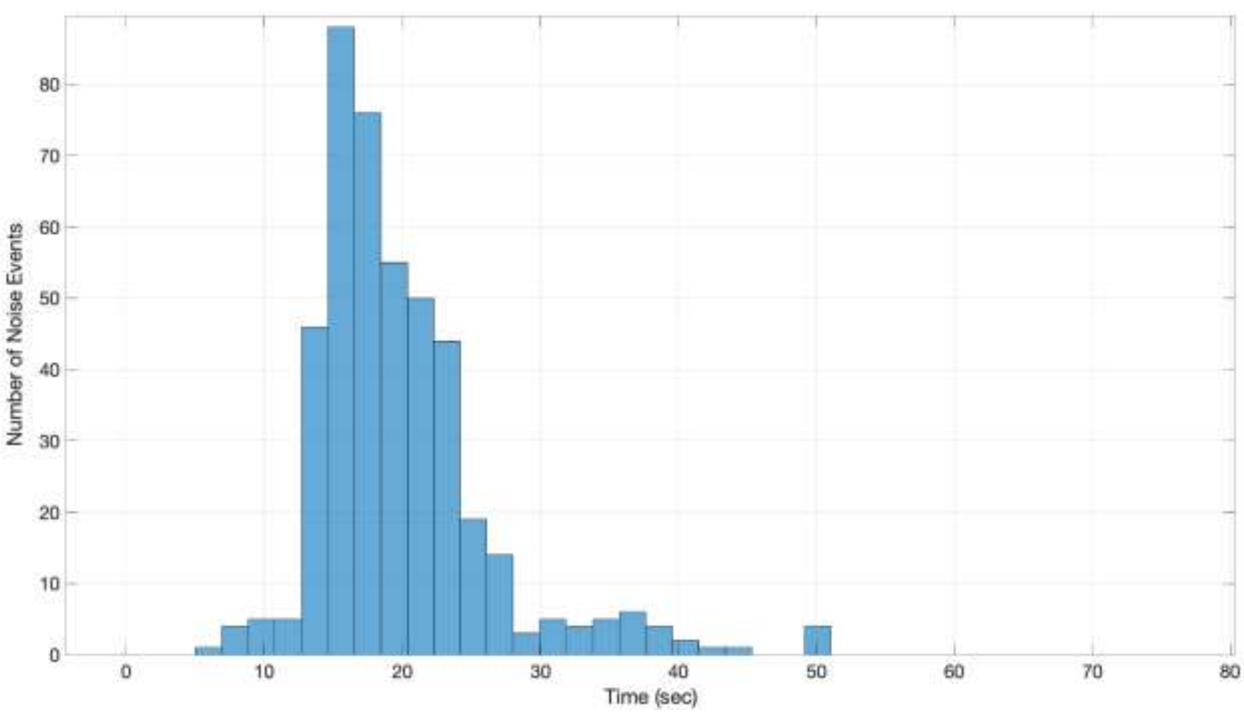
Loudness Level for an Aircraft Engine Run Operation.



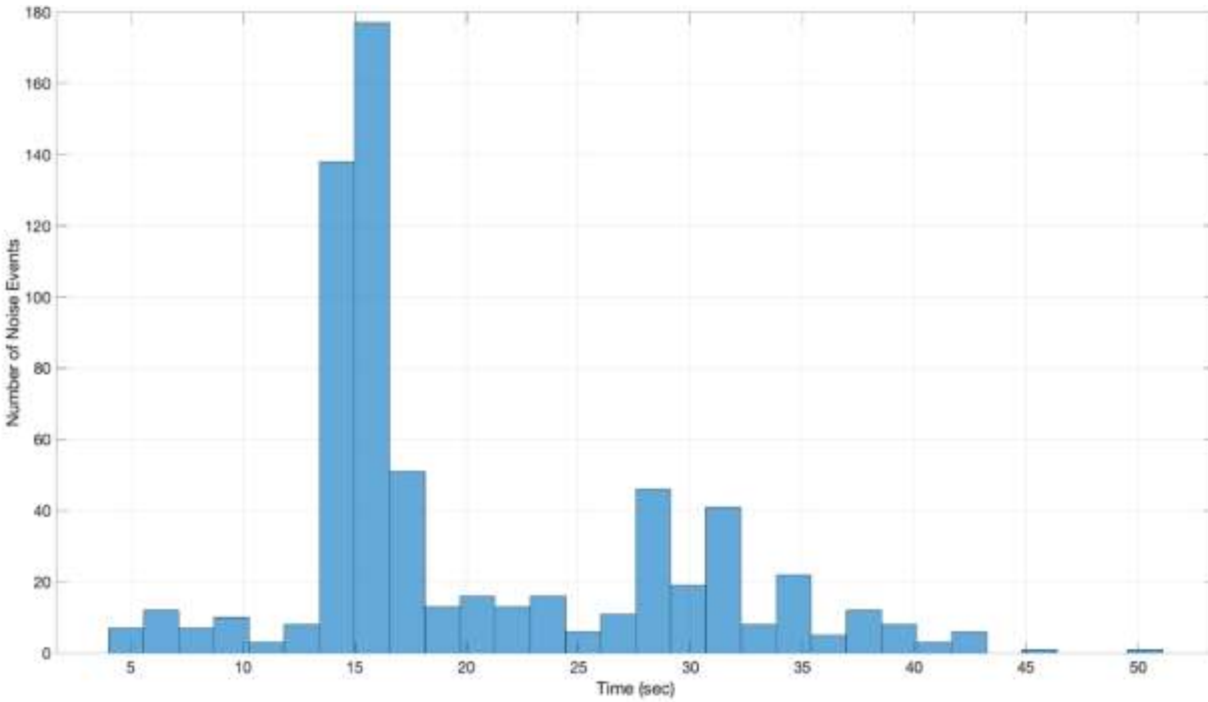
Loudness Level at Martello Harbour View.



Distribution of Duration of Noise Events at Runway 12.



Distribution of Duration of Noise Events at Runway 30.



Distribution of Duration of Noise Events at Port Henderson.

8.2 Appendix 2: Ecological Survey

8.2.1 Flora Species list

8.2.2 Grab Sample Coordinates

Table 8.3 Grab Sample Coordinates

STATION #	LOCATION (JAD2001)	
	NORTHINGS	EASTINGS
1	643519.701	771270.681
2	643514.406	771122.374
3	643346.565	771081.332
4	643265.751	770912.457
5	643261.328	770766.747
6	643459.258	770852.654
7	643577.349	770970.633
8	643706.104	771074.671
9	643749.549	770903.705
10	643642.313	770762.834
11	643460.067	770721.288
12	642559.432	772697.317
13	642560.395	772701.403
14	642788.792	772071.892
15	643214.995	771267.777
16	643997.542	773845.819
17	643850.424	773655.672
18	643139.316	770391.392
19	643556.119	770080.054
20	642424.674	773048.655
21	642503.611	773017.833
22	642524.986	772973.413
23	642455.807	772998.535
24	642395.139	772965.596
25	642369.619	772915.113
26	642318.924	772880.244
27	642404.720	772887.414
28	642460.248	772893.102
29	642526.361	772909.499
30	642541.022	772830.374
31	642483.050	772739.692
32	642411.100	772778.092
33	642338.657	772769.697
34	642267.046	772775.027
35	642341.029	772812.485
36	642306.221	772696.159
37	642371.703	772618.712
38	642721.624	772176.137
39	642820.600	772133.377
40	642596.028	772700.401

41	642535.147	772609.410
42	642497.506	772516.718
43	642445.661	772581.417
44	642634.386	772608.920
45	642697.163	772537.442
46	642631.931	772425.291
47	642633.351	772313.344
48	642766.466	772323.030
49	642809.621	772231.772
50	642839.462	772171.169
51	642882.925	772074.282
52	642829.690	772005.787
53	642779.734	771928.980
54	642739.779	771833.781
55	642935.786	771961.973
56	642853.331	771927.755
57	642807.240	771785.894
58	643005.733	771728.043
59	642884.705	771613.908
60	642974.118	771481.163
61	643105.698	771434.808
62	643172.111	771352.980
63	643088.211	771357.063
64	643015.331	771341.918
65	643213.533	771245.924
66	643216.154	771253.224
67	643239.643	771176.642
68	643247.617	771176.321
69	643326.115	771187.314
70	643391.376	771205.093
71	643498.776	771247.360
72	643552.256	771331.814
73	643586.614	771443.282
74	643541.389	771544.649
75	643460.969	771733.445
76	643406.900	771869.515
77	643358.567	771989.832
78	643296.639	772136.333
79	643236.641	772305.013
80	643178.519	772435.987
81	643101.700	772625.824
82	643045.969	772808.682
83	642972.364	772973.157
84	643074.947	772928.346
85	643175.730	772777.726
86	643263.429	772538.698
87	643375.552	772326.042

88	643463.193	772126.262
89	643574.299	771941.886
90	643654.671	771785.058
91	643715.533	771604.713
92	643767.283	771394.818
93	642420.007	773008.582

8.2.3 Zooplankton Species

Figure 8.3 Materials Used in the Laboratory Analysis of Zooplankton Sampl

Table 8.4 Table of Total Numbers per Run

	ZOOPLANKTON			LOBSTER LARVAE			FISH LARVAE			CONCH LARVAE		
STATION	RUN 1	RUN 2	RUN 3	RUN 1	RUN 2	RUN 3	RUN 1	RUN 2	RUN 3	RUN 1	RUN 2	RUN 3
1	3630	7207	7669	0	0	1	6	5	57	0	0	0
2	7914	6487	4315	0	0	3	18	345	60	0	0	0
3	11154	3108	5250	0	0	3	12	161	126	0	0	0
4	10151	5329	524	0	0	0	41	49	9	0	0	0
5	13713	8835	7258	0	3	0	6	73	97	0	0	0
6	9612	13287	6969	0	0	0	12	40	95	0	0	0
7	18189	8364	5398	3	0	0	59	29	124	0	0	0
8	4215	15887	2350	0	0	0	80	60	28	0	0	0
9	4308	5389	2164	5	5	1	36	107	83	0	0	0
10	6921	6851	8557	0	0	2	41	97	756	0	0	0
11	7169	7979	5580	0	2	0	24	60	551	0	0	0
12	1444	814	712	0	0	0	76	48	22	0	0	0

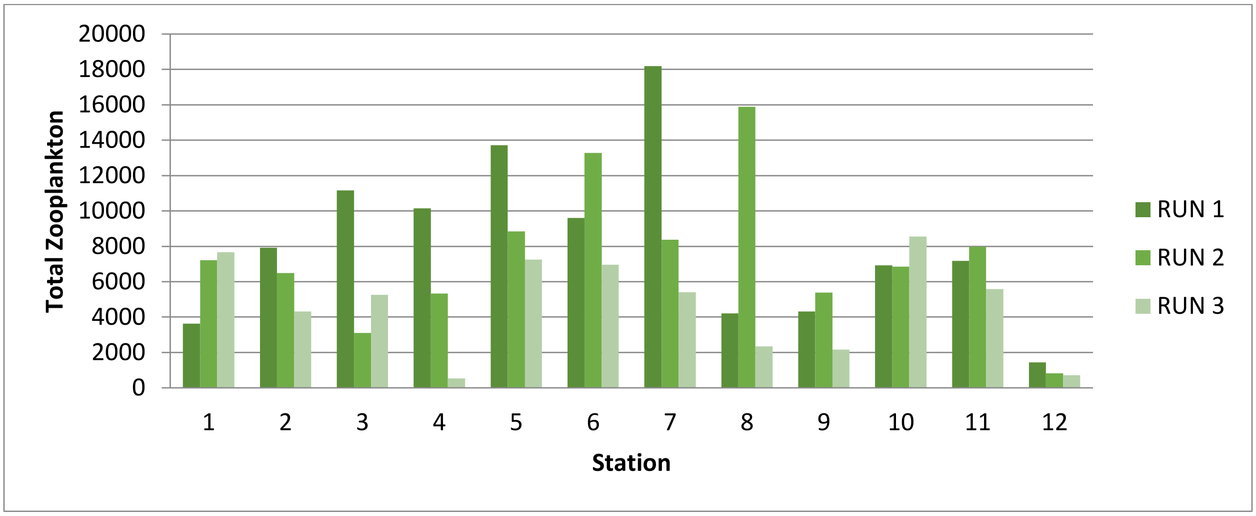


Figure 8.4 Total Zooplankton per station for runs 1, 2 and 3.

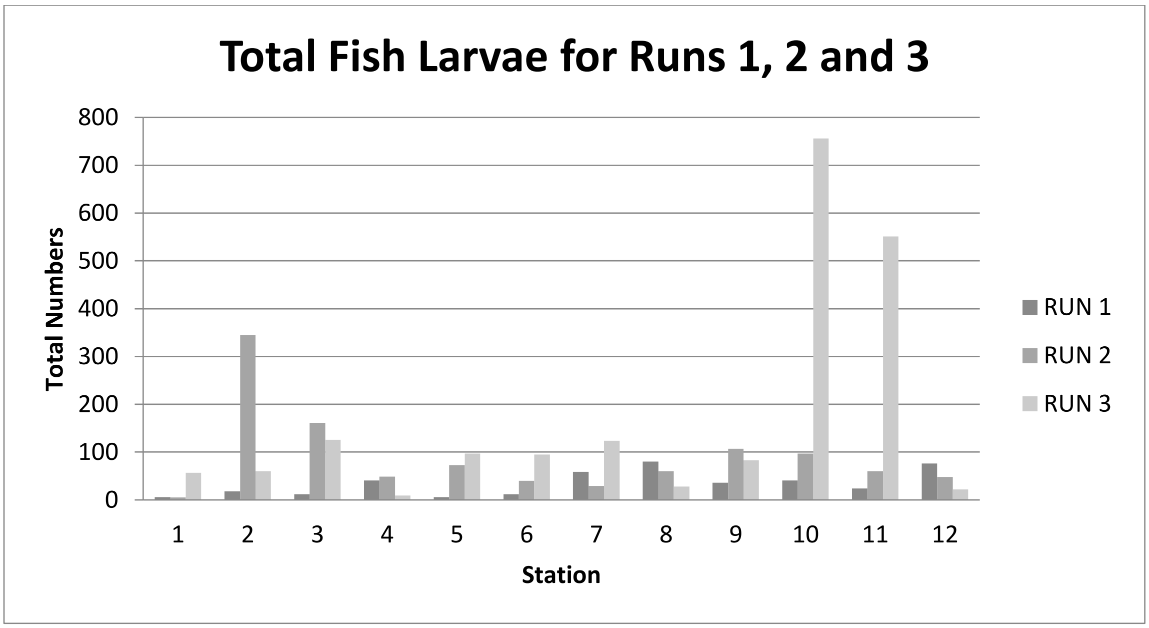


Figure 8.5 Total Fish Larvae per Stations for runs 1, 2 and 3.

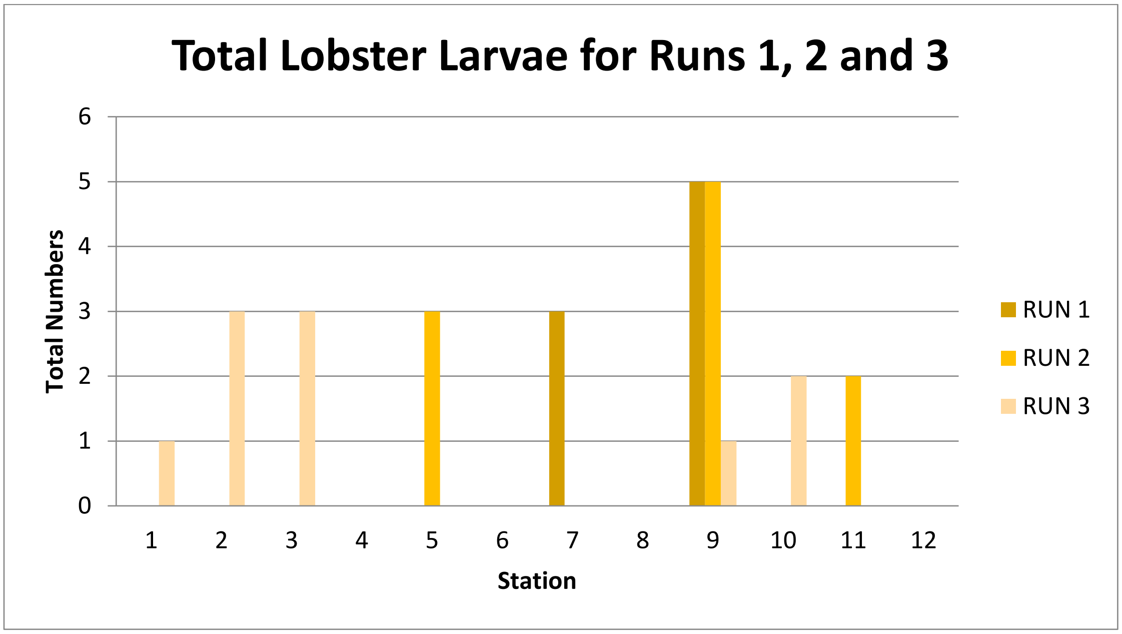


Figure 8.6 Total Lobster Larvae per Station for runs 1, 2 and 3.

Table 8.5 Raw Data Sheet for Run 1

Date	Station	Sample	Zooplankton/ Subsample	Lobster Larvae/ Subsample	Fish Larvae/ Subsample	Conch Larvae/ Substation	Total Zooplankton	Total Lobster Larvae	Total Fish Larvae	Total Conch Larvae
1	1	A	1714	0	4	0	3630	0	6	0
		B	1916	0	2	0				
1	2	A	3486	0	13	0	7914	0	18	0
		B	4428	0	5	0				
1	3	A	3737	0	7	0	11154	0	12	0
		B	7417	0	5	0				
1	4	A	3210	0	18	0	10151	0	41	0
		B	6941	0	23	0				
1	5	A	6346	0	3	0	13713	0	6	0
		B	7367	0	3	0				
1	6	A	4420	0	6	0	9612	0	12	0
		B	5192	0	6	0				
1	7	A	7277	3	22	0	18189	3	59	0
		B	10912	0	37	0				
1	8	A	2552	0	71	0	4215	0	80	0
		B	1663	0	9	0				
1	9	A	1925	5	6	0	4308	5	36	0
		B	2383	0	30	0				
1	10	A	3766	0	31	0	6921	0	41	0
		B	3155	0	10	0				
1	11	A	3692	0	12	0	7169	0	24	0
		B	3477	0	12	0				
1	12	A	632	0	33	0	1444	0	76	0
		B	812	0	43	0				

Table 8.6 Raw Data Sheet for Run 2

Date	Station	Sample	Zooplankton / Subsample	Lobster Larvae/ Subsample	Fish Larvae/ Subsample	Conch Larvae/ Substation	Total Zooplankton	Total Lobster Larvae	Total Fish Larvae	Total Conch Larvae
2	1	A	3222	0	4	0	7207	0	5	0
		B	3985	0	1	0				
2	2	A	3153	0	149	0	6487	0	345	0
		B	3334	0	196	0				
2	3	A	1593	0	98	0	3108	0	161	0
		B	1515	0	63	0				
2	4	A	2619	0	21	0	5329	0	49	0
		B	2710	0	28	0				
2	5	A	4344	3	43	0	8835	3	73	0
		B	4491	0	30	0				
2	6	A	5007	0	10	0	13287	0	40	0
		B	8280	0	30	0				
2	7	A	3358	0	11	0	8364	0	29	0
		B	5006	0	18	0				
2	8	A	7633	0	36	0	15887	0	60	0

		B	8254	0	24	0				
2	9	A	2877	4	50	0	5389	5	107	0
		B	2512	1	57	0				
2	10	A	3057	0	49	0	6851	0	97	0
		B	3794	0	48	0				
2	11	A	3004	0	14	0	7979	2	60	0
		B	4975	2	46	0				
2	12	A	289	0	15	0	814	0	48	0
		B	525	0	33	0				

Table 8.7 Raw data sheet for Run 3

ate	Station	Sample	Zooplankton / Subsample	Lobster Larvae/ Subsample	Fish Larvae/ Subsample	Conch Larvae/ Substation	Total Zooplankton	Total Lobster Larvae	Total Fish Larvae	Total Conch Larvae
3	1	A	3871	1	32	0	7669	1	57	0
		B	3798	0	25	0				
3	2	A	2240	2	31	0	4315	3	60	0
		B	2075	1	29	0				
3	3	A	2627	2	81	0	5250	3	126	0
		B	2623	1	45	0				
3	4	A	224	0	3	0	524	0	9	0
		B	300	0	6	0				
3	5	A	3719	0	55	0	7258	0	97	0
		B	3539	0	42	0				
3	6	A	3588	0	47	0	6969	0	95	0
		B	3381	0	48	0				
3	7	A	2033	0	48	0	5398	0	124	0
		B	3365	0	76	0				
3	8	A	704	0	3	0	2350	0	28	0
		B	1646	0	25	0				
3	9	A	1129	1	41	0	2164	1	83	0
		B	1035	0	42	0				
3	10	A	3987	2	374	0	8557	2	756	0
		B	4570	0	382	0				
3	11	A	2974	0	312	0	5580	0	551	0

		B	2606	0	239	0				
3	12	A	447	0	12	0	712	0	22	0
		B	265	0	10	0				

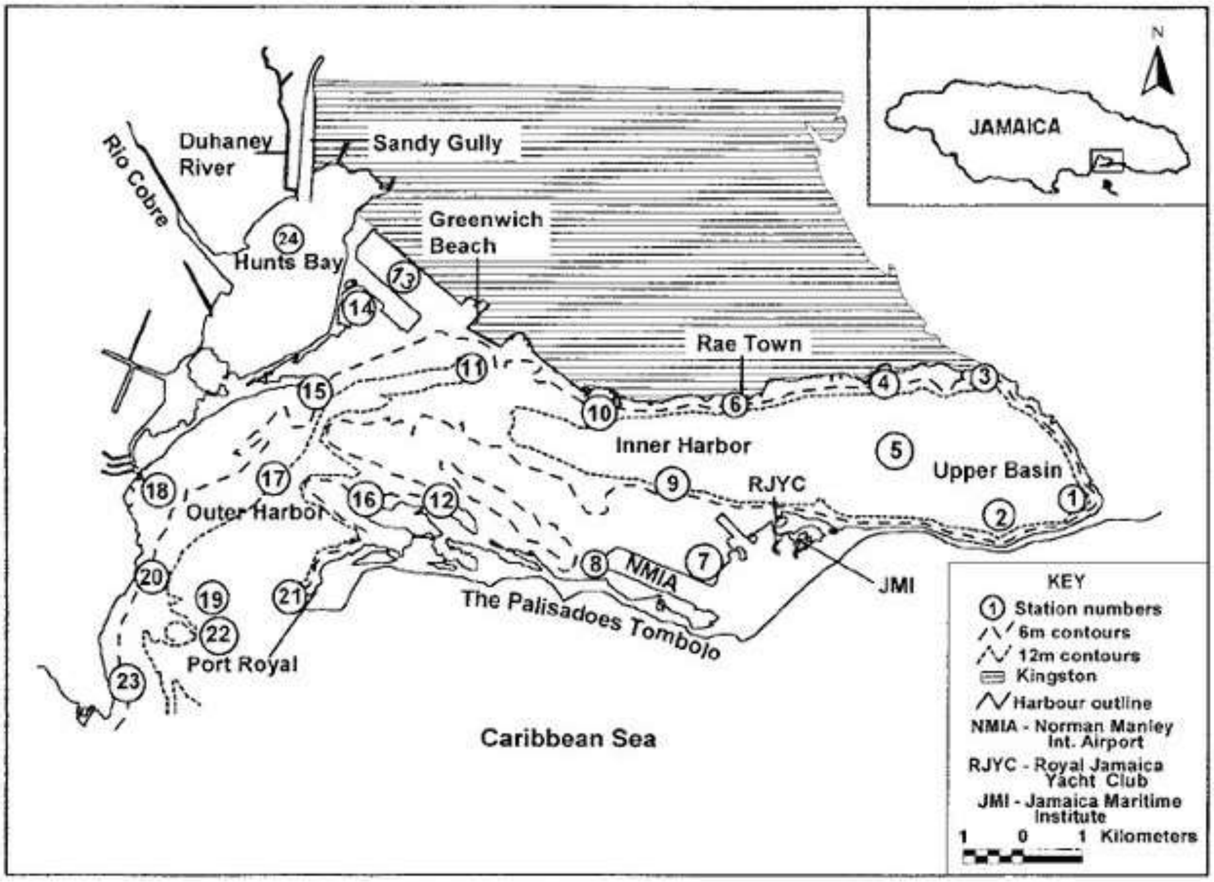


Figure 8.7 Map of the study area showing the major features and the stations sampled. (Dunbar and Webber 2003)

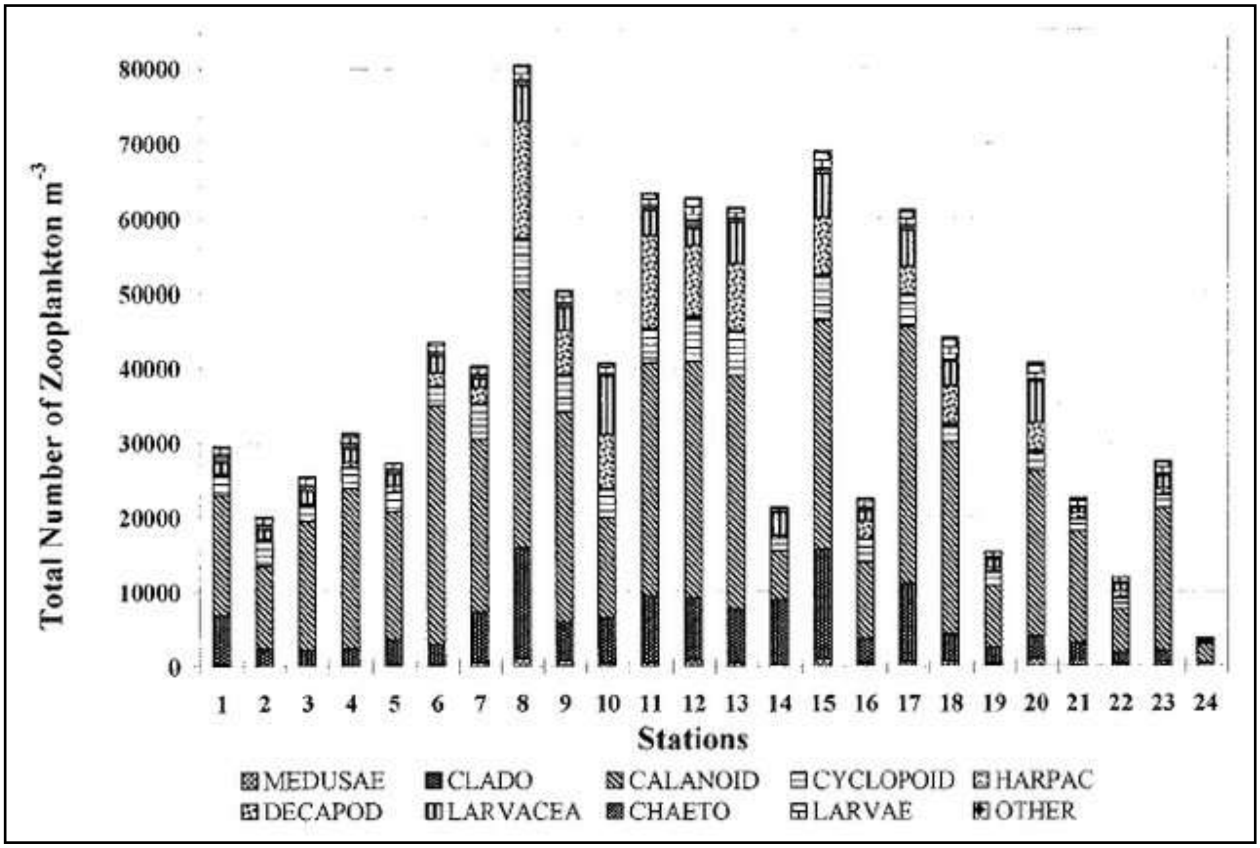


Figure 8.8 Mean total number of zooplankton m - 3 at each station for the sampling period December 1993–February 1995. (Dunbar and Webber 2003)

Figure 8.9 Satellite image of the location of the six sample stations (yellow pins) used in the present study showing Kingston Harbour, with Port Royal at bottom left and tip of Manley International airport runway at bottom far right. Northeast refuge Cay in centre is Station 5. (Image from Google Earth). (Aiken et al., 2009)

Table 8.8 List of all species found in present study with notes on trophic relationships (feeding ecology) (Aiken, 2009)

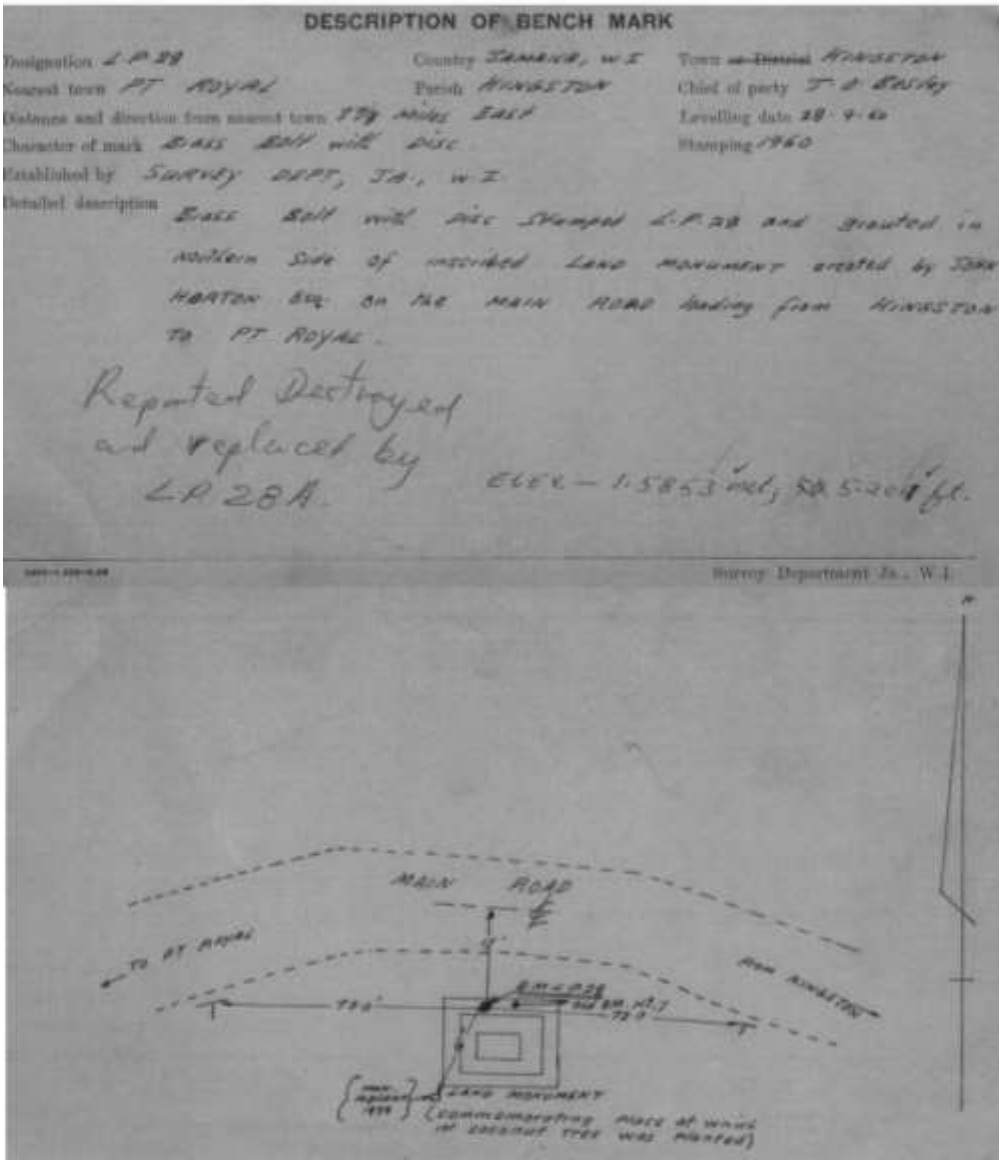
VERTEBRATES			INVERTEBRATES		OTHER
Scientific (common) Names	**Family**	**Feeding Guild**	**Scientific Name**	**Common Name**	
Scorpaena plumieri (spotted scorpoinfish)	Scorpaenidae	Piscivore	*Lytechinus sp*	Green Sea Urchin	*Halimeda sp*
Archosargus rhomboidalis (sea bream)	Sparidae	Herbivore	*Callinectes ornatus*	Green swimming crab	*Dictyota sp*
Eucinostomus gula (silver jenny)	Gerreidae	Zoobenthivore	*Holothuroidae*	Sea Cucumbers	*Caulerpa sp*
Urolophus jamaicensis (yellowspotted stingray)	Dasyatidae	Zoobenthivore	*Callinectes apidus (exasperatus?)*	Blue swimming crab	*Thalassia sp*
Diodon holacanthus (balloonfish)	Diodontidae	Zoobenthivore	*Penaeus schmitti*	Southern White Shrimp	*Gracillaria*
Rypticus saponaceus (greater soapfish)	Grammistidae	Piscivore	*Oreaster reticulatus*	Reticulated starfish	
Ocyurus chrysurus (yellowtail snapper)	Lutjanidae	Piscivore	*Lytechinus variegatus*	Green sea urchin	
Haemulon sciurus (bluestriped grunt)	Haemulidae	Zoobenthivore	*Luidia clathrata*	Striped sea star	
Lutjanus synagris (lane snapper)	Lutjanidae	Piscivore	*Actinopyga sp*	Sea Cucumber	
Diodon hystrix (porcupine fish)	Diodontidae	Piscivore	*Actinopyga agassizii*	Five toothed sea cucumber	
Sphoeroides testudineus (checkered puffer)	Tetraodontidae	Piscivore	*Penaeus?*	Grass shrimp	
Lutjanus griseus (grey snapper, mangrove snapper)	Lutjanidae	Piscivore	*Aplysia dactylomela*	Sea hare	
Umbrina coroides (sand drum)	Sciaenidae	Zoobenthivore	*Fasciolaria tulipa*	Tulip Shell	
Haemulon aurolineatum (tomtate grunt)	Haemulidae	Zoobenthivore	*Ecteinascidia turbinata*	Mangrove tunicate	
Gerres cinereus (yellowfin mojarra)	Gerreidae	Zoobenthivore			
Odontoscion dentex (reef croaker)	Sciaenidae	Zoobenthivore			
Holocentrus ascensionis (longjaw squirrel fish)	Holocentridae	Zoobenthivore			
Lutjanus apodus (schoolmaster snapper)	Lutjanidae	Piscivore			
Lutjanus analis (mutton snapper0	Lutjanidae	Piscivore			
Chilomycterus antillarum (web burrfish)	Diodontidae	Zoobenthivore			
Bothus ocellatus (eyed flounder)	Bothidae	Omnivore			
Hippocampus erectus (lined seahorse)	Sygnathididae	Planktivore			
Haemulon bonariense (black grunt)	Haemulidae	Omnivore			
Epinephelus itajara (goliath grouper)	Serranidae	Piscivore			
Sparisoma chrysopterum (redtail parrot)	Scaridae	Herbivore			
Serranus tabacarius (tobaccofish)	Serranidae	Zoobenthivore			
Monacanthus ciliatus (fringed filefish)	Monacanthidae	Zoobenthivore			
Cantherinus pullus (orangespotted filefish)	Monacanthidae	Zoobenthivore			

8.3 Appendix 3: Obstacle Limitation Surface

8.3.1 LiDar GCP Static Data

8.3.2 Descriptions of Known Control Marks

LP28



DESCRIPTION OF BENCH MARK

Designation L.P.28
Country JAMAICA, W.I.
Town KINGSTON
Nearest town PT ROYAL
Parish KINGSTON
Chief of party J. A. Bailey
Distance and direction from nearest town 3¾ miles EAST
Levelling date 28 · 9 · 60
Character of mark BRASS BOLT with DISC
Stamping 1960
Established by SURVEY DEPT, JA., W.I.
Detailed description BRASS BOLT with DISC STAMPED L.P.28 and grouted in northern side of inscribed LAND MONUMENT erected by JOHN HARTON ESQ. on the MAIN ROAD leading from KINGSTON TO PT ROYAL.

Reported Destroyed and replaced by LP 28A.

ELEV. – 1.5853 met, 5.20 ft.

Survey Department Ja., W.I.

STATION MARK

Parish: Kingston	**Name:---**	**No.: 537L**
Date established: Nov-29-2016	**Description of mark**	**Diagram of mark**
Ellipsoid: WGS 84	Mark is an aluminium disc	
Projection: Lambert Conical	grouted flush in sidewalk.	
Grid coordinates	The mark is stamped with	
E= 770507.045 m	the number 537L on it. It is	
N= 646543.532 m	intervisible with 538L. It is at	
Orthometric Height: 1.230m *	same road centreline level.	
Geographic coordinates		
φ = N17°58'07.22619"		
λ = W76°48'23.03240"		
Ellipsoidal height:-12.727m	F/B No:…T06/12 **pg.---79**	**Height of top of mark above G.L:** 0.00m

METHOD OF APPROACH

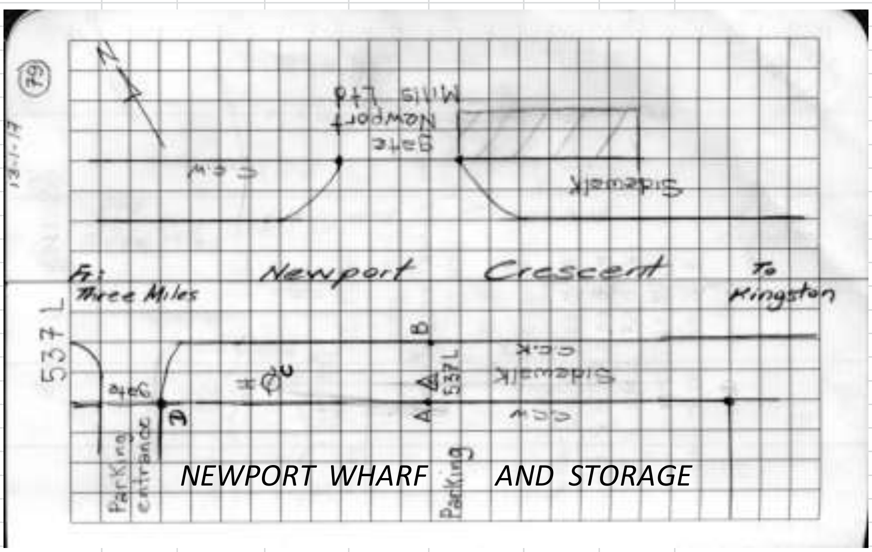
The mark is located on Newport Crescent in Kingston approximately 30 metres south east of the gate to parking area of Newport Wharf and Storage. See sketch.

537L to	A =0.63m-----------	Concrete wall
	B =1.97m-----------	Concrete kerb
	C =10.33m-----------	Fire hydrant
	D =13.33m------------	Concrete wall corner

1:12500 map sheet: 106A

** Note: Orthometric height was obtained by means of Spirit levelling*

SKETCH



Name :.. No. BM LS28

Station Mark	Sited by :	Date:	Diagram of Mark
	Built by:	Date: 06/10/04	

Description of Approach :

Across from Passagefort Hosuing scheme, mark is on the island at the intersection of Portmore Parkway & Dawkins Dr.

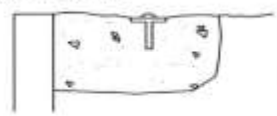
Grid Coordinate (JAD2001)
647101.256N 763907.308E
Orthometric Height: 2.0725m

Geographic Coordinate (WGS84)
Latitude: N17°58'25.55491"
Longitude: W76°52'07.32242"
Ellipsoidal Height: -11.929m

Field Book No. SDT14/00 Page 19

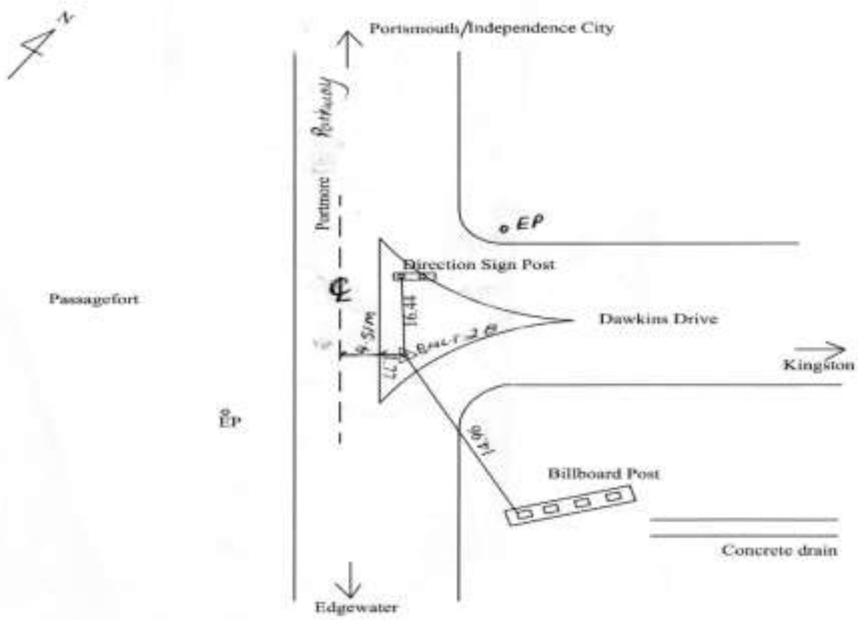
Approx. Co-ords Grid/Geog.................... Hgt..........m

Diagram of Mark



Description of Mark

Brass bolt set in concrete



NB: Sketch Not Drawn to scale
Distances are in metres

STATION MARK

Parish: Kingston	Name:---	No.: 538L
Date established: Nov-29-2016	**Description of mark**	**Diagram of mark**
Ellipsoid: WGS 84	Mark is an aluminium disc.	
Projection: Lambert Conical	It is grouted flush in sidewalk.	
Grid coordinates	The mark is stamped with	
E= 770475.146 m	the number 538L on it. It is	
N= 646567.275 m	intervisible with 537L and is	
Orthometric Height: 1.290m *	approximetley 0.20m above	
Geographic coordinates	road centreline level.	
φ =N17°58'07.99957"		
λ =W76°48'24.11570"		
Ellipsoidal height:-12.667m	F/B No:…T06/12 pg.---80	**Height of top of mark above G.L:** 0.00m

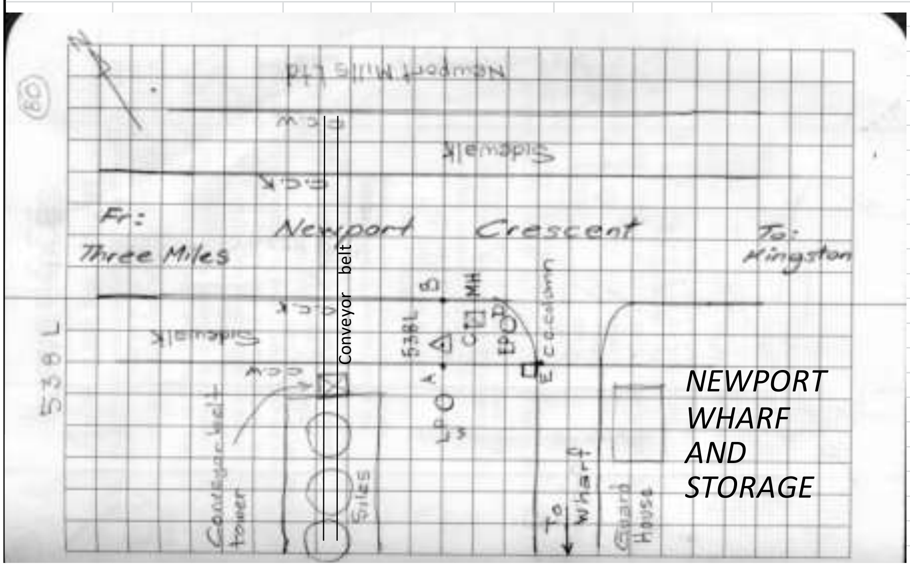
METHOD OF APPROACH

The mark is located on Newport Crescent in Kingston approximately 30 metres south east of the overhead conveyor belt and approximately 4 metres from gate post. See sketch.

538L to	A =0.47m-----------	Concrete wall
	B =2.25m-----------	Concrete kerb
	C =0.58m-----------	Manhole
	D =3.02m--------------	Utility pole
	E =4.04m--------------	Concrete column

1:12500 map sheet:	106A	** Note: Orthometric height was obtained by means of Spirit levelling*

SKETCH



Name :.. No. BM LS25

Station Mark	Sited by :	Date:	Diagram of Mark
	Built by:	Date: 06/10/04	

Description of Approach :

Travelling from Naggo Head towards Old Braeton, mark is located at first traffic light controlled intersection after crossing intersection onto Braeton Rd. mark is on R.H.S. of road behind bridgewall.

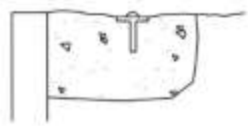
Grid Coordinate (JAD2001)
645063.645N 760753.685E
Orthometric Height: 5.1831m

Geographic Coordinate (WGS84)
Latitude: N17°57'19.34358"
Longitude: W76°53'54.54475"
Ellipsoidal Height: N/A

Field Book No. SDT 14/00 Page 17

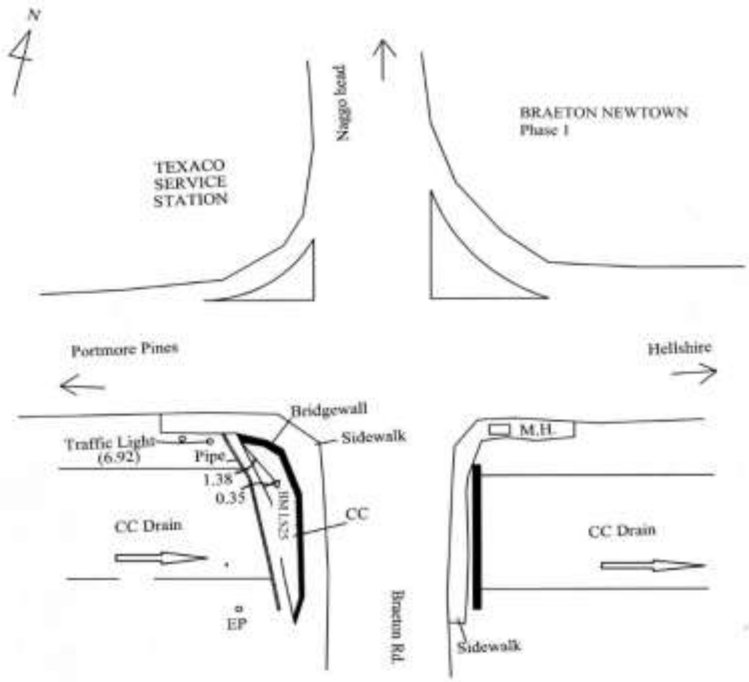
Approx. Co-ords Grid/Geog .... Hgt......... m

Diagram of Mark

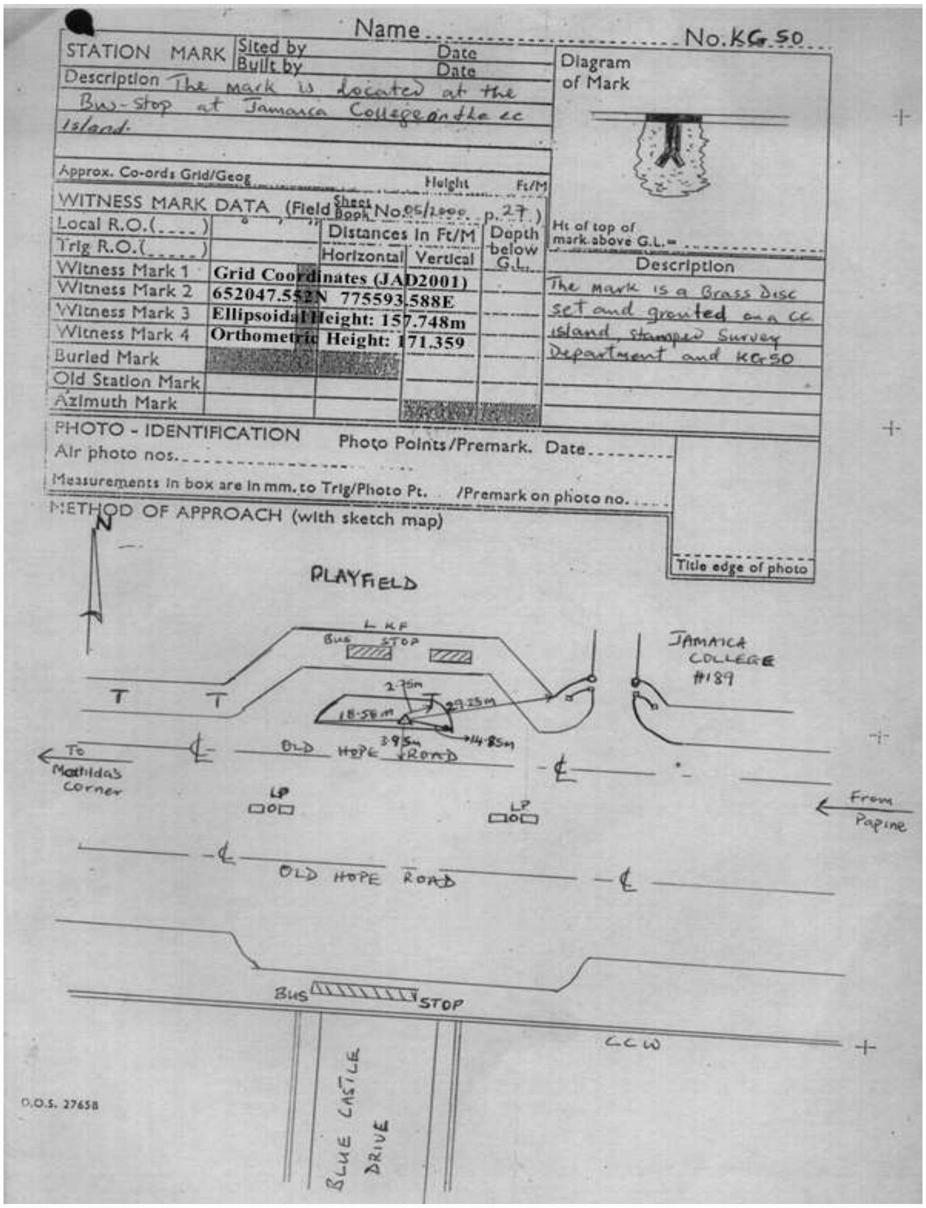


Description of Mark

Brass bolt set in CC



NB: Sketch Not Drawn to scale
Distances are in metres



STATION MARK | Sited by ... Date | Built by ... Date

Name .... No. KG 50

Description: The mark is located at the Bus-Stop at Jamaica College on the cc island.

Diagram of Mark

Approx. Co-ords Grid/Geog ... Height ... Ft/M

WITNESS MARK DATA (Field Sheet/Book No. 05/2000 p. 27)

Ht of top of mark above G.L. =

		Distances in Ft/M		Depth below G.L.	Description
Local R.O.(.....)		Horizontal	Vertical		
Trig R.O.(.....)					
Witness Mark 1	Grid Coordinates (JAD2001)				The mark is a Brass Disc
Witness Mark 2	652047.552N 775593.588E				set and grouted on a cc
Witness Mark 3	Ellipsoidal Height: 157.748m				island, stamped Survey
Witness Mark 4	Orthometric Height: 171.359				Department and KG50
Buried Mark					
Old Station Mark					
Azimuth Mark					

PHOTO - IDENTIFICATION — Photo Points/Premark. Date ....

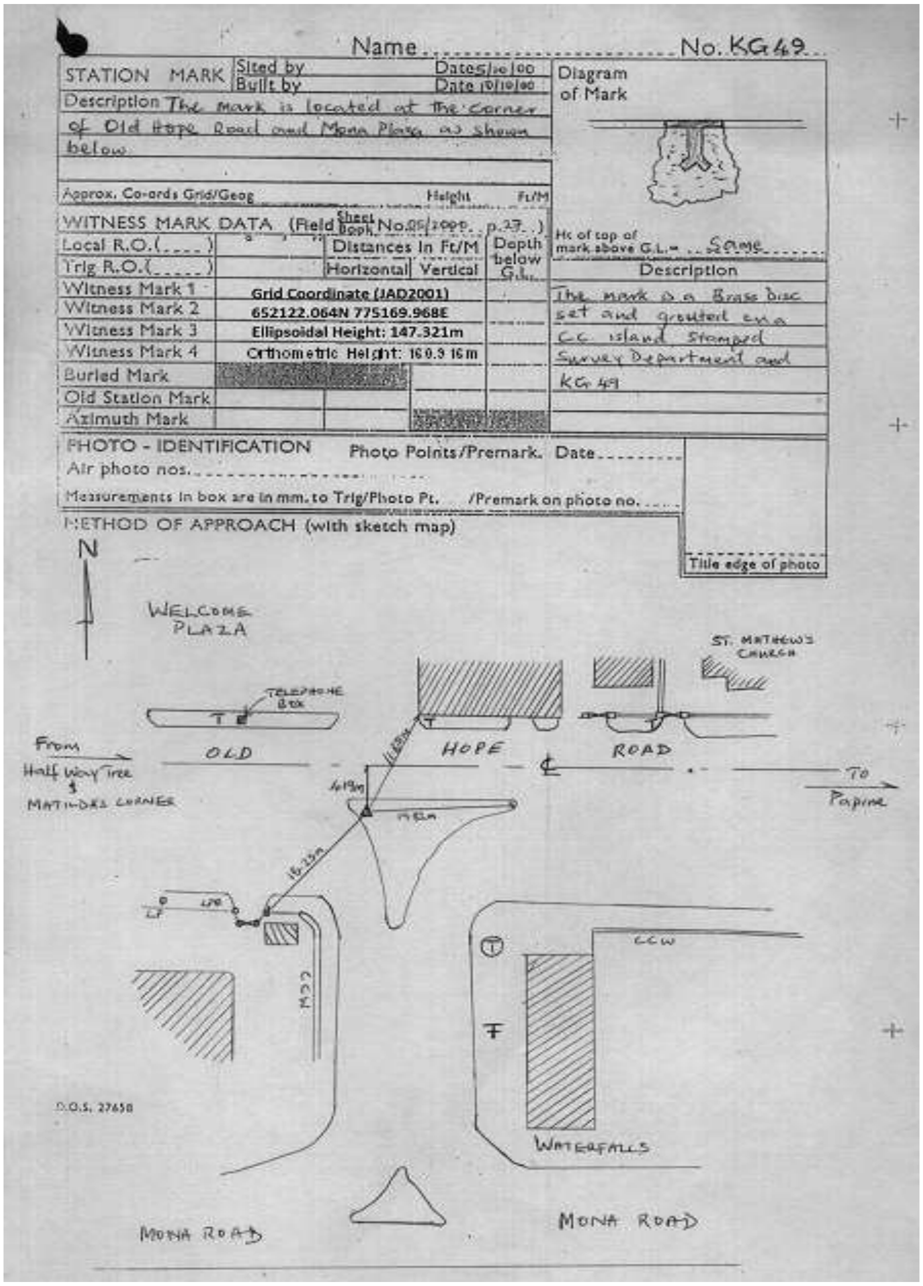
Air photo nos. ....

Measurements in box are in mm. to Trig/Photo Pt. ... /Premark on photo no. .....

Title edge of photo

METHOD OF APPROACH (with sketch map)

D.O.S. 27658



Name .... No. KG49

STATION MARK — Sited by — Date 5/10/00
Built by — Date 10/10/00

Description: The mark is located at the corner of Old Hope Road and Mona Plaza as shown below

Approx. Co-ords Grid/Geog — Height Ft/M

Diagram of Mark

WITNESS MARK DATA (Field Sheet/Book No. 05/2000 p.27)

		Distances in Ft/M Horizontal	Vertical	Depth below G.L.
Local R.O.( )				
Trig R.O.( )				
Witness Mark 1	Grid Coordinate (JAD2001)			
Witness Mark 2	652122.064N 775169.968E			
Witness Mark 3	Ellipsoidal Height: 147.321m			
Witness Mark 4	Orthometric Height: 160.916m			
Buried Mark				
Old Station Mark				
Azimuth Mark				

Ht of top of mark above G.L. = Same

Description: The mark is a Brass disc set and grouted on a C.C. island stamped Survey Department and KG 49

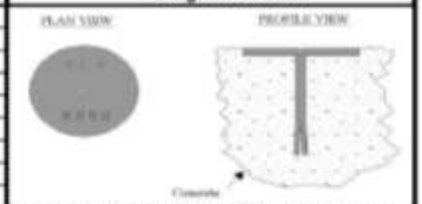
PHOTO - IDENTIFICATION Photo Points/Premark. Date ....
Air photo nos. ....
Measurements in box are in mm. to Trig/Photo Pt. /Premark on photo no. .....

Title edge of photo

METHOD OF APPROACH (with sketch map)

STATION MARK

Parish: Kingston	**Name:**---	**No.: 289 L**
Date established: 22-11-06	**Description of mark**	**Diagram of mark**
Ellipsoid: WGS 84	Mark is a brass disc set and	
Projection: Lambert Conic	grouted in the concrete base	
Grid coordinates	of flag pole in the Habour View	
E= 779651.836m	round-a-bout with No 289L	
N= 644430.796m	stamped on it.	
Orthometric Height: 7.667m SL		
Geographic coordinates		
φ = 17°56'58.12714"N	**F/B No:T08/06** **p..3**	
λ = 76°43'12.33956"W		
Ellipsoidal height: -6.652m		**Height of top of mark above G.L:** 0.12 m



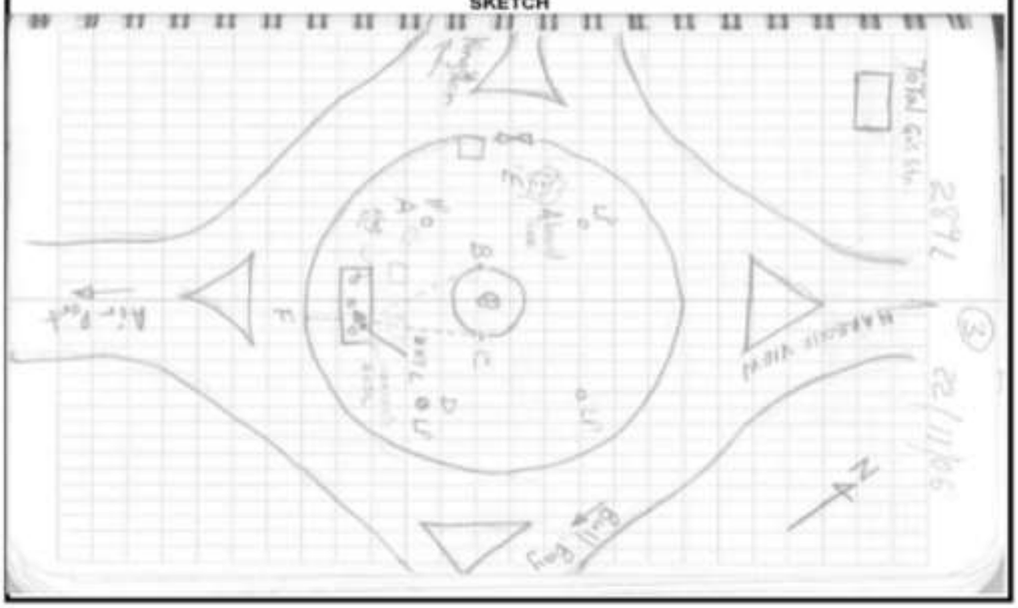
METHOD OF APPROACH

The mark is located in the Habour View round-a-bout. Enter the round-a-bout through the gate, which is on the western side, the mark is located on the RHS (the south western side of the round-a-bout) on top of the concrete flag pole base. Mark can be seen as per sketch.

289L to	A = 11.05m	Iron Peg
	B = 15.70m	CC Structure
	C = 15.60m	CC Structure
	D = 11.94m	Light Pole
	E = 27.38m	Almond Tree
	F = 9.16m	Concrete Kerb

1:12500 map sheet: Sheet South of 106B

SKETCH



LP29

DESCRIPTION OF BENCH MARK

Designation L.P. 29
Country JAMAICA, W.I.
Town ~~or District~~ KINGSTON

Nearest town PT ROYAL
Parish KINGSTON
Chief of party J. O. Besley

Distance and direction from nearest town 2¼ miles east
Levelling date 27.9.60

Character of mark Brass Bolt with Disc.
Stamping 1960

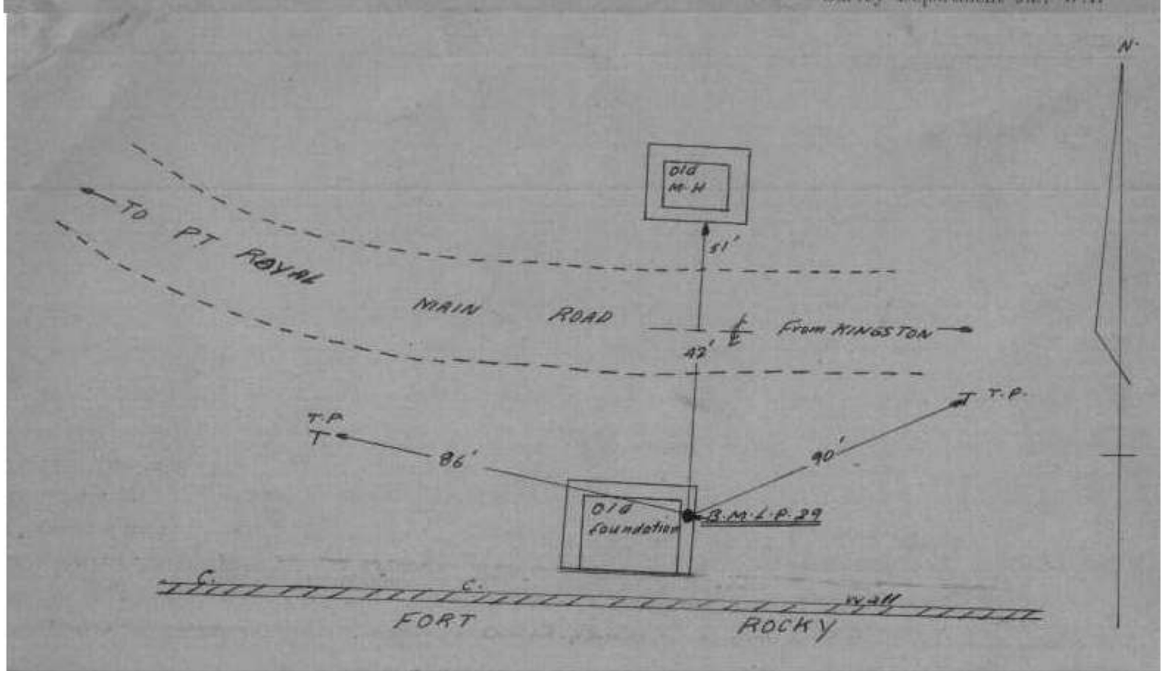
Established by SURVEY DEPT, JAMAICA, W.I.

Detailed description
Brass Bolt with Disc Stamped and grouted in N.E. corner of old foundation north of FORT ROCKY on the main ROAD from PT ROYAL. TO KINGSTON.

ELEV — 1.4859 met., 4.875 ft.

2499—1,000—9,58

Survey Department Ja., W.I.



8.3.3 Network Adjustment Report

8.3.3.1 *Julian Day 014*

8.3.3.2 *Adjustment Settings*

Set-Up Errors

GNSS

Error in Height of Antenna: 0.000 m

Centering Error: 0.000 m

Covariance Display

Horizontal:

Propagated Linear Error [E]: U.S.

Constant Term [C]: 0.000 m

Scale on Linear Error [S]: 1.960

Three-Dimensional

Propagated Linear Error [E]: U.S.

Constant Term [C]: 0.000 m

Scale on Linear Error [S]: 1.960

8.3.3.3 *Adjustment Statistics*

Number of Iterations for Successful Adjustment: 2

Network Reference Factor: 1.00

Chi Square Test (95%): Passed

Precision Confidence Level: 95%

Degrees of Freedom: 15

Post Processed Vector Statistics

Reference Factor: 1.00

Redundancy Number: 15.00

A Priori Scalar: 0.67

8.3.3.4 *Adjusted Grid Coordinates*

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Fixed
289L	779651.836	N/A	644430.796	N/A	7.667	N/A	NEe
GCP 1	766999.524	0.003	643122.899	0.002	2.063	0.008	
GCP 2	771182.242	0.003	643038.233	0.002	1.218	0.007	
GCP 3	774660.153	0.002	643247.131	0.002	4.556	0.006	
GCP 4	779665.122	0.002	644422.863	0.001	7.520	0.004	
GCP 5	783756.226	0.003	643514.387	0.002	2.509	0.007	
GCP 7	780340.657	0.002	645270.463	0.002	26.833	0.004	
GCP 8	781257.593	0.002	649079.969	0.003	272.427	0.006	

8.3.3.5 *Adjusted Geodetic Coordinates*

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Fixed
289L	N17°56'58.12714"	W76°43'12.33956"	-8.668	N/A	NEe
GCP 1	N17°56'16.07487"	W76°50'22.34214"	-14.126	0.008	
GCP 2	N17°56'13.18878"	W76°48'00.21313"	-15.132	0.007	
GCP 3	N17°56'19.85145"	W76°46'02.02257"	-11.841	0.006	
GCP 4	N17°56'57.86846"	W76°43'11.88847"	-8.816	0.004	
GCP 5	N17°56'28.10434"	W76°40'52.91357"	-13.884	0.007	
GCP 7	N17°57'25.40411"	W76°42'48.88728"	10.582	0.004	
GCP 8	N17°59'29.26580"	W76°42'17.51962"	256.512	0.006	

8.3.3.6 *Error Ellipse Components*

Point ID	Semi-major axis (Meter)	Semi-minor axis (Meter)	Azimuth
GCP 1	0.004	0.003	71°
GCP 2	0.003	0.003	74°
GCP 3	0.003	0.002	69°
GCP 4	0.002	0.001	93°
GCP 5	0.004	0.002	96°
GCP 7	0.003	0.002	1°
GCP 8	0.004	0.003	4°

8.3.3.7 *Adjusted GPS Observations*

Observation ID		Observation	A-posteriori Error	Residual	Standardized Residual
GCP 1 --> GCP 2 (PV11)	Az.	91°12'33"	0.106 sec	0.109 sec	2.275
	ΔHt.	-1.006 m	0.007 m	-0.004 m	-1.011
	Ellip Dist.	4183.572 m	0.003 m	-0.001 m	-0.478
GCP 3 --> GCP 1 (PV1)	Az.	269°08'34"	0.058 sec	-0.058 sec	-1.682
	ΔHt.	-2.285 m	0.007 m	-0.003 m	-0.804
	Ellip Dist.	7661.632 m	0.003 m	0.002 m	1.229
289L --> GCP 4 (PV6)	Az.	120°55'43"	16.555 sec	-1.862 sec	-0.677
	ΔHt.	-0.148 m	0.004 m	0.001 m	1.526
	Ellip Dist.	15.474 m	0.002 m	0.000 m	0.435
289L --> GCP 5 (PV4)	Az.	102°40'22"	0.091 sec	0.021 sec	0.536
	ΔHt.	-5.216 m	0.007 m	-0.004 m	-1.509
	Ellip Dist.	4205.449 m	0.003 m	0.000 m	-0.395
GCP 4 --> GCP 5 (PV7)	Az.	102°36'24"	0.092 sec	-0.024 sec	-0.527
	ΔHt.	-5.068 m	0.007 m	0.005 m	1.508
	Ellip Dist.	4190.757 m	0.003 m	0.001 m	0.433
GCP 3 --> GCP 2 (PV12)	Az.	266°38'05"	0.105 sec	0.049 sec	1.202
	ΔHt.	-3.291 m	0.006 m	0.002 m	0.823
	Ellip Dist.	3484.177 m	0.002 m	-0.001 m	-1.417
289L --> GCP 7 (PV5)	Az.	39°27'01"	0.336 sec	-0.040 sec	-0.565
	ΔHt.	19.251 m	0.004 m	0.001 m	1.410
	Ellip Dist.	1086.054 m	0.002 m	0.000 m	0.703
GCP 8 --> GCP 7 (PV9)	Az.	193°37'29"	0.116 sec	-0.009 sec	-0.175
	ΔHt.	-245.930 m	0.006 m	-0.004 m	-1.386
	Ellip Dist.	3918.303 m	0.003 m	0.001 m	0.699
289L --> GCP 8 (PV8)	Az.	19°08'26"	0.095 sec	0.007 sec	0.157
	ΔHt.	265.180 m	0.006 m	-0.003 m	-1.307
	Ellip Dist.	4918.664 m	0.003 m	-0.001 m	-0.515
289L --> GCP 2 (PV10)	Az.	260°44'58"	0.050 sec	0.037 sec	1.078
	ΔHt.	-6.464 m	0.007 m	0.000 m	0.047
	Ellip Dist.	8583.308 m	0.003 m	0.002 m	0.937

289L --> GCP 1 (PV2)	**Az.**	264°11'05"	0.038 sec	-0.021 sec	-0.770
	ΔHt.	-5.458 m	0.008 m	-0.001 m	-0.142
	Ellip Dist.	12719.726 m	0.003 m	-0.001 m	-0.666
289L --> GCP 3 (PV3)	**Az.**	256°44'47"	0.071 sec	-0.007 sec	-0.300
	ΔHt.	-3.173 m	0.006 m	0.000 m	0.098
	Ellip Dist.	5130.101 m	0.002 m	0.000 m	-0.273

8.3.3.8 *Covariance Terms*

From Point	To Point		Components	A-posteriori Error	Horiz. Precision (Ratio)	3D Precision (Ratio)
289L	GCP 2	Az.	260°44'58"	0.050 sec	1 : 3292563	1 : 3293468
		ΔHt.	-6.464 m	0.007 m		
		ΔElev.	-6.449 m	0.007 m		
		Ellip Dist.	8583.308 m	0.003 m		
289L	GCP 4	Az.	120°55'43"	16.571 sec	1 : 9442	1 : 9459
		ΔHt.	-0.148 m	0.004 m		
		ΔElev.	-0.147 m	0.004 m		
		Ellip Dist.	15.474 m	0.002 m		
289L	GCP 8	Az.	19°08'26"	0.095 sec	1 : 1672488	1 : 1662190
		ΔHt.	265.180 m	0.006 m		
		ΔElev.	264.760 m	0.006 m		
		Ellip Dist.	4918.664 m	0.003 m		
GCP 1	289L	Az.	84°08'52"	0.038 sec	1 : 4410143	1 : 4411058
		ΔHt.	5.458 m	0.008 m		
		ΔElev.	5.534 m	0.008 m		
		Ellip Dist.	12719.726 m	0.003 m		
GCP 1	GCP 2	Az.	91°12'33"	0.106 sec	1 : 1582733	1 : 1582766
		ΔHt.	-1.006 m	0.007 m		
		ΔElev.	-0.916 m	0.007 m		
		Ellip Dist.	4183.572 m	0.003 m		
GCP 3	289L	Az.	76°43'55"	0.072 sec	1 : 2389766	1 : 2390335
		ΔHt.	3.173 m	0.006 m		
		ΔElev.	3.111 m	0.006 m		
		Ellip Dist.	5130.101 m	0.002 m		
GCP 3	GCP 1	Az.	269°08'34"	0.058 sec	1 : 2917768	1 : 2918438
		ΔHt.	-2.285 m	0.007 m		
		ΔElev.	-2.422 m	0.007 m		
		Ellip Dist.	7661.632 m	0.003 m		
GCP 3	GCP 2	Az.	266°38'05"	0.106 sec	1 : 1557165	1 : 1557716
		ΔHt.	-3.291 m	0.006 m		
		ΔElev.	-3.338 m	0.006 m		
		Ellip Dist.	3484.177 m	0.002 m		
GCP 5	289L	Az.	282°41'05"	0.091 sec	1 : 1425567	1 : 1425779
		ΔHt.	5.216 m	0.007 m		
		ΔElev.	5.158 m	0.007 m		
		Ellip Dist.	4205.449 m	0.003 m		
GCP 5	GCP 4	Az.	282°37'06"	0.093 sec	1 : 1389473	1 : 1389704
		ΔHt.	5.068 m	0.007 m		
		ΔElev.	5.011 m	0.007 m		
		Ellip Dist.	4190.757 m	0.003 m		
GCP 7	289L	Az.	219°27'08"	0.337 sec	1 : 565839	1 : 563044
		ΔHt.	-19.251 m	0.004 m		
		ΔElev.	-19.166 m	0.004 m		
		Ellip Dist.	1086.054 m	0.002 m		

GCP 7	GCP 8	**Az.**	13°37'19"	0.116 sec	1 : 1317689	1 : 1302776
		ΔHt.	245.930 m	0.006 m		
		ΔElev.	245.595 m	0.006 m		
		Ellip Dist.	3918.303 m	0.003 m		

8.3.4 Network Adjustment Report

8.3.4.1 Julian Day 017

8.3.4.1.1 Adjustment Settings

Set-Up Errors

GNSS

Error in Height of Antenna: 0.000 m

Centering Error: 0.000 m

Covariance Display

Horizontal:

Propagated Linear Error [E]: U.S.

Constant Term [C]: 0.000 m

Scale on Linear Error [S]: 1.960

Three-Dimensional

Propagated Linear Error [E]: U.S.

Constant Term [C]: 0.000 m

Scale on Linear Error [S]: 1.960

8.3.4.1.2 Adjustment Statistics

Number of Iterations for Successful Adjustment: 2

Network Reference Factor: 1.00

Chi Square Test (95%): Passed

Precision Confidence Level: 95%

Degrees of Freedom: 67

Post Processed Vector Statistics

Reference Factor:	1.00
Redundancy Number:	67.00
A Priori Scalar:	9.81

8.3.4.1.3 Control Coordinate Comparisons

Values shown are control coordinates minus adjusted coordinates.

Point ID	ΔEasting (Meter)	ΔNorthing (Meter)	ΔElevation (Meter)	ΔHeight (Meter)
NLA 537L	0.009	0.031	-0.018	N/A

8.3.4.1.4 Adjusted Grid Coordinates

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Fixed
GCP 10	774963.818	0.027	649163.334	0.036	69.278	0.069	
GCP 11	775181.701	0.031	647012.686	0.024	12.764	0.071	
GCP 12	771297.139	0.022	646800.796	0.018	4.442	0.040	
GCP 13	771796.504	0.035	651017.947	0.021	77.378	0.080	
GCP 14	769108.286	0.019	647643.744	0.014	1.764	0.036	
GCP 15	769410.658	0.033	653508.292	0.031	50.337	0.080	
GCP 16	766070.044	0.039	652690.183	0.044	4.582	0.082	
GCP 6	777262.992	0.036	646466.540	0.031	3.234	0.082	
GCP 9	775479.955	0.026	652061.433	0.015	168.411	0.057	
KG 49	775169.968	N/A	652122.064	N/A	160.916	N/A	NEe
NLA 537L	770507.036	0.021	646543.501	0.015	1.248	0.043	
NLA 538L	770475.146	N/A	646567.275	N/A	1.290	N/A	NEe

8.3.4.1.5 Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Fixed
GCP 10	N17°59'32.27039"	W76°45'51.44817"	53.202	0.069	
GCP 11	N17°58'22.30912"	W76°45'44.13577"	-3.434	0.071	
GCP 12	N17°58'15.56665"	W76°47'56.17023"	-11.770	0.040	
GCP 13	N18°00'32.71634"	W76°47'39.03911"	61.339	0.080	
GCP 14	N17°58'43.05776"	W76°49'10.53524"	-14.401	0.036	
GCP 15	N18°01'53.79870"	W76°49'00.06095"	34.384	0.080	

GCP 16	N18°01'27.28710"	W76°50'53.66053"	-11.385	0.082	
GCP 6	N17°58'04.45472"	W76°44'33.42366"	-12.971	0.082	
GCP 9	N18°01'06.51254"	W76°45'33.77621"	152.496	0.057	
KG 49	N18°01'08.49762"	W76°45'44.31195"	144.995	N/A	NEe
NLA 537L	N17°58'07.22519"	W76°48'23.03269"	-14.968	0.043	
NLA 538L	N17°58'07.99956"	W76°48'24.11569"	-14.926	N/A	NEe

8.3.4.1.6 Error Ellipse Components

Point ID	Semi-major axis (Meter)	Semi-minor axis (Meter)	Azimuth
GCP 10	0.045	0.033	6°
GCP 11	0.039	0.030	89°
GCP 12	0.028	0.023	89°
GCP 13	0.044	0.026	92°
GCP 14	0.024	0.017	80°
GCP 15	0.041	0.037	64°
GCP 16	0.055	0.049	177°
GCP 6	0.045	0.038	99°
GCP 9	0.032	0.019	95°
NLA 537L	0.027	0.017	67°

8.3.4.1.7 Adjusted GPS Observations

Transformation Parameters

Azimuth Rotation: 0.761 sec **(95%)** 0.540 sec

Scale Factor: 1.00000155 **(95%)** 0.00000301

Observation ID		Observation	A-posteriori Error	Residual	Standardized Residual
NLA 538L --> GCP 15 (PV24)	Az.	351°20'27"	1.010 sec	5.853 sec	3.473
	ΔHt.	49.309 m	0.080 m	0.023 m	0.205
	Ellip Dist.	7022.157 m	0.027 m	-0.106 m	-3.940
NLA 537L --> NLA 538L (PV7)	Az.	306°45'52"	102.933 sec	27.078 sec	0.415
	ΔHt.	0.043 m	0.043 m	0.052 m	1.766
	Ellip Dist.	39.777 m	0.016 m	-0.019 m	-2.412
NLA 537L --> GCP 15 (PV22)	Az.	351°06'51"	0.896 sec	-0.551 sec	-0.849
	ΔHt.	49.352 m	0.082 m	-0.014 m	-0.231
	Ellip Dist.	7050.546 m	0.026 m	0.040 m	1.871
KG 49 --> GCP 15 (PV21)	Az.	283°36'25"	0.999 sec	1.104 sec	1.582
	ΔHt.	-110.612 m	0.080 m	0.001 m	0.016
	Ellip Dist.	5923.779 m	0.029 m	0.025 m	1.261
NLA 537L --> GCP 13 (PV18)	Az.	16°08'10"	1.536 sec	0.141 sec	0.113
	ΔHt.	76.308 m	0.084 m	0.027 m	0.353
	Ellip Dist.	4656.536 m	0.023 m	0.027 m	1.432
NLA 537L --> GCP 14 (PV4)	Az.	308°14'54"	2.273 sec	-1.884 sec	-1.421
	ΔHt.	0.567 m	0.051 m	0.016 m	0.411
	Ellip Dist.	1779.614 m	0.017 m	0.002 m	0.141
KG 49 --> GCP 9 (PV26)	Az.	101°08'26"	9.882 sec	4.031 sec	1.173
	ΔHt.	7.500 m	0.057 m	0.001 m	0.043
	Ellip Dist.	315.860 m	0.026 m	0.002 m	0.169
GCP 16 --> GCP 15 (PV30)	Az.	76°17'11"	2.299 sec	-1.377 sec	-1.064
	ΔHt.	45.769 m	0.095 m	-0.023 m	-0.425
	Ellip Dist.	3439.326 m	0.038 m	-0.019 m	-0.844
KG 49 --> NLA 537L (PV11)	Az.	219°57'53"	0.453 sec	-0.147 sec	-0.501
	ΔHt.	-159.963 m	0.043 m	0.066 m	0.931
	Ellip Dist.	7270.704 m	0.017 m	-0.003 m	-0.239
NLA 537L --> GCP 10 (PV3)	Az.	59°36'42"	1.347 sec	0.239 sec	0.241
	ΔHt.	68.170 m	0.072 m	-0.043 m	-0.894
	Ellip Dist.	5169.752 m	0.031 m	-0.003 m	-0.132
GCP 14 --> GCP 15 (PV23)	Az.	3°00'27"	1.156 sec	-0.623 sec	-0.440
	ΔHt.	48.785 m	0.085 m	-0.022 m	-0.172
	Ellip Dist.	5872.328 m	0.029 m	0.029 m	0.863
NLA 538L --> GCP 14 (PV2)	Az.	308°16'56"	2.062 sec	0.679 sec	0.776
	ΔHt.	0.524 m	0.036 m	-0.013 m	-0.813
	Ellip Dist.	1739.851 m	0.015 m	0.002 m	0.432
NLA 537L --> GCP 9 (PV27)	Az.	42°05'10"	0.705 sec	-0.381 sec	-0.413

	ΔHt.	167.464 m	0.066 m	0.011 m	0.127
	Ellip Dist.	7428.144 m	0.024 m	0.023 m	0.778
KG 49 --> GCP 10 (PV12)	Az.	184°03'34"	1.830 sec	0.130 sec	0.182
	ΔHt.	-91.793 m	0.069 m	0.021 m	0.773
	Ellip Dist.	2965.899 m	0.035 m	-0.004 m	-0.264
KG 49 --> GCP 14 (PV13)	Az.	233°37'01"	0.523 sec	-0.022 sec	-0.040
	ΔHt.	-159.396 m	0.036 m	0.039 m	0.721
	Ellip Dist.	7536.522 m	0.023 m	-0.012 m	-0.557
NLA 537L --> GCP 11 (PV6)	Az.	84°19'43"	0.970 sec	-0.227 sec	-0.270
	ΔHt.	11.535 m	0.073 m	-0.040 m	-0.648
	Ellip Dist.	4698.144 m	0.030 m	0.001 m	0.068
NLA 537L --> GCP 16 (PV32)	Az.	324°14'11"	0.983 sec	-0.161 sec	-0.231
	ΔHt.	3.583 m	0.083 m	-0.035 m	-0.641
	Ellip Dist.	7580.793 m	0.034 m	0.013 m	0.517
KG 49 --> GCP 13 (PV17)	Az.	251°57'02"	1.283 sec	-0.510 sec	-0.631
	ΔHt.	-83.656 m	0.080 m	0.008 m	0.161
	Ellip Dist.	3549.548 m	0.033 m	0.007 m	0.330
KG 49 --> NLA 538L (PV16)	Az.	220°16'40"	0.540 sec	-0.034 sec	-0.060
	ΔHt.	-159.921 m	0.000 m	0.004 m	0.076
	Ellip Dist.	7273.023 m	0.022 m	-0.013 m	-0.596
NLA 538L --> GCP 12 (PV9)	Az.	74°12'02"	4.470 sec	0.826 sec	0.525
	ΔHt.	3.155 m	0.040 m	0.001 m	0.043
	Ellip Dist.	854.518 m	0.023 m	0.002 m	0.188
KG 49 --> GCP 12 (PV10)	Az.	216°07'15"	0.830 sec	0.173 sec	0.183
	ΔHt.	-156.766 m	0.040 m	0.030 m	0.524
	Ellip Dist.	6581.380 m	0.026 m	-0.009 m	-0.338
KG 49 --> GCP 16 (PV31)	Az.	273°38'46"	0.871 sec	0.346 sec	0.512
	ΔHt.	-156.380 m	0.082 m	0.022 m	0.361
	Ellip Dist.	9117.626 m	0.032 m	0.007 m	0.295
GCP 14 --> GCP 12 (PV8)	Az.	111°07'05"	1.877 sec	-0.107 sec	-0.081
	ΔHt.	2.631 m	0.047 m	-0.010 m	-0.330
	Ellip Dist.	2345.553 m	0.024 m	-0.007 m	-0.404
KG 49 --> GCP 11 (PV15)	Az.	179°56'32"	1.196 sec	-0.173 sec	-0.180
	ΔHt.	-148.429 m	0.071 m	0.020 m	0.365
	Ellip Dist.	5109.383 m	0.020 m	0.005 m	0.336
KG 49 --> GCP 6 (PV14)	Az.	159°45'54"	1.116 sec	-0.115 sec	-0.122
	ΔHt.	-157.967 m	0.082 m	0.026 m	0.357
	Ellip Dist.	6030.388 m	0.027 m	0.004 m	0.173
GCP 11 --> GCP 13 (PV20)	Az.	319°52'11"	1.336 sec	0.048 sec	0.035
	ΔHt.	64.773 m	0.096 m	-0.034 m	-0.343
	Ellip Dist.	5244.196 m	0.033 m	-0.001 m	-0.042
GCP 11 --> GCP 9 (PV29)	Az.	3°27'16"	1.412 sec	0.005 sec	0.004
	ΔHt.	155.929 m	0.080 m	-0.023 m	-0.310
	Ellip Dist.	5057.541 m	0.021 m	0.003 m	0.187
NLA 537L --> GCP 6 (PV5)	Az.	90°42'46"	0.803 sec	0.173 sec	0.067
	ΔHt.	1.997 m	0.085 m	-0.035 m	-0.228

	Ellip Dist.	6756.383 m	0.035 m	-0.013 m	-0.305
GCP 6 --> GCP 9 (PV28)	Az.	342°24'11"	1.301 sec	-0.415 sec	-0.271
	ΔHt.	165.467 m	0.091 m	-0.015 m	-0.136
	Ellip Dist.	5872.133 m	0.028 m	0.009 m	0.284
GCP 16 --> GCP 10 (PV33)	Az.	111°40'41"	1.052 sec	0.083 sec	0.072
	ΔHt.	64.587 m	0.098 m	0.014 m	0.142
	Ellip Dist.	9567.528 m	0.038 m	0.011 m	0.275
GCP 9 --> GCP 13 (PV25)	Az.	254°15'28"	1.265 sec	-0.205 sec	-0.234
	ΔHt.	-91.156 m	0.086 m	-0.016 m	-0.269
	Ellip Dist.	3828.397 m	0.036 m	0.005 m	0.199
GCP 11 --> GCP 6 (PV1)	Az.	104°46'37"	2.108 sec	-0.079 sec	-0.105
	ΔHt.	-9.538 m	0.076 m	0.000 m	-0.003
	Ellip Dist.	2151.751 m	0.032 m	0.001 m	0.069
GCP 6 --> GCP 13 (PV19)	Az.	309°51'38"	1.004 sec	-0.008 sec	-0.005
	ΔHt.	74.311 m	0.106 m	-0.002 m	-0.012
	Ellip Dist.	7113.202 m	0.040 m	0.000 m	-0.002

From Point	To Point		Components	A-posteriori Error	Horiz. Precision (Ratio)	3D Precision (Ratio)
GCP 10	GCP 16	Az.	291°42'14"	1.181 sec	1 : 202880	1 : 202775
		ΔHt.	-64.587 m	0.098 m		
		ΔElev.	-64.696 m	0.098 m		
		Ellip Dist.	9567.543 m	0.047 m		
GCP 10	KG 49	Az.	4°03'31"	1.840 sec	1 : 81858	1 : 81460
		ΔHt.	91.793 m	0.069 m		
		ΔElev.	91.638 m	0.069 m		
		Ellip Dist.	2965.903 m	0.036 m		
GCP 10	NLA 537L	Az.	239°37'28"	1.370 sec	1 : 159464	1 : 159300
		ΔHt.	-68.170 m	0.072 m		
		ΔElev.	-68.030 m	0.072 m		
		Ellip Dist.	5169.760 m	0.032 m		
GCP 11	GCP 13	Az.	319°52'10"	1.435 sec	1 : 143093	1 : 143265
		ΔHt.	64.773 m	0.096 m		
		ΔElev.	64.614 m	0.096 m		
		Ellip Dist.	5244.204 m	0.037 m		
GCP 11	GCP 6	Az.	104°46'36"	2.180 sec	1 : 66067	1 : 65996
		ΔHt.	-9.538 m	0.076 m		
		ΔElev.	-9.530 m	0.076 m		
		Ellip Dist.	2151.754 m	0.033 m		
GCP 11	GCP 9	Az.	3°27'15"	1.482 sec	1 : 194369	1 : 192574
		ΔHt.	155.929 m	0.080 m		
		ΔElev.	155.647 m	0.080 m		
		Ellip Dist.	5057.549 m	0.026 m		
GCP 11	KG 49	Az.	359°56'31"	1.247 sec	1 : 209306	1 : 207262
		ΔHt.	148.429 m	0.071 m		
		ΔElev.	148.152 m	0.071 m		
		Ellip Dist.	5109.391 m	0.024 m		
GCP 11	NLA 537L	Az.	264°20'31"	1.027 sec	1 : 148433	1 : 148430
		ΔHt.	-11.535 m	0.073 m		
		ΔElev.	-11.515 m	0.073 m		
		Ellip Dist.	4698.151 m	0.032 m		
GCP 12	KG 49	Az.	36°06'34"	0.658 sec	1 : 331512	1 : 330846
		ΔHt.	156.766 m	0.040 m		
		ΔElev.	156.474 m	0.040 m		
		Ellip Dist.	6581.391 m	0.020 m		
GCP 13	GCP 9	Az.	74°14'48"	1.360 sec	1 : 101773	1 : 100966
		ΔHt.	91.156 m	0.086 m		
		ΔElev.	91.033 m	0.086 m		
		Ellip Dist.	3828.403 m	0.038 m		
GCP 14	GCP 12	Az.	111°07'05"	1.943 sec	1 : 91139	1 : 91128
		ΔHt.	2.631 m	0.047 m		
		ΔElev.	2.678 m	0.047 m		
		Ellip Dist.	2345.557 m	0.026 m		
GCP 14	GCP 15	Az.	3°00'26"	1.164 sec	1 : 186924	1 : 187484
		ΔHt.	48.785 m	0.085 m		

		ΔElev.	48.573 m	0.085 m		
		Ellip Dist.	5872.337 m	0.031 m		
GCP 14	KG 49	Az.	53°35'57"	0.417 sec	1 : 405175	1 : 404801
		ΔHt.	159.397 m	0.036 m		
		ΔElev.	159.152 m	0.036 m		
		Ellip Dist.	7536.533 m	0.019 m		
GCP 14	NLA 537L	Az.	128°14'38"	2.402 sec	1 : 101689	1 : 101711
		ΔHt.	-0.567 m	0.051 m		
		ΔElev.	-0.515 m	0.051 m		
		Ellip Dist.	1779.617 m	0.018 m		
GCP 15	GCP 16	Az.	256°17'45"	2.396 sec	1 : 87495	1 : 87724
		ΔHt.	-45.769 m	0.095 m		
		ΔElev.	-45.755 m	0.095 m		
		Ellip Dist.	3439.332 m	0.039 m		
GCP 6	GCP 13	Az.	309°51'37"	1.137 sec	1 : 157101	1 : 157015
		ΔHt.	74.311 m	0.106 m		
		ΔElev.	74.144 m	0.106 m		
		Ellip Dist.	7113.213 m	0.045 m		
GCP 6	GCP 9	Az.	342°24'11"	1.388 sec	1 : 176463	1 : 175077
		ΔHt.	165.467 m	0.091 m		
		ΔElev.	165.177 m	0.091 m		
		Ellip Dist.	5872.142 m	0.033 m		
GCP 6	KG 49	Az.	339°46'15"	1.196 sec	1 : 187604	1 : 185819
		ΔHt.	157.967 m	0.082 m		
		ΔElev.	157.682 m	0.082 m		
		Ellip Dist.	6030.398 m	0.032 m		
GCP 6	NLA 537L	Az.	270°43'56"	0.906 sec	1 : 174080	1 : 174071
		ΔHt.	-1.997 m	0.085 m		
		ΔElev.	-1.985 m	0.085 m		
		Ellip Dist.	6756.393 m	0.039 m		
KG 49	GCP 13	Az.	251°57'02"	1.336 sec	1 : 105037	1 : 104224
		ΔHt.	-83.656 m	0.080 m		
		ΔElev.	-83.538 m	0.080 m		
		Ellip Dist.	3549.554 m	0.034 m		
KG 49	GCP 15	Az.	283°36'24"	1.088 sec	1 : 185521	1 : 185935
		ΔHt.	-110.612 m	0.080 m		
		ΔElev.	-110.579 m	0.080 m		
		Ellip Dist.	5923.788 m	0.032 m		
KG 49	GCP 16	Az.	273°38'45"	0.992 sec	1 : 230956	1 : 230936
		ΔHt.	-156.380 m	0.082 m		
		ΔElev.	-156.334 m	0.082 m		
		Ellip Dist.	9117.640 m	0.039 m		
KG 49	GCP 9	Az.	101°08'25"	9.962 sec	1 : 12293	1 : 12199
		ΔHt.	7.500 m	0.057 m		
		ΔElev.	7.495 m	0.057 m		
		Ellip Dist.	315.860 m	0.026 m		
NLA 537L	GCP 13	Az.	16°08'10"	1.535 sec	1 : 188320	1 : 187702

		ΔHt.	76.308 m	0.084 m		
		ΔElev.	76.129 m	0.084 m		
		Ellip Dist.	4656.544 m	0.025 m		
NLA 537L	GCP 15	Az.	351°06'50"	1.018 sec	1 : 210363	1 : 210784
		ΔHt.	49.352 m	0.082 m		
		ΔElev.	49.089 m	0.082 m		
		Ellip Dist.	7050.557 m	0.034 m		
NLA 537L	GCP 16	Az.	324°14'10"	1.103 sec	1 : 184914	1 : 184881
		ΔHt.	3.583 m	0.083 m		
		ΔElev.	3.334 m	0.083 m		
		Ellip Dist.	7580.805 m	0.041 m		
NLA 537L	GCP 9	Az.	42°05'09"	0.747 sec	1 : 267259	1 : 266106
		ΔHt.	167.464 m	0.066 m		
		ΔElev.	167.163 m	0.066 m		
		Ellip Dist.	7428.155 m	0.028 m		
NLA 537L	KG 49	Az.	39°57'03"	0.439 sec	1 : 359033	1 : 359720
		ΔHt.	159.964 m	0.043 m		
		ΔElev.	159.668 m	0.043 m		
		Ellip Dist.	7270.715 m	0.020 m		
NLA 538L	GCP 12	Az.	74°12'01"	4.471 sec	1 : 38513	1 : 38474
		ΔHt.	3.155 m	0.040 m		
		ΔElev.	3.152 m	0.040 m		
		Ellip Dist.	854.520 m	0.022 m		
NLA 538L	GCP 14	Az.	308°16'55"	2.053 sec	1 : 104339	1 : 104379
		ΔHt.	0.524 m	0.036 m		
		ΔElev.	0.474 m	0.036 m		
		Ellip Dist.	1739.854 m	0.017 m		
NLA 538L	GCP 15	Az.	351°20'26"	0.968 sec	1 : 232690	1 : 233252
		ΔHt.	49.309 m	0.080 m		
		ΔElev.	49.047 m	0.080 m		
		Ellip Dist.	7022.168 m	0.030 m		
NLA 538L	KG 49	Az.	40°15'49"	0.000 sec	1 : 0	1 : 0
		ΔHt.	159.921 m	0.000 m		
		ΔElev.	159.626 m	0.000 m		

8.3.5 Network Adjustment Report

8.3.5.1 *Julian Day 019*

8.3.5.2 *Adjustment Settings*

Set-Up Errors

GNSS

Error in Height of Antenna: 0.000 m

Centering Error: 0.000 m

Covariance Display

Horizontal:

Propagated Linear Error [E]: U.S.

Constant Term [C]: 0.000 m

Scale on Linear Error [S]: 1.960

Three-Dimensional

Propagated Linear Error [E]: U.S.

Constant Term [C]: 0.000 m

Scale on Linear Error [S]: 1.960

8.3.5.2.1 Adjustment Statistics

Number of Iterations for Successful Adjustment:	2
Network Reference Factor:	1.00
Chi Square Test (95%):	Passed
Precision Confidence Level:	95%
Degrees of Freedom:	37

Post Processed Vector Statistics

Reference Factor:	1.00
Redundancy Number:	37.00
A Priori Scalar:	5.21

8.3.5.2.2 Adjusted Grid Coordinates

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Fixed
BM LS25	760753.685	N/A	645063.645	N/A	5.183	N/A	NEe
BM LS28	763907.308	N/A	647101.256	N/A	2.073	N/A	NEe
GCP 17	762439.170	0.021	652168.362	0.022	6.635	0.042	
GCP 20	762723.467	0.010	644812.754	0.010	2.905	0.026	
GCP18	761914.265	0.011	648336.828	0.010	7.966	0.028	
GCP19	764821.527	0.012	647633.034	0.010	1.260	0.029	
GCP21	760166.114	0.014	642487.551	0.014	3.261	0.029	
GCP22	761036.778	0.022	638873.771	0.023	1.623	0.041	

8.3.5.2.3 Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Fixed
BM LS25	N17°57'19.34358"	W76°53'54.54475"	-10.886	N/A	NEe
BM LS28	N17°58'25.55491"	W76°52'07.32242"	-14.027	N/A	NEe
GCP 17	N18°01'10.40008"	W76°52'57.11194"	-9.292	0.042	
GCP 20	N17°57'11.14474"	W76°52'47.60884"	-13.220	0.026	
GCP18	N17°59'05.78591"	W76°53'15.03589"	-8.063	0.028	
GCP19	N17°58'42.82987"	W76°51'36.23657"	-14.844	0.029	
GCP21	N17°55'55.56307"	W76°54'14.55818"	-12.844	0.029	
GCP22	N17°53'58.00477"	W76°53'45.04222"	-14.604	0.041	

8.3.5.2.4 Error Ellipse Components

Point ID	Semi-major axis (Meter)	Semi-minor axis (Meter)	Azimuth
GCP 17	0.028	0.025	32°
GCP 20	0.013	0.011	53°

GCP18	0.015	0.012	68°
GCP19	0.016	0.012	71°
GCP21	0.018	0.016	44°
GCP22	0.029	0.026	31°

8.3.5.2.5 Adjusted GPS Observations

Transformation Parameters

Azimuth Rotation: 0.996 sec **(95%)** 0.426 sec

Scale Factor: 1.00000269 **(95%)** 0.00000241

Observation ID		Observation	A-posteriori Error	Residual	Standardized Residual
BM LS25 --> GCP 20 (PV20)	Az.	97°17'25"	1.055 sec	-0.165 sec	-0.297
	ΔHt.	-2.333 m	0.026 m	0.041 m	2.719
	Ellip Dist.	1985.690 m	0.010 m	-0.001 m	-0.189
BM LS25 --> GCP18 (PV27)	Az.	19°33'17"	0.659 sec	-0.068 sec	-0.141
	ΔHt.	2.823 m	0.028 m	0.055 m	2.302
	Ellip Dist.	3472.838 m	0.011 m	0.000 m	-0.033
BM LS28 --> GCP 20 (PV18)	Az.	207°23'36"	0.786 sec	0.006 sec	0.013
	ΔHt.	0.807 m	0.026 m	-0.043 m	-2.258
	Ellip Dist.	2576.564 m	0.011 m	-0.001 m	-0.113
BM LS25 --> GCP21 (PV26)	Az.	192°52'49"	0.886 sec	0.018 sec	0.048
	ΔHt.	-1.958 m	0.029 m	0.028 m	2.183
	Ellip Dist.	2642.244 m	0.011 m	0.001 m	0.304
BM LS28 --> GCP21 (PV3)	Az.	219°04'44"	0.410 sec	-0.028 sec	-0.083
	ΔHt.	1.183 m	0.029 m	-0.059 m	-2.152
	Ellip Dist.	5939.915 m	0.013 m	-0.001 m	-0.059
BM LS28 --> GCP18 (PV4)	Az.	301°50'15"	0.919 sec	0.036 sec	0.070
	ΔHt.	5.964 m	0.028 m	-0.037 m	-2.123
	Ellip Dist.	2344.958 m	0.010 m	0.000 m	-0.012
BM LS28 --> GCP19 (PV5)	Az.	59°51'19"	1.765 sec	0.322 sec	0.400
	ΔHt.	-0.817 m	0.029 m	-0.029 m	-1.996
	Ellip Dist.	1057.629 m	0.011 m	0.000 m	0.002
BM LS25 --> GCP19 (PV23)	Az.	57°45'13"	0.440 sec	0.045 sec	0.106
	ΔHt.	-3.958 m	0.029 m	0.067 m	1.981
	Ellip Dist.	4811.338 m	0.013 m	-0.001 m	-0.083
BM LS28 --> BM LS25 (PV24)	Az.	237°10'25"	0.426 sec	-0.041 sec	-0.160
	ΔHt.	3.140 m	0.000 m	-0.087 m	-1.959
	Ellip Dist.	3754.613 m	0.009 m	-0.001 m	-0.230
BM LS28 --> GCP 17 (PV13)	Az.	343°52'57"	0.681 sec	0.013 sec	0.033
	ΔHt.	4.735 m	0.042 m	-0.044 m	-1.696
	Ellip Dist.	5275.494 m	0.016 m	0.001 m	0.122
BM LS25 --> GCP 17 (PV21)	Az.	13°22'39"	0.469 sec	-0.008 sec	-0.024
	ΔHt.	1.595 m	0.042 m	0.049 m	1.491
	Ellip Dist.	7301.888 m	0.017 m	0.003 m	0.248
BM LS28 --> GCP22 (PV2)	Az.	199°16'28"	0.380 sec	-0.007 sec	-0.019
	ΔHt.	-0.577 m	0.041 m	-0.061 m	-1.452
	Ellip Dist.	8713.836 m	0.017 m	-0.003 m	-0.202
BM LS25 --> GCP22 (PV25)	Az.	177°24'47"	0.543 sec	0.001 sec	0.003

	ΔHt.	-3.718 m	0.041 m	0.034 m	1.041
	Ellip Dist.	6196.323 m	0.016 m	0.001 m	0.067
GCP 20 --> GCP19 (PV17)	Az.	36°41'01"	0.686 sec	-0.149 sec	-0.250
	ΔHt.	-1.625 m	0.035 m	0.025 m	0.804
	Ellip Dist.	3515.077 m	0.013 m	0.002 m	0.205
GCP22 --> GCP 17 (PV14)	Az.	6°03'15"	0.318 sec	0.030 sec	0.099
	ΔHt.	5.312 m	0.053 m	0.007 m	0.136
	Ellip Dist.	13368.311 m	0.020 m	-0.006 m	-0.326
GCP21 --> GCP 17 (PV15)	Az.	13°14'37"	0.370 sec	0.004 sec	0.014
	ΔHt.	3.552 m	0.047 m	0.013 m	0.307
	Ellip Dist.	9944.059 m	0.018 m	-0.002 m	-0.121
GCP21 --> GCP22 (PV1)	Az.	166°29'02"	0.905 sec	0.040 sec	0.096
	ΔHt.	-1.760 m	0.041 m	0.006 m	0.297
	Ellip Dist.	3717.171 m	0.015 m	0.002 m	0.300
GCP18 --> GCP 20 (PV19)	Az.	167°06'10"	0.740 sec	0.005 sec	0.010
	ΔHt.	-5.156 m	0.033 m	-0.002 m	-0.074
	Ellip Dist.	3615.775 m	0.011 m	0.002 m	0.261
GCP18 --> GCP19 (PV6)	Az.	103°38'36"	0.780 sec	-0.111 sec	-0.216
	ΔHt.	-6.781 m	0.035 m	-0.001 m	-0.025
	Ellip Dist.	2991.229 m	0.013 m	-0.002 m	-0.223

Covariance Terms

From Point	To Point		Components	A-posteriori Error	Horiz. Precision (Ratio)	3D Precision (Ratio)
BM LS28	BM LS25	Az.	237°10'24"	0.000 sec	1 : 0	1 : 0
		ΔHt.	3.140 m	0.000 m		
		ΔElev.	3.111 m	0.000 m		
		Ellip Dist.	3754.623 m	0.000 m		
BM LS28	GCP 17	Az.	343°52'56"	0.829 sec	1 : 251149	1 : 251177
		ΔHt.	4.735 m	0.042 m		
		ΔElev.	4.563 m	0.042 m		
		Ellip Dist.	5275.508 m	0.021 m		
BM LS28	GCP 20	Az.	207°23'35"	0.751 sec	1 : 248390	1 : 248391
		ΔHt.	0.807 m	0.026 m		
		ΔElev.	0.833 m	0.026 m		
		Ellip Dist.	2576.571 m	0.010 m		
BM LS28	GCP19	Az.	59°51'18"	1.929 sec	1 : 85505	1 : 85522
		ΔHt.	-0.817 m	0.029 m		
		ΔElev.	-0.813 m	0.029 m		
		Ellip Dist.	1057.632 m	0.012 m		
GCP 17	BM LS25	Az.	193°22'56"	0.574 sec	1 : 333955	1 : 333968
		ΔHt.	-1.595 m	0.042 m		
		ΔElev.	-1.452 m	0.042 m		
		Ellip Dist.	7301.907 m	0.022 m		
GCP 20	BM LS25	Az.	277°17'45"	1.024 sec	1 : 200193	1 : 200237
		ΔHt.	2.333 m	0.026 m		

		ΔElev.	2.278 m	0.026 m		
		Ellip Dist.	1985.695 m	0.010 m		
GCP18	BM LS25	Az.	199°33'28"	0.649 sec	1 : 324737	1 : 324645
		ΔHt.	-2.823 m	0.028 m		
		ΔElev.	-2.783 m	0.028 m		
		Ellip Dist.	3472.847 m	0.011 m		
GCP18	BM LS28	Az.	121°49'53"	0.973 sec	1 : 222049	1 : 222171
		ΔHt.	-5.964 m	0.028 m		
		ΔElev.	-5.894 m	0.028 m		
		Ellip Dist.	2344.964 m	0.011 m		
GCP18	GCP 20	Az.	167°06'09"	0.845 sec	1 : 263309	1 : 263241
		ΔHt.	-5.156 m	0.033 m		
		ΔElev.	-5.061 m	0.033 m		
		Ellip Dist.	3615.785 m	0.014 m		
GCP18	GCP19	Az.	103°38'35"	0.878 sec	1 : 209685	1 : 209825
		ΔHt.	-6.781 m	0.035 m		
		ΔElev.	-6.706 m	0.035 m		
		Ellip Dist.	2991.237 m	0.014 m		
GCP19	BM LS25	Az.	237°45'55"	0.426 sec	1 : 390106	1 : 390181
		ΔHt.	3.958 m	0.029 m		
		ΔElev.	3.923 m	0.029 m		
		Ellip Dist.	4811.351 m	0.012 m		
GCP19	GCP 20	Az.	216°41'22"	0.765 sec	1 : 236765	1 : 236772
		ΔHt.	1.625 m	0.035 m		
		ΔElev.	1.645 m	0.035 m		
		Ellip Dist.	3515.087 m	0.015 m		
GCP21	BM LS25	Az.	12°52'42"	1.044 sec	1 : 186778	1 : 186815
		ΔHt.	1.958 m	0.029 m		
		ΔElev.	1.922 m	0.029 m		
		Ellip Dist.	2642.252 m	0.014 m		
GCP21	BM LS28	Az.	39°04'04"	0.448 sec	1 : 407281	1 : 407245
		ΔHt.	-1.183 m	0.029 m		
		ΔElev.	-1.189 m	0.029 m		
		Ellip Dist.	5939.931 m	0.015 m		
GCP21	GCP 17	Az.	13°14'36"	0.547 sec	1 : 340985	1 : 341003
		ΔHt.	3.552 m	0.047 m		
		ΔElev.	3.374 m	0.047 m		
		Ellip Dist.	9944.086 m	0.029 m		
GCP21	GCP22	Az.	166°29'01"	1.002 sec	1 : 212112	1 : 212130
		ΔHt.	-1.760 m	0.041 m		
		ΔElev.	-1.638 m	0.041 m		
		Ellip Dist.	3717.181 m	0.018 m		
GCP22	BM LS25	Az.	357°24'49"	0.721 sec	1 : 272554	1 : 272576
		ΔHt.	3.718 m	0.041 m		
		ΔElev.	3.560 m	0.041 m		
		Ellip Dist.	6196.339 m	0.023 m		
GCP22	BM LS28	Az.	19°15'57"	0.495 sec	1 : 372077	1 : 372075

		ΔHt.	0.577 m	0.041 m		
		ΔElev.	0.449 m	0.041 m		
		Ellip Dist.	8713.860 m	0.023 m		
GCP22	GCP 17	**Az.**	6°03'14"	0.522 sec	1 : 355069	1 : 355082
		ΔHt.	5.312 m	0.053 m		
		ΔElev.	5.012 m	0.053 m		
		Ellip Dist.	13368.347 m	0.038 m		

8.4 Appendix 4: Declination GPS Observation Data

Table 8.9 Equipment being executed in field surveys: (a) GCP1; (b) GCP3; (c) GCP4; (d) GCP5; (e) GCP7; (f) GCP17; (g) GCP8; (h) NLA BM 289L; (i) GCP2; (j) NLA BM LS25

(a)

(b)

(c)

(d)

 (e)	 (f)
 (g)	 (h)


(i)

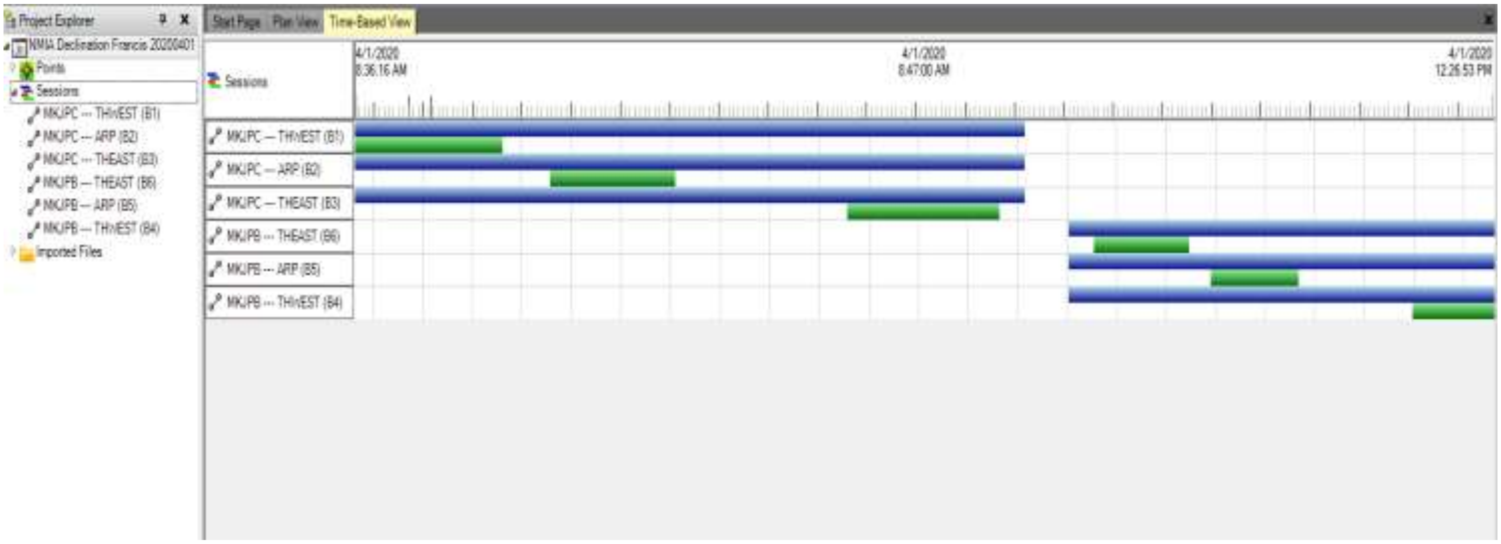

(j)

8.4.1 Occupation Spreadsheet

Project: NMIA Declination Survey

Point ID	Start Time (Local)	Duration	Field Method	File Name	Ant. Height	Ant. Method	Ant. Manufacturer	Ant. Type	Ant. Serial #
MKJPC	4/1/2020 8:08	2:42:45	Static	log0092m.20o	1.425	Bottom of antenna mount	Topcon	HiPer II	EOZ7WXNEY9S
THWEST	4/1/2020 8:36	0:29:58	Static	log0092n.20o	1.380	Bottom of antenna mount	Topcon	HiPer II	EN0EYTW55OG
ARP	4/1/2020 9:15	0:25:23	Static	log0092o.20o	1.385	Bottom of antenna mount	Topcon	HiPer II	EN0EYTW55OG

THEAST	4/1/2020 10:15	0:30:45	Static	log0092p.20o	1.380	Bottom of antenna mount	Topcon	HiPer II	EN0EYTW55OG
MKJPB	4/1/2020 11:02	1:32:06	Static	log0092s.20o	1.410	Bottom of antenna mount	Topcon	HiPer II	EOZ7WXNEY9S
THEAST	4/1/2020 11:05	0:19:20	Static	log0092q.20o	1.380	Bottom of antenna mount	Topcon	HiPer II	EN0EYTW55OG
ARP	4/1/2020 11:29	0:17:50	Static	log0092q00.20o	1.380	Bottom of antenna mount	Topcon	HiPer II	EN0EYTW55OG
THWEST	4/1/2020 12:10	0:16:59	Static	log0092r.20o	1.375	Bottom of antenna mount	Topcon	HiPer II	EN0EYTW55OG


Project Explorer
NMIA Declination Francis 20200401
Points
Sessions
MKJPC --- THWEST (B1)
MKJPC --- ARP (B2)
MKJPC --- THEAST (B3)
MKJPB --- THEAST (B6)
MKJPB --- ARP (B5)
MKJPB --- THWEST (B4)
Imported Files
Start Page
Plan View
Time-Based View
Sessions
4/1/2020
8:36:16 AM
4/1/2020
8:47:00 AM
4/1/2020
12:26:53 PM

8.4.1.1 *Network Adjustment Report*

Project : NMIA Declination Survey

User name	A.W.	**Date & Time**	14:02:55 AM 17-Apr-2020
Coordinate System	Jamaica	**Zone**	JAD2001
Project Datum	WGS 1984		
Vertical Datum		**Geoid Model**	CARIB97 (Caribbean)
Coordinate Units	Meters		
Distance Units	Meters		
Height Units	Meters		

8.4.1.1.1 Adjustment Statistics

Number of Iterations for Successful Adjustment:	2
Network Reference Factor:	1.00
Chi Square Test (95%):	Passed
Precision Confidence Level:	95%
Degrees of Freedom:	18

Post Processed Vector Statistics

Reference Factor:	1.00
Redundancy Number:	18.00
A Priori Scalar:	4.64

8.4.1.1.2 Individual GPS Observation Statistics

Observation ID	Reference Factor		Redundancy Number
B1	0.62		1.10
B2	0.49		1.77
B3	0.89		1.30
B4	0.46		1.10
B5	1.32		1.37
B6	0.89		1.17

8.4.1.1.3 Adjusted Coordinates

Adjustment performed in WGS 1984

Number of Points : 5

Number of Constrained Points : 2

Horizontal and Height Only : 2

8.4.1.1.4 Adjusted Grid Coordinates

Errors are reported using 1.96σ.

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Fixed
MKJPB	773684.289	N/A	642338.258	N/A	5.829	N/A	LLh
MKJPC	771736.640	N/A	643124.118	N/A	3.877	N/A	LLh
THEAST	773762.648	0.012	642388.299	0.008	7.560	0.033	
ARP	772508.766	0.012	642893.460	0.007	4.840	0.039	
THWEST	771254.973	0.012	643398.664	0.008	4.619	0.035	

8.4.1.1.5 Adjusted Geodetic Coordinates

Errors are reported using 1.96σ.

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Fixed
MKJPB	N17°55'50.32829"	W76°46'35.22066"	-10.598	N/A	LLh
MKJPC	N17°56'15.96262"	W76°47'41.37110"	-12.480	N/A	LLh
THEAST	N17°55'51.95284"	W76°46'32.55598"	-8.866	0.033	
ARP	N17°56'08.43188"	W76°47'15.14263"	-11.678	0.039	
THWEST	N17°56'24.90969"	W76°47'57.72844"	-11.719	0.035	

8.4.1.1.6 Coordinate Deltas

Point Name	ΔNorthing	ΔEasting	ΔElevation	ΔHeight	ΔGeoid Separation
MKJPB	0.000m	0.000m	N/A	0.000m	N/A
MKJPC	0.000m	0.000m	N/A	0.000m	N/A
THEAST	0.000m	0.000m	N/A	0.000m	N/A
ARP	0.000m	0.000m	N/A	0.000m	N/A
THWEST	0.000m	0.000m	N/A	0.000m	N/A

8.4.1.1.7 Adjusted Observations

Adjustment performed in WGS-84

GPS Observations

GPS Transformation Group: <GPS Default>

Deflection in Longitude : 0°00'00.1191" **(1.96σ)** : 0°00'00.3000"

Deflection in Latitude : 0°00'00.2029" **(1.96σ)** : 0°00'00.4984"

Azimuth Rotation : 0°00'00.3224" **(1.96σ)** : 0°00'00.0379"

Network Scale : 1.00000062 **(1.96σ)** : 0.00000019

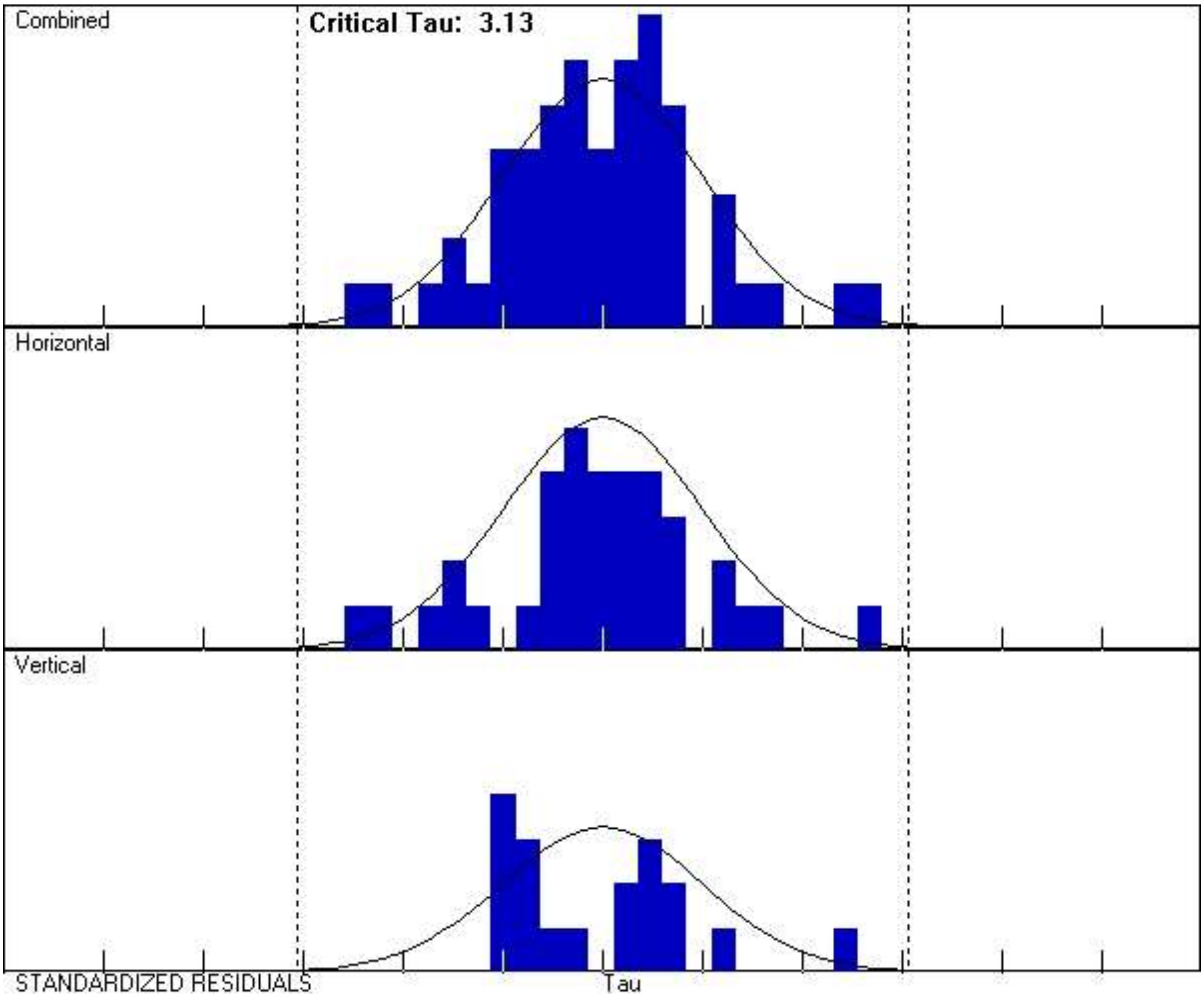
Number of Observations : 6

Number of Outliers : 0

Observation Adjustment (Critical Tau = 3.13). Any outliers are in red.

Obs. ID	From Pt.	To Pt.		Observation	A-posteriori Error (1.96σ)	Residual	Stand. Residual
B1	MKJPC	THWEST	**Az.**	299°41'17.4066"	0°00'00.0379"	0°00'00.0950"	2.68
			ΔHt.	0.894m	0.024m	0.008m	0.41
			Dist.	554.491m	0.003m	0.000m	0.09
B3	MKJPC	THEAST	**Az.**	110°01'37.6752"	0°00'00.0379"	-0°00'00.1428"	-2.49
			ΔHt.	3.323m	0.023m	-0.023m	-0.98
			Dist.	2155.360m	0.002m	-0.007m	-2.29
B2	MKJPC	ARP	**Az.**	106°43'12.1104"	0°00'00.0977"	-0°00'00.0597"	-0.76
			ΔHt.	0.257m	0.024m	0.032m	2.49
			Dist.	805.618m	0.005m	-0.002m	-0.42
B6	MKJPB	THEAST	**Az.**	57°29'16.6662"	0°00'00.2891"	0°00'00.3476"	1.82
			ΔHt.	1.702m	0.022m	-0.007m	-0.65
			Dist.	93.101m	0.007m	-0.001m	-0.22
B5	MKJPB	ARP	**Az.**	295°20'45.6284"	0°00'00.0600"	-0°00'00.0718"	-1.70
			ΔHt.	-1.363m	0.026m	-0.013m	-0.51
			Dist.	1300.048m	0.005m	0.001m	0.50
B4	MKJPB	THWEST	**Az.**	293°39'26.9612"	0°00'00.0723"	0°00'00.0130"	0.26
			ΔHt.	-0.727m	0.029m	0.016m	0.53
			Dist.	2650.567m	0.005m	-0.005m	-1.62

8.4.1.1.8 Histograms of Standardized Residuals



8.4.1.1.9 Error Ellipse Components

Point ID	Semi-major axis (Meter)	Semi-minor axis (Meter)	Azimuth
THEAST	0.018	0.013	108°
ARP	0.014	0.011	105°
THWEST	0.013	0.008	83°

8.5 Appendix 5: Navigational Aids

OBJECTID	Type	JAD2001		WGS84 GCS		Z
		X	Y	Lat	Lon	
1	Lighting Mask	773833.1	642343.8	17.9307	-76.775	4.96
2	Lighting Mask	773834.2	642346.3	17.93072	-76.775	4.96
3	Lighting Mask	773835.2	642349	17.93074	-76.775	4.94
4	Lighting Mask	773836.3	642351.5	17.93076	-76.775	3.83
5	Lighting Mask	773837.2	642354.1	17.93079	-76.775	4.97
6	Lighting Mask	773838.8	642357.9	17.93082	-76.775	4.95
7	Lighting Mask	773840.4	642362	17.93086	-76.775	4.92

8	Lighting Mask	773841.3	642364.5	17.93088	-76.775	3.89
9	Lighting Mask	773842.4	642366.9	17.9309	-76.775	4.99
10	Lighting Mask	773843.4	642369.3	17.93093	-76.7749	4.38
11	Lighting Mask	773844.5	642371.7	17.93095	-76.7749	4.98
12	End of Runway lights	773803	642369.8	17.93093	-76.7753	4.98
13	End of Runway lights	773803.4	642370.7	17.93094	-76.7753	5.54
14	End of Runway lights	773803.8	642371.6	17.93095	-76.7753	5.14
15	End of Runway lights	773804.2	642372.6	17.93096	-76.7753	4.83
16	End of Runway lights	773804.6	642373.6	17.93096	-76.7753	5.18
17	End of Runway lights	773759.6	642365.2	17.93089	-76.7757	5.13
18	End of Runway lights	773760.7	642368	17.93091	-76.7757	5.2
19	End of Runway lights	773761.8	642370.7	17.93094	-76.7757	5.31
20	End of Runway lights	773762.9	642373.6	17.93096	-76.7757	5.3
21	End of Runway lights	773764.1	642376.3	17.93099	-76.7757	5.26
22	End of Runway lights	773765.3	642379.1	17.93101	-76.7757	5.28
23	End of Runway lights	773766.2	642381.9	17.93104	-76.7757	5.28
24	End of Runway lights	773767.4	642384.6	17.93106	-76.7757	5.31
25	End of Runway lights	773768.6	642387.4	17.93109	-76.7757	5.28
26	End of Runway lights	773769.7	642390.2	17.93111	-76.7756	5.31
27	End of Runway lights	773770.8	642393	17.93114	-76.7756	5.28
28	End of Runway lights	773772	642395.7	17.93117	-76.7756	5.27
29	End of Runway lights	773773.1	642398.6	17.93119	-76.7756	5.25
30	End of Runway lights	773774.2	642401.4	17.93122	-76.7756	5.22
31	End of Runway lights	773775.3	642404.1	17.93124	-76.7756	5.2
32	End of Runway lights	773776.4	642406.7	17.93126	-76.7756	5.21
33	End of Runway lights	773776	642409.8	17.93129	-76.7756	5.16
34	Runway	773704.3	642385.4	17.93107	-76.7763	4.39
35	RunWay	773649.4	642407.5	17.93127	-76.7768	3.73
36	VOR	773558.9	642293.9	17.93025	-76.7776	9.15
37	RunWay	773594.8	642429.6	17.93147	-76.7773	3.21
38	RunWay	773540.1	642451.7	17.93167	-76.7778	2.97
39	RunWay	773485.4	642473.7	17.93187	-76.7783	2.87
40	RunWay	773430.5	642495.8	17.93207	-76.7788	2.79
41	RunWay	773375.8	642517.9	17.93227	-76.7794	2.73
42	RunWay	773321.1	642540	17.93247	-76.7799	2.62
43	RunWay	773266.1	642562	17.93267	-76.7804	2.56
44	RunWay	773211.4	642584.2	17.93287	-76.7809	2.5
45	RunWay	773156.7	642606	17.93307	-76.7814	2.47
46	RunWay	773102.1	642628.1	17.93327	-76.7819	2.43
47	RunWay	773047.5	642650.4	17.93347	-76.7825	2.33
48	RunWay	772992.6	642672.3	17.93367	-76.783	2.33
49	RunWay	772828.5	642738.6	17.93427	-76.7845	2.27
50	RunWay	772773.6	642760.6	17.93447	-76.785	2.22
51	RunWay	772718.8	642782.6	17.93467	-76.7856	2.2
52	RunWay	772663.9	642804.6	17.93487	-76.7861	2.22
53	RunWay	772609.3	642826.6	17.93507	-76.7866	2.14

54	RunWay	772554.4	642848.8	17.93527	-76.7871	2.16
55	RunWay	772499.9	642870.8	17.93547	-76.7876	2.22
56	RunWay	772444.9	642892.9	17.93567	-76.7881	2.15
57	RunWay	772390.2	642915	17.93587	-76.7887	2.15
58	RunWay	772335.4	642937.1	17.93607	-76.7892	2.15
59	RunWay	772280.6	642959	17.93627	-76.7897	2.14
60	RunWay	772225.9	642981.1	17.93647	-76.7902	2.14
61	RunWay	772171.2	643003.1	17.93667	-76.7907	2.16
62	RunWay	772116.3	643025.2	17.93687	-76.7912	2.17
63	RunWay	772061.4	643047.5	17.93707	-76.7918	2.18
64	RunWay	772006.7	643069.3	17.93727	-76.7923	2.17
65	RunWay	771952	643091.4	17.93747	-76.7928	2.17
66	RunWay	771897.1	643113.6	17.93767	-76.7933	2.19
67	RunWay	771842.4	643135.6	17.93787	-76.7938	2.2
68	RunWay	771787.7	643157.7	17.93807	-76.7943	2.27
69	RunWay	771733	643179.7	17.93827	-76.7949	2.23
70	RunWay	771678.1	643201.7	17.93847	-76.7954	2.2
71	RunWay	771623.5	643223.9	17.93867	-76.7959	2.25
72	RunWay	771568.7	643245.9	17.93887	-76.7964	2.2
73	RunWay	771513.9	643268	17.93907	-76.7969	2.16
74	RunWay	771459.1	643290	17.93927	-76.7974	2.16
75	RunWay	771404.5	643312	17.93947	-76.798	2.15
76	RunWay	771351.9	643333.3	17.93966	-76.7985	2.13
77	RunWay	771332.7	643325.2	17.93959	-76.7986	1.94
78	RunWay	771312.6	643316.5	17.93951	-76.7988	1.7
79	RunWay	771285.3	643327.7	17.93961	-76.7991	1.69
80	RunWay	771257.7	643338.7	17.93971	-76.7993	1.68
81	RunWay	771249.2	643358.8	17.93989	-76.7994	1.9
82	End of Runway lights	771236.5	643369.1	17.93999	-76.7995	1.86
83	End of Runway lights	771237.4	643371.4	17.94001	-76.7995	1.95
84	End of Runway lights	771238.4	643373.8	17.94003	-76.7995	2
85	End of Runway lights	771239.4	643376.1	17.94005	-76.7995	2.06
86	End of Runway lights	771240.3	643378.5	17.94007	-76.7995	2.1
87	End of Runway lights	771241	643380.2	17.94009	-76.7995	2.09
88	End of Runway lights	771242.1	643382.9	17.94011	-76.7995	2.14
89	End of Runway lights	771243.3	643385.7	17.94014	-76.7995	2.14
90	End of Runway lights	771244.3	643388.5	17.94016	-76.7995	2.19
91	End of Runway lights	771245.4	643391.2	17.94019	-76.7995	2.19
92	End of Runway lights	771246.6	643394	17.94021	-76.7994	2.26
93	End of Runway lights	771247.8	643396.8	17.94024	-76.7994	2.32
94	End of Runway lights	771248.8	643399.6	17.94026	-76.7994	2.33
95	End of Runway lights	771250	643402.3	17.94029	-76.7994	2.31
96	End of Runway lights	771251.1	643405.1	17.94031	-76.7994	2.28
97	End of Runway lights	771252.2	643407.9	17.94034	-76.7994	2.28
98	End of Runway lights	771253.4	643410.7	17.94036	-76.7994	2.22
99	End of Runway lights	771254.5	643413.5	17.94039	-76.7994	2.2

100	End of Runway lights	771255.6	643416.3	17.94041	-76.7994	2.15
101	End of Runway lights	771256.7	643419	17.94044	-76.7994	2.13
102	End of Runway lights	771257.8	643421.9	17.94046	-76.7993	2.11
103	End of Runway lights	771258.5	643423.6	17.94048	-76.7993	2.09
104	End of Runway lights	771259.5	643425.9	17.9405	-76.7993	2.09
105	End of Runway lights	771260.4	643428.2	17.94052	-76.7993	2.04
106	End of Runway lights	771261.3	643430.5	17.94054	-76.7993	2.01
107	End of Runway lights	771262.3	643432.8	17.94056	-76.7993	1.97
108	Taxi Way	771273.2	643460	17.94081	-76.7992	1.87
109	Taxi Way	771286.7	643481.9	17.941	-76.7991	1.9
110	Taxi Way	771313.9	643464.9	17.94085	-76.7988	1.8
111	Taxi Way	771302.5	643448.3	17.9407	-76.7989	1.81
112	Taxi Way	771306.6	643498.2	17.94115	-76.7989	1.92
113	Taxi Way	771331.3	643474.6	17.94094	-76.7986	1.83
114	Taxi Way	771356.4	643507.1	17.94123	-76.7984	1.97
115	Taxi Way	771351.3	643476	17.94095	-76.7985	1.87
116	Taxi Way	771379.8	643473.9	17.94093	-76.7982	1.91
117	Taxi Way	771384.1	643502.5	17.94119	-76.7981	1.98
118	Taxi Way	771356.4	643507.1	17.94123	-76.7984	1.97
119	Taxi Way	771407.9	643471.7	17.94091	-76.7979	1.99
120	Taxi Way	771440.1	643493.5	17.94111	-76.7976	1.98
121	Taxi Way	771435.8	643467.8	17.94088	-76.7977	2.04
122	Taxi Way	771467.6	643489	17.94107	-76.7974	2.53
123	Taxi Way	771495.8	643484.3	17.94102	-76.7971	2.02
124	Taxi Way	771491.6	643458.8	17.94079	-76.7971	2.03
125	Taxi Way	771463.3	643463.4	17.94084	-76.7974	2
126	Taxi Way	771523.4	643480	17.94098	-76.7968	1.98
127	Taxi Way	771519.4	643454	17.94075	-76.7969	1.98
128	Taxi Way	771554	643473.4	17.94093	-76.7965	1.94
129	Taxi Way	771544	643449.2	17.94071	-76.7966	1.94
130	Taxi Way	771598.6	643427.2	17.94051	-76.7961	1.88
131	Taxi Way	771609.7	643450.9	17.94072	-76.796	1.89
132	Taxi Way	771665.3	643428.4	17.94052	-76.7955	1.86
133	Taxi Way	771655.4	643404.3	17.9403	-76.7956	1.85
134	Taxi Way	771711	643381.8	17.9401	-76.7951	1.88
135	Taxi Way	771720.9	643405.9	17.94031	-76.795	1.87
136	Taxi Way	771766.8	643359.4	17.93989	-76.7945	1.86
137	Taxi Way	771776.7	643383.7	17.94011	-76.7944	1.87
138	Taxi Way	771822.6	643337	17.93969	-76.794	1.87
139	Taxi Way	771832.1	643361.1	17.93991	-76.7939	1.86
140	Taxi Way	771878	643314.8	17.93949	-76.7935	1.86
141	Taxi Way	771887.8	643338.6	17.9397	-76.7934	1.88
142	Taxi Way	771933.7	643292.1	17.93928	-76.793	1.84
143	Taxi Way	771943.7	643316.3	17.9395	-76.7929	1.85
144	Taxi Way	771989.2	643270	17.93908	-76.7924	1.84
145	Taxi Way	771999	643293.9	17.9393	-76.7923	1.86

146	Taxi Way	772009.1	643262.1	17.93901	-76.7923	1.92
147	Taxi Way	771996.5	643250.8	17.93891	-76.7924	1.88
148	Taxi Way	771988.3	643235.9	17.93877	-76.7924	1.9
149	Taxi Way	771983.9	643216.8	17.9386	-76.7925	1.88
150	Taxi Way	771987.1	643195.3	17.93841	-76.7925	1.87
151	Taxi Way	772019.4	643206.8	17.93851	-76.7922	1.58
152	Taxi Way	772017.6	643215.2	17.93859	-76.7922	1.58
153	Taxi Way	772021	643225.7	17.93868	-76.7921	1.61
154	Taxi Way	772028.1	643233.6	17.93875	-76.7921	1.7
155	Taxi Way	772044.1	643237.9	17.93879	-76.7919	1.82
156	Taxi Way	772061.6	643233.3	17.93875	-76.7918	1.79
157	Taxi Way	772003.7	643168.5	17.93817	-76.7923	1.91
158	Taxi Way	772031.3	643185.7	17.93832	-76.792	1.6
159	Taxi Way	772044.7	643164.5	17.93813	-76.7919	1.68
160	Taxi Way	772020.7	643146.3	17.93796	-76.7921	1.98
161	Taxi Way	772038.5	643124	17.93776	-76.792	2.04
162	Taxi Way	772057.8	643143.1	17.93794	-76.7918	1.79
163	Taxi Way	772073.1	643122.4	17.93775	-76.7916	1.92
164	Taxi Way	772088.9	643102.5	17.93757	-76.7915	2.04
165	RunWay	772055.9	643102.4	17.93757	-76.7918	2.18
166	RunWay	772025.2	643114.7	17.93768	-76.7921	2.22
167	RunWay	771969.8	643136.5	17.93788	-76.7926	2.19
168	RunWay	771915.6	643158.7	17.93808	-76.7931	2.21
169	RunWay	771861	643180.8	17.93828	-76.7937	2.23
170	RunWay	771805.8	643202.9	17.93848	-76.7942	2.23
171	RunWay	771751.5	643225	17.93868	-76.7947	2.2
172	RunWay	771696.3	643247	17.93888	-76.7952	2.22
173	RunWay	771586.9	643290.9	17.93928	-76.7962	2.2
174	RunWay	771532.1	643313.1	17.93948	-76.7968	2.17
175	RunWay	771477.5	643335.1	17.93968	-76.7973	2.17
176	RunWay	771422.6	643357	17.93988	-76.7978	2.14
177	RunWay	771367.6	643379.1	17.94008	-76.7983	2.12
178	RunWay	771313.3	643401.4	17.94028	-76.7988	2.07
179	RunWay	771297.7	643409.6	17.94035	-76.799	2.07
180	Taxi Way	771296.5	643430.3	17.94054	-76.799	1.91
181	Nav Lights	771667.6	643273.4	17.93912	-76.7955	1.88
182	Nav Lights	771670.5	643281.7	17.93919	-76.7954	2.54
183	Nav Lights	771674	643290.3	17.93927	-76.7954	2.14
184	Nav Lights	771677.4	643298.5	17.93934	-76.7954	1.5
185	Taxi Way	772129.4	643241.3	17.93882	-76.7911	1.84
186	Taxi Way	772119.8	643216.8	17.9386	-76.7912	1.84
187	Taxi Way	772174.1	643195.1	17.9384	-76.7907	1.83
188	Taxi Way	772183.6	643219.6	17.93863	-76.7906	1.85
189	Taxi Way	772228.3	643173.2	17.93821	-76.7902	1.85
190	Taxi Way	772237.9	643197.5	17.93843	-76.7901	1.85
191	Taxi Way	772282.5	643151.4	17.93801	-76.7897	1.84

192	Taxi Way	772292.7	643175.4	17.93823	-76.7896	1.83
193	Taxi Way	772337	643129.5	17.93781	-76.7892	1.85
194	Taxi Way	772346.3	643154	17.93803	-76.7891	1.85
195	Taxi Way	772390.9	643108	17.93761	-76.7886	1.83
196	Taxi Way	772400.7	643131.8	17.93783	-76.7886	1.84
197	Taxi Way	772455.4	643109.8	17.93763	-76.788	1.83
198	Taxi Way	772445.3	643086	17.93742	-76.7881	1.8
199	Taxi Way	772500	643063.9	17.93722	-76.7876	1.81
200	Taxi Way	772509.7	643088	17.93743	-76.7875	1.8
201	Taxi Way	772555.8	643041.6	17.93701	-76.7871	1.82
202	Taxi Way	772565.4	643065.8	17.93723	-76.787	1.8
203	Taxi Way	772614.5	643045.7	17.93705	-76.7865	1.8
204	Taxi Way	772579.2	643020.8	17.93683	-76.7869	1.76
205	Taxi Way	772586.3	642989.6	17.93654	-76.7868	1.87
206	Taxi Way	772583.8	642969.1	17.93636	-76.7868	1.87
207	Taxi Way	772587.2	642951.7	17.9362	-76.7868	1.85
208	Taxi Way	772596.2	642936.1	17.93606	-76.7867	1.87
209	Taxi Way	772622.4	642958.4	17.93626	-76.7865	1.55
210	Taxi Way	772618.4	642966.8	17.93634	-76.7865	1.54
211	Taxi Way	772620.2	642983	17.93648	-76.7865	1.57
212	Taxi Way	772633.8	642939.9	17.93609	-76.7864	1.55
213	Taxi Way	772610	642918.3	17.9359	-76.7866	1.89
214	Taxi Way	772646.4	642918.9	17.9359	-76.7862	1.65
215	Taxi Way	772624.7	642899.3	17.93573	-76.7864	1.93
216	Taxi Way	772659.3	642898.2	17.93572	-76.7861	1.76
217	Taxi Way	772640.3	642879.9	17.93555	-76.7863	2.03
218	Runway	772655.2	642860.5	17.93538	-76.7862	2.14
219	Runway	772627.1	642871.8	17.93548	-76.7864	2.15
220	Runway	772572.6	642893.9	17.93568	-76.7869	2.17
221	Runway	772517.8	642915.8	17.93588	-76.7875	2.17
222	Runway	772462.9	642938.1	17.93608	-76.788	2.19
223	Runway	772408.3	642960	17.93628	-76.7885	2.16
224	Runway	772353.6	642982.3	17.93648	-76.789	2.17
225	Runway	772298.9	643004.2	17.93668	-76.7895	2.15
226	Runway	772244	643026.4	17.93688	-76.79	2.17
227	Runway	772189.3	643048.5	17.93708	-76.7906	2.16
228	Runway	772134.4	643070.6	17.93728	-76.7911	2.17
229	Taxi Way	772663.1	643026.3	17.93687	-76.7861	1.81
230	Taxi Way	772626.6	642990.7	17.93655	-76.7864	1.63
231	Taxi Way	772650	642994.6	17.93659	-76.7862	1.73
232	Taxi Way	772701.6	642980.3	17.93646	-76.7857	1.75
233	Taxi Way	772712.3	643006.6	17.9367	-76.7856	1.77
234	Taxi Way	772750.7	642963	17.9363	-76.7853	1.78
235	Taxi Way	772760.3	642987.2	17.93652	-76.7852	1.78
236	Taxi Way	772806.3	642940.5	17.9361	-76.7847	1.79
237	Taxi Way	772815.9	642964.8	17.93632	-76.7846	1.79

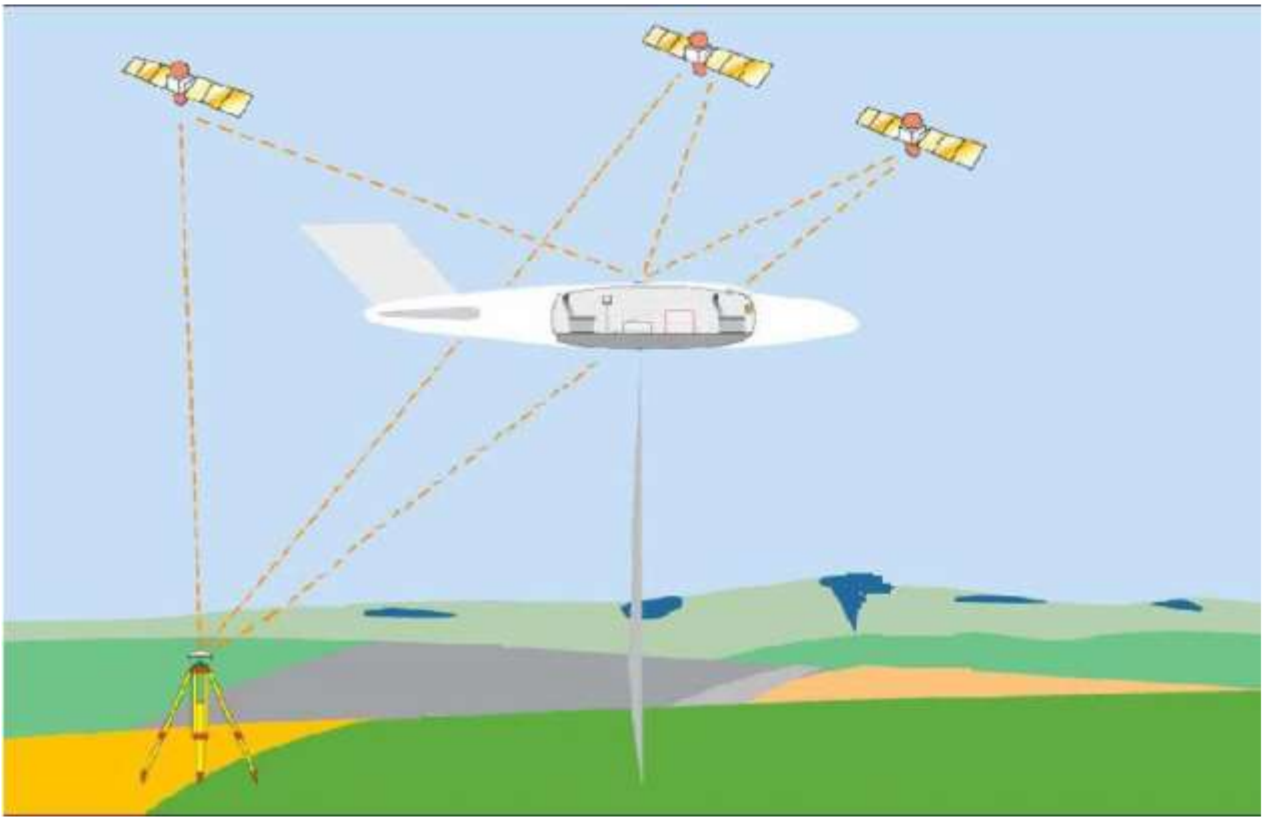
238	Taxi Way	772871.7	642942.3	17.93611	-76.7841	1.79
239	Taxi Way	772861.9	642918.3	17.9359	-76.7842	1.77
240	Taxi Way	772927.3	642919.9	17.93591	-76.7836	1.78
241	Taxi Way	772917.6	642895.7	17.93569	-76.7837	1.78
242	Taxi Way	772982.8	642897.5	17.93571	-76.7831	1.75
243	Taxi Way	772973.1	642873.3	17.93549	-76.7832	1.76
244	Taxi Way	773029	642850.8	17.93528	-76.7826	1.79
245	Taxi Way	773039	642876.1	17.93551	-76.7825	1.73
246	Taxi Way	773097	642859.3	17.93536	-76.782	1.71
247	Taxi Way	773123.3	642872	17.93548	-76.7817	1.47
248	Taxi Way	773133.2	642890.9	17.93565	-76.7816	1.3
249	Taxi Way	773146	642914.8	17.93586	-76.7815	1.56
250	Taxi Way	773159.9	642942.7	17.93611	-76.7814	1.64
251	Taxi Way	773182.4	642998.4	17.93662	-76.7812	1.7
252	Taxi Way	773204.7	643054.1	17.93712	-76.781	1.69
253	Taxi Way	773227.1	643109.7	17.93762	-76.7808	1.68
254	Taxi Way	773107.7	642815.7	17.93497	-76.7819	1.86
255	Taxi Way	773084.1	642827.7	17.93508	-76.7821	1.86
256	Taxi Way	773137.9	642800.2	17.93483	-76.7816	1.88
257	Taxi Way	773150.8	642789.7	17.93473	-76.7815	1.88
258	Taxi Way	773157.6	642774.4	17.93459	-76.7814	1.88
259	Taxi Way	773156.9	642757.8	17.93444	-76.7814	1.95
260	Taxi Way	773148.6	642743.4	17.93431	-76.7815	1.92
261	Taxi Way	773134.6	642734.2	17.93423	-76.7816	1.93
262	Taxi Way	773107.7	642724.4	17.93414	-76.7819	2.04
263	Taxi Way	773081	642723.4	17.93413	-76.7821	2.09
264	Taxi Way	773054.1	642723.6	17.93413	-76.7824	2.13
265	Taxi Way	773027.3	642725.2	17.93415	-76.7826	2.16
266	Runway	772973.6	642732.4	17.93422	-76.7832	2.29
267	Runway	772956.1	642739.6	17.93428	-76.7833	2.35
268	Runway	772901.4	642761.7	17.93448	-76.7838	2.28
269	Runway	772846.4	642783.6	17.93468	-76.7844	2.23
270	Runway	772791.7	642805.7	17.93488	-76.7849	2.25
271	Runway	772737.1	642827.9	17.93508	-76.7854	2.2
272	Runway	773074.9	642691.7	17.93385	-76.7822	2.36
273	Runway	773120.5	642673.5	17.93368	-76.7818	2.39
274	Taxi Way	773109.5	642696.9	17.93389	-76.7819	2.21
275	Taxi Way	773142.7	642701.3	17.93393	-76.7816	2.02
276	Taxi Way	773174.8	642706.5	17.93398	-76.7813	1.88
277	Runway	773175.1	642651	17.93348	-76.7813	2.48
278	Runway	773229.8	642629.3	17.93328	-76.7807	2.52
279	Taxi Way	773207.3	642711.2	17.93402	-76.7809	1.88
280	Taxi Way	773239.5	642716	17.93406	-76.7806	1.85
281	Taxi Way	773271.5	642720.6	17.93411	-76.7803	1.88
282	Taxi Way	773302.4	642723	17.93413	-76.7801	1.82
283	Runway	773284.3	642607	17.93308	-76.7802	2.57

284	Runway	773339.2	642584.9	17.93288	-76.7797	2.64
285	Nav Lights	773337.3	642600.6	17.93302	-76.7797	2.32
286	Nav Lights	773340.9	642608.9	17.9331	-76.7797	2.97
287	Nav Lights	773344	642617.2	17.93317	-76.7797	2.06
288	Nav Lights	773347.5	642625.6	17.93325	-76.7796	2.96
289	Runway	773394	642563.1	17.93268	-76.7792	2.71
290	Taxi Way	773439.8	642685.3	17.93378	-76.7788	1.78
291	Taxi Way	773330.1	642723.1	17.93413	-76.7798	1.87
292	Taxi Way	773356.8	642716.3	17.93407	-76.7795	1.76
293	Taxi Way	773386.3	642706.8	17.93398	-76.7793	1.76
294	Taxi Way	773439.8	642685.3	17.93378	-76.7788	1.78
295	Runway	773763.7	642439.2	17.93156	-76.7757	4.65
296	Runway	773749.8	642464.7	17.93179	-76.7758	4.26
297	Runway	773727.8	642477.4	17.9319	-76.776	3.96
298	Runway	773703.2	642483.5	17.93196	-76.7763	3.62
299	Runway	773675.6	642474.8	17.93188	-76.7765	3.46
300	Runway	773647.5	642465	17.93179	-76.7768	3.38
301	Runway	773613	642474.8	17.93188	-76.7771	3.18
302	Runway	773578.6	642488.8	17.93201	-76.7774	2.99
303	Taxi Way	773575.2	642500.1	17.93211	-76.7775	2.97
304	Taxi Way	773576.9	642511.5	17.93221	-76.7775	2.93
305	Taxi Way	773582.6	642524.1	17.93233	-76.7774	2.83
306	Taxi Way	773594.7	642531.6	17.93239	-76.7773	2.86
307	Taxi Way	773609.4	642530.6	17.93238	-76.7772	2.89
308	Taxi Way	773622.7	642525.3	17.93234	-76.777	2.88
309	Taxi Way	773646.9	642525.4	17.93234	-76.7768	2.87
310	Taxi Way	773664.7	642542.5	17.93249	-76.7766	2.61
311	Taxi Way	773674.5	642566.9	17.93271	-76.7765	2.43
312	Taxi Way	773684.5	642591.6	17.93294	-76.7764	2.19
313	Taxi Way	773683.8	642618.4	17.93318	-76.7765	2.07
314	Taxi Way	773664.9	642636.2	17.93334	-76.7766	2.11
315	Taxi Way	773634.1	642648.7	17.93345	-76.7769	2.21
316	Taxi Way	773603.7	642660.8	17.93356	-76.7772	2.04
317	Taxi Way	773588	642671.8	17.93366	-76.7774	1.96
318	Taxi Way	773579.3	642684.7	17.93378	-76.7774	1.91
319	Taxi Way	773575.3	642703.1	17.93394	-76.7775	1.85
320	Taxi Way	773591.2	642750.6	17.93437	-76.7773	1.54
321	Taxi Way	773603.3	642781.3	17.93465	-76.7772	1.53
322	Taxi Way	773615.9	642808	17.93489	-76.7771	1.58
323	Taxi Way	773621.9	642815.2	17.93496	-76.777	1.61
324	Taxi Way	773629.7	642821	17.93501	-76.777	1.64
325	Taxi Way	773602.7	642832.3	17.93511	-76.7772	1.89
326	Taxi Way	773593.5	642822.6	17.93502	-76.7773	1.9
327	Taxi Way	773493.3	642664.5	17.9336	-76.7782	1.83
328	Taxi Way	773555.5	642631.7	17.9333	-76.7777	1.86
329	Taxi Way	773569.5	642617.7	17.93317	-76.7775	2

330	Taxi Way	773569.2	642598.5	17.933	-76.7775	2.15
331	Taxi Way	773558.3	642561	17.93266	-76.7776	2.45
332	Taxi Way	773539.8	642526.4	17.93235	-76.7778	2.74
333	Runway	773448.7	642541.2	17.93248	-76.7787	2.85
334	Runway	773503.4	642519.2	17.93228	-76.7782	2.84
335	Runway	773521.8	642511.8	17.93222	-76.778	2.9
336	Taxi Way	773533.3	642517.3	17.93227	-76.7779	2.84
337	Approach lights	771190	643422.9	17.94047	-76.8	1.75
338	Approach lights	771190.2	643423.7	17.94048	-76.8	1.89
339	Approach lights	771190.5	643424.3	17.94049	-76.8	1.76
340	Approach lights	771190.8	643424.7	17.94049	-76.8	1.92
341	Approach lights	771190.9	643425.3	17.94049	-76.8	1.92
342	Approach lights	771191.4	643426.5	17.9405	-76.8	0.52
343	Approach lights	771191.1	643425.6	17.9405	-76.8	1.87
344	Runway	772937.9	642694.4	17.93387	-76.7835	2.27
345	Runway	772883.1	642716.4	17.93407	-76.784	2.25
346	Runway	772704.7	642840.7	17.9352	-76.7857	2.15
347	Taxi Way	772689	642859.9	17.93537	-76.7858	2.02
348	Taxi Way	772674	642878.8	17.93554	-76.786	1.88
349	Taxi Way	772036.4	643278.7	17.93916	-76.792	1.84
350	Taxi Way	772073.7	643263.7	17.93902	-76.7916	1.84
351	Taxi Way	772111.3	643198.7	17.93844	-76.7913	1.55
352	Taxi Way	773578.5	642719.9	17.9341	-76.7774	1.73
353	Air Traffic Control	773179.2	643218.6	17.93861	-76.7812	39.96
354	ARP	772508.8	642893.5	17.93568	-76.7875	2.39

8.6 Appendix 6: LiDAR Equipment Calibration Data

ALS Calibration Certificate



	Model	Serial Number
This certificate is valid for	**ALS80**	**SN8228**
Calibration certificate issued on	**20 December 2016**	Inspector
By	**Vetter Michael**	

Certificate and calibration data ID ***SN8228_161214_CalibrationReport_161216***

Leica Geosystems AG Heinrich-Wild-Strasse
9435 Heerbrugg
Switzerland

Components of ALS80

Component	**Device**	**Type**	**Serial Number**
LS80	Laser Scanner		8228
SC80	System Controller		8228
DL80	Data Logger	XP embedded	8228
GC80	Galvo Controller	"ALS_80" performance	X13451857Y Rev.:L
INS	SPAN System	OEM638 V1.03	BMAW16240098K
IMU	Inertial Measurement Unit	CUS6-"uIRS"	56082622
GPS	Firmware	SPAN	OMP060603RN0000
	Hardware	SPAN	OIF000004RN0000
Receivers	Optical Paths	1	11.07.16 006 - 2526
		2	11.07.16 003 - 2528

Nominal Laser Characteristics

	Valu
Beam diameter ($1/e^2$, mm)	5
Beam divergence ($1/e$ and $1/e^2$, mr)	0.2
Pulse width (maximum, Full Width Half Max, ns)	2.
Maximum single-pulse energy (mJ)	0.
Emitted center wavelength (nm)	106

Key parameters - Threshold Discriminator

Threshold discriminator channel	Threshold	
	General Operation	**Power line or other low altitude (<400m**
Discriminator AG	**150**	**205**
Discriminator AN	45	45
Discriminator BG	**150**	**205**
Discriminator BN	45	45

Calibrated Parameter

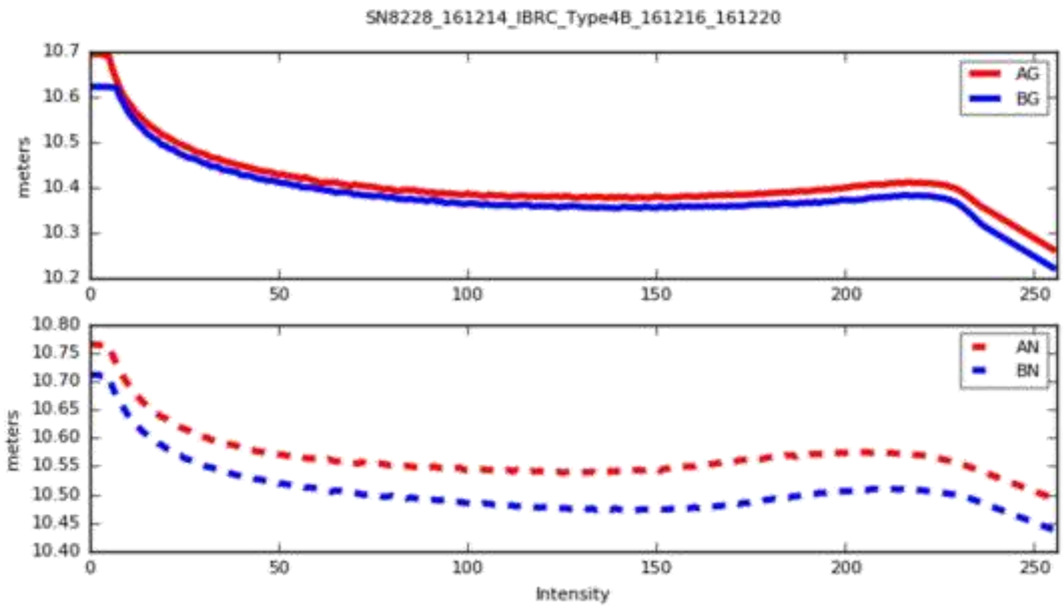
Intensity based range correction (IBRC)

	Passed	Date	Inspector
RIVIT (raw IBRC) measurements	*OK*	*14-Dec-16*	Heierli René
IBRC table	*OK*	*14-Dec-16*	Heierli René
Integrated Range Offset (Mission Date)	***OK***	***20-Dec-16***	**Vetter Michael**

File *SN8228_161214_IBRC_Type4B_161216_161220.csv*

Objective To correct for the effect of varying range based on return signal strength. Note

The range biases are in meters. The bias values derived from test data are for intensity values of 0 (low intensity) to 255 (high intensity).



Intensity based range correction (IBRC) – curve

Gain based intensity correction (GBIC) and Intensity Scale Factors

	Passed	Date	Inspector
GBIC (raw IBRC) measurements	*OK*	*14-Dec-16*	Heierli René
Float-Gain: GBIC table	*OK*	*14-Dec-16*	Heierli René
Fixed-Gain: Intensity Scale Factors	*OK*	*20-Dec-16*	Vetter Michael

Files *SN8228_161214_GBIC_Type31_161216_161220.csv*

SN8228_IntensityCorrectionTable_161216_161220.xlsx

Objective GBIC – To correct for the effect of varying AGC value on intensity.

ISF – To adjust intensity values throughout a flight

Note Correction factor values are unit less and are derived from test data through the range of AGC values.

Gain based intensity correction (GBIC) curve

	400m		1300m		3500m	
	ISFs When Above or Equal Transition Pulserate		ISFs When Above or Equal Transition Pulserate		ISFs When Above or Equal Transition Pulserate	
	Slope	Offset	Slope	Offset	Slope	Offset
AG	60.0000	0.0000	63.0000	0.0000	178.5000	0.0000
AN	347.6160	11000.0000	537.5570	11000.0000	1500.0000	31686.0000
BG	60.0000	0.0000	63.0000	0.0000	170.0000	0.0000
BN	321.6000	11000.0000	490.0000	11000.0000	1500.0000	33296.0000

Intensity Scale Factors can be optimized by customer

Flight and data processing

	Passed	Date	Inspector
Test flight – Locarno (Switzerland)	*OK*	*16-Dec-16*	Weber Raphael
Data Quality Check	*OK*	*20-Dec-16*	Heierli René
Calibration	*OK*	*20-Dec-16*	Vetter Michael

File *SN8228_161216_Calibration_161220.xml*

Objective To correct for systematic effects of this ALS System.

Validation An 'on-site' calibration has to be performed after a new system installation to adjust calibration parameters for this particular installation.

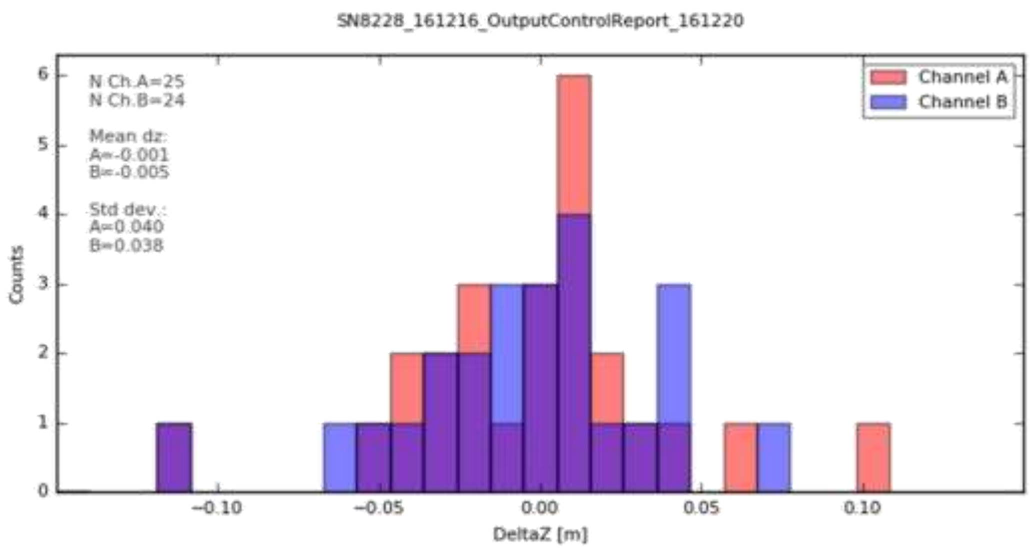
ALS Calibration Parameter Summary		
Parameter (units)	Receiver A	Receiver B
Scanner Correction		
Encoder Offset (number of	-	
ticks/counts) Encoder Latency	250	
(microseconds)	0	
Torsion Constant (Nm/rad)	0.6	
Encoder Scale Factor (Ticks/counts per Rev)	0	
POS Errors Entry	0	
Roll Boresight (radians)	838860	
Pitch Boresight (radians)	8	
Heading Boresight		
(radians)	-0.0006379108	-
	0.0006739977	
Pitch Error Slope (radians/degree)	-0.0019872619	-
PPS Correction (uSec)	0.0018042469	
IMU Latency (uSec) [Maintain in	-0.0025679030	-
ALSPP] Forward Laser Angle (Degrees)	0.0025972245	
Down Laser Angle (Degrees)	0	
Forward Mirror Normal Angle (Degrees)		
Range Correction	0	
Intensity Based Range Correction	0	
[IBRC] Transition Pulse Rate (Hz)	0	
Elevation Offset	0.03149	-
Intensity Correction	0.03808	
See Intensity Scale Factors below	8.87579	
		11.1242
Waveform Processing	1	
Trigger Delay - (pico seconds)	0.000	
GBIC Inputs		0.00
Optional Gain Based Intensity Correction [GBIC]	22	22

Accuracy Check

	Passed	Date	Inspector
Two perpendicular lines to GCP	*OK*	*20-Dec-16*	Vetter Michael
Two perpendicular lines – Ch. comparison	*OK*	*20-Dec-16*	Vetter Michael
One line difference of Ch.A and Ch.B	*OK*	*20-Dec-16*	Vetter Michael

Objective	To verify the calibration quality. Checks are based on measured Ground Control Points (GCP) on two perpendicular lines of the calibration pattern. Used GCP's

RangeOffset-LocarnoCity_UTM32N_WGS84_120605.txt



Multi-line accuracy to control points.

Multi-line accuracy between perpendicular lines of ChA (AG&AN) and ChB (BG&BN). Surface subtraction, for ChA (left) and ChB (right) - Demonstrates calibration **accuracy**