EMERGING and SUSTAINABLE CITIES

SUSTAINABLE NASSAU ACTION PLAN

Hazard and Risk Study

Environmental Resources Management Inc.

Washington D.C.

January 2017

Hazard and Risk Study

Emerging and Sustainable Cities Program - Nassau

Environmental Resources Management

Abbreviations

Acronym	Meaning
AAL	Average Annual Losses
BCA	Benefit-Cost Analysis
BEST	Bahamas Environment, Science and Technology Commission
BNGIS	Bahamas National Geographic Information Systems Department
BNT	Bahama National Trust
CN	Curve Number
DOS	Department of Statistics
EVI	Economic Vulnerability Index
ERM	Environmental Resources Management
ESC	IDB Emerging and Sustainable Cities Program
FOLUM	First Order Existing Land Use Map of the 2010 PS Act
FOZM	First Order Zoning Map of the 2010 PS Act
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GIS	Geographic Information System
IDB	Inter-American Development Bank
ICM	Integrated Coastal Management
LAC	Latin America and the Caribbean (LAC)
NEMA	National Emergency Management Agency
NGO	Non-Governmental Organization
NIAZ	Nassau Inland Adaptation Zones
NPI	Nassau and New Providence Island
PML	Probable Maximum Losses
PS Act	Planning and Subdivision Act (of 2010)
PVI	Population Vulnerability Index
RO	Reverse Osmosis
SCS	Soil Conservation Service
SLR	Sea Level Rise
USD	US Dollars
USGS	United States Geological Survey
WSC	Water and Sewerage Corporation of The Bahamas

Team

This study was elaborated by the following ERM team:

Project Director	Peter Rawlings, Partner, ERM Washington DC
Technical Director	Arturo Samper, M.Arch., M.C.P. Principal, URD Consultants, Washington DC
Assistant Project Manager and Urban Planning Specialist	Paula Alvarez, Staff Specialist, ERM
Geo Spatial Model Expert	Noam Raffel, Staff Scientist, ERM
Natural Hazards and Risks Analyst	Oliver Obregon, PhD Senior Project Engineer, ERM
Climate Change Analyst	Wairimu Mwangi Project Engineer, ERM
Population and Economic Analyst	Sara Nawaz, Staff Scientist, ERM
Map Developer	Wilson Lizarazo, Topographic Engineer URD Consultants

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Inter-American Development Bank Management Team

Juan Pablo Bonilla	Sector Manager Climate Change and Sustainable Development Department
Ellis J. Juan	Division Chief Housing and Urban Development Division

Inter-American Development Bank Technical Team

Gilberto Chona	Lead Specialist, Urban Development Economics and Regional Coordinator, Emerging and Sustainable Cities Program
Gerard P. Alleng	Climate Change Senior Specialist, Infrastructure and Environment Sector
Roland Krebs	Consultant, Emerging and Sustainable Cities Program, Coordinator Urban Design Lab (UDL)
Brian Mc Nish	Transportation Senior Specialist
Hori Tsuneki	Disaster Risk Management Specialist
Yvon Mellinger	Water and Sanitation Lead Specialist
D. Avelina Ruiz Vilar	Consultant, Emerging and Sustainable Cities Program

Inter-American Development Bank The Bahamas Country Office

Maria Florencia Attademo-Hirt	Country Representative
Michael Nelson	Chief Operations
Allen Wright	Country Economist
Camile A. Davis-Thomson	Operations Specialist
Syreta Roberts	Operations Senior Analyst
Endric Deleveaux	Consultant

The Office of the Prime Minister

Nicola Virgil-Rolle, PhD	Director, Economic Development and Planning Unit. ESC Program Liaison
Brett Lashley	Program Manager
Samantha Rolle	Program Manager
Michaelle Bereaux	Communications Policy Advisor
Kemie Jones	Consultant
Hellen Mukiri-Smith	Consultant
Denise Hinds-Jordan	Consultant
Kevin Surujal	Senior Project Officer
Daniella Pratt	Project Officer
Myra Farquharson	Administrative Cadet

Key stakeholders and participants in the process (alphabetic)

Alanna Rodgers	Tru Bahamian Food Tours
Amanda Coulson	National Art Gallery of the Bahamas
Anthony Jervis	Professional Architects Board
Arlene Nash-Ferguson	Ministry of Tourism, Educulture Bahamas
Camille Johnson	Ministry of Environment and Housing
Captain Stephen Russell	National Emergency Management Agency
Carl Oliver	Ministry of Finance
Carolann Albury	Bahamas National Geographic Information Systems (BNGIS)
Charles Zonicle	Department of Physical Planning
Chaswell Hanna	Ministry of National Security (RBPF)
Christopher Russell	Forestry Unit, Ministry of Environment and Housing
Courtney Strachan	Antiquities, Monuments & Museums Corporation
Craig Delancy	Ministry of Public Works and Urban Development
Danielle Hannek	Forestry Unit, Ministry of Environment and Housing
Donella Bodie	Ministry of Education, Science and Technology
Earlston McPhee	Ministry of Tourism
Gevon Moss	Downtown Nassau Partnership
Glen Laville	Water and Sewerage Corporation
Ian Poitier	Ministry of Tourism

Kevin Basden	Bahamas Power & Light
Leona Wilson	Department of Statistics
Lorraine Armbrister	Ministry of Transport and Aviation
Mellany Zonicle	Ministry of Social Services and Community Development
Melony McKenzie	Department of Environmental Health Services
Michael Major	Department of Physical Planning
Phill Weech	Bahamas Environment Sciences & Technology Commission
Richard Hardy	Department of Land and Surveys
Stephen Bereaux	Utilities Regulation & Competition Authority (URCA)
Valentino "Scrooge" Brown	Movement For Change

ERM Partners

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Executive Summary

Nassau in The Commonwealth of The Bahamas has been selected by the Inter-American Development Bank (IDB) to be part of its Emerging and Sustainable Cities (ESC program). By virtue of the fact that Nassau and its surrounding urban areas occupy the majority of New Providence Island, the study area selected has comprises New Providence Island (including Paradise Island), collectively referred to as NPI. The ESC program's objective is to contribute to the improvement of the quality of life in Latin America and the Caribbean (LAC) cities in terms of environmental, urban, and fiscal sustainability. To accomplish this, the program provides decision makers with tools, data, and initial frameworks for managing urban growth and territorial expansion. One essential component of the program includes outcomes from a hazard and risk assessment, which analyses three priority natural hazards which in the case of NPI are inland flooding, coastal flooding and groundwater salinization. The outcomes from the hazard and risk assessment are used to understand and evaluate the vulnerability of infrastructure and human assets and risks associated with natural hazards. The prioritized hazards evaluated for NPI were selected based on a literature review of hazard records and information, discussions with IDB specialists and key Bahamian stakeholders.

Approach

The hazard and risk assessment considers the evaluation of a series of current and future scenarios which include different conditions and factors that can produce impacts on economic and human assets. The process to evaluate hazard and risk in NPI under these scenarios consists of:

- identifying climate change projections (obtained from *The Second National Communication Report of The Commonwealth of The Bahamas*);
- developing profiles for the prioritized hazards;
- assessing vulnerability (exposed buildings and population);
- estimating losses; conducting economic and population-based risk assessment; and
- proposing and evaluating five mitigation/adaptation measures that can be implemented in high risk areas.

Hazards

Coastal flooding occurs most severely along the southern coast of NPI, where there are the lower elevations and the predicted storm surge is the highest. For a coastal flooding event with a 100-year return period, and with projected sea level rise (SLR) to 2050, there is a large area of the island that could experience high hazard flooding.

Assessment of inland flooding hazards indicate that with climate change and current land use, the total potential inundated area is estimated to be approximately 106 km^2 for a 100-year event[1]. These areas vulnerable to flooding will change and may increase depending upon the future growth trajectory NPI may follow. The main drivers producing inland flooding are associated to the increase in developed areas (mainly on the east side of NPI) that have produced an increase of impervious surfaces in the form of roads, buildings, parking lots, and shopping centers. The soils of NPI are calcareous and sandy which are considered to be highly permeable. These types of soils can quickly infiltrate water avoiding the formation of natural perennial streams. However, NPI's soils rapidly become saturated due to the high water table and associated tidal influences on groundwater levels, producing floods, which are then exacerbated by the seepage to the sea of flood waters being a slow process and is the only natural way to deal with the excess runoff.

NPI is considered highly vulnerable to groundwater salinization, both because the freshwater lenses is being overexploited and due to contamination. Aquifers in NPI have been historically threated and the projected reduction of precipitation and increase in population for the 2050 horizon would continue affecting freshwater availability and demand in NPI. In addition to groundwater salinization, groundwater resources in NPI are prone to natural and anthropogenic contamination given the nature of freshwater resources (high water table), soil, climate and geology (low-lying limestone) of NPI as well as the limited wastewater disposal network. Swamps and/or marshes are often used for waste disposal and untreated domestic wastes and effluents are directly discharged to groundwater, representing one of the main threatens to groundwater resources in NPI.

Risks

High risk areas in NPI occur due to the most severe flooding, and are concentrated in central parts of Nassau where there is low lying ground, many buildings, and a high population density. Much of the western side of NPI has been assessed as a low risk to population due to the low population density. Because population density is assigned for each district, the population risk within a neighborhood of the district can be greater than the average risk across the district. A district may have an overall low density, but a neighborhood within it may have a higher

[1] A 100-year recurrence interval or a probability of 1 in 100 chance that a particular event will occur during any year.

density. In addition, economic losses will be largely impacted (an increase of 8-13%) by climate change. Land use changes, either increases or decreases in urbanization, can affect the flood losses, although to a lesser extent than climate change.

Conclusions

Results from this hazard and risk assessment can assist decision makers to better understand natural hazards; to identify which assets and areas are most exposed to the prioritized natural hazards; to estimate the probabilistic damage and loss with and without climate change consideration; and to improve decision-making for risk mitigation in order to reduce infrastructure and human life losses and damages. This study also includes a list of potential adaptation and mitigation measures that can be implemented to increase the resilience of NPI to the prioritized natural hazards and its exacerbation produced by climate change. Cost-Benefit Analysis was conducted for five adaptation measures resulting to illustrate the benefits and opportunities for adaptation and management.

1. Introduction

1.1 Background and ESC

Cities and urban areas play a key role in the economy of Latin America and the Caribbean (LAC) through generating opportunities, such as diffusion of expertize and innovation, concentration of specialized labor, and provision of educational, cultural, and recreational services. With these opportunities come challenges such as poverty created by in-migration and an increasing and often unsatisfied demand for urban and social services, decent housing conditions, and opportunities to generate income. Overcoming these challenges require a comprehensive approach that promotes both sustainable growth and the improvement of citizens' quality of life.

Formal and informal growth often leads to negative environmental, social, and economic impacts. Municipal policy makers usually lack adequate data and analysis to inform the design of policies that help promote growth in a sustainable way. In many cases, the implications for the municipal budget in terms of financing infrastructure development and operation costs have not been clarified in newly urbanized areas. Additionally, the environmental impacts of city growth are often not typically fully considered. Areas for conservation and aquifer recharge need to be established or protected, and vulnerability to natural disaster and the effects of climate change reduced. Anticipatory planning can also help reduce greenhouse gas emissions (GHG) as a major factor affecting climate change.

In response to this situation and in light of the continuing urbanization process in the LAC region, the Inter-American Development Bank (the IDB) launched its Emerging and Sustainable Cities Program (ESC). The purpose of this program is to contribute to the improvement of the quality of life in LAC's cities in terms of environmental, urban, and fiscal sustainability. To accomplish this, the ESC provides decision makers with tools, data and initial frameworks for managing urban growth and territorial expansion

Through the ESC, the Bank combines the expertise of its different sector departments in the formulation of comprehensive action plans designed to facilitate sustainable city planning. It leverages its capacities as the leading source of development financing for the region and applies its long experience in supporting the countries of LAC.

1.2 About this Study

Environmental Resources Management, Inc. (ERM) has been retained by the IDB to perform a series of studies for Nassau in The Commonwealth of The Bahamas (The Bahamas). This study addresses the second task and focuses on a hazard and risk study that analyses three priority hazards in order to understand and assess the vulnerability and risks associated with natural hazards.

1.3 Objective of the Study

This study focuses on undertaking a baseline risk assessment and vulnerability analysis of Nassau and New Providence Island (NPI), comprising a probabilistic risk assessment, impact analysis and mapping of prioritized hydro-meteorological hazards. The analysis utilizes a common risk framework, where risk is a function of hazard, exposure and vulnerability. The results from this aspect of the study will assist decision makers:

- to better understand natural hazards;
- to identify which assets and areas are most exposed to natural hazards;
- to estimate the probabilistic damage and loss with no climate change consideration (baseline conditions);
- to understand the most serious potential consequences of climate change (i.e., physical damage, economic loss, and loss of human life); and
- to improve decision-making for risk mitigation, in order to reduce infrastructure and human life losses and damages.

This report presents the results of the study, as well as recommendations to address the identified hazards and risks.

1.4 Area of Study

The area of study comprises New Providence Island (which includes Paradise Island) and comprises the following 'realms' that appear illustrated in Figure 1: , beginning with the smallest:

1. **Nassau**: This is the area comprised by the urban footprint that grew as a continuation of the grid established for historic Nassau (noting that historic Nassau is the area where Charles Towne rose up during the 18th century), to approximately the middle of the 20th Century. It also includes the lands of Paradise Island, Treasure Island

and Athol Island, as well as the Cays named North, Long, Silver, and Potter.

2. **Greater Nassau:** This is the area East and South of the latter, which experienced the largest process of growth by zoning order and consolidated the city that today can be appreciated as 'metropolitan Nassau.
3 **New Providence:** This would be the remainder of NPI.

Because of the nature of this study – hazard and risk – the focus of the analyses and recommendations is to be placed on at the NPI level.

1.5 Report Structure

In this document, ERM presents the results of the hazard and risk study conducted for Nassau and NPI shown in Figure 1. This study is comprised of the following sections.

- Section 1 contains the conceptual framework that supports the analyses carried out.
- Section 2 presents the analysis and results of three evaluated hazards (inland flooding, coastal flooding and groundwater salinization) including a description of their main drivers;
- Section 3 describes the study area's vulnerable areas to hazards described in Section 2. The vulnerability assessment considers the study area's population exposure as well as the assets exposed;

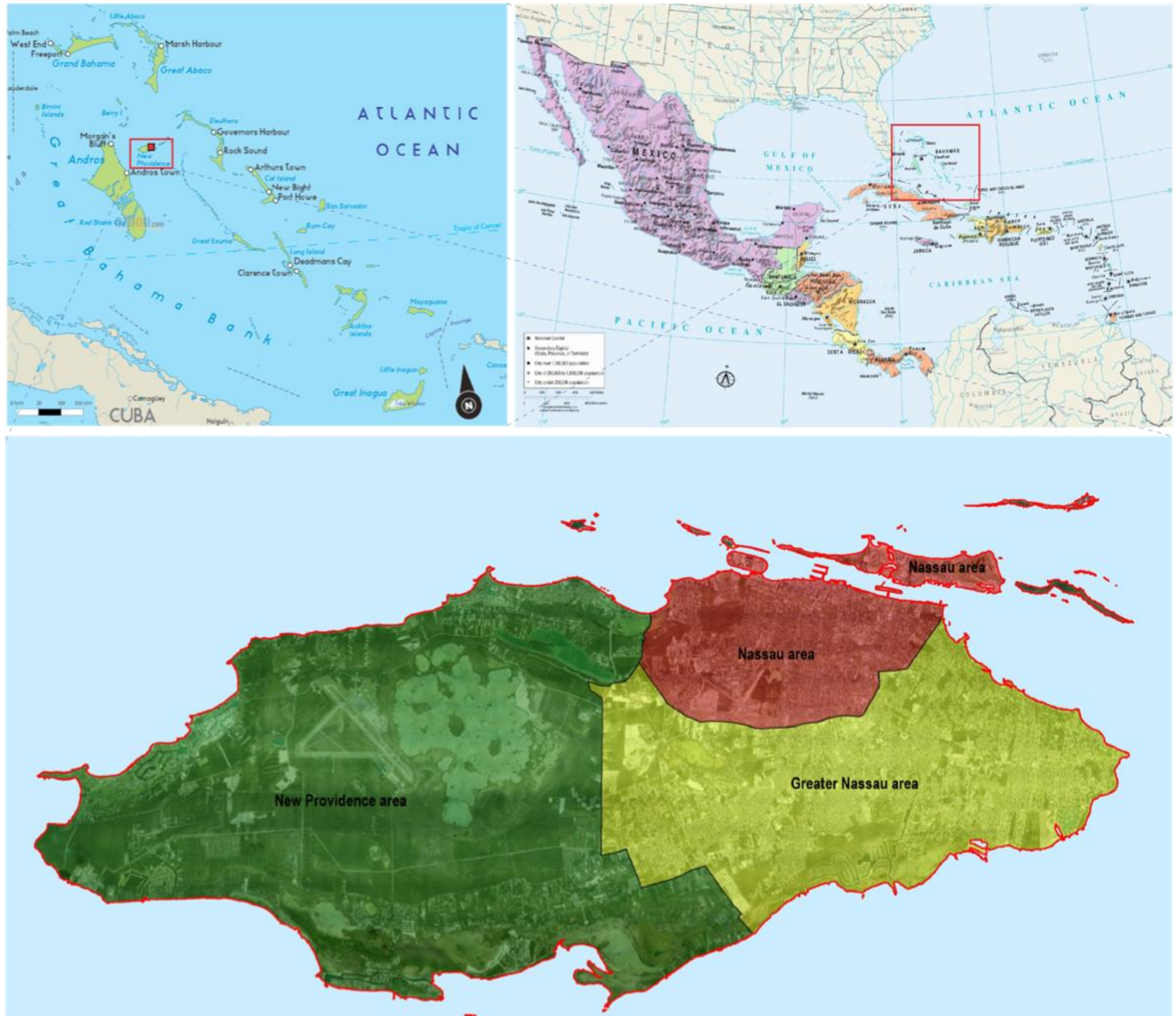


Figure 1: Area of Study and main division of the Island for the purposes of the Study.

- Section 4 describes methods, inputs and tools used to conduct the risk assessment for Nassau and NPI. This chapter also describes the indicators used to estimate economic losses (Probable Maximum Loss, Loss Exceedance Curve and Average Annualized Loss). Finally this chapter provides a list of recommended steps for interested stakeholders to further advance the hazard and risk work in Nassau and NPI;
- Section 5 provides a list of several sustainability options for adapting or mitigating risks associated with inland/coastal flooding and groundwater salinization hazards. Five proposed adaptation/mitigation strategies were used to assess the possible costs and benefits by using a Benefit Cost Analysis (BCA) model. These five strategies included upgrading urban drainage infrastructure, protection/restoration mangrove at the southern shoreline, use of green infrastructure, protection of coastal flooding and erosion, and property protection. Four of the adaptations are structural while the mangrove protection is a non-structural adaptation that will also provide benefits to the wider environment in terms of supporting environmental protection, aquifer recharge and biodiversity enhancement, in addition to the flood management and hazard protections.

The information outlined in this document should be used to inform citizens and decision makers about hazards and the risks under existing and future projected climate change conditions. This hazard and risk study in particular provides a basis for understanding the hazard impacts and prioritizing actions by laying out general sustainability interventions that should be considered for building more climate change resilience in Nassau and NPI.

2 Context and Approach

Natural hazards and their associated disasters are the result of naturally occurring processes that have occurred throughout Earth's history and have the potential to be exacerbated by climate change (UNISDR, 2007). Risk is characterized by the relationship between humans or assets with natural hazards. Figure 2 presents a diagram that summarizes ERM's approach to conducting natural hazard and risk assessments for NPI. The assessment of hazard profiles consists of determining the location of hazardous process, its severity (magnitude), frequency of occurrence, likely effects of a given magnitude and making all this information available in a form that can be useful to decision makers, planners and stakeholders responsible for responding to disasters. Risk assessment (and associated risk maps) involves the assessment of hazards and socio-economic impacts associated to a hazard event. Risk combines the probability of a hazardous event and its negative consequences through interaction between hazards, exposure and vulnerability components. Vulnerability are the characteristics and circumstances of a community or asset that make it susceptible to damaging effects of a hazard (UNISDR, 2007).

This section contains the conceptual framework that supports the hazard and risk assessment conducted for NPI including a description of the prioritized hazards, climate change projections used and the different scenarios analyzed.

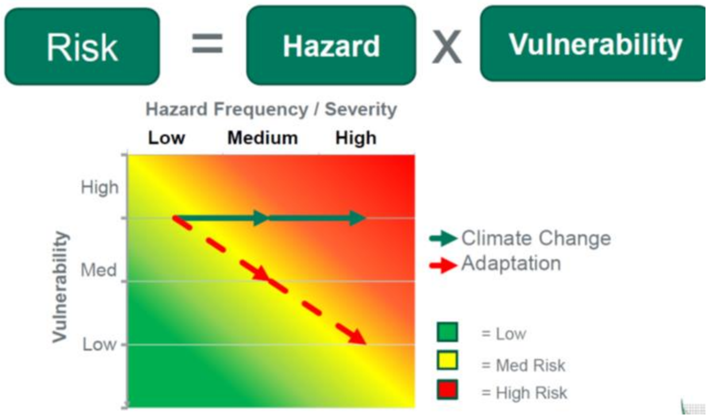


Figure 2: Risk, hazard and vulnerability framework

2.1 Prioritized Hazards

Based on a literature review of hazards records and information, discussions with the IDB specialists and Bahamian stakeholders (see Table 2-1), the following three hazards for NPI were prioritized and evaluated in this study:

- ***Coastal Flooding:*** This occurs when sea level rises during tropical storms and hurricanes and has the potential to severely impact low-lying coastal development and infrastructure. On NPI, coastal flooding usually occurs during the hurricane season. Coastal flooding can be exacerbating by projected increases in sea levels (USACE, 2004).
- ***Inland Flooding:*** This is caused by rainfall-induced accumulation of water on NPI, poor drainage, and saturated soil (high water table). Away from the coasts, floods and storms are the primary natural disasters that have caused death and damage in the Bahamas due to its geographical location that makes it susceptible to flooding by tropical storms and hurricanes (USACE, 2004).
- ***Groundwater Salt Intrusion:*** There are no rivers on NPI and the groundwater sources are already affected by salinization. Existing freshwater lenses overlay sea water and present signs of salinization produced by their overexploitation. This is why the potable water supply for the islands relies on Reverse Osmosis (RO) treatment techniques for desalinization. The increased intrusion of salinity to fresh groundwater aquifers is caused by increased demand and can be aggravated by sea level rise and climate change (increase in water demand). According to the Water and Sewerage Corporation (WSC), many households in Nassau and NPI use private wells as a water supply source, but in most of cases those wells do not receive appropriate treatment representing a risk for the users' health.

Table 1: Bahamian Stakeholders

Stakeholders engaged	
• IDB's Specialists in DC and Bahamas • Water and Sewerage Corporation (WSC); • Department of Meteorology; • Bahamas Environment Science and Technology Commission (BEST) • Ministry of Housing; • The College of The Bahamas;	• Ministry of Works and Urban Development • National Emergency Management (NEMA) • Bahamas National Trust (BNT) • Department of Lands and Survey • Bahamas National Geographic Information Systems Department (BNGIS)

Figure 3: Flooding at Nassau, Bahamas during Hurricane Joaquin in 2015 (source: bahamas.com)

2.2 Approach

The process to evaluate hazards and risks in NPI consists of the following steps:

i. Identification of climate change projections for the area;
ii. Development of hazard profiles;
iii. Assessment of vulnerability (exposed buildings and population);
iv. Estimation of losses; and
v. Risk analysis framework.

Section 6of this study presents risk reduction recommendations (adaptations), where hazard losses are compared and recommendations to mitigate selected hazards are identified. Cost-benefit analysis for the selected adaptations is also presented in section 6.

2.3 Climate Change Projections

The climate change projections used for the hazard and risk analysis were taken from *The BahamasSimCLIM* system reported in *The Second National Communication Report of The Commonwealth of The Bahamas* (SNC, 2014). The *BahamasSimCLIM* is a tool used to generate climate change and sea level rise (SLR) projections based on the use of different Special Report on Emissions Scenarios (SRES). This tool uses 21 Global Climate Model (GCM) patterns for generating climate change and SLR projections for the Bahamas. The Climate Change projections assumed an A1FI emissions scenario which was defined by IPCC. The SNC (2014) report does not provide details about why A1FI emission scenario was used. The A1FI assumes a future world of very rapid economic growth with fossil fuel intensive technological emphasis. The projections for the Bahamas are based on outputs from for the 2050 horizon. For the hazard and risk assessment studies, the following projected variables were used:

Temperature

According to *The BahamasSimCLIM* system's projections using a group of 21 GCM's and considering the A1FI emission scenario, the maximum daily temperatures for the 2050 horizon are expected to increase by 1.97℃ for The Bahamas. Average daily maximum temperature increases for winter months will be less than 2℃ while summer months will be over 2℃. Table 3 presents the increase in average daily maximum temperature for the 2050 horizon under A1FI emission scenarios projected for NPI.

Precipitation

Table 2 also presents the percentage of change in precipitation projected for the 2050 horizon from *The BahamasSimCLIM*. These projections suggest an average decrease in annual precipitation of 10% in The Bahamas with 20% during some months for most of the islands. As shown in Table 2, it is projected that precipitation on NPI would experience a reduction up to 20% during the dry and wet seasons from March to August (SNC, 2014).

According to the SNC (2014) report, extreme precipitation events are expected to increase between 6% and 11% on NPPI. These extreme events were evaluated by using an extreme value analysis and historical precipitation data collected at the Nassau Airport meteorological station, which has the most complete and long-term climatological records for New Providence Island (see Table 3).

Table 2: Projected Most Extreme Precipitation Events at Nassau International Airport Meteorological Station for 2050

Return Period (years)	Existing Daily Precipitation (mm)	Climate Change Daily Precipitation Projected for 2050 (mm)	% Change
2	108	102	-6
5	200	206	+3
10	271	287	+6
25	375	405	+8
50	468	508	+9
100	559	622	+11

Source: Adapted from UNFCCC (2014) mm= millimeters

Sea Level Rise

Sea Level Rise (SLR) has direct effects on freshwater discharge and groundwater salinization along small islands like NPI. As reported by SNC (2014) and CCCCC (2015), the IPCC climate change estimation for sea level rise for 2050 in the Bahamas is 20 mm. The SLR Projections for A1FI emission scenario generated from *The BahamasSimCLIM* system indicate that sea level will rise 9.0 cm, 20 cm, and near 70 cm by 2030, 2050 and 2100, respectively. The projected SLR from *The BahamasSimCLIM* is consistent with the global SRL trend. Figure 4 shows the SLR projections generated from *The BahamasSimCLIM* for Bahamas.

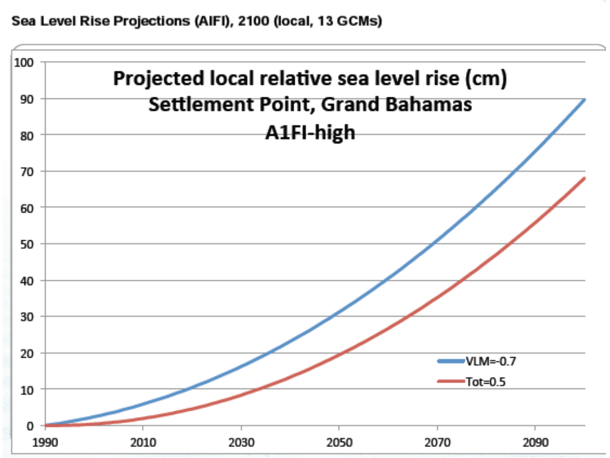


Figure 4: SLR Projections (A1FI) Generated with The BahamasSimCLIM (Source: UNFCC, 2014). VLM = Vertical Land Movement and Tot = Total Sea Level Rise. The y-axis is in centimeters.

According to the SNC (2014) report, extreme precipitation events are expected to increase between 6% and 11% on NPI. These extreme events were evaluated by using an extreme value analysis and historical precipitation data collected at the Nassau Airport meteorological station, which has the most complete and long-term climatological records for New Providence Island (see Table 3).

Table 3: Summary of Climate Change Projects for New Providence for 2050

Monthly or Annually	Average Daily Maximum Temperature increase ℃	Decrease in Precipitation in %	SLR in cm
Year	2.03	-11.76	20
December to February	1.88	-6.50	---
March to May	1.88	-19.79	---
June to August	2.16	-19.85	---
September to November	2.16	+0.86	---

Source: Adapted from SNC (2014). C = Degrees Celsius; mm = millimeters; % = percentage.

2.4 Scenario Analysis

For the hazard and risk analysis, the following scenarios were assessed:

- ***Baseline*** – representing the situation today on NPI;
- ***Business-As-Usual*** growth scenario for 2050 as defined in ERM's Urban Growth Study (including climate change projections); and
- ***Intelligent Growth*** scenario for 2050 as defined in ERM's Urban Growth Study (including climate change projections).

3 Hazard Profiles

3.1 Background

The United Nations Office for Disaster Risk Reduction (UNISDR) defines a natural hazard as a natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage (UNISDR, 2007). There have been different natural hazards affecting Bahamas throughout history, that include coastal flooding, hurricanes, inland flooding, sea level rise (SLR), droughts, and groundwater salinization. As described in Section 1 three hazards were prioritized based on a literature review of hazards records and information, discussions with IDB specialists and Bahamian stakeholders (see Table 1). Profiles were developed for the three prioritized hazards (coastal flooding, inland flooding and groundwater salinization) by investigating their occurrence and frequency on NPI. The hazards identification process on NPI included consultation with key governmental, NGO, and community stakeholders, as well as observations during field missions. Information on past hazard events were also downloaded from Bahamas Disaster and Risk Profile (http://www.preventionweb.net/countries/bhs/data/) and from The International Disaster Database (http://www.emdat.be/country_profile/index.html). The hazard profiles include the spatial extent of hazards, where possible (i.e., maps), understanding the frequency or probability of future events, their magnitude, and climate variability factors that may affect their severity. Each identified hazard has unique characteristics that can impact NPI. *Appendix A1* provides details of the selected hazards and the methods used for their analysis. The analyzed hazards are summarized below:

3.2 Hurricanes and Coastal Flooding

Tropical cyclones are rapidly rotating storm systems characterized by a low-pressure center and a spiral arrangement of thunderstorms. They usually bring strong winds and produce heavy rain. Depending on the storm intensity, tropical cyclones are classified as tropical depressions, tropical storms, and hurricanes. Storms in the hurricane category are particularly dangerous and have the potential of producing heavy coastal flooding. Hurricanes are further divided into five categories based on the maximum wind speed, central pressure, and resulting potential damages. This classification is known as the Saffir-Simpson Hurricane Intensity Scale and is described in Table 4.

Table 4: Saffir-Simpson hurricane damage-potential scale (Adapted from USACE 2008)

Hurricane	Wind speed (kt)	Central pressure (millibars)	Surge (m)	Damage
Category 1	64 – 82	> 980	~ 1.5	Minimal
Category 2	83 – 95	965 – 979	2 – 2.5	Moderate
Category 3	96 – 112	945 – 964	2.6 – 3.9	Extensive
Category 4	113 – 136	920 – 944	4 – 5.5	Extreme
Category 5	> 137	< 920	> 5.5	Catastrophic
Kt = knots; m = meters				

Hurricanes gain their energy from warm waters as they move across the Atlantic Ocean. As the system moves inland over islands, the system loses strength and dissipates. Hurricanes as well as tropical storms typically have enough moisture to cause extensive flooding throughout a large geographical area. In addition to flooding, hurricanes and tropical storms can bring severe winds, extensive coastal erosion, extreme rainfall, thunderstorms, lightning, and tornadoes (USACE, 2008).

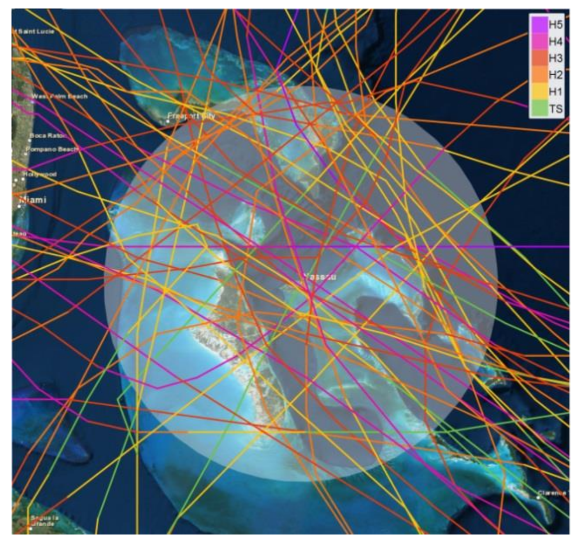


Figure 5: Hurricanes that passed within 200 km of the island of New Providence since 1850 (Data source: NOAA, 2015b)

The tracks of historical hurricanes that passed within 200 kilometers (km) of NPI since 1850 are shown in Figure 5. The two principal directions of movement are towards the north-west and towards the north-east. Figure 6 shows the total number of hurricane per year since 1850. The figure indicates that the peak of hurricane activities was in the 1930s and two minor peaks occurred in the 1890s and 1960s.

Coastal flooding occurs when the sea level rises during tropical storms and hurricanes and has the potential to severely impact low-lying coastal settlements such as cities, villages and infrastructure. The United States National Oceanic and Atmospheric Administration (NOAA) identifies the rise in sea water level during storm conditions as storm surge, which is defined as an abnormal rise of water generated by a storm, over and above the predicted astronomical high tide (NOAA, 2015a). The increase of sea water level can inundate coastal land through two major paths:

1. *Direct inundation*, where the sea level exceeds the elevation of the land; or
2. *Overtopping of a barrier*, where the sea level overtops or breaches a natural or artificial barrier.

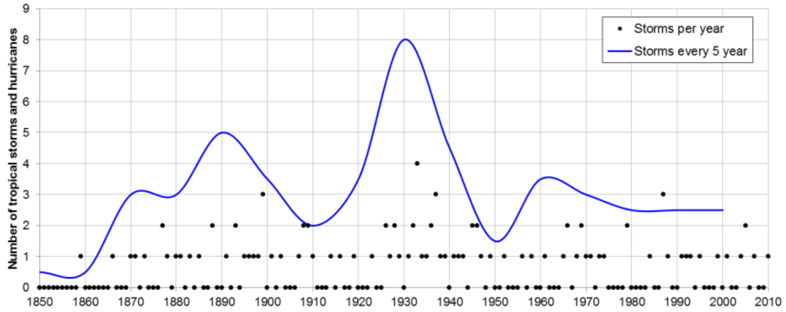


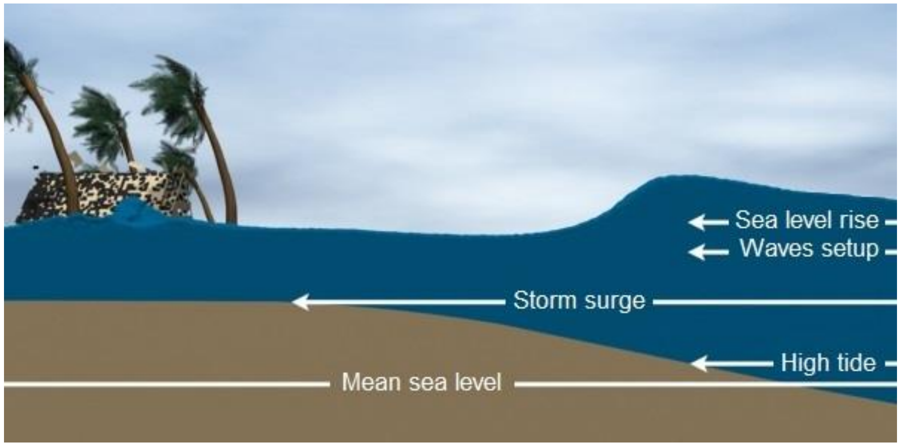
Figure 6: Number of tropical storms and hurricane that passed within 200 km of the island of New Providence.

Coastal flooding is largely a naturally occurring event. However, human influence on the coastal environment can exacerbate damages.

On NPI, coastal flooding is a hazard of national concern, in particular during the hurricane season. Predictions of climate change and global warming indicate an increase in flooding due to a rise in sea level (USACE, 2004).

Processes contributing to total storm surge

Coastal flooding occurs mostly because of the storm surge created by the hurricane and its backwater effects on inland stormwater systems. Several other processes also contribute to coastal flooding and each needs to be evaluated separately. Figure 7 shows the process contributing to the total storm surge.



Source: Adapted from NOAA (2015a)

Figure 7: Processes Contributing to Total Storm Surge

Storm surge is the combination of wind setup and pressure setup during hurricanes and tropical storms. High tides depend on the combined effects of the gravitational forces exerted by the Moon and the Sun and the rotation of the Earth. Wave setup is the increase in mean water level due to the presence of waves. Wave setup is largest during tropical storms and hurricanes.

Figure 8 shows the 100-year return flood map (water depth) for the study area indicating the potential for inundation and showing the vulnerabilities of coastal settlements to flooding while Table 6 presents the results of coastal flooding under baseline conditions and projected SLR for the 2050 horizon. *Appendix A1* presents details of how total surge for four return periods (10-, 25-, 50-, and 100-years) were calculated for the study area. A 100-year return event can be described as an event (flood or total surge) having a 100-year recurrence interval or a probability of 1 in 100 chance that a particular event will occur during any year. Statistical techniques, through a process known as frequency analysis, are used to estimate the probability of the occurrence of a given extreme event.

Figure 9 to Figure 12 present coastal flooding hazards profiles for NPI for a 100-year return period under baseline, baseline with climate change (climate change) for 2050, Business-As-Usual, and Intelligent Growth Scenario, respectively. *Appendix A1* presents coastal flooding hazard profiles for other return periods (10-, 25-, 50-, and 100-years) under these four scenarios for NPI, as well as a detailed description of the approach followed to create the hazard maps.

Coastal flooding occurs most severely along the southern coast of New Providence. The southern coast has lower elevations, and the predicted storm surge is highest. For a coastal flooding event with a 100-year return period, and with sea level rise to 2050, there is a large area of the island that could experience high hazard flooding. Land use did not affect the areas of inundation for coastal flooding. Due to the sustained large depths from a storm surge, infiltration does not reduce the flooding. Land use will determine the number and types of buildings within the flooded areas, which will affect the total damages.

Table 5: Coastal Flooding Projections for New Providence and Paradise Island (including for SLR to 2050)

Return period (yr)	Baseline (km^2)	Climate Change (km^2)	Intelligent Growth (km^2)	Business-As-Usual (km^2)
10	0.2	0.7	0.7	0.7
25	0.3	11.1	11.1	11.1
50	22.2	25.6	25.6	25.6
100	33.7	37.3	37.3	37.3
km^2= square kilometers				

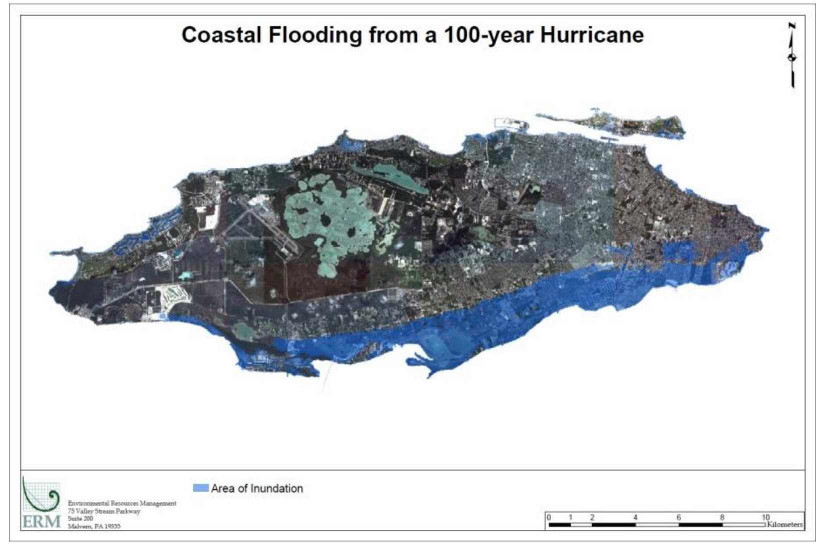


Figure 8: Coastal Flooding for a 100-year event under Baseline Conditions

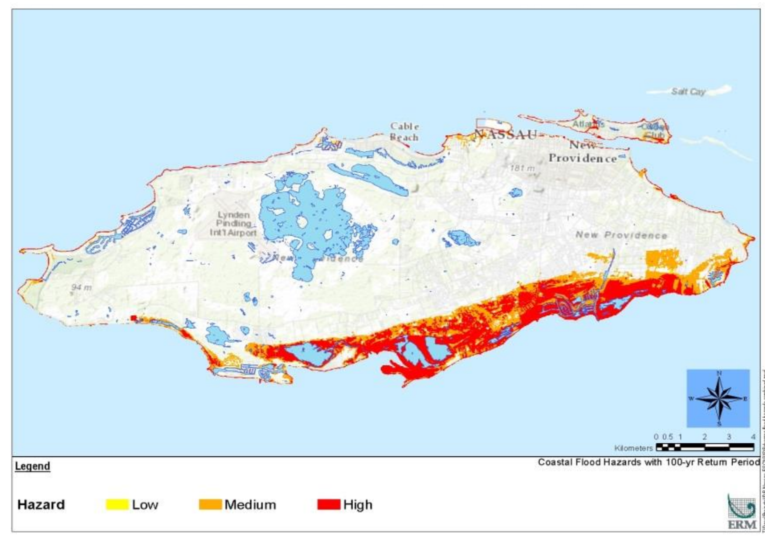


Figure 9: Coastal Flooding Hazard Map for a 100-year event under Baseline Conditions

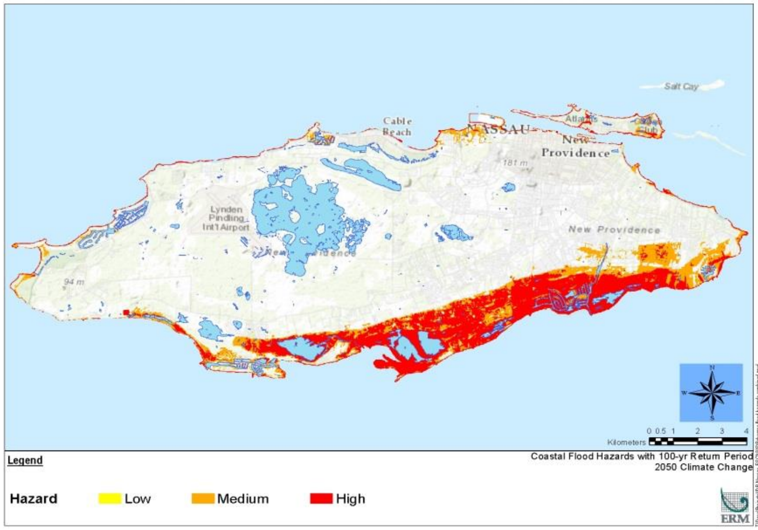


Figure 10: Coastal Flooding Hazard Map for a 100-year Return Period under Climate Change for 2050 Horizon

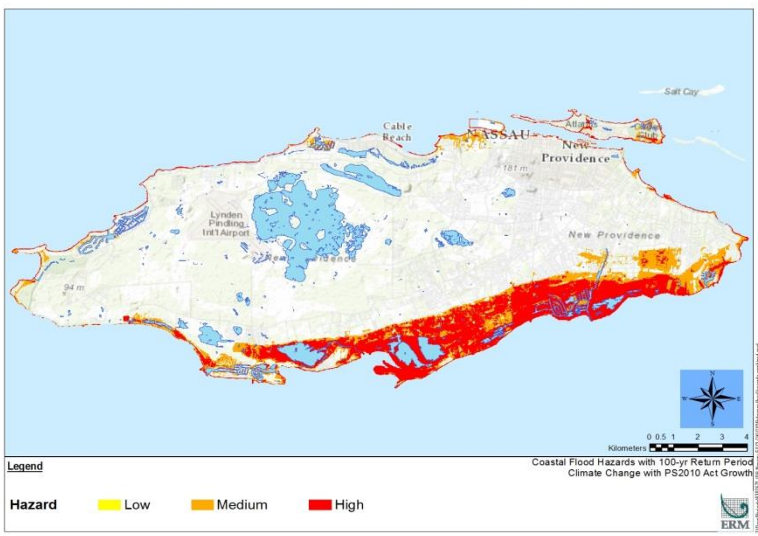


Figure 11: Coastal Flooding Hazard Map for a 100-year Return Period with 2050 SLR and Business-As-Usual Scenario

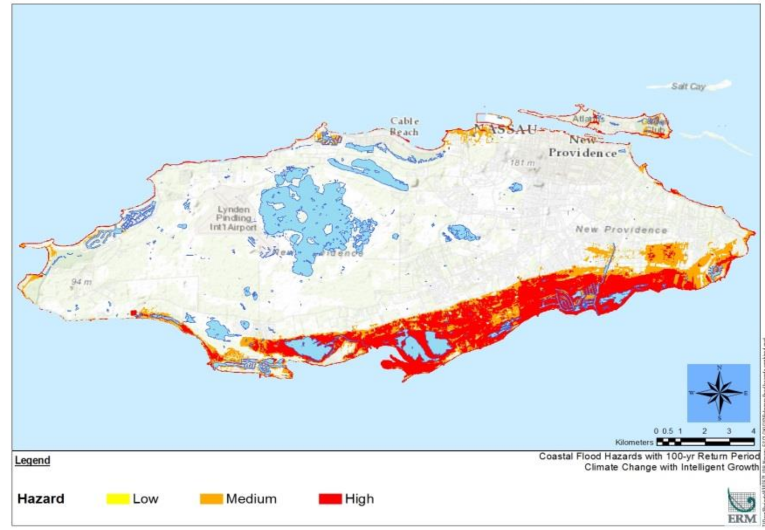


Figure 12: Coastal Flooding Hazard Map for a 100-year Return Period with 2050 SLR and Intelligent Growth Scenario

3.3 Inland Flooding

Floods in The Bahamas, as in other Caribbean islands, follow tropical weather patterns. NPI has two well defined seasons, wet and dry, with an average annual total rainfall of 1248 mm (SNC, 2014). The wet season occurs from May to October (summer) while the dry season occurs from December to April. According to Diamond (2011) and information obtained from in-country workshops with stakeholders, precipitation events are short and intense with sunshine returning shortly after rain stops.

Most of the areas on NPI have been developed with a high density of population (i.e., Nassau City). The increase in developed areas (mainly on the east side) has produced the increase of impervious surfaces in the form of roads, buildings, parking lots, and shopping centers. The soils of NPI are calcareous and sandy which are considered to be highly permeable. These types of soils can quickly infiltrate water avoiding the formation of natural perennial streams. However, the NPI's soils become saturated due to the high water table producing floods since seepage to the sea is a slow process and is the only natural way to deal with the excess runoff (USACE 2004). These saturated and groundwater influenced conditions are typical for small islands according to UNESCO (2010).

The inland flooding hazards for NPI were determined using the flood routing model FLO-2D which is a two-dimensional finite difference model that simulates clear-water flood hazards, mudflows, debris flows on alluvial fans and urban floodplains, channel flow, unconfined overland flow, and street flow over complex topography (FLO-2D Reference Manual, 2004). This software is approved by the United States Federal Emergency Management Agency (FEMA) for Flood Insurance Studies. FLO-2D models two dimensional overland flow across a floodplain by conducting volume conservation. Flow within stream channels is modeled as one-dimensional. The model is set up with uniform, square grid elements. Inflow to the model occurs at inflow nodes with a specified hydrograph. Velocities and flow rates are computed for each grid element based on inflow water surface elevation, ground surface elevation, and Manning's roughness coefficient. The transfer of water mass between grid elements occurs in the eight compass directions: E, S, W, N, NE, SE, SW, and NW.

For this study, ERM used the following input data for FLO-2D to determine the inland flooding hazard:

- Elevation from Digital Terrain Model (from 2-m DTM resolution);
- Land use and soil type (SCS Curve Number method and Manning's n values);
- Rainfall (extreme rainfall events at the Nassau International Airport – see Table 6);
- Coastal Flooding (Total Storm Surge with and without SLR); and
- Exposed Assets (i.e., buildings, streets) and Population.

Appendix A1 includes details for the inputs, approach and assumptions used to evaluate inland flooding hazards in NPI.

Table 6: Daily rainfall return periods for baseline and climate change scenarios

Return period (year)	Baseline rainfall (mm)	Climate Change rainfall (mm)
10	271	287
25	375	405
50	468	508
100	559	622

Source: Adapted from SNC (2014). mm = millimeters

Figure 13 shows a 3D inland flooding map for the 100-year event under baseline conditions, showing the maximum flood depth in the Downtown Area of Nassau in New Providence Island. According to the FLO-2D Reference Manual (2004), flood hazard can be defined by the product of maximum flood depth and maximum flood velocity, as shown in Table 7.

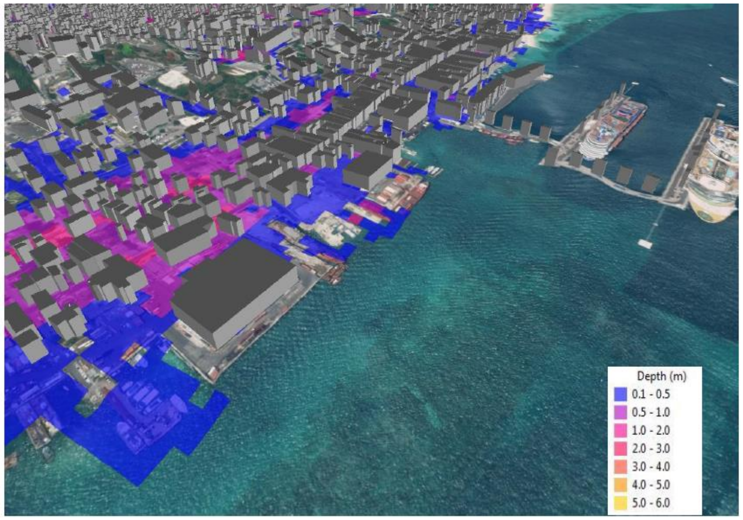


Figure 13: Inland flooding 3D Map for 100-year event zooming in Downtown Area of Nassau

Figures 14 to 17 present the results of the inland flooding hazards profiles for the entirety of NPI for the 100-year precipitation event for the following scenarios:

- *Baseline:* This scenario considers the existing land use and climatological conditions (see Table 6).
- *Climate Change (2050):* This scenario uses the existing land use and climate change projections for the study area (see Table 6).
- *Business-As-Usual plus climate change:* This scenario uses land use from the First Order Zoning Map of New Providence (FOZM) that was produced as part of the 2010 Planning and Development Act is implemented; and projected future climate change projections for the study area (see Table 6).

- *Intelligent Growth plus climate change-* This scenario uses land use generated from the intelligent growth analyses carried out by ERM. In this instance, the footprint reaches 54% of the land and the NSS reach 46% of the land. Details of this Intelligent Growth Scenario for New Providence Island are included in Section 14 of the Urban Growth Study. This scenario also considers the projected future climate change projections for the study area (see Table 6).

A detailed description of the approach followed to create the inland flooding hazard maps and assumptions are also included in *Appendix A1*. The Business as usual scenario is the one in which the FOZM that was produced as part of the 2010 Planning and Development Act is implemented. In this case, the footprint reaches 70% of the island and the NSS reach 30%. The reason why this is called the business-as-usual scenario is because it produces and identical footprint as the one resulting from the geo-spatial, predictive analyses carried out on the basis of the historical evolution of land cover. The intelligent scenario results from the intelligent growth analyses carried out by ERM. In this instance, the footprint reaches 54% of the land and the NSS reach 46% of the land. More details of these urban growth scenarios are included in the Urban Growth Study.

Table 7 summaries the criteria used to determine floods hazard levels while Table 8 presents a summary of the inland flooding results across the study area. These results indicate that with climate change and current land use the total inundated area will be approximately 106 km^2 for the 100-year event while with the Intelligent Scenario and climate change the total inundated area will be approximately 105.9 km^2 for the 100-year event.

Table 7: Definitions of Flood Intensity

Flood Intensity	Maximum depth h (m)		Maximum depth h times maximum velocity v (m^2/s)	Hazard Level
High	h > 1.5 m	OR	v * h > 1.5 m^2/s	High
Medium	0.5 m < h < 1.5 m	OR	0.5 m^2/s < v * h < 1.5 m^2/s	Medium
Low	0.1 m < h < 0.5 m	AND	0.1 m^2/s < v* h < 0.5 m^2/s	Low

Source: FLO-2D Reference Manual (2014). m = meters; m^2/s= square meters per second

Table 8: Inland Flooding Projections for NPI under Four Scenarios

Return period (years)	Baseline				Climate Change			
	Low Hazard (km^2)	Medium Hazard (km^2)	High Hazard (km^2)	Total Inundated Area (km^2)	Low Hazard (km^2)	Medium Hazard (km^2)	High Hazard (km^2)	Total Inundated Area (km^2)
10	1.1	36.2	1.0	38.3	1.2	39.2	1.2	41.7
25	1.7	65.0	3.0	69.7	1.9	69.5	3.6	75.0
50	2.1	76.8	5.2	84.2	2.4	82.0	6.8	91.2
100	2.6	86.2	9.6	98.4	2.9	89.1	14.3	106.3
Return period (years)	Business-As-Usual				Intelligent Growth			
	Low Hazard (km^2)	Medium Hazard (km^2)	High Hazard (km^2)	Total Inundated Area (km^2)	Low Hazard (km^2)	Medium Hazard (km^2)	High Hazard (km^2)	Total Inundated Area (km^2)
10	1.2	40.2	1.3	42.7	1.2	38.7	1.2	41.1
25	1.9	70.4	3.8	76.0	1.9	69.1	3.5	74.5
50	2.4	82.6	7.0	92.0	2.4	81.8	6.6	90.7
100	2.9	89.4	14.7	107.0	2.9	89.3	13.8	105.9

km^2= square kilometers

Sea level variations produce effects on freshwater discharge (high water table) on small islands like NPI and also have effects on groundwater salinization. The variation of freshwater lenses and transition zone thickness in small islands are spatially and temporally variable and both thicknesses are influenced by natural conditions and human activities such as climatic influences on rainfall patterns, tidal changes and water extractions. That being said, it is important to mention that in the FLO-2D models prepared to evaluate coastal and inland flooding, the groundwater component was conceptually incorporated by adjusting the soil type from Group A (high infiltration) to Group D (high runoff due to high groundwater table). The model did not consider the fluctuation (time-varying) of groundwater levels that are influenced by sea level and tides in small islands (UNESCO, 2010) like NPI, because hazard maps were prepared for single extreme events (not seasonal changes). The simulated events included extreme precipitation events (10-, 25-, 50- and 100-years including baseline conditions and % increase due to climate change) and total storm surge extreme events (SLR, waves, storm surge and high tide). In other words, the simulations include an extreme precipitation event (e.g., 100-year) + total storm surge extreme event (e.g., 100-year) with a saturated soil type representing the high groundwater table that reduces infiltration. The evaluation of seasonal sea level variations on flooding requires the use of a detail hydrogeological model but in this study ERM assumed the worst condition (full saturation of the soils).

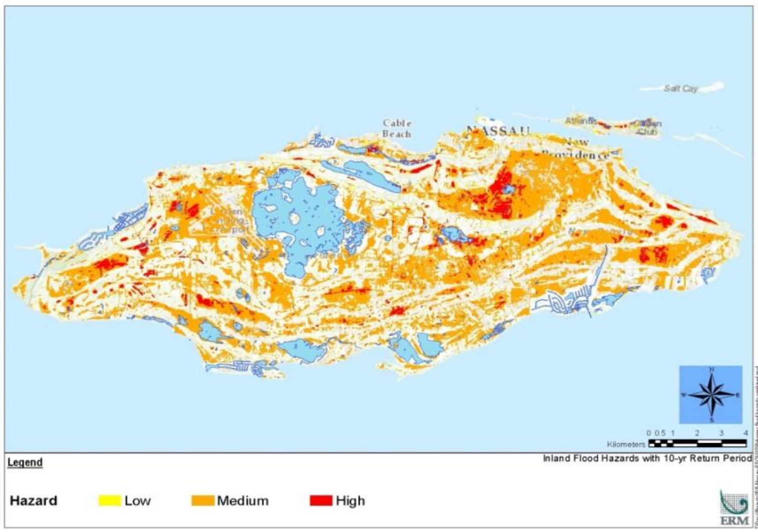


Figure 14: Inland Flooding for a 100-Year Rainfall Event under Baseline Conditions

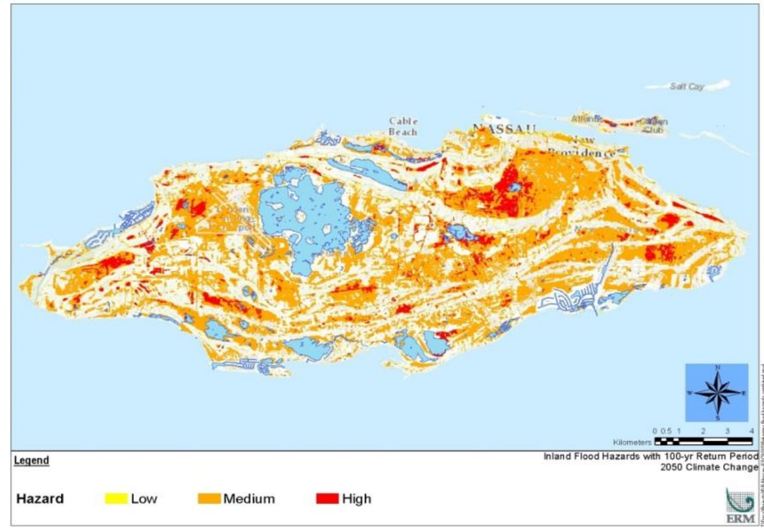


Figure 15: Inland Flooding for a 100-Year Rainfall Event with 2050 Climate Change

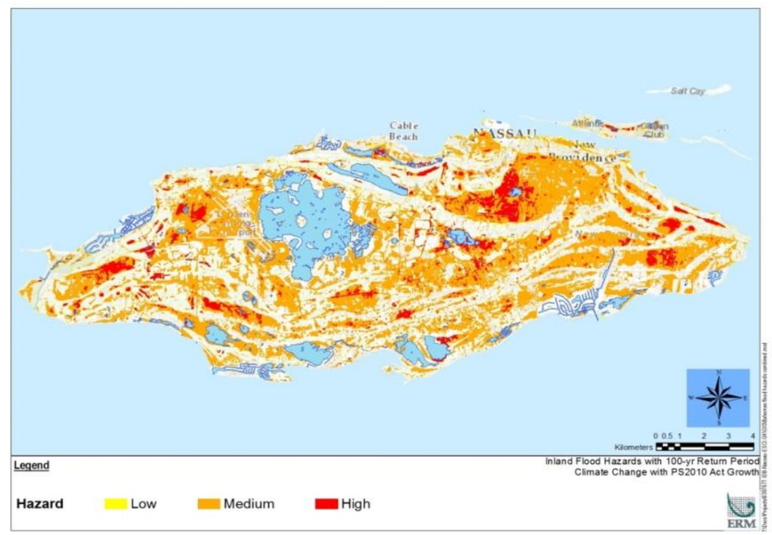


Figure 16: Inland Flooding for a 100-Year Rainfall Event under Business-As-Usual and 2050 Climate Change

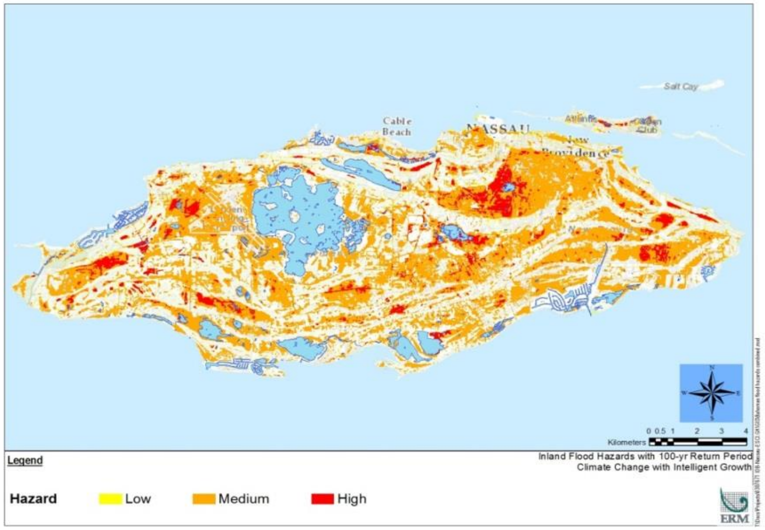


Figure 17: Inland Flooding for a 100-Year Rainfall Event under Intelligent Growth and 2050 Climate Change

3.4 Groundwater Salt Intrusion

Water in small islands like NPI is typically found as either fresh or saline water. Groundwater is the most important freshwater resource in many small islands, including NPI and it can still be considered freshwater when salinity levels are low. Water with higher salinity, ranging from slightly brackish to seawater is also often found in small islands. Groundwater in small islands such as NPI occurs as two main types of aquifers, perched and basal. Perched aquifers are found over confining layers or aquicludes and some are under artesian pressure, while basal lenses can be found on both high and low islands in the form of coastal aquifers or freshwater lenses above seawater. The migration of seawater into the freshwater aquifer is known as seawater intrusion. Generally, groundwater salinization occurs in an unconfined aquifer that contacts the sea at the shoreline or seaward and the freshwater, which is less dense than seawater floats as a lens above the seawater (USGS 2000). Since the fresh groundwater sources in NPI are threatened by salinization, the Bahamas use Reverse Osmosis (RO) treatment techniques to desalinate groundwater for potable use (USACE, 2004).

Groundwater resources in NPI also include fresh, brackish, saline and hypersaline waters found in the near and deep subsurface of the islands and in permanent and ephemeral water bodies. These groundwater resources are affected by precipitation, geology, orientation and shape of surface and subsurface limestone (Maul and Cant, 2013). According to Cant and Weech (1980), there are nine aquifers in New Providence Island with a total area of 70.8 km^2 (17,503 acres). The recharge of these aquifers primarily depends on the quantity and distribution of precipitation, type of the vegetation and permeability of surface materials comprised of limestone rock (USACE, 2004). *Appendix A1* presents more details of groundwater sources in New Providence.

The main source of freshwater in NPI comes from freshwater lenses located below surface. These lenses can be found in shallow depths (within a few meters) and extend to approximately 33 meters (110 ft) as shown in **Error! Reference source not found.**. In some cases, these freshwater lenses are known as blue holes when they are exposed to the surface (Cant 1986). The height of groundwater level above sea level is sometimes observed less than one meter above sea level (asl) in New Providence (Cant 1996; Diamond, 2011).

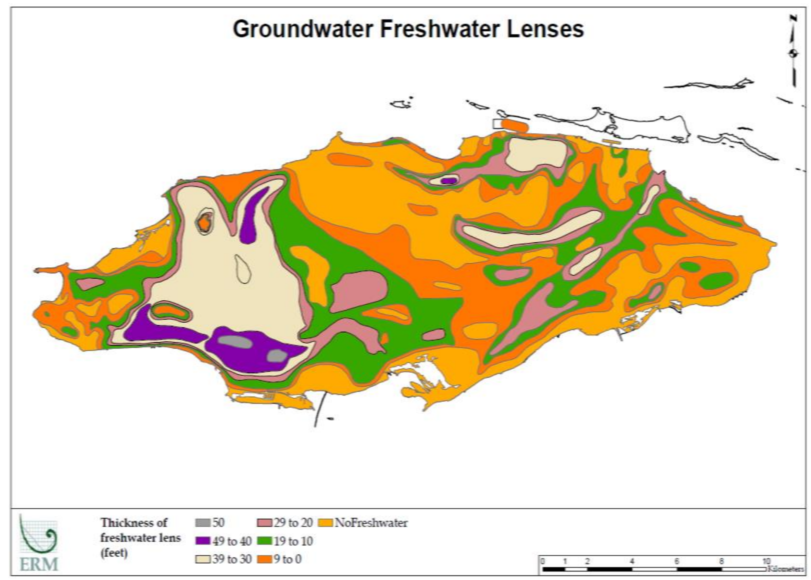


Figure 18: Thickness of Freshwater Lens in New Providence Island (Adapted from The UNDP/Bahamas Government Groundwater Studies in New Providence 1976-1984)

3.5 Groundwater Contamination

In addition to groundwater salinization, groundwater contamination, principally due to uncontrolled use of disposal of untreated wastewaters (domestic and industrial), represents another source of pollution for groundwater. Contamination of groundwater in NPI is produced by natural and anthropogenic activities such as severe weather (hurricanes and tropical storms); solid waste; sewerage (pathogens and nitrates);agriculture (pesticides, fertilizers, fungicides); coastal construction; landfills (leachate); tourism; residential; service and distribution services (release of toxic chemicals and oils); underground fuel storage tanks (leakage or spillage);and water extraction (SNC, 2014; The Bahamas National Report, 2016).

In NPI, the appropriate disposal of wastes becomes critical to maintain the quality of freshwater sources. All the inland activities in NPI like industry, agriculture, and domestic have a high probability to impact soil and groundwater quality given the nature of freshwater resources, soil, climate and geology (low-lying limestone) of The Bahamas (The Bahamas National Report, 2016). According to WSC and SNC (2014), sites for disposing wastes are limited and swamps and/or marshes are often used for this purpose. Also, untreated domestic wastes and effluents are directly discharged to water table, representing one of the main threatens to groundwater resources in NPI and The Bahamas.

Even though, the scope of this work does not include the study of groundwater contamination, it is important to highlight groundwater resources in NPI are extremely vulnerable and prone to pollution. It is recommended to design and implement a Master Water Resources Management Plan that must be synchronized with Waste Management and Development Plans for NPI in order to preserve and restore (within the possible) the groundwater resources of NPI.

4 Vulnerability Assessment

The vulnerability assessment considers the study area's population exposure as well as the assets exposed. The population exposure assessment seeks to identify which populated areas are more vulnerable to inland and coastal flooding hazards, while the more traditional vulnerability assessment identifies assets, characterizes structures and infrastructure in order to determine the built environment's potential performance to different levels of hazard intensity (i.e., flood velocity, flood depth, etc.). A vulnerability assessment is conducted to assess the specific damage and loss characteristics of each asset identified by following two general steps:

- Exposure analysis (assets and population); and
- Definition of vulnerability index.

These two steps are summarized below and further details of the approach, assumptions are presented in *Appendix A2*.

4.1 Characteristics of Assets Exposed

The inventory of exposed assets involves understanding the distribution of buildings and infrastructure that may be affected by the evaluated hazards. In Nassau, there was insufficient detailed information to assessments of all buildings, and therefore an inventory of buildings and property values was performed through rapid field assessments and a review of geospatial databases to estimate the number and distribution of assets in NPI. From the data review and mapping process, a table of average property values of a single unit/building for each land use was constructed and is provided in Table 10 by considering prices from the Bahamas Real Estate Association. Mapping the land use and property values provided a basis for classifying buildings, and the geographical distribution of average property values is presented in Figure 19.

Table 9: Estimated Land Use Property Values for NPI

Land use	Mean value per property unit in US Dollars
Informal	$100,000
Agriculture	$100,000
Industrial	$1,000,000
Airport	$1,000,000
Commerce (C)	$1,000,000
High Density Residential (HDR)	$125,000
Medium Density Residential (MDR)	$250,000
Cultural Heritage (CH)	$1,000,000
Institutional	$10,000,000
Luxury (L)	$10,000,000
Beach or Waterfront Park	$1,000,000
Low Density Residential (LDR)	$500,000
Unprotected Forest	$100,000
Mixed Dwelling Agriculture	$125,000
Protected Forest	$100,000
Protected Wetland	$100,000
Recreational (parks and manicured grass like traffic circles)	$500,000
Golf	$1,000,000
Tourism (T)	$10,000,000
Unprotected Wetland	$100,000
Vacant Vegetation	$100,000

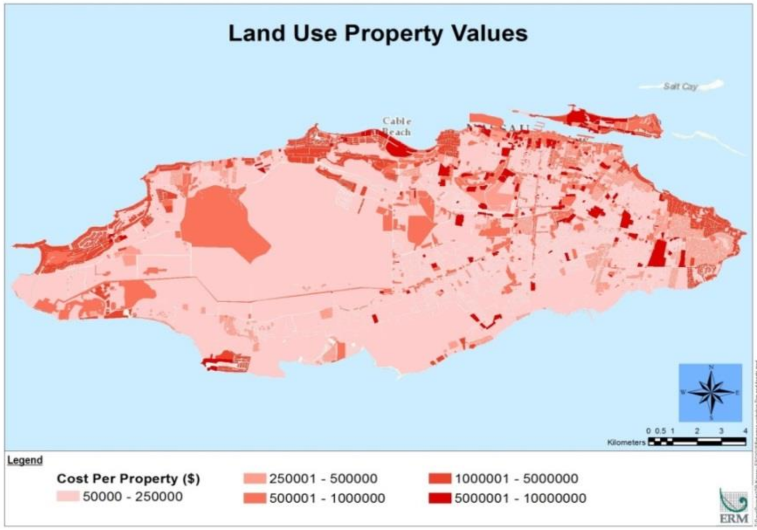


Figure 19: Land Use Property Values (in USD) Estimated for NPI

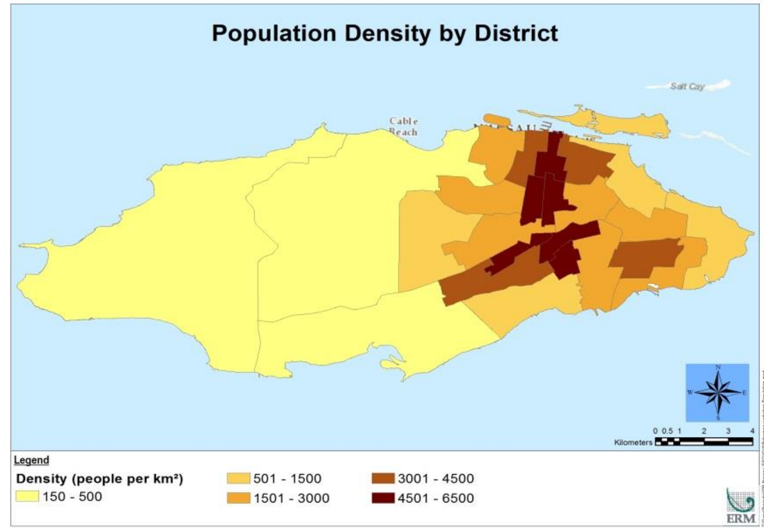


Figure 20: Population Density in NPI by District

4.2 Population Exposure Assessment

In addition to buildings and infrastructure, exposed assets include human exposure. Information on the geographical distribution of population density was analyzed with geographic information systems (GIS). A map of the population density throughout the study area (NPI) is shown in Figure 20. NPI comprises a range of population densities, from low on the western end (<500/km^2), to high within the city (>4500/km^2). There is also a correlation between the property values and the population density. Less dense, more disperse areas with larger property boundaries tend to have higher property values. The exception is the downtown area which is dense but also has high property values due to the commercial and tourism buildings in those areas.

4.3 Vulnerability Index

Coastal and Inland Flooding

Once the costs by land use and population density were estimated, the vulnerability index for each type of land use and population density were assigned by using hazard profiles (see *Appendix A1*) and the method given by Huizinga (2007) adapted for NPI (see *Appendix A2*). Two types of vulnerability indices were estimated:

- The economic vulnerability index (EVI) that considers five main grouped categories of land use in NPI. The EVI ranges from 0 to 1, where 0 is no damage, and 1 is a total loss. Table 10 shows the EVI assigned to each grouped categories of land use and hazard in NPI which are based on the hazard categories presented in Table 7; and
- The population vulnerability index (PVI) that was assigned based on hazard ratings. The index also ranges from 0 to 1 where 0 indicates that danger to person is very low or non-existent, and 1 indicates a high or

very high danger to persons. Table 11 shows the PVI assigned to different hazard ratings.

Table 10: Economic Vulnerability Index (EVI) by Land Use and Hazard

Grouped Land Use	Land Use from Table 3-1	Hazard		
		low	medium	high
Residential	Informal, High Density Residential (HDR), Medium Density Residential (MDR), Luxury (L), Beach or Waterfront Park, Low Density Residential (LDR)	0.25	0.50	1.0
Commerce	Commerce (C), Cultural Heritage, Institutional, Recreation, Golf, Tourism (T)	0.15	0.45	1.0
Industry	Industrial	0.15	0.40	1.0
Infrastructure	Airport	0.25	0.55	1.0
Agriculture	Agriculture, unprotected forest, Mixed Dwelling Agriculture, Protected Forest, Protected Wetland, Unprotected Wetland, Vacant Vegetation.	0.30	0.65	1.0

Source: Adapted from Huizinga, 2007

Appendix A2 provides details of methods and assumptions used to estimate EVI and PVI for coastal and inland flooding hazards. Vulnerability of groundwater aquifers to salinization is also described in *Appendix A2* and a summary of methods and results is provided below.

Table 11: Population Vulnerability Index (PVI)

Hazard	PVI
Low	0.25
Medium	0.50
High	1.00

Groundwater Salinity Intrusion

To assess the vulnerability of groundwater aquifers to salinization, the GALDIT was used. GALDIT is an index method based on the following information for each aquifer:

- **G**roundwater Occurrence;
- **A**quifer hydraulic conductivity;
- Groundwater **L**evel relative to sea level;
- **D**istance of site from seawater;
- **I**mpact of exiting status of saltwater intrusion in the area; and
- **T**hickness of the aquifer which is being mapped.

According to Lobo-Ferreira (2005), the GALDIT factors are measurable parameters for which data are generally available from different sources without detailed reconnaissance. Each factor is assigned a relative weighting and a rating. The weightings are pre-determined with values ranging between 1 and 4 while ratings values vary from 1 to 10. A local index of vulnerability is calculated by multiplying each rating by their weighting and adding all six products. The indices range between 13 and 130. *Appendix A2* presents more details of GALDIT including input data, method, assumptions, and results considered to evaluate groundwater salinization vulnerability of NPI.

Figure 21 shows a map with the estimated vulnerability indexes for groundwater salinization in NPI. The results indicate that groundwater is highly vulnerable to salinization based on the GALDIT index method. Also, the results are consistent with what NPI has experienced.

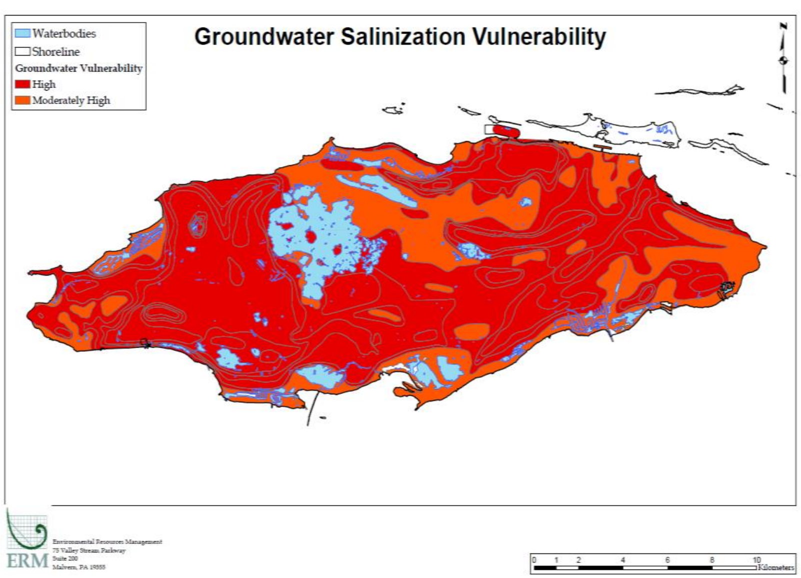


Figure 21: Groundwater Salinization Vulnerability Map Estimated with the GALDIT Index Method

Climate Change Effects on Fresh Groundwater Availability

ERM conducted an evaluation of how aquifers in NPI have been historically threatened and how the projected reduction of precipitation and increase in population for the 2050 horizon would affect freshwater availability and demand in NPI. To conduct this assessment, ERM used historical monthly precipitation for the 1951-2015 period from the rain gauge located at the Nassau International Airport (see Figure 22); area and volume of the New Providence aquifers (71 km^2 and 120.4 cubic million meters), water consumption per capita; and estimated volumes of desalinated or barged water. Figure 23 shows results from the New Providence aquifer calculation used to evaluate the historical changes in groundwater availability. The color lines shown in Figure 23 indicate the changes in the following three variables:

- *Water availability (Precipitation):* This variable is calculated from monthly historical precipitation, infiltration, and aquifer area;
- *Water use:* This variable depends on population, including seasonal population fluctuations, and estimated water consumption from other sectors (i.e., agriculture, industrial);
- *In-Out:* This is the difference between water availability and water use.

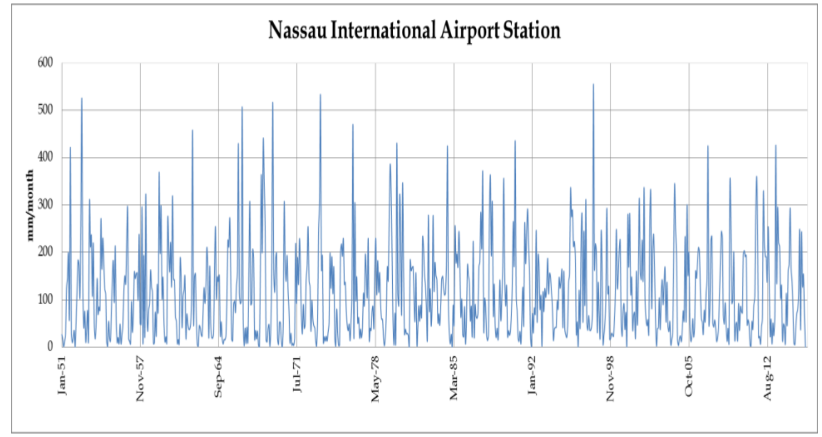


Figure 22: Monthly Precipitation at Nassau International Airport Station, 1951-2015

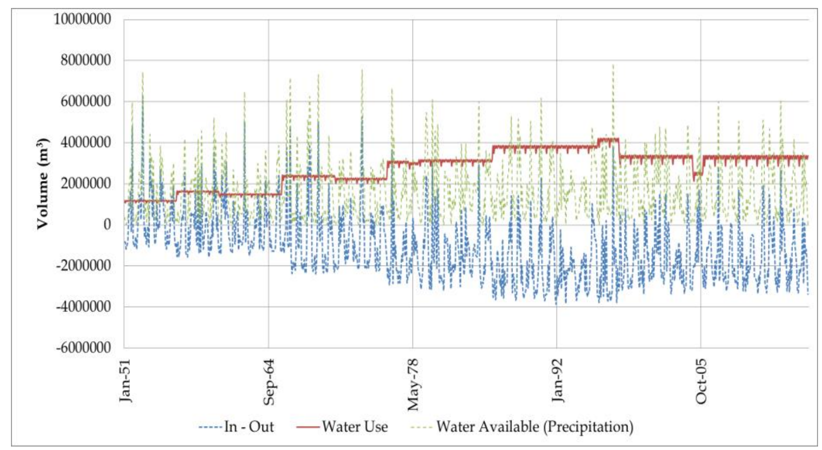


Figure 23: New Providence Aquifer Calculation

The effects of climate change on the New Providence aquifer were also evaluated. For this, reductions in precipitation up to 20% (see Table 3) were used for this assessment and results indicate that climate change would exacerbate the current lack of fresh groundwater combined with increases on water demands from future population growth.

5 Risk Estimation

Probabilistic loss estimates were then determined for coastal and inland flooding hazards by using standard risk assessment methodologies that take into consideration hazard parameters, in conjunction with vulnerability indices (*EVI* and *PVI*)[2], to determine the economic and human losses potential for coastal and inland flooding hazards. Economic and human losses for groundwater salinization were not evaluated because groundwater sources in NPI are already considered overexploited. *Appendix A2* provides a more detailed description of the methods applied for loss estimation, limitations, and the associated results. Figure 24 presents a diagram that summarizes the methodology used to estimate risk by asset and population. Like the hazard maps, described in Section 3 of this Hazard and Risk Assessment, the two-dimensional hydraulic-hydrologic model FLO-2D and Geographic Information Systems (GIS) model were used to create assets and population-based risks maps for NPI (see Figure 25).

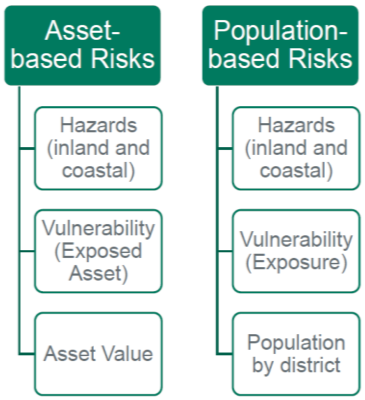


Figure 24: Risk Approach Diagram

The economic loss results are presented here using three risk indicators:

- *Probable Maximum Loss (PML)*- An estimate of losses that are likely to occur;
- *Loss Exceedance Curve* – Plots consequences (losses) against the probability for different events with different return periods; and
- *Average Annualized Loss (AAL)* - Estimated long-term value of losses to asset in any single year with the study area.

The risk metrics described above, particularly, the *AAL*, can be used to provide an understanding of the spatial extent of losses and help to identify and prioritize the urban areas or localities that are under risk. A street light indicator methodology, where the colors on the map coincide with the level of risk, has been used to map risk (see *Appendix A2* for details).

With the EVI calculated from the land use and hazard ratings for each return period, the economic risk to properties were mapped (see Figure 26 to Figure 29). These maps illustrate different levels of economic and population risks across NPI under different land use scenarios and considering the projected future climate change factor. Using the EVI maps and an inventory of buildings as exposed assets in the study area, Probable Maximum Losses (*PML*) for each event and the Average Annual Losses (*AAL*) were estimated. Table 12 compares the *PML* calculated for NPI while Figure 30 shows the exceedance curves under four different scenarios. The estimated total AAL for NPI for both inland and coastal flooding is USD $1.3 billion under baseline conditions and USD $1.5 billion if the projected future climate change factor is included. These estimates consider only the direct impacts or damages to property. Indirect impacts such as losses from a decrease in tourism require further economic analysis. For comparison, the PreventionWeb results list an *AAL* for storm surge (coastal flooding) only throughout the Bahamian islands as USD $1.3 billion (UNISDR, 2015).

[2] Vulnerability index is a measure of the exposure of assets (EVI) or population (PVI). Typically, the index is a composite of multiple quantitative indicators that via some formula, delivers a single numerical result.

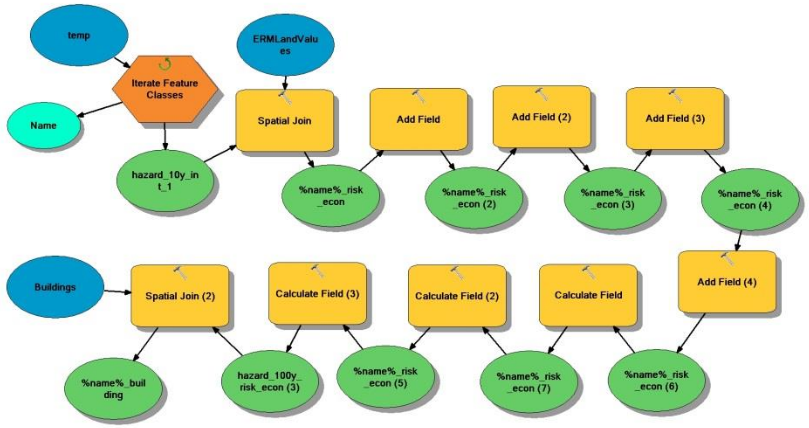


Figure 25: GIS model for creating assets and population-based risk maps

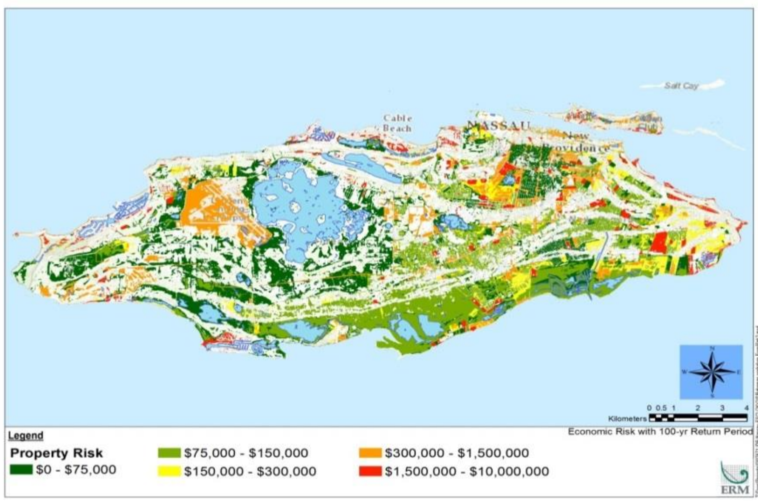


Figure 26: Economic risk with a 100-year return period under baseline conditions

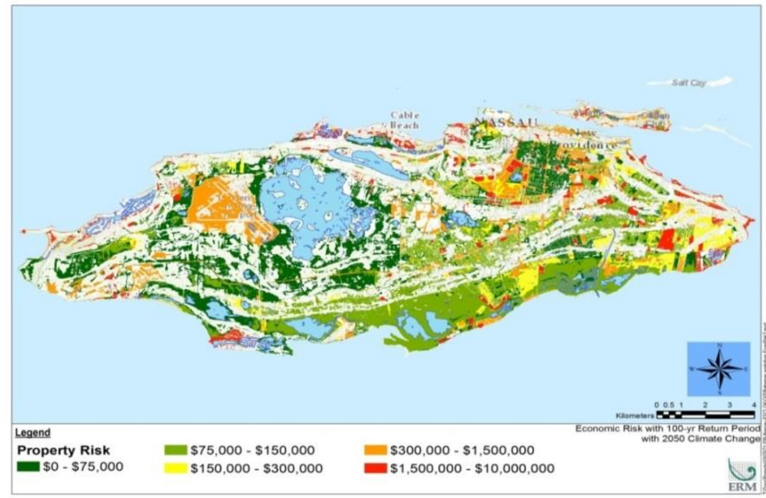


Figure 27: Economic Risk with a 100-year Return Period and with 2050 Climate Change

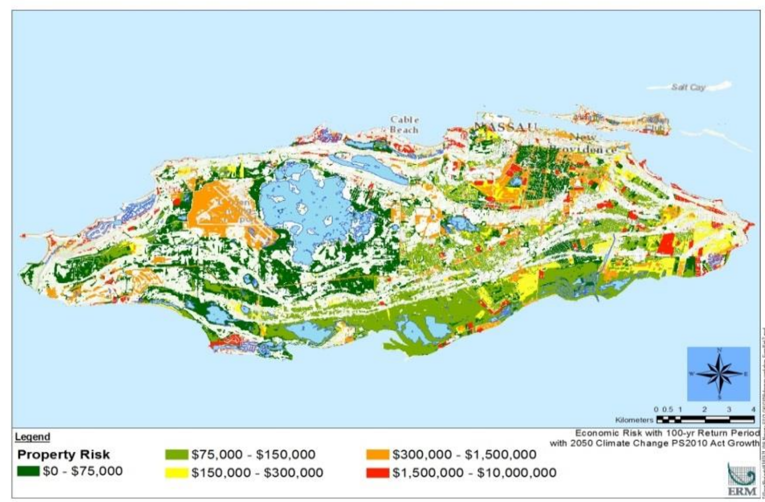


Figure 28: Economic risk with a 100-year return period and with 2050 climate change and Business-As-Usual growth

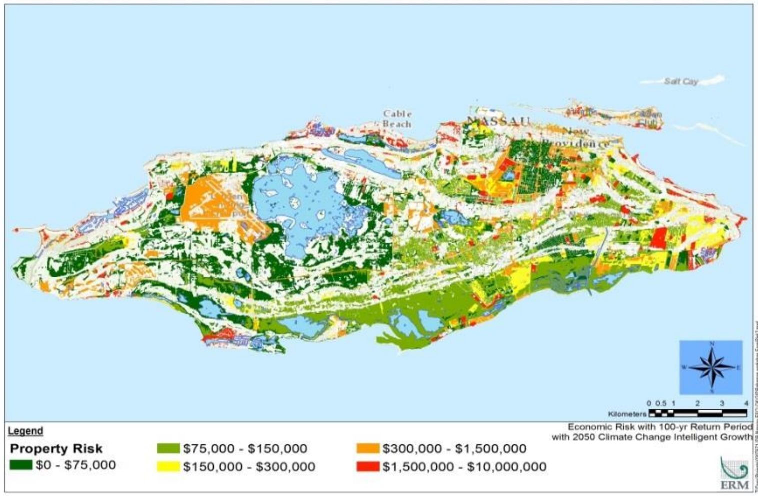


Figure 29: Economic risk with a 100-year return period and with 2050 climate change and intelligent growth

Table 12: Probable maximum losses (PML) for baseline, climate change, intelligent growth plus climate change, and Business-As-Usual plus climate change scenarios

Return period	Baseline PML Millions USD $	Climate change PML Millions USD $	Business-As-Usual * PML Millions USD $	Intelligent Growth* PML Millions USD $
100	15,453	17,398	17,425	17,349
50	11,762	13,152	13,181,	13,089
25	8,686	9,735	9,766	9,674
10	6,075	6,530	6,568	6,476
*Plus climate change				

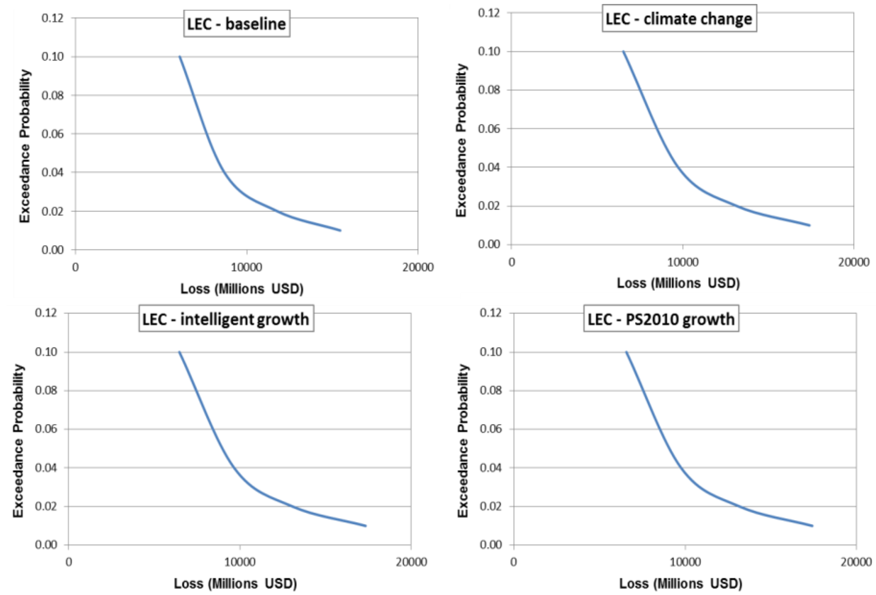


Figure 30: Probable maximum losses (PML) for baseline, climate change, intelligent growth, and Business-As-Usual scenarios

Population risk was estimated as the population density multiplied by the *PVI* (*Population Risk = PVI*Population Density*). A scale of the population risk was assigned ranging from very low to very high as shown in Table 13. This table is based on a Gaussian distribution where each category is above or below the mean risk by a number of standard deviations:

- Moderate risk is between -0.5 to +0.5 standard deviations of the mean risk for a 100-year event;
- High risk is +1.5 to +2.5 standard deviations above the mean;
- Very high risk is +2.5 to +3.5 standard deviations above the mean; low risk is -1.5 to -2.5 standard deviations below the mean; and very low risk is -2.5 to -3.5 standard deviations below the mean.

Areas with a very low risk are least impacted by inland and coastal flooding, moderate areas are average (i.e. what most people will encounter), and very high risk areas are heavily impacted. Figures 31 to 34 show maps of population risk for 100-year return period under climate change scenario 2050, Business-As-Usual

Growth and Intelligent Growth scenarios, respectively. *Appendix A2* includes population risk maps for other return periods and four scenarios.

Table 13: Population Risk Ratings for Risk Maps

Population risk (persons in danger per km^2)	Risk
0 - 350	Very Low
351 - 1050	Low
1051 - 1760	Moderate
1761 - 2461	High
2461 - 5505	Very High

km^2 = square kilometers

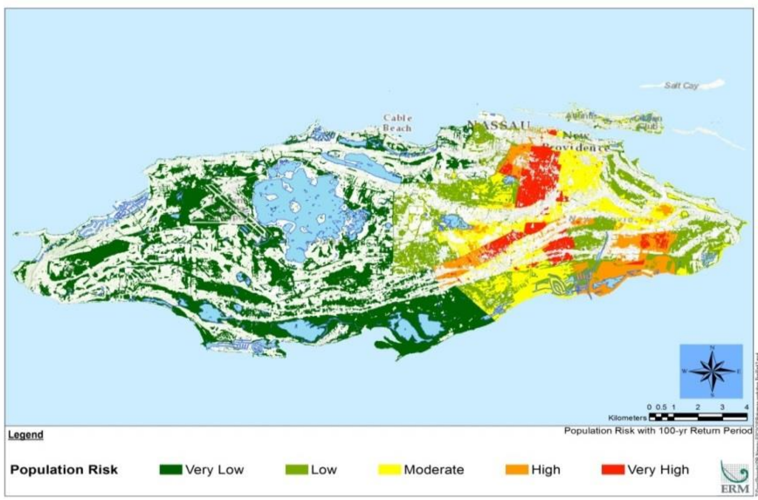


Figure 31: Population Risk Map with a 100-year Return Period and 2050 Climate Change

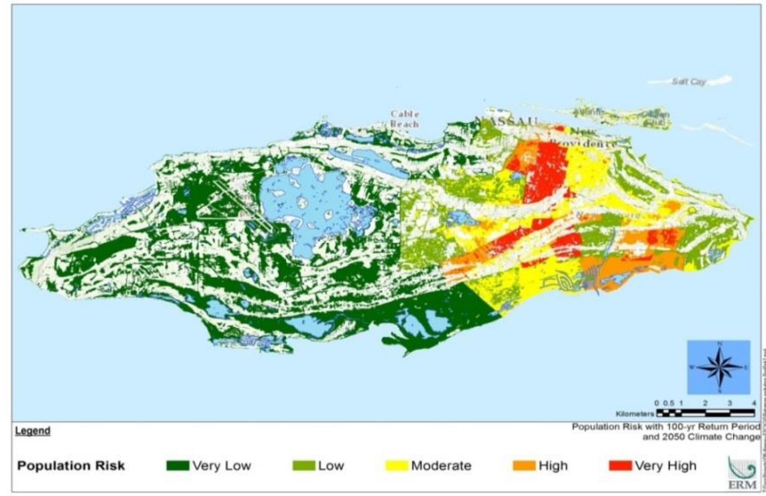


Figure 32: Population Risk Map with a 100-year Return Period and 2050 Climate Change

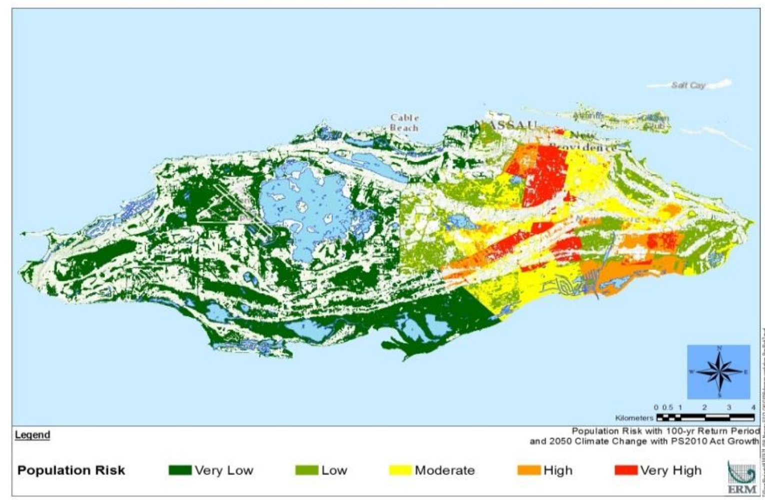


Figure 33: Population risk with a 100-year return period for Business-As-Usual growth Plus 2050 climate change Scenario

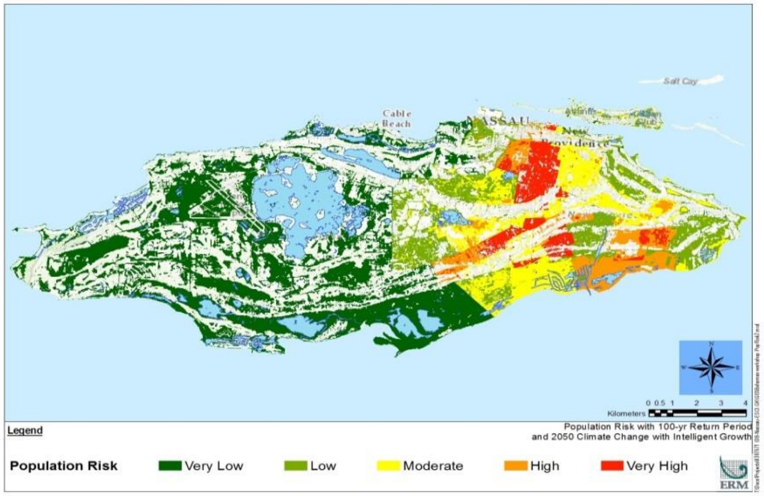


Figure 34: Population risk with a 100-year return period for the intelligent growth Plus 2050 climate change scenario

Figure 35 shows a map that combines economic and population risk for a 100-year return period. As illustrated in this figure, the high risk areas are in and around Bain and Grant's town, St. Cecilia, Englerston, Marathon, Pinewood, and Sea Breeze amongst the most important.

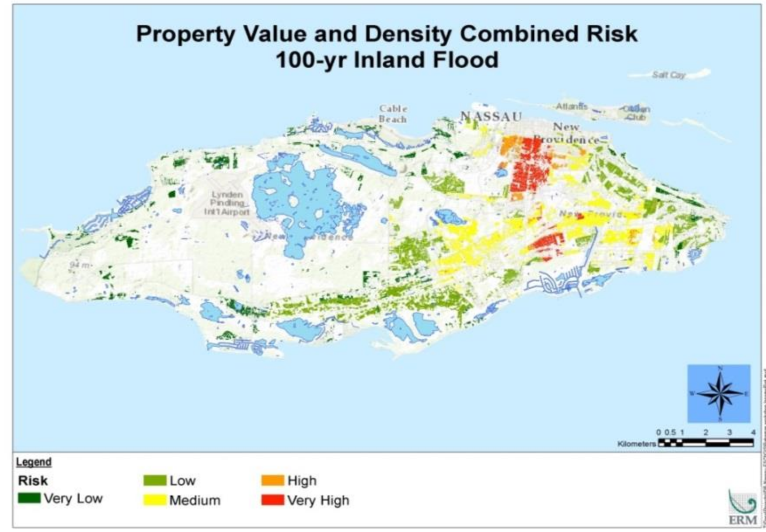


Figure 35: Combined Population and Economic Risk for a 100-year Return Period Inland Flood under Climate Change Scenario (2050).

In conclusion, areas of very high risk occur due to the most severe flooding and are concentrated in central parts of Nassau where there is low lying ground, many buildings, and a high population density. Much of the western side of New Providence Island is a low or very low population risk due to the low population density. Because population density is assigned for each district, the population risk within a neighborhood of the district can be greater than the average risk across the district. A district may have an overall low density, but a neighborhood within it with a higher density. In addition, economic losses will be largely impacted (an increase of 8-13%) by climate change. Land use changes, either increases or decreases in urbanization, can affect the flood losses, although to a lesser extent than climate change.

The estimated risks presented above should be used to understand relative risk from hazards and potential losses and are not intended to be predictive of precise results. Uncertainties are inherent in any loss estimation methodology arising in part from incomplete scientific knowledge concerning natural hazards and their effects on the built environment. Uncertainties also result from approximations and simplifications used in the development of hazard maps or the inability to perform a more detailed inventory assessment.

5.1 Future Studies

The hazard and risk assessment studies presented in this section represent initial attempts to define and understand the scale and magnitude of risks facing Nassau and NPI. Further studies would enable this work to progress and improve. The following provides a summary of recommended next steps for interested stakeholders to further advance the hazard and risk work:

- Record, study and map severe repetitive loss properties/infrastructure occurring at NPI, conduct limited fieldwork, and evaluate hazard mitigation measures that would cost-effectively address clustered repetitive loss properties/infrastructure.
- Conduct bathymetric survey of coastal areas geared toward regional coastal hazard modeling, sediment management, environmental assessment, emergency response.
- Conduct economic analysis to evaluate indirect impacts such as losses from a decrease in tourism.
- Continue collecting meteorological data including historical records to evaluate natural hazards in the study area (flooding and drought).
- Continue improving and updating emergency response mechanisms to minimize losses.
- Keep records of losses associated with natural hazards at national and local level.
- Continue improving and updating groundwater monitoring in NPI to evaluate levels of salinization of groundwater.
- Conduct hydrogeological studies in NPI to define potential areas and depths where appropriate wastewater injection can be taken.

6 Risk Reduction Recommendations

This section is built upon results obtained from the hazard and risk assessments conducted for NPI (see sections 3, 4 and 5) and urban growth scenarios (see Urban Growth Study). There are several sustainability options for adapting or mitigating risks associated with inland/coastal flooding and groundwater salinization hazards. Below is a list of potential adaptation measures identified during the February 2016 workshop. These adaptations are candidates to be implemented in New Providence and Paradise Islands (NPI) to reduce risks associated with the three prioritized hazards.

6.1 Inland Flooding

- Education and awareness of conservation measures;
- Adapted construction and design regulations, zoning;
- Reforestation and land use planning;
- Low Impact Development (LID) such as roof gardens, porous pavement, bio-swales;
- Avoid development in low-lying areas exposed to flooding under existing and future conditions;
- Property protection;
- Provide adequate drainage ahead of new developments;
- Implement flood protection measures to existing developments by stipulating Codes and Requirements such as minimum platform levels;
- Improve drainage in flood prone areas by continually increasing drainage capacity and elevating assets in low-lying areas.

6.2 Coastal Flooding

- Installing/updating early warning systems;
- Restrict development along the coast;
- Restore/protect coastal buffer zones and natural environment, mangroves, similar features;
- Develop a hurricane preparedness and evacuation plan;
- Design and implement a coastal management plan;
- Prohibit excavation of canals, waterways and areas below the water table;
- Protect/nourish beaches and coastal dune formations;
- Adopt appropriate physical planning policies that will protect infrastructure from storm surges

6.3 Groundwater Salinization

- Implement Reverse Osmosis (RO) technologies (desalinization) or alternative sources of drinking water. RO is currently used in The Bahamas;
- Perform hydro-census of all wells and septic systems;
- Improve sewage system, avoid using sink holes, swamps, and marshes as dump sites;
- Create and implement an Integrated Coastal Management (ICM) program that allow the Government of The Bahamas design appropriate planning, management and investment interventions to continue threating groundwater resources in NPI;
- Plan and implement a comprehensive public education program to prevent groundwater pollutions and increase conservation;
- Control rock and sand mining activities below water table;
- Prohibit excavation of canals, waterways and areas below the water table;
- Conduct a detail groundwater study for NPI that includes components like groundwater modeling and monitoring (groundwater levels and salinity concentrations). The collected information should be used as input for building and calibrating a groundwater model so it can be used as a tool to manage groundwater resources (e.g., locate extraction and injection wells) across NPI.

The adaptations mentioned above should be supported with education and outreach programs to increase their efficiency. In this regard, effective inter-institutional support and strengthening legal framework on risk management will be essential. In general, it is recommended that the Government of The Bahamas continues and reinforces its commitment related to the development and implementation of adaptation and mitigation measures to create resilience against natural hazards and climate change effects. All these adaptation and mitigation measures designed for addressing natural disasters and responding to adverse effects of Climate Change should be coordinated with the National Emergency Management Agency (NEMA) and supported with an effective early warning system.

Based on results from the hazard and risks assessments and consultations with key stakeholders, five adaptation strategies were explored in more detail through a cost-benefit analysis (see *Appendix A3-Risk Reduction Assessment*).

7 Risk Reduction Case Studies

Specific recommendations and projects that are assessed in this section were identified based upon field observations, stakeholder discussions, and from ensuring tangible and practical projects could be implemented. The selection of five proposed adaptations also considered outcomes from previous studies related to climate change vulnerability (i.e, SNC, 2014), and the Bahamian National Policy for the Adaptation of Climate Change (NPACC, 2005). Given the intensity and frequency of flooding (both inland and coastal), these hazards were prioritized by risk reduction assessment.

A Benefit Cost Analysis (BCA) model (see Figure 36) was used to assess the possible costs and benefits of identified adaptation measures, focusing on the following adaptation strategies in high risk areas:

- Upgrade urban drainage infrastructure;
- Mangrove protection/restoration at the southern shoreline;
- Green infrastructure (green roofs in urban areas);
- Protection of coastal flooding and erosion; and
- Property protection.

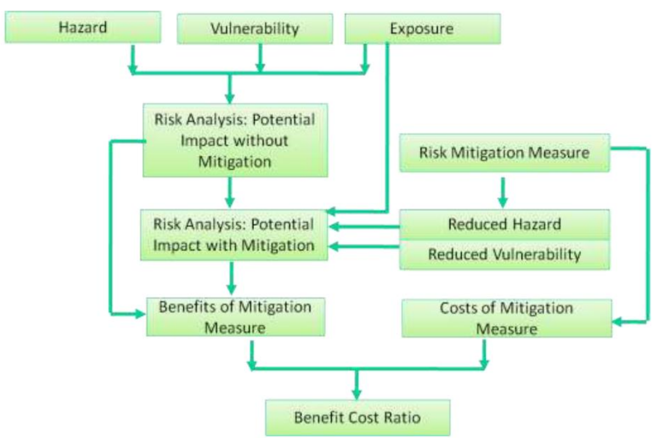


Figure 36: Benefit-Cost Analysis Flowchart

The five adaptations mentioned above were recommended for the seven Nassau Inland Adaptation Zones (NIAZs) and the Coastal Adaptation Zones identified for NPI (see Figure 37) from the Urban Growth Study. These seven NIAZs were selected by considering medium, high and very high risk areas identified form the Hazard and Risk Assessment conducted for NPI.

Appendix A3-Risk Reduction Assessment contains the details of the five strategies explored and the approach applied while **Error! Reference source not found.** presents results of the BCA.

Figure 37: Seven Nassau Inland Adaptation Zones (NIAZs)

7.1 Risk Reduction Summary

The information outlined in this section should be used to inform citizens and decision makers about hazards and the risks under existing and climate change conditions. This section in particular provides a basis for understanding the hazard impacts and prioritizing actions by laying out general sustainability interventions that should be considered for building more climate change resilience in NPI.

These analyses are preliminary and they indicate options to be taken forward for more detailed analysis (see Table 14). Four of the adaptations are structural while the mangrove protection is a non-structural adaptation that will also provide benefits to the wider environment in terms of supporting environmental protection, aquifer recharge and biodiversity enhancement, in addition to the flood management and hazard protections.

Green roofs can also provide additional benefits to the environment such as improving air quality in the city, benefiting wildlife, providing greater thermal performance and roof insulation for the buildings they are laid on. Other benefits include visually softening of the built environment, aiding people's mental and physical health, and providing a communal focus and sense of place.

Structural adaptations such as the urban drainage upgrade, hard- and soft-engineering structures for coastal protection, and flooding barriers will be beneficial immediately after implementation. These structures will minimize losses associated with inland and coastal flooding hazards. In addition, these structures can improve aesthetic aspects of the city.

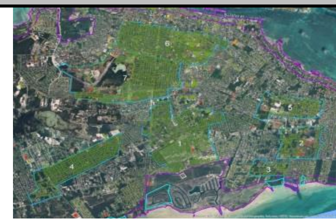
Considering the satisfactory benefit-cost ratio of these five scenarios, these adaptations should be taken forward for possible planning and pre-feasibility studies. Finally our analysis provides a basis for examining how risks may increase significantly if growth continues in an unplanned manner (as business as usual), and how through the intelligent growth scenarios, where the hazard maps are considered and factored into future growth models, the future losses can be significantly reduced and Bahamian authorities and other key stakeholders can meet the following goals:

- Provide information to planners and reviewers who make land use decisions to channel development to low hazard areas and/or flag development proposed in high hazard areas.
- Recommend sustainable locations for major developments projects and/or infrastructure projects, including public facilities, residential, commercial, and industrial development.
- Support the conservation of natural resources, and the designation of critical areas.

Risk adaptation strategies are needed in NPI to reduce economic and human losses associated with natural hazards and their exacerbation due to climate and land use changes. This is recognized and recommended by the International Strategy for Disaster Reduction (ISDR)[3]that emphasizes the importance of evaluating local risk patterns and developing strategies to identify responsibilities at different levels (federal, state and municipal). The risk strategies that include risk reduction policies and adaptations (non-structural and structural) should be integrated into national and local development plans in The Bahamas and particularly in NPI.

[3] www.unisdr.org

Table 14: Summary of risk adaptation measures

Upgrade urban drainage infrastructure	**Mangrove protection/restoration at the southern shoreline**	**Green roofs in urban areas**	**Protection of coastal flooding and erosion**	**Property protection**
				
• Nassau Inland Adaptation Zones (NIAZs) 6 and 7 used as a case study • Upgrade drainage to cope with flooding during heavy rain (increase capacity) • Increase in open drainage (assumed 150 km)	• Southeast of New Providence used as a case study. • Mangrove restoration to absorb volume of advancing water and have a dissipating effect on wave energy. • Mangrove restoration/protection (assumed 1.2 km^2).	• Buildings located within the seven Nassau Inland Adaptation Zones (NIAZs) used as a case study (assumed 10% of roofs are appropriate for installation of green roofs) • Green roofs to reduce flooding during heavy rain. • Installation of green roofs (assumed 0.4 km^2).	• Six coastal areas within New Providence Island used as a case study • Protection of coastal flooding and erosion. • Installation of hard and soft engineering structures (assumed 22 km).	• Several institutional buildings (i.e., Her Majesty's Prison and the Sandilands Rehabilitation Centre) in Nassau used as a case study • Protection of buildings and communities during floods. • Installation of flood barriers such as berms, flood proofing, or invisible Flood Control Walls (assumed 3.6 km).
Over 20 years: • Costs USD$ 42.8 million (obtained from economic risk maps) • Benefits: USD$ 1,677 million[4] • BCA: 39, which represents a good investment	Over 20 years: • Costs USD$ 11.8 million • Benefits: USD$ 105.3 million[4] • BCA: 8.9, which represents a good investment	Over 20 years: • Costs USD$ 218 million • Benefits: USD$ 1,870 million[4] • BCA: 8.6, which represents a good investment	Over 20 years: • Costs USD$ 72.9 million • Benefits: USD$ 454 million[4] • BCA: 6.2, which represents a good investment	Over 20 years: • Costs USD$ 2.27 million • Benefits: USD$ 48 million[4] • BCA: 21, which represents a good investment

[4] Calculated by comparing the base case (AAL) and the AAL with the adaptation options in place.

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Appendix A1: Hazard Profiles

Emerging and Sustainable Cities Program - Nassau

Environmental Resources Management

Appendix A1: Hazard Profiles

A1.1 Introduction

This appendix describes the three hazards selected and evaluated for NPI. A description of the processes contributing to the hazard and the approach utilized to determine and characterize each hazard profile is provided. Detailed maps that delineate the spatial extent of the hazards are reported to identify hazard prone areas within the study area. Table A1-1 provides a characterization of hazards identified during this study.

Table A1- 1: Categorization of natural hazards for New Providence and Paradise Islands

Natural hazard	Affected by climate change	Affected by land use
Coastal flood	Yes	Yes
Inland flood	Yes	Yes
Groundwater salinization	Yes	Yes

It is important to mention that climate change projections for the study area were obtained from The Commonwealth of the Bahamas report (SNC, 2014). The climate change projections are critical inputs to applicable hazard models and analysis (coastal flooding, inland flooding, and groundwater salinization). All hazards were determined or mapped using the best available data. Hazards maps, where applicable, were developed to identify the areas of general susceptibility. The hazard mapping uses a qualitative classification scheme that identifies hazard prone areas as low, moderate, and high.

A1.2 Climate Change Projections

The climate change projections used for the hazard and risk analysis were taken from the *BahamasSimCLIM* system reported in *The Second National Communication Report of The Commonwealth of The Bahamas* (SNC, 2014). The *BahamasSimCLIM* is a tool used to generate climate change and sea level rise (SLR) projections based on the use of different SRES emission scenarios. This tool uses 21 Global Climate Model (GCM) patterns for generating climate change and Sea Level Rise projections for the Bahamas. The Climate Change projections assumed an A1FI emissions scenario. The A1FI assumes a future world of very rapid economic growth with fossil fuel intensive technological emphasis. The projections for the Bahamas are based on outputs from for the 2050 horizon. For the hazard and risk assessment studies, the following projected variables were used:

Temperature

According to *the BahamasSimCLIM* system's projections using a group of 21 GCM's and considering the A1FI emission scenario[5], the maximum daily temperatures for the 2050 horizon are expected to increase by 1.97℃ for The Bahamas. The A1FI assumes a future world of very rapid economic growth with fossil fuel intensive technological emphasis. Average daily maximum temperatures for winter months will increase less than 2℃ while summer months will increase over 2℃. Table A1-2 presents the increase in average daily maximum temperature for the 2050 horizon under A1FI emission scenarios projected for New Providence.

Precipitation

Table A1-2 presents the percentage of change in precipitation projected for the 2050 horizon from *The BahamasSimCLIM*. These projections suggest an average decrease in annual precipitation of 10% in The Bahamas with 20% during some months for most of the islands. As shown in Table A1-2, it is projected that precipitation on New Providence and Paradise islands (NPI) would experience a reduction up to 20% during the dry and wet seasons from March to August (SNC, 2014).

Table A1- 2: Summary of Climate Change Projects for New Providence for 2050

Monthly or Annually	Temperature increase ℃	Change in Precipitation %	SLR cm
Annual	2.03	-11.76	20
December to February	1.88	-6.50	---
March to May	1.88	-19.79	---
June to August	2.16	-19.85	---
September to November	2.16	+0.86	---

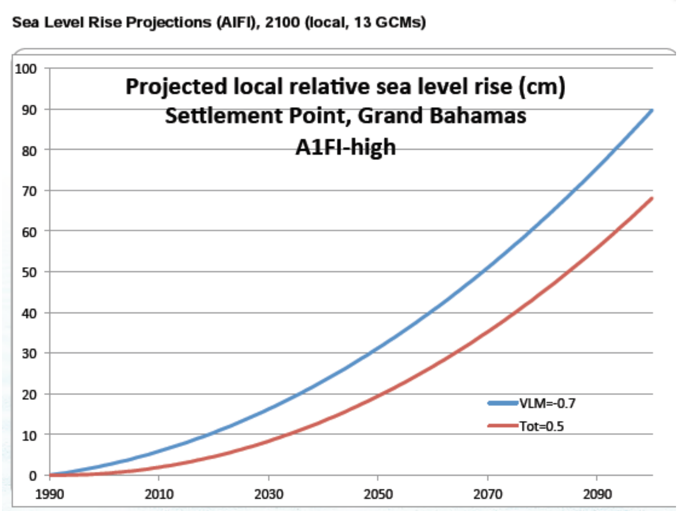
C = Degrees Celsius; cm = centimeters; % = percentage.

Source: Adapted from SNC, 2014

[5] A1FI: A1 storyline describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. A1FI corresponds to a fossil intensive technological emphasis.

Sea Level Rise

As reported by SNC (2014) and CCCCC (2015), the IPCC climate change estimation for sea level rise for 2050 in the Bahamas is 20 centimeters (cm). The Sea Level Rise (SLR) Projections for A1FI emission scenario generated from *The BahamasSimCLIM* system indicate that sea level will rise 9.0 cm, 20 cm, and near 70 cm by 2030, 2050 and 2100, respectively. The A1FI assumes a future world of very rapid economic growth with fossil fuel intensive technological emphasis. The projected SLR from *The BahamasSimCLIM* is consistent with the global SRL trend. Figure A1-1 shows the SLR projections generated from *The BahamasSimCLIM* for Bahamas.



Source: SNC2014. VLM = Vertical Land Movement and Tot = Total Sea Level Rise. The y-axis is in centimeters.

Figure A1- 1: SLR Projections (A1FI) Generated with The BahamasSimCLIM

According to the SNC (2014) report, extreme precipitation events are expected to increase between 6% and 11% on New Providence Island. These extreme events were evaluated by using an extreme value analysis and historical precipitation data collected at the Nassau Airport meteorological station, which has the most complete and long-term climatological records for New Providence Island (see Table A1-4).

Table A1- 3: Projected Most Extreme Precipitation Events at Nassau International Airport Meteorological Station for 2050

Return Period (years)	Existing 24-hr Precipitation (mm)	Climate Change 24-hr Precipitation Projected for 2050 (mm)	Change in precipitation %
2	108	102	-6
5	200	206	+3
10	271	287	+6
25	375	405	+8
50	468	508	+9
100	559	622	+11

mm= millimeters; %=Percentage

Source: Adapted from SNC, 2014

A1.3 Coastal Flood Modeling

Coastal Dynamic Characterization

Coastal flooding occurs when the sea water level rises during tropical storms and hurricanes have the potential to severely impact low-lying coastal settlements such as cities, villages and infrastructures. The United States National Oceanic and Atmospheric Administration (NOAA) identifies the rise in sea water level during storm conditions as storm surge, which is defined as an abnormal rise of water generated by a storm, over and above the predicted astronomical high tide (NOAA, 2015a). The raised sea water can inundate the coastal land via two major paths:

- *Direct inundation*, where the sea level exceeds the elevation of the land; or
- *Overtopping of a barrier*, where the sea level overtops or breaches a natural or artificial barrier.

Coastal flooding is largely a naturally occurring event. However, human influence on the coastal environment can facilitate the sea level rise and exacerbate the damage. For example, extraction of water from groundwater reservoirs in the coastal zone can enhance subsidence and increase the risk of flooding.

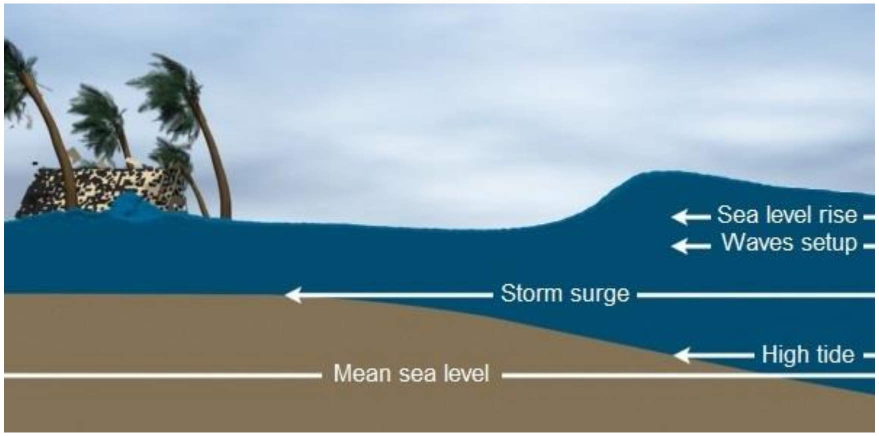
In the island of New Providence, coastal flooding is a hazard of national concern in particular during the summer months when downbursts from thunderstorms are experienced, and predictions of climate change and global warming indicate an increase in flooding due to a rise in sea level (USACE, 2004).

Processes contributing to total storm surge

Coastal flooding occurs mostly because of the storm surge created by hurricanes and its backwater effects on inland rivers and stormwater systems. Other processes also contribute to coastal flooding and each needs to be assessed separately. These processes include:

1. Storm surge;
2. High tides;
3. Waves setup; and
4. Sea level rise (SLR).

These processes contributing to the total storm surge are shown in Figure A1-2.



Source: Adapted from NOAA, 2015a

Figure A1- 2: Processes contributing to total storm surge

Storm surge is the combination of wind setup and pressure setup during hurricanes and tropical storms. High tides depend on the combined effects of the gravitational forces exerted by the Moon and the Sun and the rotation of the Earth. Wave setup is the increase in mean water level due to the presence of waves. Wave setup is largest during tropical storms and hurricanes.

Hurricanes

Tropical cyclones are rapidly rotating storm systems characterized by a low-pressure center and a spiral arrangement of thunderstorms. These tropical cyclones usually bring strong winds and produce heavy rain. Depending on the storm intensity, tropical cyclones are classified as tropical depressions, tropical storms, and hurricanes. The hurricane category is particularly dangerous and has the potential of producing heavy coastal flooding. Hurricanes are further divided into five categories based on the maximum wind speed, central pressure and resulting potential damages. This classification is known as the Saffir-Simpson Hurricane Intensity Scale and is described in Table A1-4.

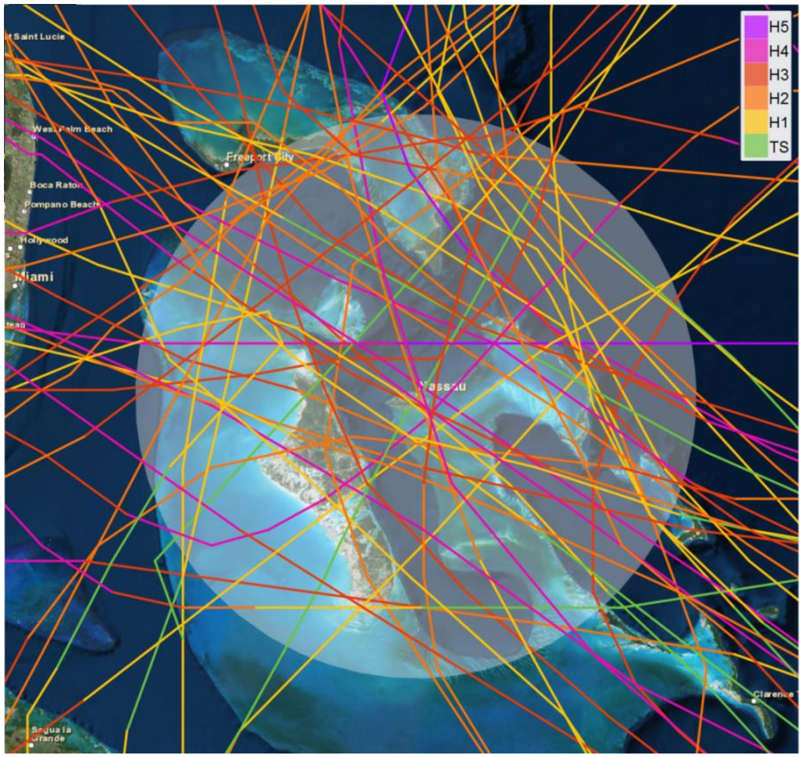
Hurricanes gain their energy from warm waters as they move across the Atlantic Ocean. At the system moves inland, the system loses strength and dissipates. Hurricanes as well as tropical storms typically have enough moisture to cause extensive flooding throughout a large geographical area. In addition to flooding, hurricanes and tropical storms can bring severe winds, extensive coastal erosion, extreme rainfall, thunderstorms, lightning, and tornadoes (USACE, 2008).

Table A1- 4: Saffir-Simpson hurricane damage-potential scale

Hurricane	Wind speed (knot)	Central pressure (millibars)	Surge (m)	Damage
Category 1	64 – 82	> 980	~ 1.5	Minimal
Category 2	83 – 95	965 – 979	2 – 2.5	Moderate
Category 3	96 – 112	945 – 964	2.6 – 3.9	Extensive
Category 4	113 – 136	920 – 944	4 – 5.5	Extreme
Category 5	> 137	< 920	> 5.5	Catastrophic

Source: Adapted from USACE, 2008

According to NOAA (2015b), the tracks of historical hurricanes that passed within 200 km of the island of New Providence since 1850 are visualized in Figure A1-3. The two principal directions of movement are towards north-west and towards north-east. Figure A1-4 shows the total number of hurricanes per year since 1850. The figure indicates that the peak of hurricane activities was in the 1930s and two minor peaks occurred in 1890s and 1960s. The average number of hurricanes per year was 0.7.



Source: NOAA, 2015b

Figure A1- 3: Hurricanes that passed within 200 km of the island of New Providence since 1850

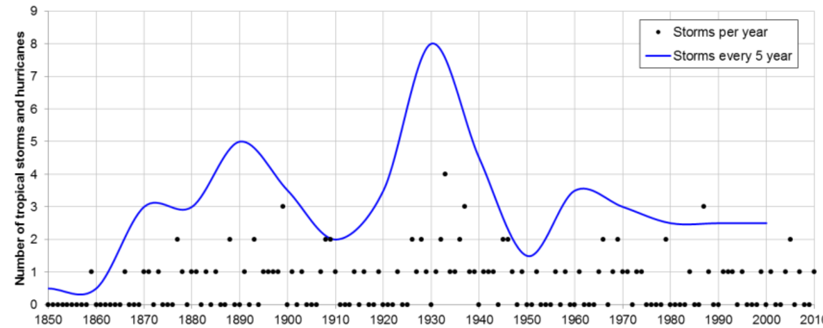


Figure A1- 4: Number of tropical storms and hurricanes that passed within 200 km of the island of New Providence.

In order to associate a return period to a particular storm, a geospatial analysis as the one reported in Figure A1-3 is not enough. Baird (2008) performed a Montecarlo simulation of hurricanes around the island of New Providence for a study prepared for the Harbor of Nassau. Table A1-5 presents their results of Baird's study for the coast in front of Nassau.

Table A1- 5: Return period for storms in the Harbor of Nassau and probable maximum loss

Return Period	Local storm surge (m)	Offshore wave height (m)	Probable maximum loss (Million US$)
10 years	0.3	5	NA
25 years	0.5	7	9,544
50 years	0.6	8	12,500
100 years	0.7	9	12,516

Source: Baird, 2008 and UNISDR, 2015

However, the different bathymetries and beach profiles around the entire island of New Providence will create different values of storm surges and waves for different locations. In order to compute a map of the total storm surge for the entire island for each return period, a Geographic Information Systems (GIS) analysis and numerical modeling were used as described in the following sections.

Storm Surge

Storm surge is the result of strong winds and low pressure that push sea waters inland. In general, surges produced by wind are larger than surges due to pressure. In order to estimate the storm surge around the island of New

Providence, the Sea, Lake and Overland Surges from Hurricanes (SLOSH) model was adopted.

The SLOSH model is a computerized numerical model developed by the National Weather Service (NWS, 2015) to estimate storm surge heights resulting from historical, hypothetical, or predicted hurricanes by taking into account the atmospheric pressure, size, forward speed, and track data. These parameters are used in SLOSH to create a numerical model of the wind field which drives the storm surge. The SLOSH model consists of a set of physics equations which are applied to a specific shoreline, incorporation of a unique bay and river configurations, water depths, bridges, roads, levees and other physical features.

The grid of the SLOSH model adopted for this study is shown in Figure A1-5. The range of grid cell around the Island of New Providence is 3-4 km which is adequate to provide a detailed map of the storm surge along the coastline.

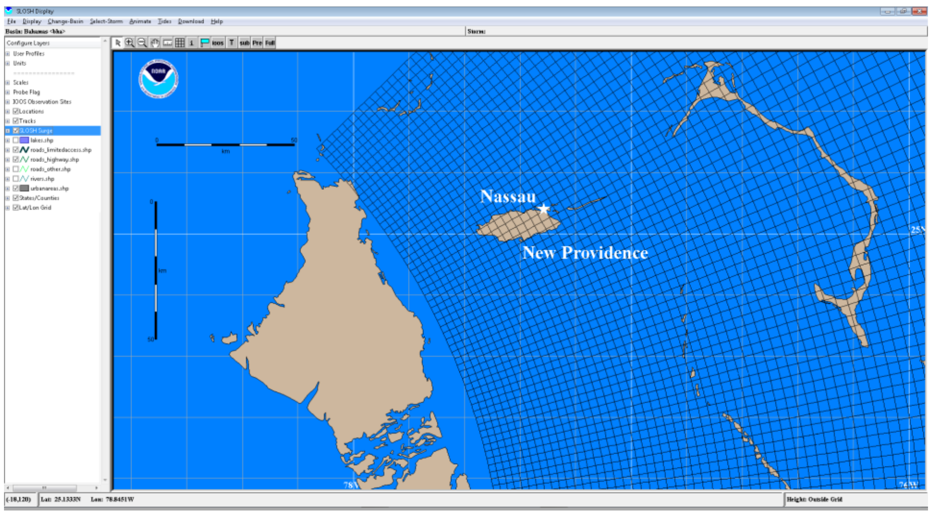


Figure A1- 5: SLOSH model grid implemented to estimate the hurricane wind and pressure storm surge around the island of New Providence.

Wave Setup

Baird (2008) conducted numerical simulations of the wave field around the island of New Providence during Hurricane Frances which occurred in 2004. The numerical simulation study used the model WAVAD[6] with a grid spacing of 5 km.

[6] A wave model; numerical model that generates wave fields in the ocean with varying winds and bathymetry.

In addition, the study estimated the offshore wave height in proximity of NPI for the return periods utilized in this analysis (see Table A1-5, above). The wave field for hurricane Frances provided by Baird (2008) was used to estimate the wave height around the entire island of New Providence and identified the areas subjected to the highest waves.

Hurricane waves contribute to the storm surge by raising the height at which coastal flooding occurs. This phenomenon is known as wave setup and occurs as the waves break along the beach (USACE, 2008). Following Goda (1985), the wave setup has been estimated as 10% of the offshore wave heights during hurricane conditions.

High Tides

The high tide in the island of New Providence was estimated to be about 0.76 m above the mean sea level (NWS, 2015). The largest recorded tidal range in Nassau was 1.44 m (Tide-Forecast, 2015). The sum of storm surge and high tide is also known as storm tide (NOAA, 2015a).

Sea Level Rise

One of the major effects of global climate change is to induce the ocean waters to raise, a process known as sea level rise (SLR). Three processes related to global warming have been identified as primary factors for SLR (CCCCC, 2015):

- *Thermal expansion:* When ocean water heats up, it expands and occupies more space. It is estimated that at nearly half of the past century's rise in sea level is due to warmer ocean waters.
- *Continental glaciers melting*: Persistently higher global temperatures led to larger summer melting and reduced snowfall. The consequent imbalance results in a larger runoff that reaches the ocean waters.
- *Greenland and West Antarctica ice loss*: Increased heat caused larger volumes of meltwater to lubricate ice streams and move more quickly into the sea. Ice shelves tend to melt from below and break off.

Higher ocean water levels can have devastating effects on coastal and near-shore habitats. As seawater reaches farther inland, it causes destructive erosion, flooding of wetlands, contamination of aquifers and agricultural soils, and lost habitat for fish, birds, and plants. When tropical storms make landfall, higher sea levels induce larger and more powerful storm surges that can propagate further inland.

Bahamas has one of the highest percentages of national population affected by sea level rise because of the large percentage of urban areas that could be inundated (CCCCC, 2015). Tourism and agriculture have been identified as key vulnerable activities affected by SLR. This is an important finding, as tourism is a major sector of the Caribbean region economies and has been overlooked in most previous assessments of the impacts of SLR. It was estimated that in 2002 tourism represented 46% of the GDP in the Bahamas.

SLR estimations vary according to the region of the world and the future year. These estimations are provided by several institutes such as the United Nations (UN) and the Intergovernmental Panel on Climate Change (IPCC) in several reports. The UNDP report (Simpson et al., 2010) provides a summary of the most recent projections of global SLR over the 21st Century and compares these newer studies to the IPCC AR4 projections and continuation of current trends. In the Caribbean region the SLR was estimated to vary between 0.09 and 0.23 meters. As reported by SNC (2014) and CCCCC (2015), the IPCC estimated SLR for the Bahamas is 20 cm to 2050.

Total Storm Surge

The total storm surge resulting from the combination of storm surge, high tides, wave setup and sea level rise due to climate changes is shown in Figure A1-6. This figure illustrates the total storm surge around NPI for 10-, 25-, 50-, and 100-year return periods.

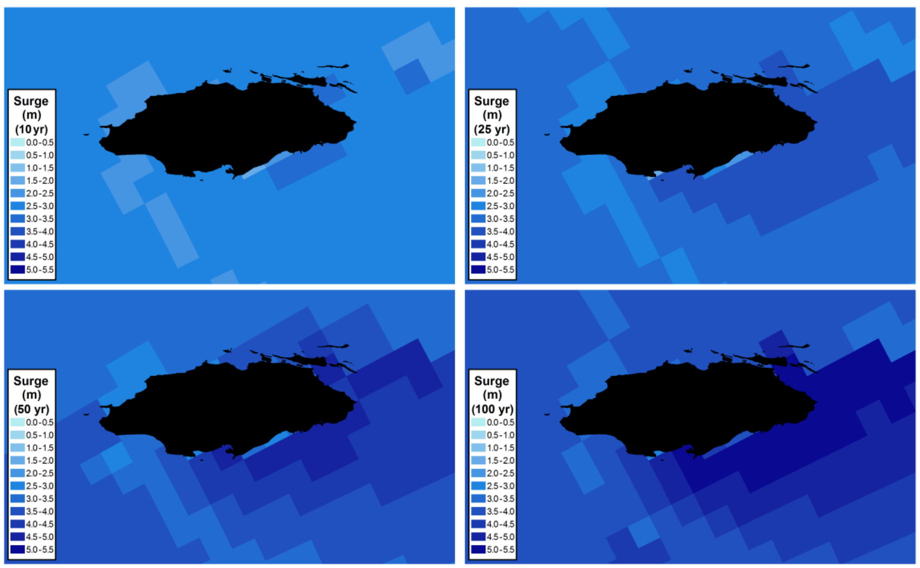


Figure A1- 6: Total storm surge around NPI for 10, 25, 50 and 100 year return periods

Hazard determination

The hurricane-induced coastal floods can be scientifically derived based on hydrodynamic numerical modeling. This type of model is data intensive and requires extensive modeling of parameters such as oceanographic and meteorological parameters, hydrological input, watershed and land elevation characteristics, coastal geometry, and information about astronomical tides. In addition, the accuracy of the surge height; the associated flood depth; and the extent of horizontal inundation depends heavily on the accuracy and resolution of the digital elevation data (DTM) that is available for coastal areas.

An overland flood routing model, FLO-2D, was used to determine the areas of inundation and the hazard levels caused by storm surges along New Providence and Paradise islands. Hazard levels are determined from an equation that relates the flow depth and velocity to potential flood damage (see Table A1- 9).

Historical coastal floods

According to the International Disaster Database (EMDAT, 2015), floods and storms are the primary natural disasters to have caused deaths and damages in the Bahamas since 1990. The average annual loss for storm surges alone is estimated at US$1,343.66 million (UNISDR, 2015). The largest historical coastal floods happened in the 1930s-40s, 1990s and 2000s (EMDAT, 2015). In 1935, fourteen deaths were reported from the occurrence of a large storm and in 1945 twenty-two deaths were reported. A large event also occurred in 1965 that affected over 1200 people, but few deaths were reported. During Hurricane Andrew in 1992, approximately 1,700 people were left homeless in across the Bahamas and the total damage of the coastal flood was estimated at 250 million US$. Throughout the decade of the 2000s, over 30,000 people were affected by storm surges and coastal flooding. Coastal floods

In this study, four return periods were used (10-yr, 25-yr, 50-yr, and 100-yr) and for each return period, four scenarios were also evaluated (baseline, climate change, climate change with intelligent growth, and climate change with Business-As-Usual growth). The combination of return periods and scenarios resulted in twelve cases for each island, New Providence and Paradise Island. For each scenario, the total storm surge was assigned to the Northeast, Southeast, Southwest, and Northwest coastal regions of New Providence, and assigned to the Northeast, Southeast, and West coastal regions of Paradise Island. A summary of the total storm surges used in the model is provided in Table A1-6.

Table A1- 6: Total storm surge (meters) along coastal regions for baseline and climate change (CC) scenarios

Return Period	New Providence				Paradise Island		
	NE	SE	SW	NW	NE	SE	W
10-yr	2.3	2.5	2.2	2.2	2.5	2.5	2.3
25-yr	2.7	3.5	2.7	2.6	3.1	3.3	2.7
50-yr	3.1	4.3	3.2	2.9	3.7	4.0	3.0
100-yr	3.4	5.0	3.7	3.2	4.3	4.8	3.3
Sea Level Rise (SLR)							
10-yr	2.5	2.7	2.4	2.4	2.7	2.7	2.5
25-yr	2.9	3.7	2.9	2.8	3.3	3.5	2.9
50-yr	3.3	4.5	3.4	3.1	3.9	4.2	3.2
100-yr	3.6	5.2	3.9	3.4	4.5	5.0	3.5

NE= Northeast; SE= Southeast; SW= Southwest; NW= Northwest; NE= Northeast; SE = Southeast; W = West.

Flooding Historical Events

The Bahamas is prone to natural disasters, especially hurricanes (IMF, 2005). In 2004, several hurricanes swept across the region, causing damages at 6.7 percent of The Bahamas' GDP (IMF, 2005). These hurricanes included Hurricane Frances, a category 4 hurricane, and Hurricane Jeanne, a category 3 in September, 2004. Estimates of damages from these hurricanes were approximately 4 percent of GDP for direct impacts, and 1.3 percent for indirect impacts (losses from reductions in tourism, business, agriculture, and fishing) (IMF, 2005). Other notable hurricanes include Hurricane Andrew, a category 5 hurricane in August, 1992, and Hurricane Ike, a category 4 in September, 2008. The damages in 1992 produced by Hurricane Andrew were estimated at 250 million US$ (Rappaport, 1993).

A1.4 Inland Flood Modeling

To evaluate inland floods in NPI, ERM used FLO-2D (FLO-2D, 2004), which is an effective model for evaluating flood hazards. FLO-2D is a flood routing model that simulates channel flow, unconfined overland flow, and street flow over complex topography. The model routes flood hydrographs and rainfall runoff with many rural and urban detail features including street flow, levees and walls, and hydraulic structures. This software is approved by the United States Federal Emergency Management Agency (FEMA) for Flood Insurance Studies.

FLO-2D models two dimensional overland flow across a floodplain by conducting volume conservation. Flow within stream channels is modeled as one-dimensional. The model is set up with uniform, square grid elements. Inflow to the model occurs at inflow nodes with a specified hydrograph. Velocities and flow rates are computed for each grid element based on inflow water surface elevation, ground surface elevation, and Manning's roughness coefficient. The transfer of water mass between grid elements occurs in the eight compass directions: E, S, W, N, NE, SE, SW, and NW.

Elevations

Floodplain elevations for each 15 meter grid cell were interpolated from a digital terrain model (DTM) of the islands developed by GlobalGeo. The elevation data was obtained at two meters resolution (see Figure A1- 7).

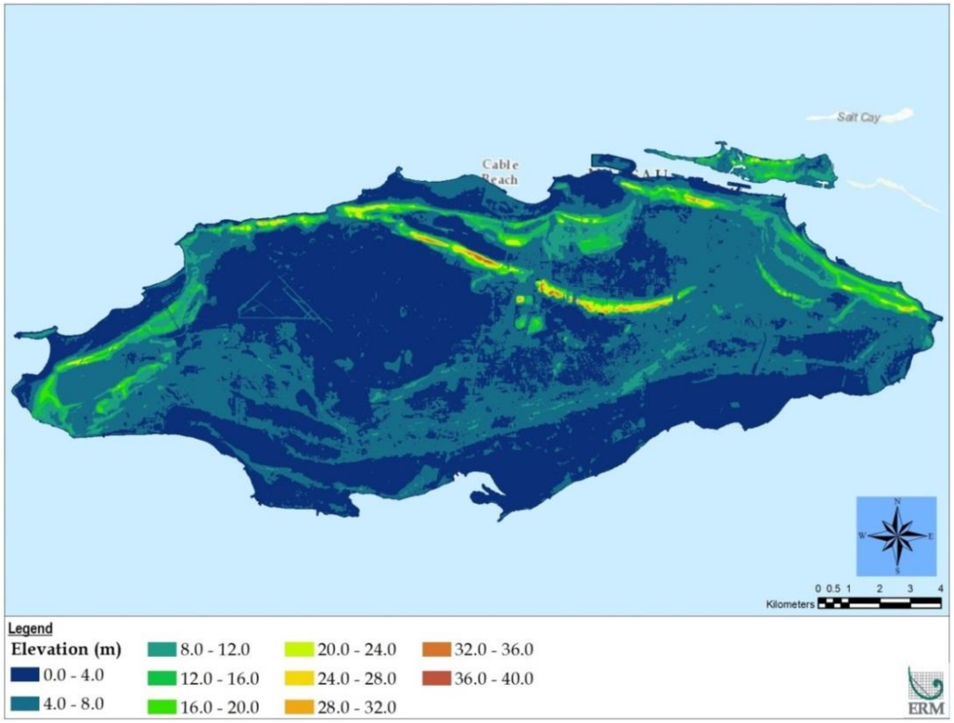


Figure A1- 7: Coastal and inland flooding model ground surface elevations

Modeled Scenarios

Four main scenarios were simulated to evaluate different coastal and inland flooding hazard in NPI. These scenarios present the following characteristics:

- *Baseline:* This scenario considers the existing land use and climatological conditions (see Table A1-4).
- *Climate Change (2050):* This scenario uses the existing land use and climate change projections for the study area (see Table A1-4).
- *Business-As-Usual plus climate change:* This scenario uses land use from the First Order Zoning Map of New Providence (FOZM) that was produced as part of the 2010 Planning and Development Act is implemented; and projected future climate change projections for the study area (see Table A1-4).
- *Intelligent Growth plus climate change-* This scenario uses land use generated from the intelligent growth analyses carried out by ERM. In this instance, the footprint reaches 54% of the land and the NSS reach 46% of the land. Details of this Intelligent Growth Scenario for New Providence Island are included in Section 14 of the Urban Growth Study. This scenario also considers the projected future climate change projections for the study area (see Table A1-4).

These scenarios were run for four different return periods (10-, 25-, 50- and 100-years).

Land Use and Soil Type

For this study, the SCS Curve Number method (USDA, 1986) was selected to represent rainfall infiltration into the soil. Areas with a higher curve number (CN)[7] have reduced infiltration due to greater impermeability, and therefore have a higher potential for flooding. A CN was assigned to each grid cell based on soil type and land use in New Providence and Paradise islands. The soil type of the islands is a classified as Calcaric Regosols (FAO, 1992), which is an unconsolidated material. Despite a high permeability of the soils on the islands (USACE, 2004), soils were classified as soil group D in the SCS CN method because based on TR-55, hydrologic soil group D includes "soils with a permanently high water table" (USDA, 1986). Also, According to the USACE (2004) Water Resources Assessment of the Bahamas, *"once the ground becomes totally saturated, flooding can occur quickly since seepage to the sea is a slow process and is the only natural way to deal with the problem*." Soil group D was selected based on references to a permanently high water table and field observations of slow infiltration after a storm. NPI's soils rapidly become saturated due to the high water table and associated tidal influences on groundwater levels, producing floods, which are then exacerbated by seepage to the sea of flood waters being a slow process and is the only natural way to deal with the excess runoff.

Land use and soil type determine the CN and Manning's roughness parameters assigned for NPI are shown in Table A1-7. Greater vegetative cover will have a lower CN, faster infiltration and lower runoff while reduction on vegetative cover will have a higher CN, lower infiltration and higher runoff volume.

Under the climate change scenarios, three types of land use were evaluated: baseline (current conditions), Business-As-Usual growth (more urbanized), and intelligent growth (less urbanized). Manning's roughness and curve numbers for the protected areas under the Intelligent Growth scenario and urban growth areas under the Business-As-Usual scenario have been modified to reflect the increased or decreased infiltration due to these future growth conditions.

Table A1- 7: Land use parameters for flood modelling applications for New Providence and Paradise Islands

Land Use	Manning's n value	Curve number
Roads	0.011	98
Agriculture	0.35	86
Airport	0.12	87
Commercial	0.08	95
Forest	0.4	77
Green Space	0.4	79
Industrial	0.05	93
Institutional	0.08	95
Mixed Use	0.08	92
Residential	0.12	90
Protected (Intelligent Growth)	0.38	81
Urban Growth (Business-As-Usual)	0.12	90

[7] Curve Number (CN) is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess. CN is based on soils, plant cover, and amount of impervious areas, interception, and surface storage.

Rainfall

Four rainfall return periods, the 10-yr, 25-yr, 50-yr, and 100-yr were modeled. Rainfall was modeled under the baseline and the climate change scenarios as a 24-hour SCS Type III storm. The UNFCC (2014) conducted an analysis of the extreme rainfall events at the Nassau International Airport from 1973-2010 as well as projected events for 2050. A 24 hour rainfall for each extreme event is listed in Table A1-8. The rainfall for the 25-yr event was interpolated from values provided in the UNFCC report (UNFCC, 2014).

Table A1- 8: 24-hour rainfall return periods for baseline and climate change scenarios

Return period (years)	Baseline rainfall (mm)	Climate Change rainfall (mm)
10	271	287
25	375	405
50	468	508
100	559	622

mm= millimeters

Source: SNC, 2014

A1.5 Flooding Hazard Results

Results of the coastal and inland flooding scenarios are presented from Figure A1- 8 to Figure A1- 39 below as hazard level. According to the FLO-2D Reference Manual (2004), flood hazard can be defined by the flood intensity, which is the product of maximum flood depth and maximum flood velocity (see Table A1-9). Table A1-10 provides a description of the default definitions and degree of impact for three hazard levels while Table A1-11 and Table A1-12 summarize the flooded areas for different return periods under baseline and climate changes conditions projected for the horizon 2050.

It is important to mention that in the model, groundwater component was conceptually incorporated by adjusting the soil type from Group A (high infiltration) to Group D (high runoff due to high groundwater table). The model did not consider the fluctuation (time-varying) of groundwater levels that are influenced by sea level and tides in small islands (UNESCO, 2010) like NPI, because hazard maps were prepared for single extreme events (not seasonal changes). The simulated events included extreme precipitation events (10-, 25-, 50- and 100-years including baseline conditions and % increase due to climate change) and total storm surge extreme events (SLR, waves, storm surge and high tide). In other words, the simulations include an extreme precipitation event (e.g., 100-year) + total storm surge extreme event (e.g., 100-year) with a saturated soil type representing the high groundwater table that reduces infiltration.

Table A1- 9: Definitions of Flood Intensity

Flood Intensity	Maximum depth h (m)		Maximum depth h times maximum velocity v (m^2/s)
High	h > 1.5 m	OR	$v * h > 1.5\ m^2/s$
Medium	0.5 m < h < 1.5 m	OR	$0.5\ m^2/s < v * h < 1.5\ m^2/s$
Low	0.1 m < h < 0.5 m	AND	$0.1\ m^2/s < v * h < 0.5\ m^2/s$

mm= millimeters; v = velocity; h= depth; m= meters; m^2/s = square meters per second.
Source: FLO-2D Reference Manual, 2004

Table A1- 10: Definitions of Flood Hazard

Hazard Level	Map Color	Description
High	Red	Persons are in danger both inside and outside. Structures are in danger of being destroyed.
Medium	Orange	Persons are in danger outside. Buildings may suffer damage and possible destruction depending of construction characteristics.
Low	Yellow	Danger to persons is low or non-existent. Buildings may suffer little damages, but flooding or sedimentation may affect structure interiors.

Source: FLO-2D Reference Manual, 2004

Table A1- 11: Inland Flooding Projections (including Climate Change to 2050)

Return period (years)	Baseline				Climate Change			
	Low Hazard (km^2)	Medium Hazard (km^2)	High Hazard (km^2)	Total Inundated Area (km^2)	Low Hazard (km^2)	Medium Hazard (km^2)	High Hazard (km^2)	Total Inundated Area (km^2)
10	1.1	36.2	1.0	38.3	1.2	39.2	1.2	41.7
25	1.7	65.0	3.0	69.7	1.9	69.5	3.6	75.0
50	2.1	76.8	5.2	84.2	2.4	82.0	6.8	91.2
100	2.6	86.2	9.6	98.4	2.9	89.1	14.3	106.3
Return period (years)	**Intelligent Growth**				**Business-As-Usual**			
	Low Hazard (km^2)	**Medium Hazard (km^2)**	**High Hazard (km^2)**	**Total Inundated Area (km^2)**	**Low Hazard (km^2)**	**Medium Hazard (km^2)**	**High Hazard (km^2)**	**Total Inundated Area (km^2)**
10	1.2	38.7	1.2	41.1	1.2	40.2	1.3	42.7
25	1.9	69.1	3.5	74.5	1.9	70.4	3.8	76.0
50	2.4	81.8	6.6	90.7	2.4	82.6	7.0	92.0
100	2.9	89.3	13.8	105.9	2.9	89.4	14.7	107.0

km^2= square kilometers

Table A1- 12: Coastal flooding total areas of inundation

Return period (yr)	Baseline (km^2)	Climate Change (km^2)	Intelligent Growth (km^2)	PS210 Act (km^2)
10	0.2	0.7	0.7	0.7
25	0.3	11.1	11.1	11.1
50	22.2	25.6	25.6	25.6
100	33.7	37.3	37.3	37.3

km^2= square kilometers

Results of the coastal and inland flooding are shown in the tables above and hazard maps for different return periods are presented below. A limitation of the modeling approach is that it does not consider the urban storm sewer system, due to the complexity of modeling the surface hydrology, sewers and the status management of the system for the entire island. It was assumed that during major storm events, the sewers would back up and provide minimal drainage. This is an assumption that may warrant further investigation.

Coastal flooding occurs most severely along the southern coast of New Providence. The southern coast has lower elevations, and the predicted storm surge is highest. For a coastal flooding event with a 100-year return period, and with sea level rise to 2050, there is a large area of the island that could experience high hazard flooding. Land use did not affect the areas of inundation for coastal flooding. Due to the sustained large depths from a storm surge, infiltration does not reduce the flooding. Land use will determine the number and types of buildings within the flooded areas, which will affect the total damages.

Inland flooding occurs throughout the entire New Providence and Paradise islands (NPI). Lower lying areas experience the most flooding. Urbanized areas also experience more flooding due to the reduction of infiltration, and the reduction of flow area due to buildings. The intelligent growth scenario reduces the total flooded area compared to current land use with climate change and the Business-As-Usual scenarios, as shown in Table A1- 13.

Table A1- 13: Inland flooding areas of inundation comparison of climate change and land use scenarios to baseline

Return period (yr)	Climate Change*	Intelligent Growth	PS210 Act
10	8.7%	7.1%	11.4%
25	7.5%	6.8%	9.0%
50	8.3%	7.8%	9.2%
100	8.1%	7.7%	8.8%

Coastal flooding hazard maps prepared for NPI under different scenarios are shown in Figures A1-8 to A1-23 while inland flooding hazard maps are shown in Figures A1-24 to A1-39. Each of the hazard maps illustrates three levels of hazards (low, medium and high) which were defined by using the criteria presented in Tables A1-9 and A1-10.

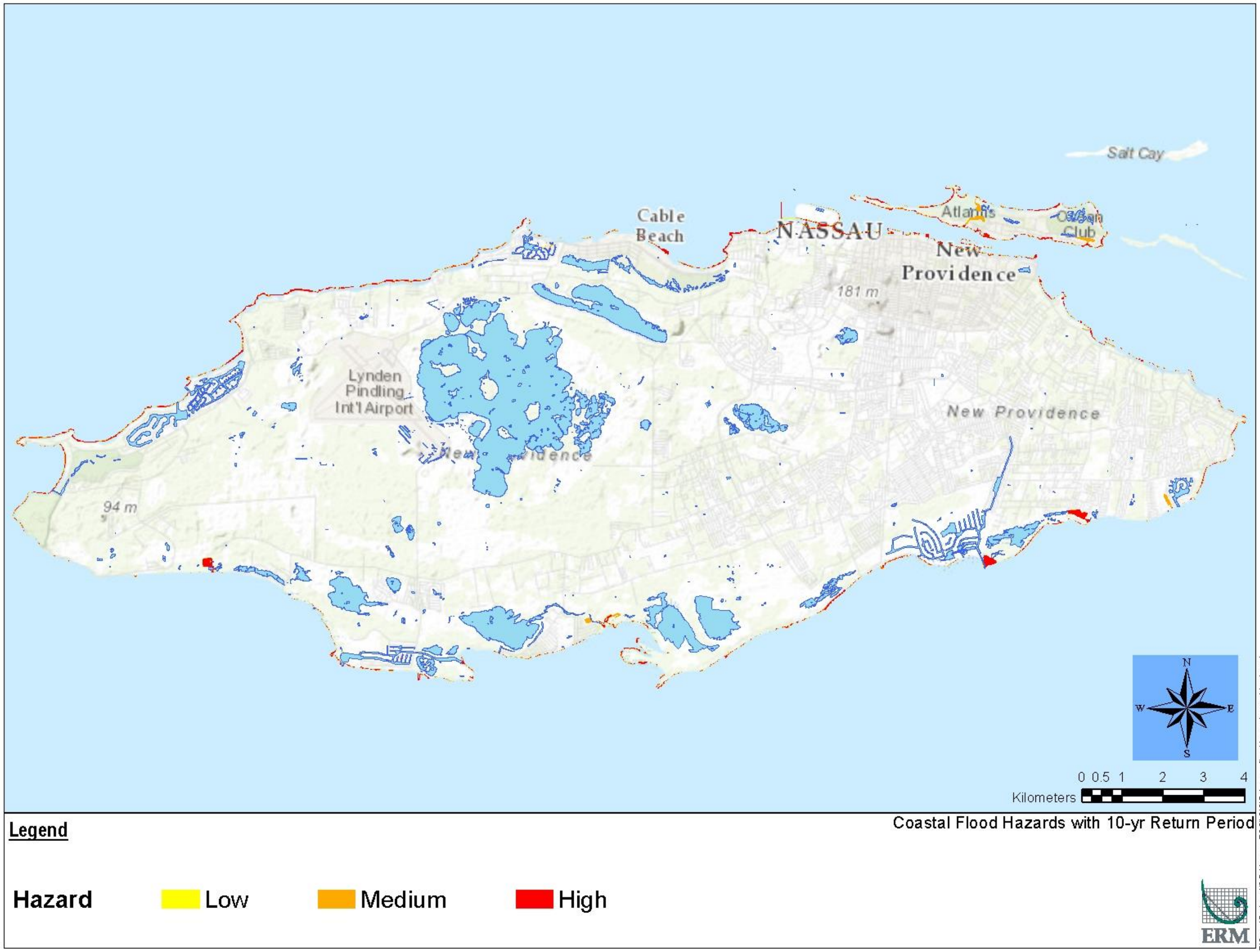


Figure A1- 8: Coastal flooding for a 10-year return period under baseline conditions

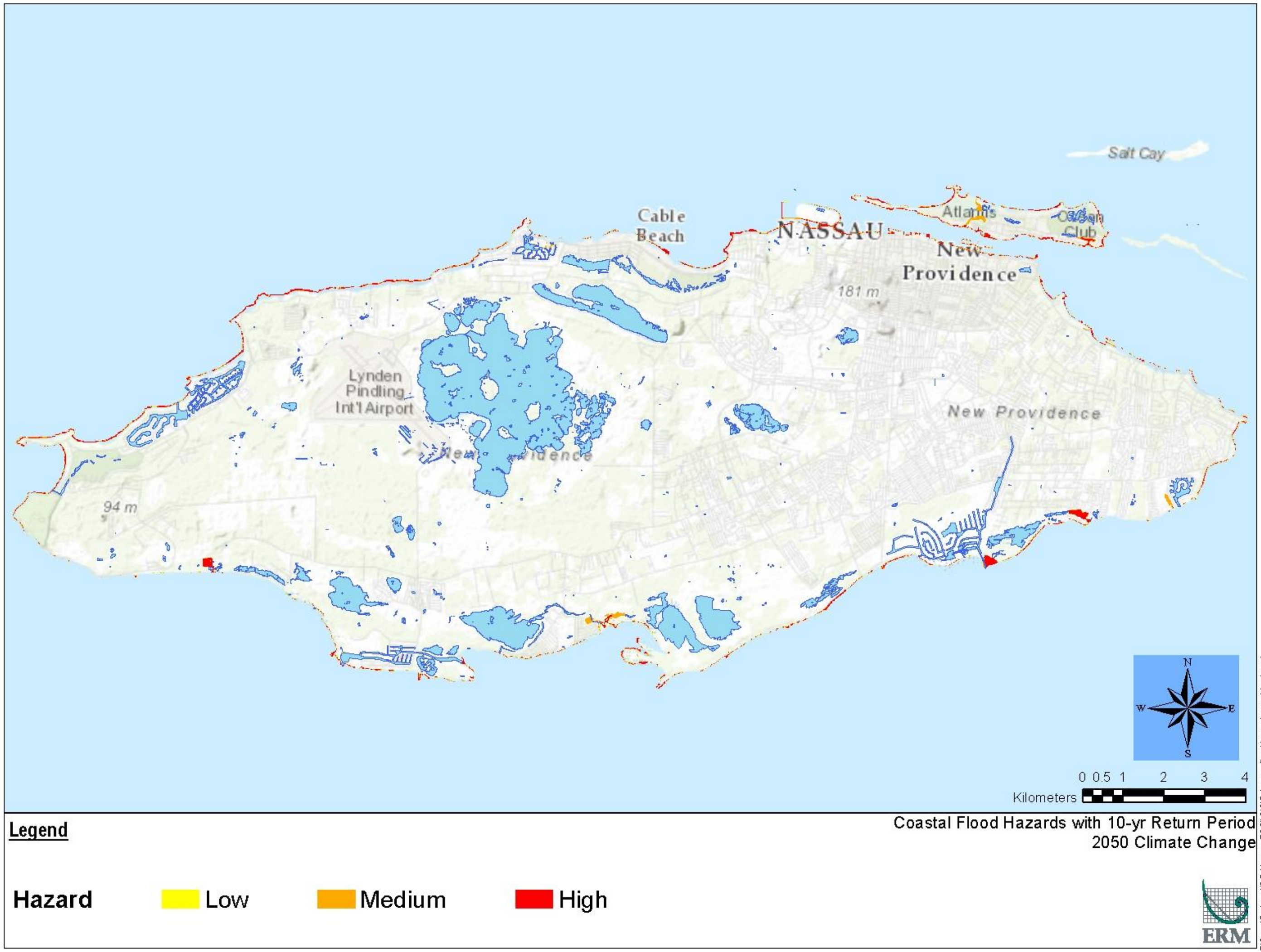


Figure A1- 9: Coastal flooding for a 10-year return period with 2050 SLR

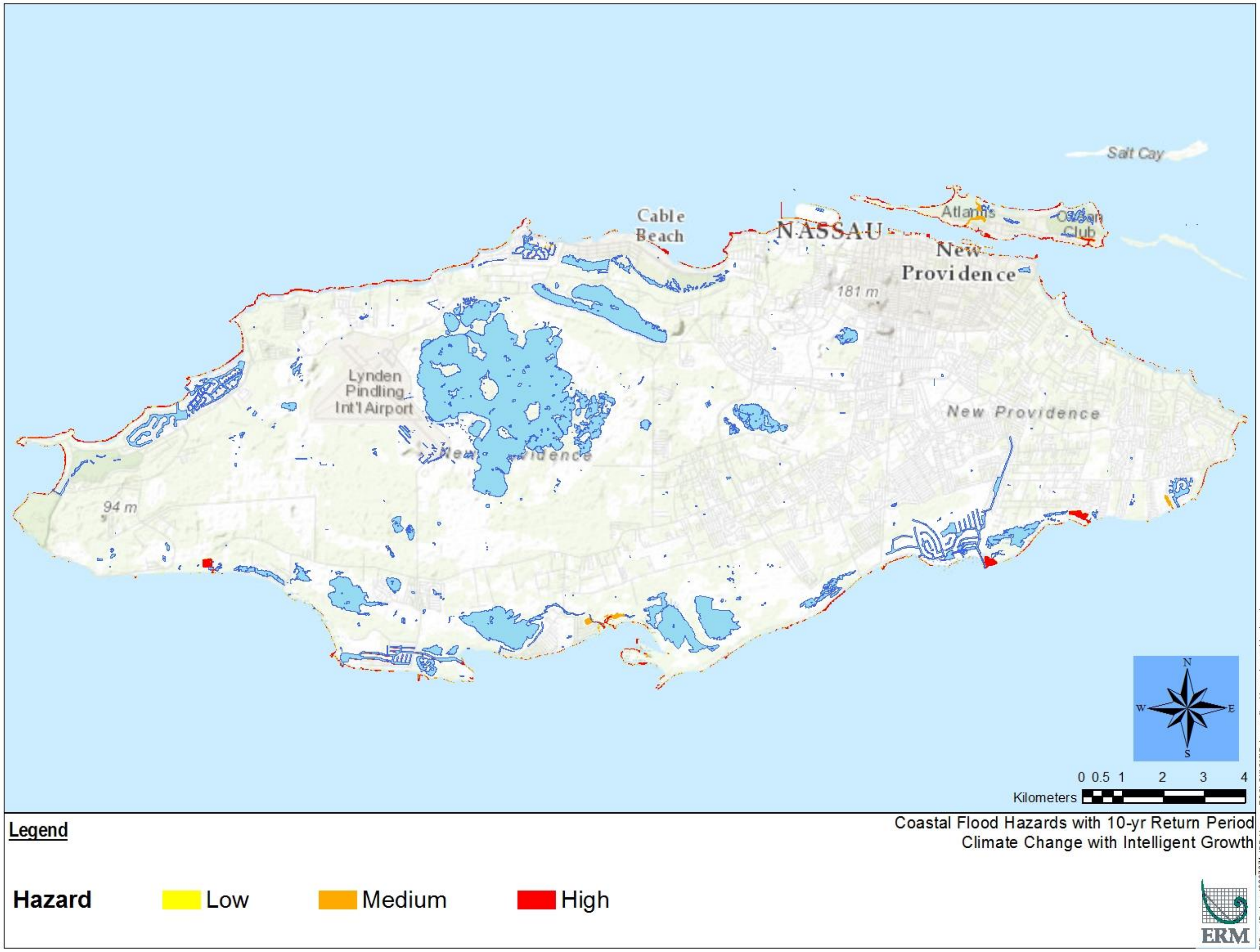


Figure A1- 10: Coastal flooding for a 10-year return period with 2050 SLR and intelligent growth scenario

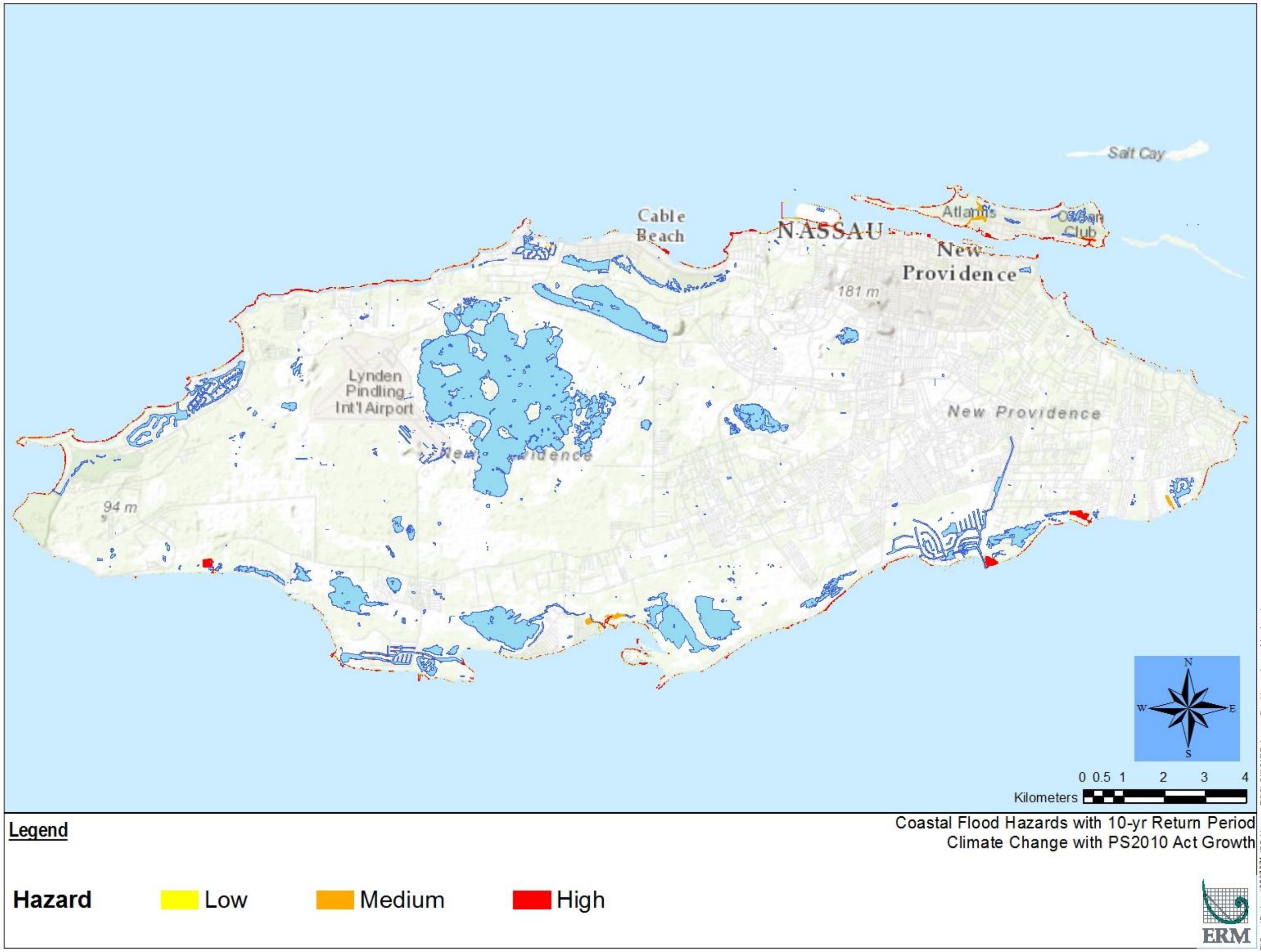


Figure A1- 11: Coastal flooding for a 10-year return period with 2050 SLR and Business-As-Usual scenario

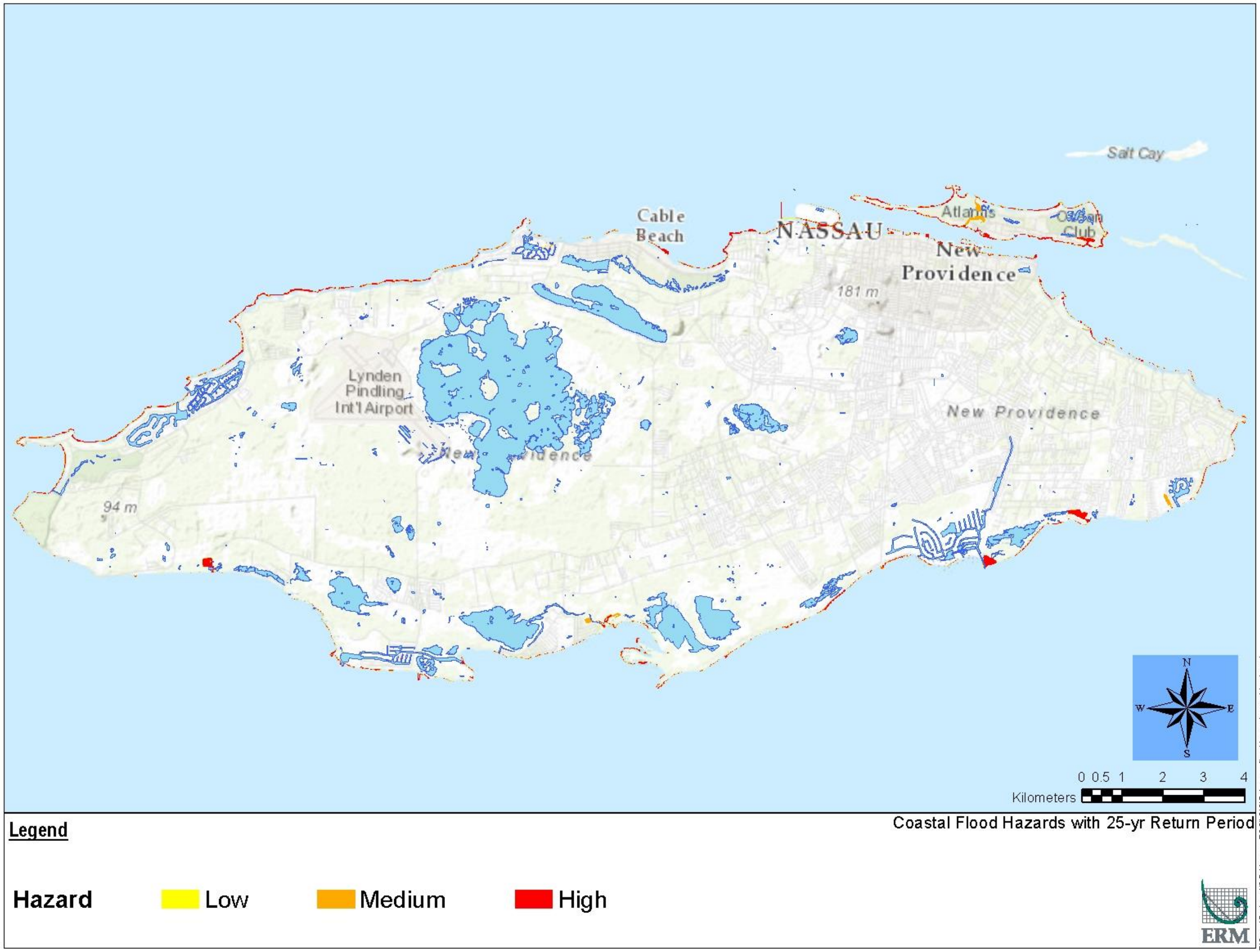


Figure A1- 12: Coastal flooding for a 25-year return period under baseline conditions

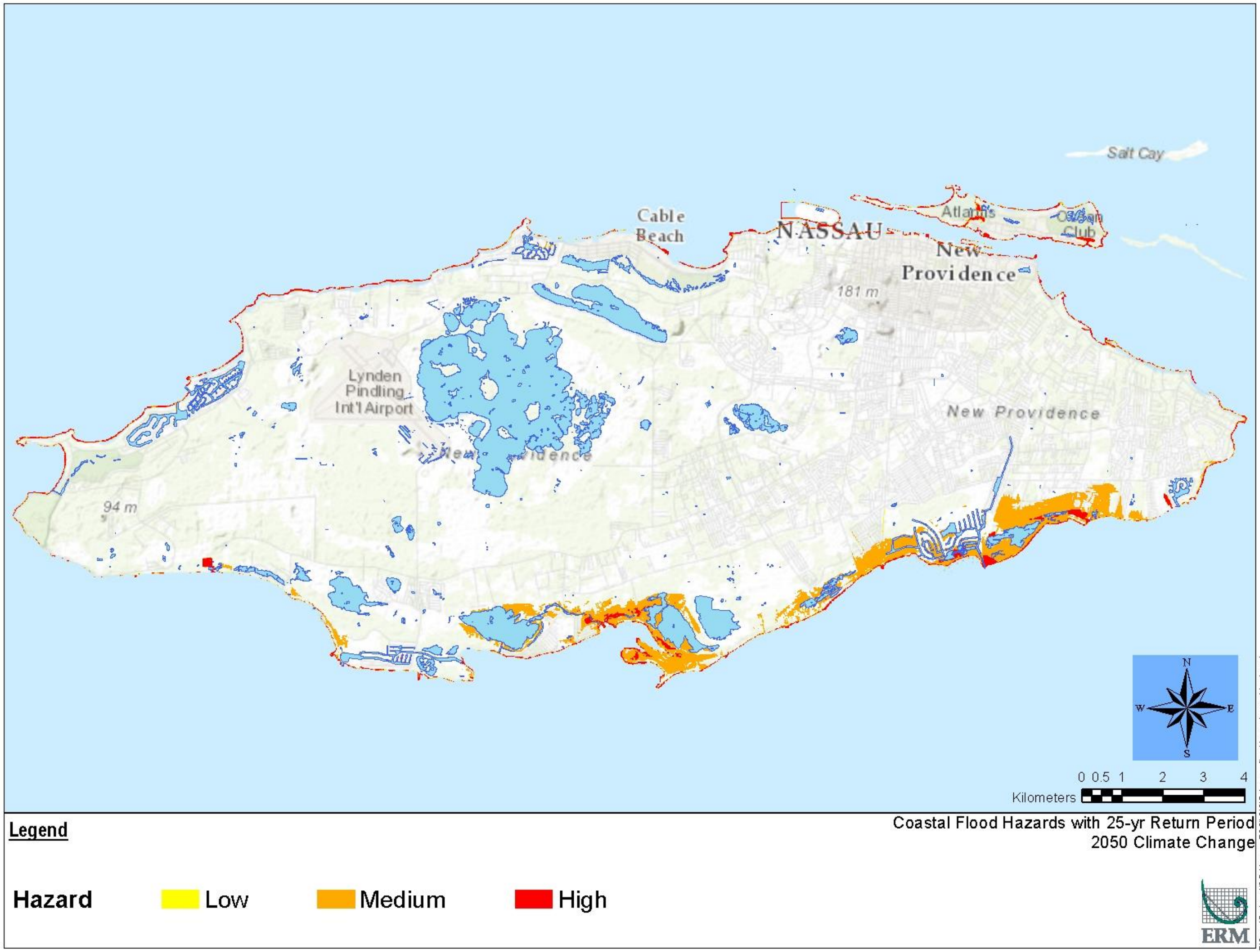


Figure A1- 13: Coastal flooding for a 25-year return period with 2050 SLR

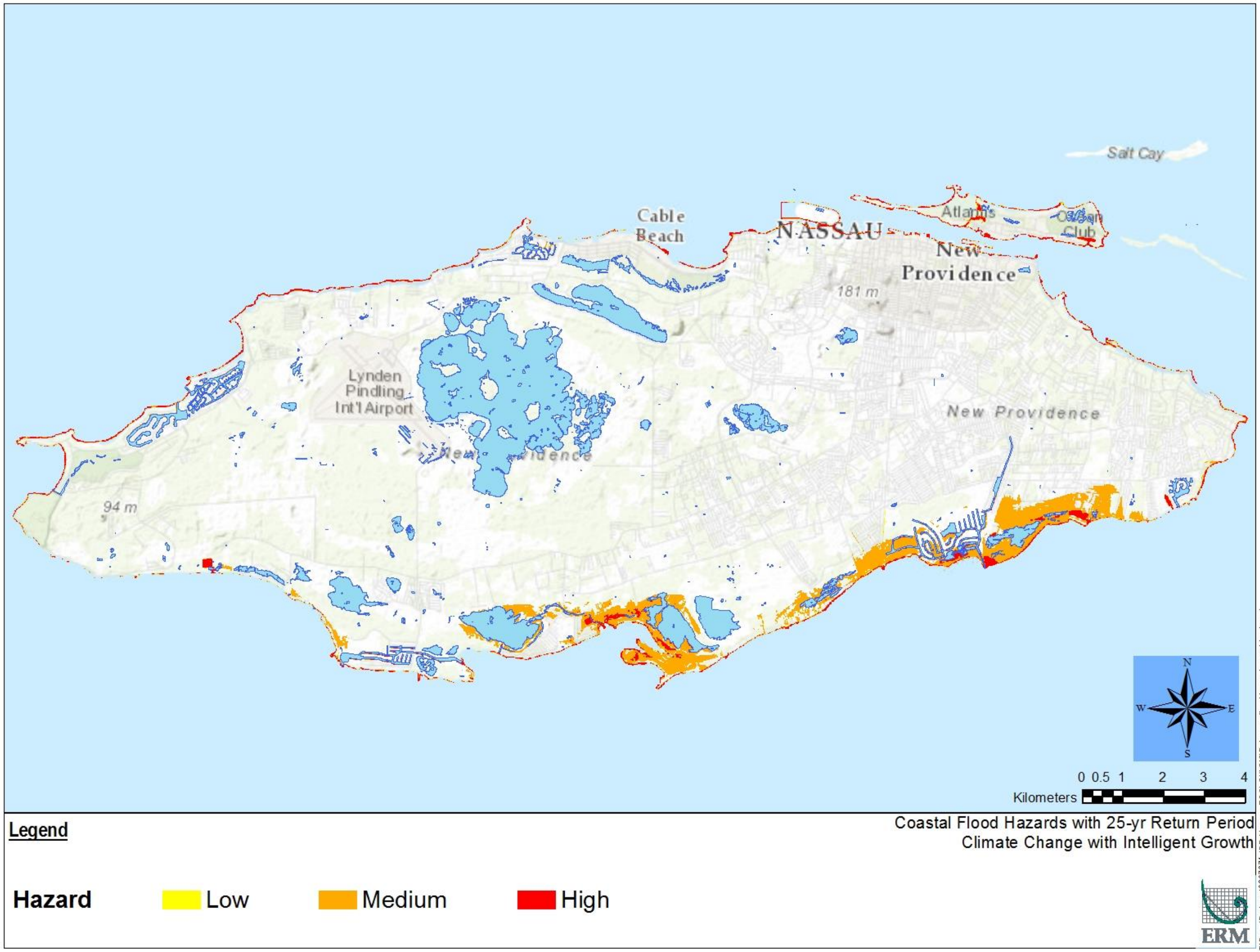


Figure A1- 14: Coastal flooding for a 25-year return period with 2050 SLR and intelligent growth scenario

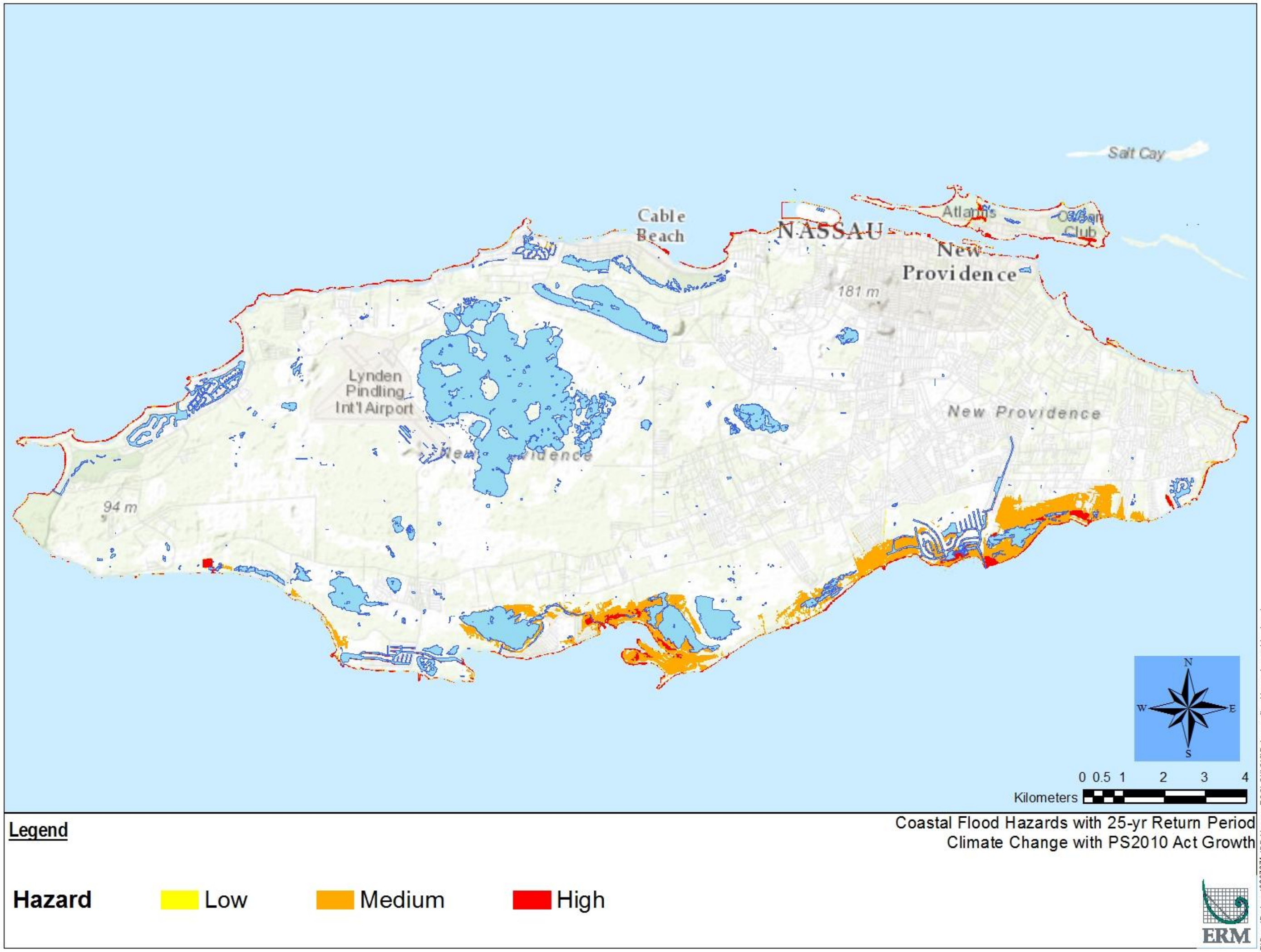


Figure A1- 15: Coastal flooding for a 25-year return period with 2050 SLR and Business-As-Usual scenario

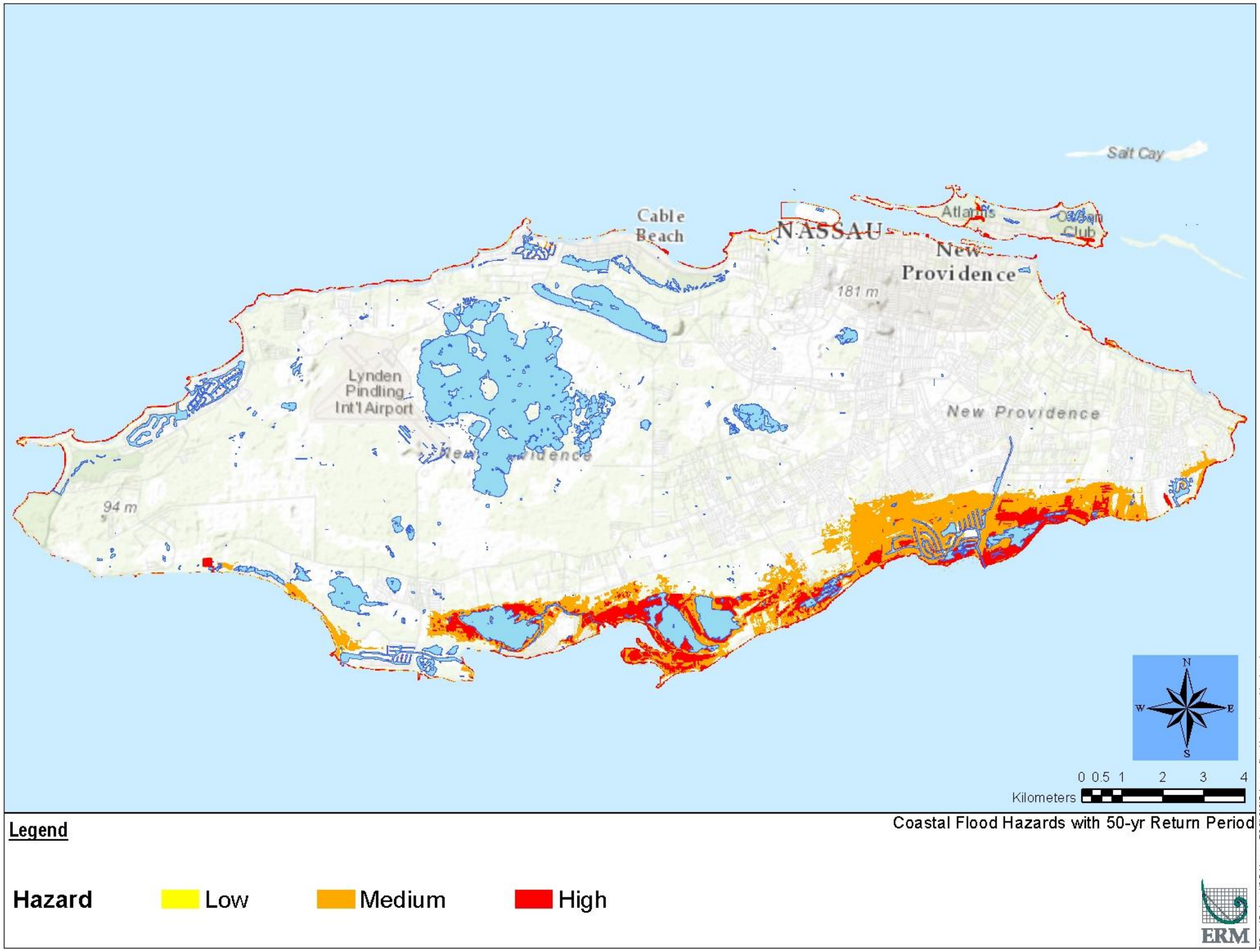


Figure A1- 16: Coastal flooding for a 50-year return period under baseline conditions

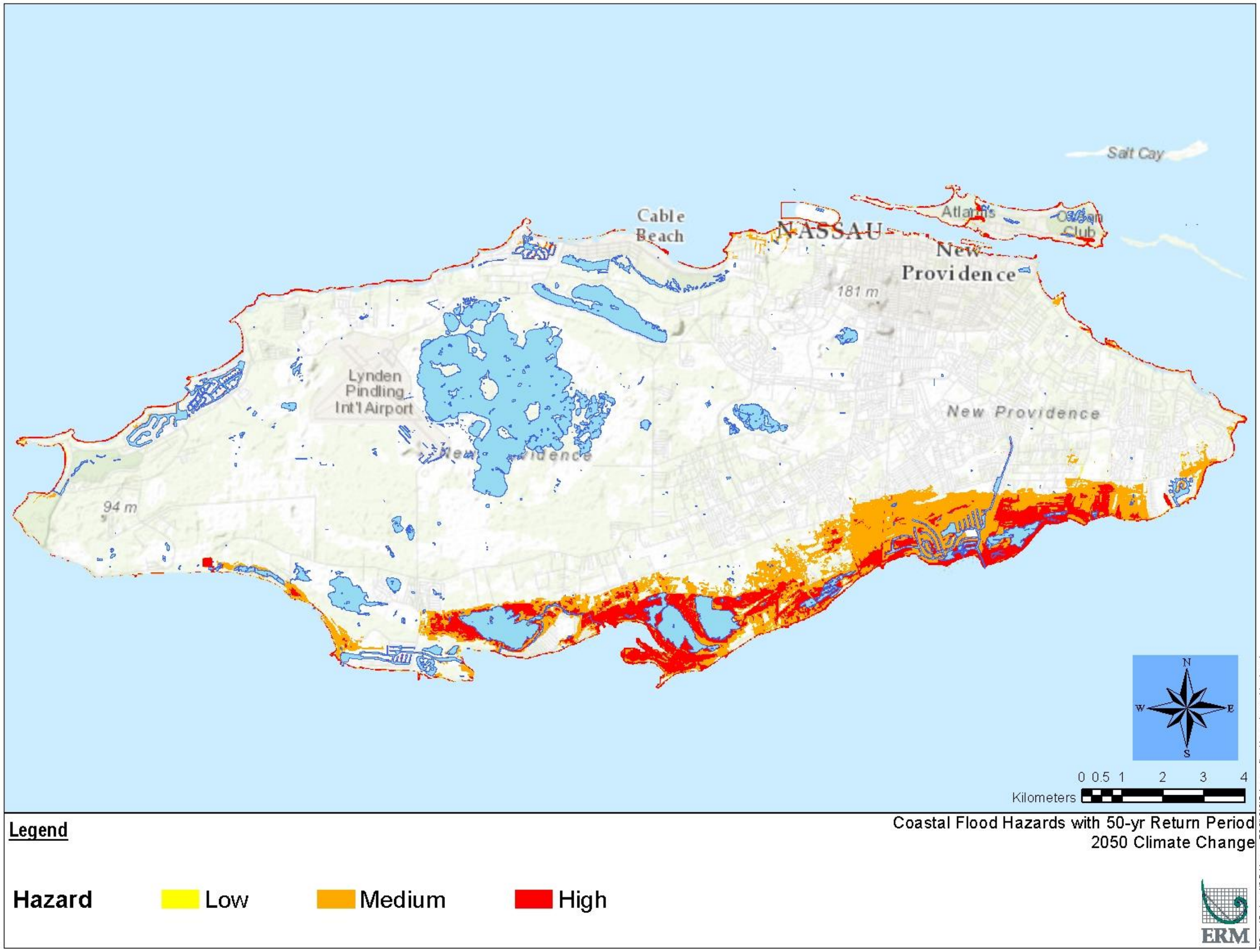


Figure A1- 17: Coastal flooding for a 50-year return period with 2050 SLR

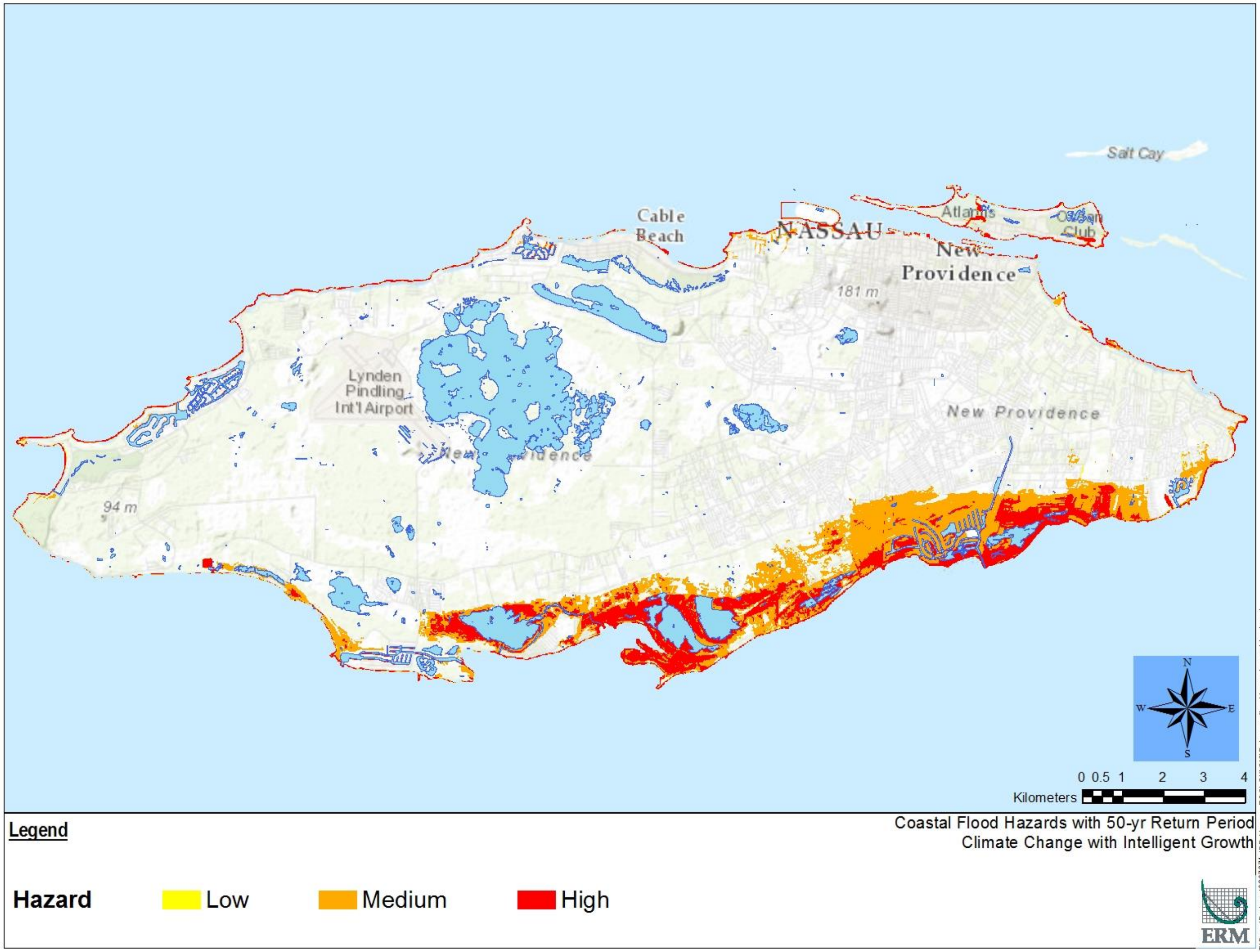


Figure A1- 18: Coastal flooding for a 50-year return period with 2050 SLR and intelligent growth scenario

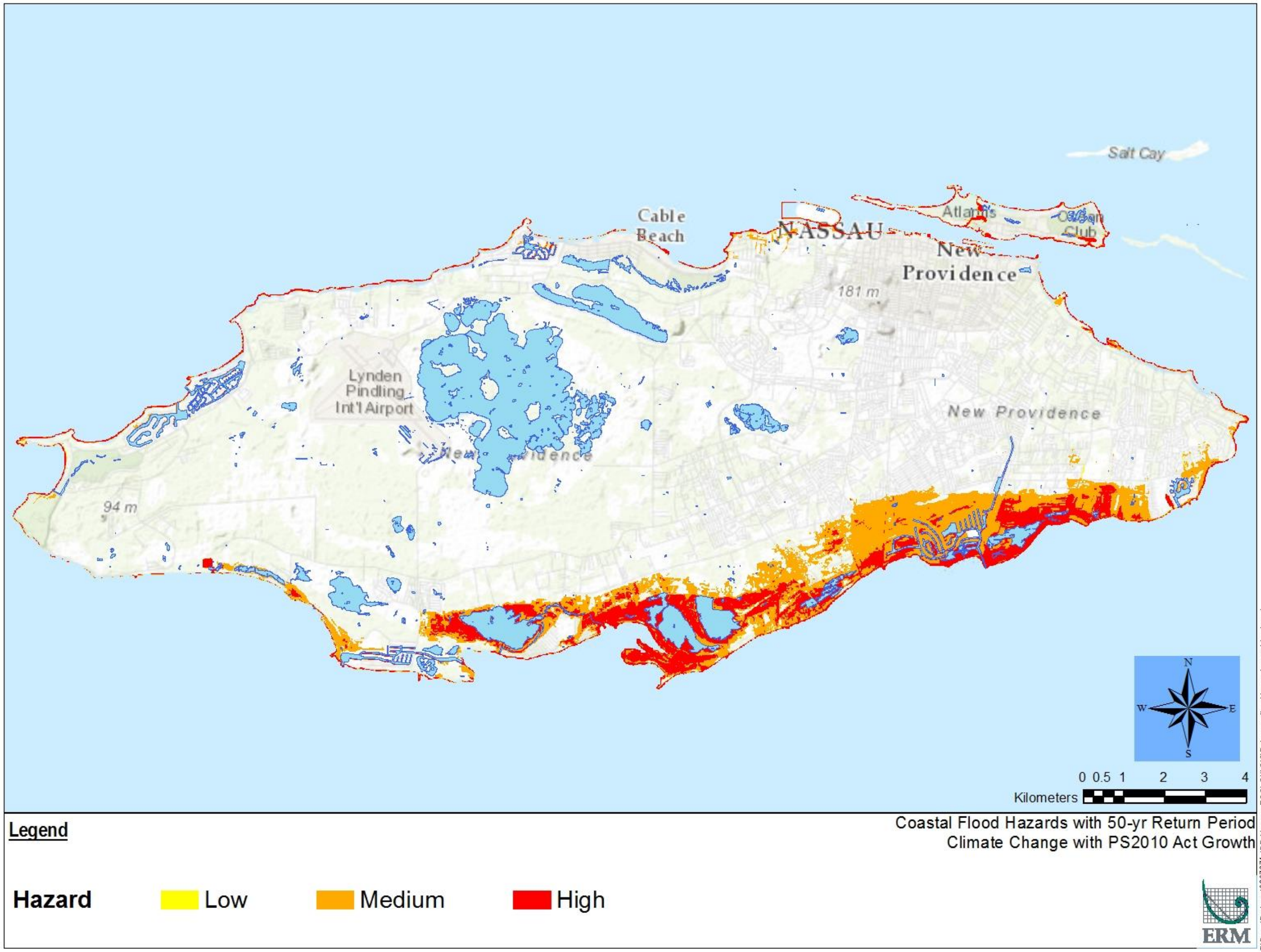


Figure A1- 19: Coastal flooding for a 50-year return period with 2050 SLR and Business-As-Usual scenario

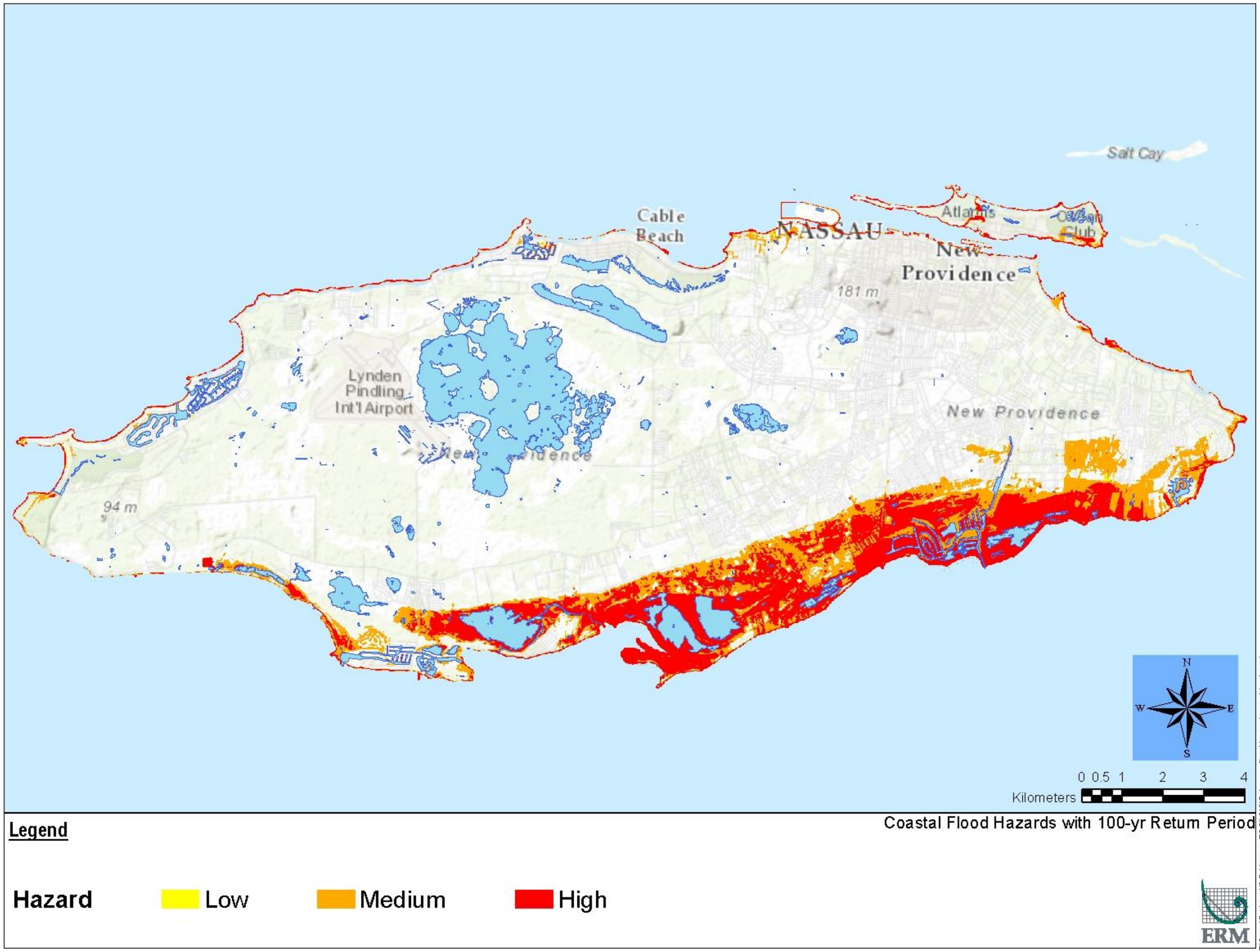


Figure A1- 20: Coastal flooding for a 100-year return period under baseline conditions

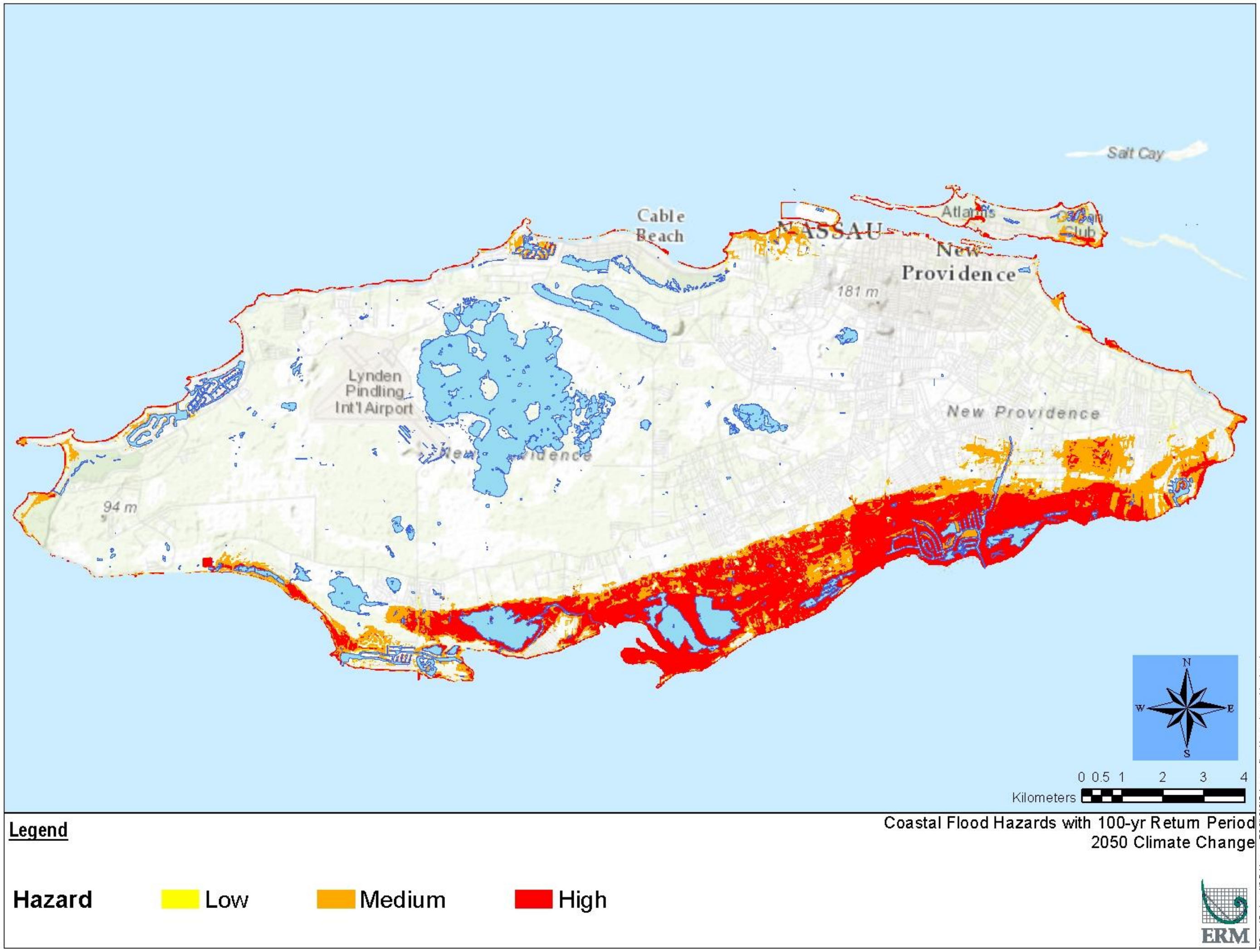


Figure A1- 21: Coastal flooding for a 100-year return period with 2050 SLR

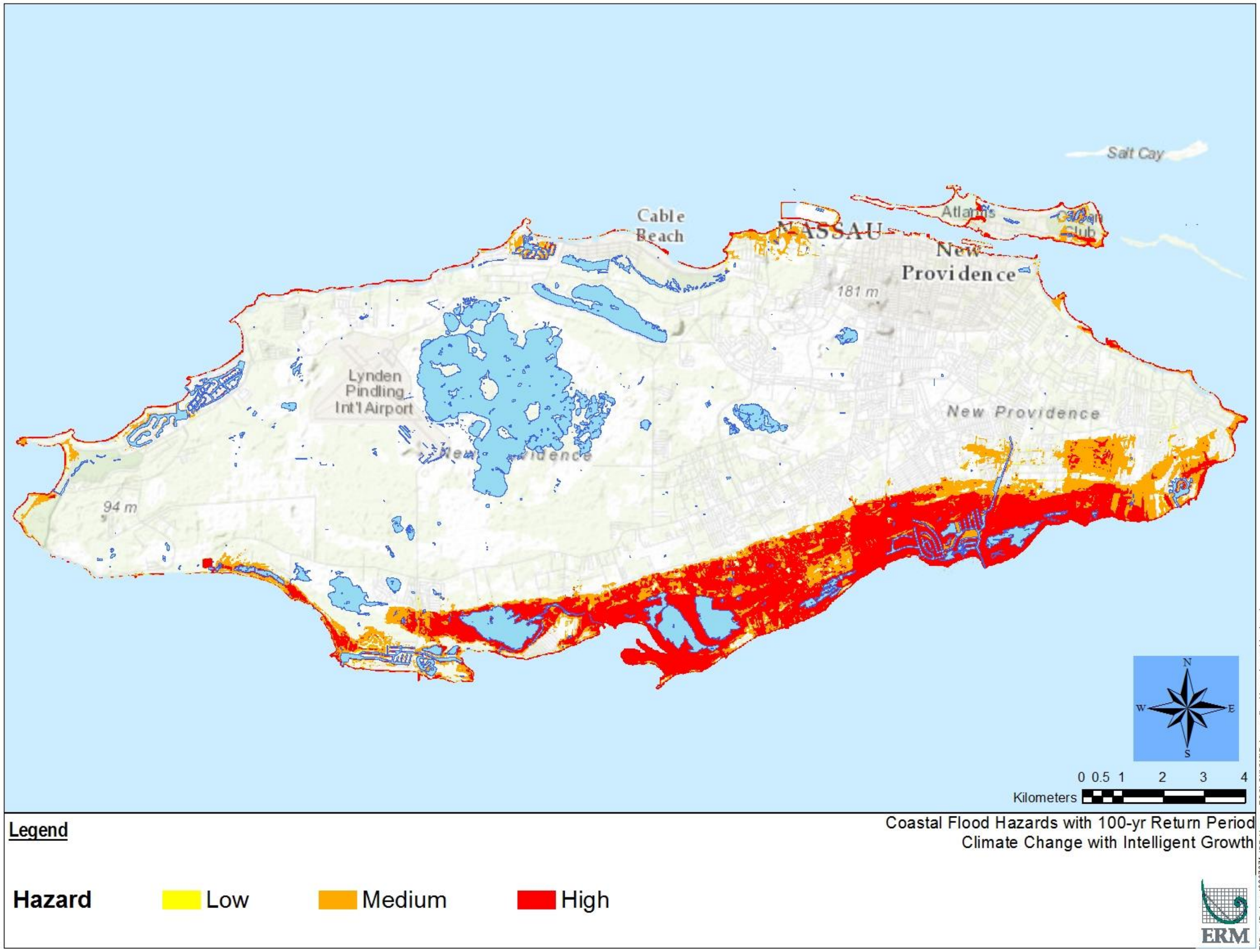


Figure A1- 22: Coastal flooding for a 100-year return period with 2050 SLR and intelligent growth scenario

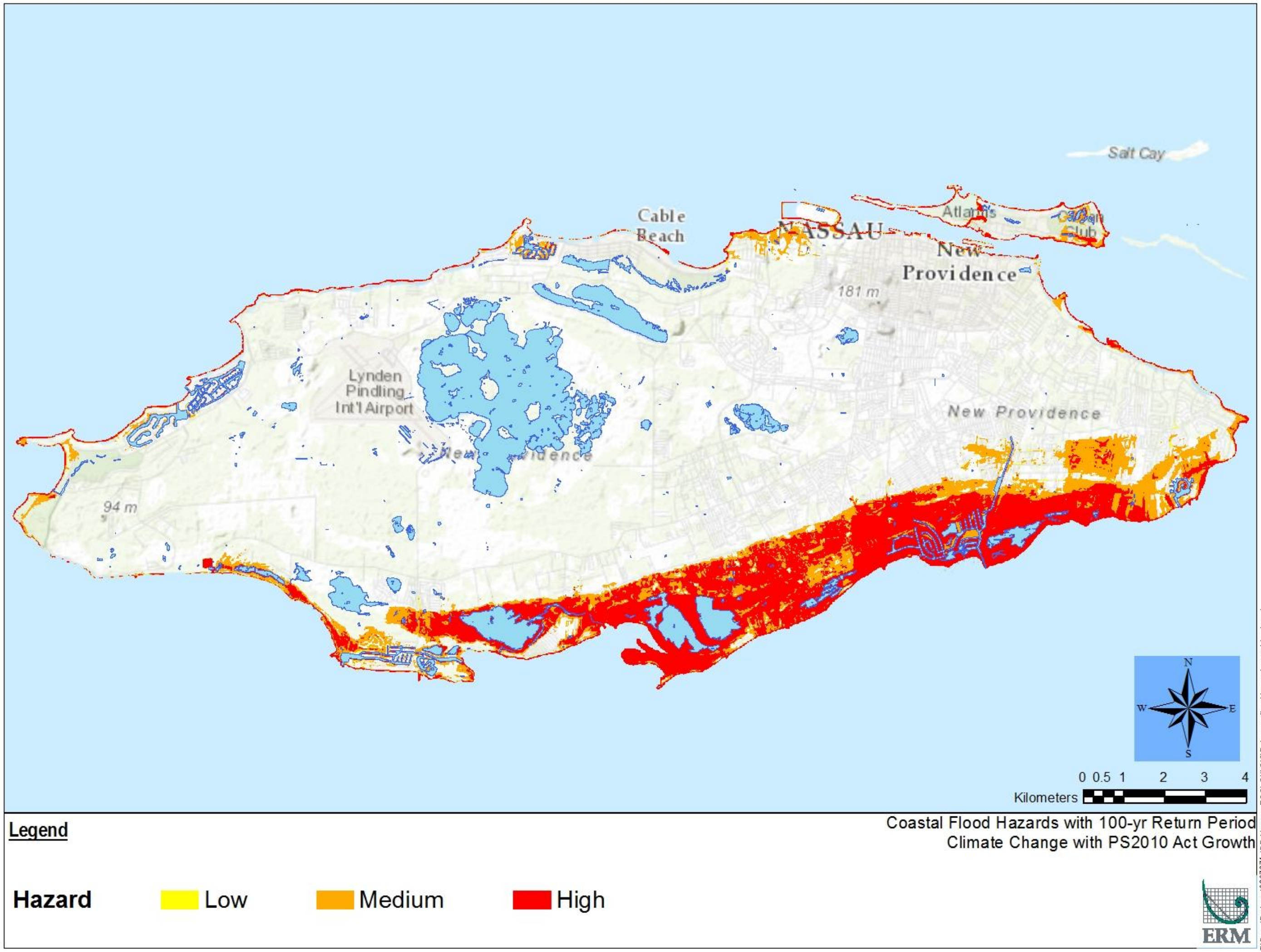


Figure A1- 23: Coastal flooding for a 100-year return period with 2050 SLR and Business-As-Usual scenario

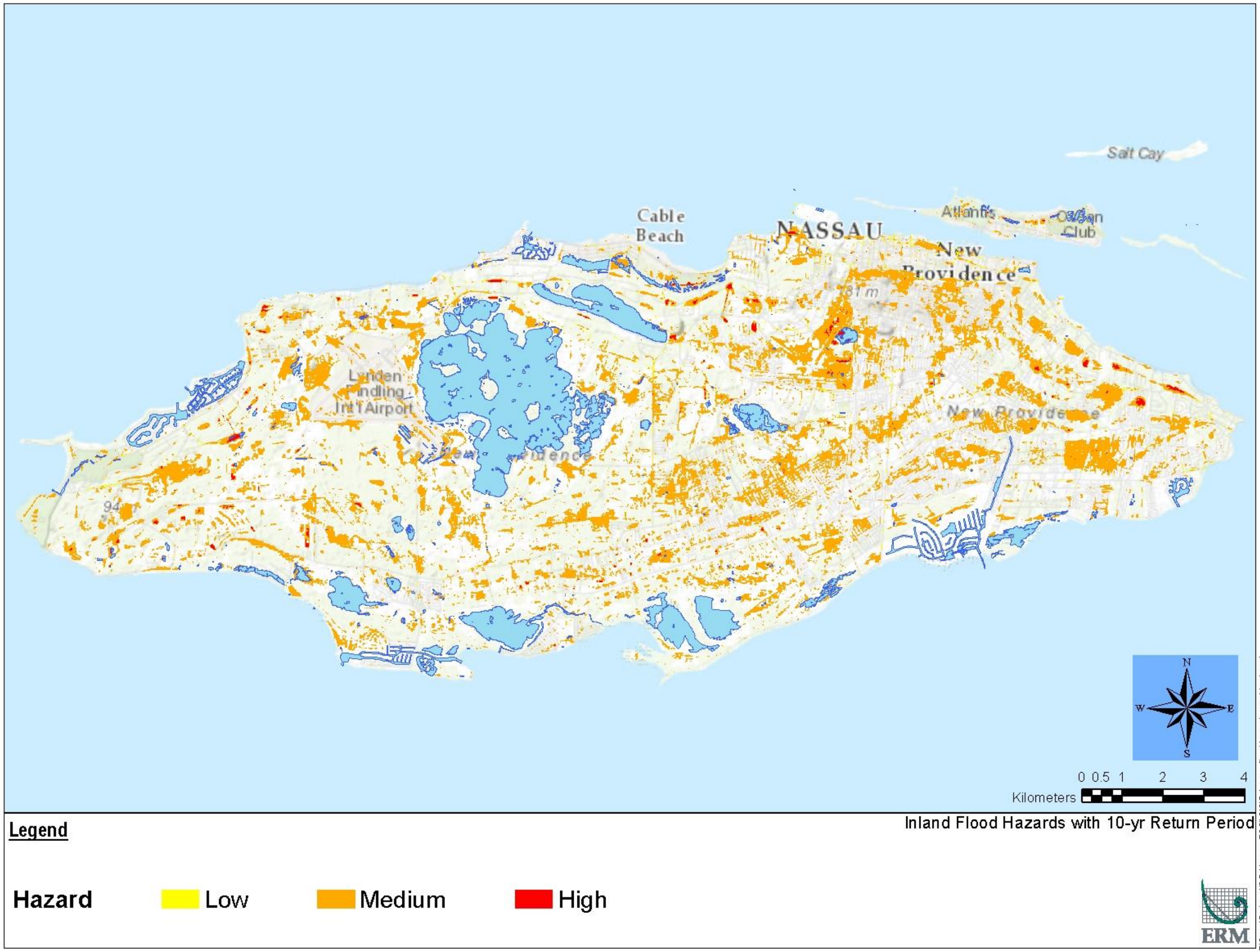


Figure A1- 24: Inland flooding for a 10-year return period under baseline conditions

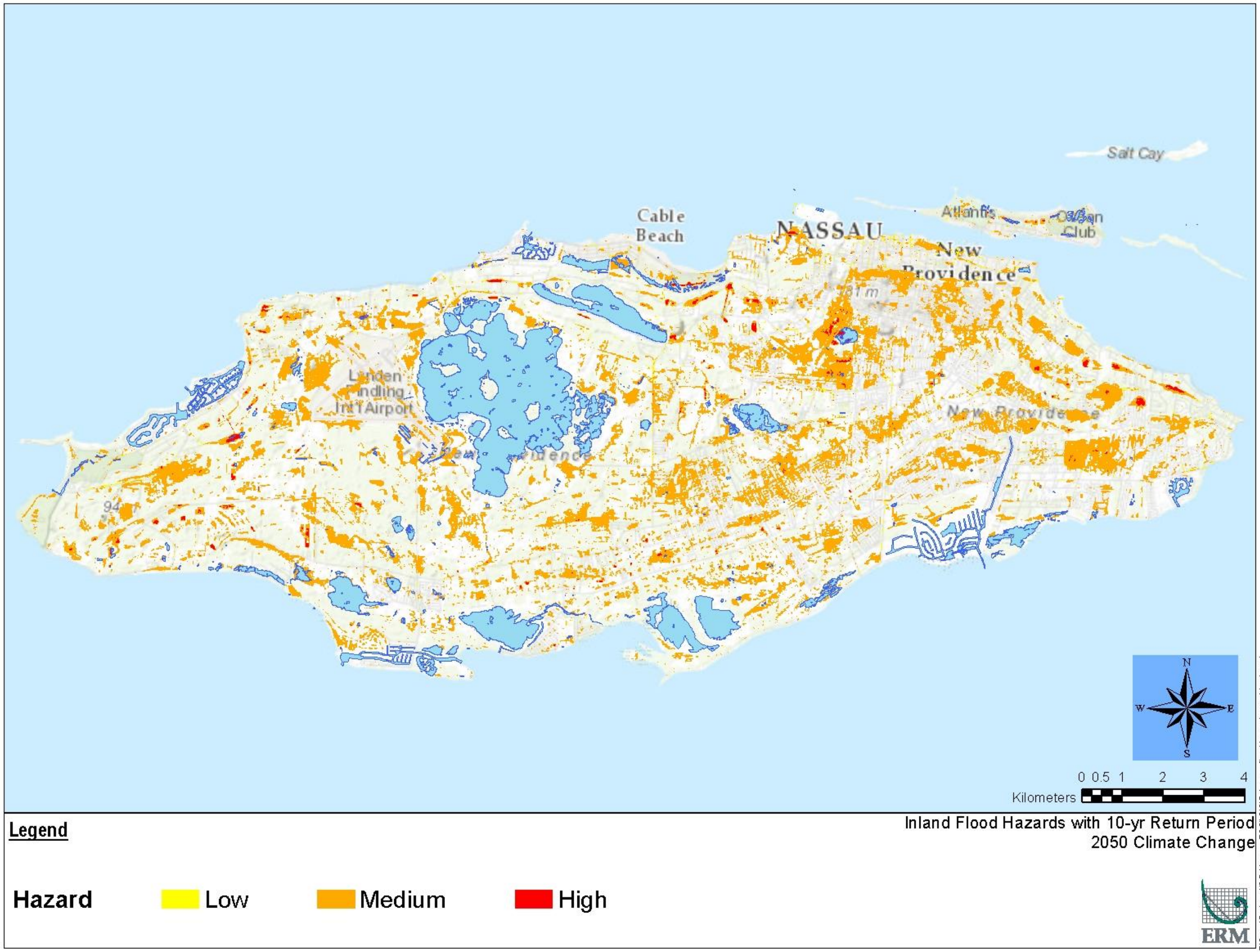


Figure A1- 25: Inland flooding for a 10-year return period with 2050 climate change

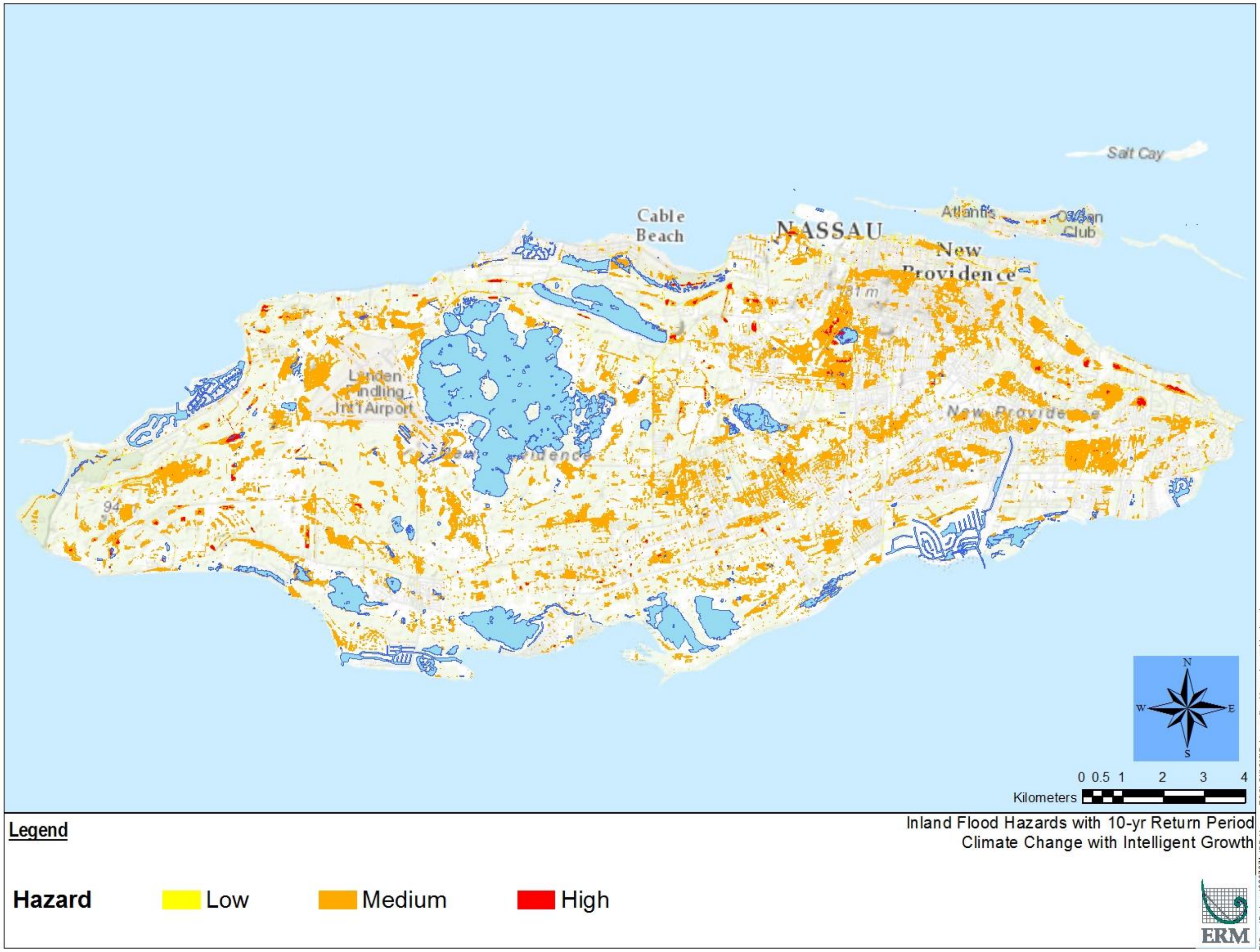


Figure A1- 26: Inland flooding for a 10-year return period with 2050 climate change and intelligent growth

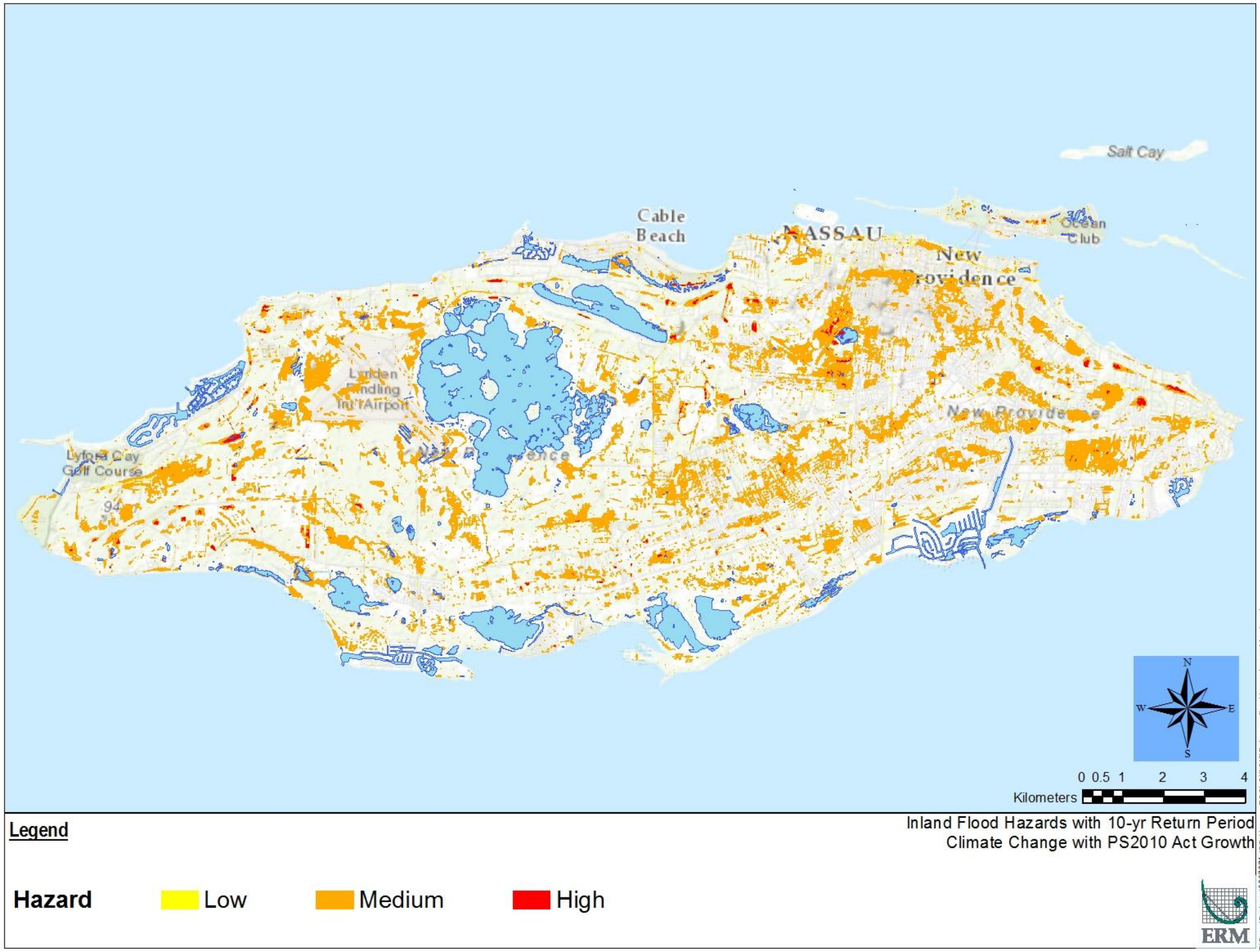


Figure A1- 27: Inland flooding for a 10-year return period with 2050 climate change and Business-As-Usual growth

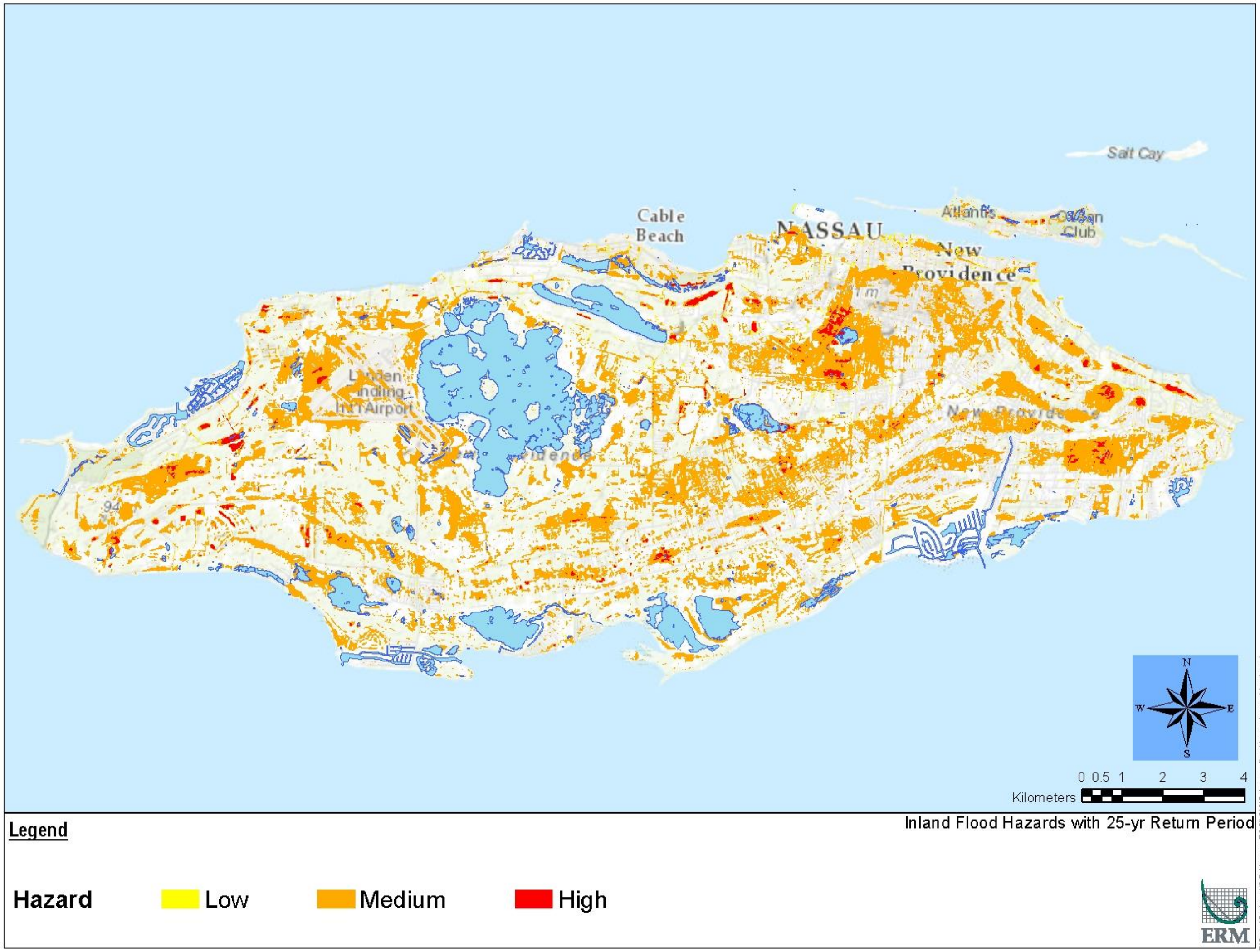


Figure A1- 28: Inland flooding for a 25-year return period under baseline conditions

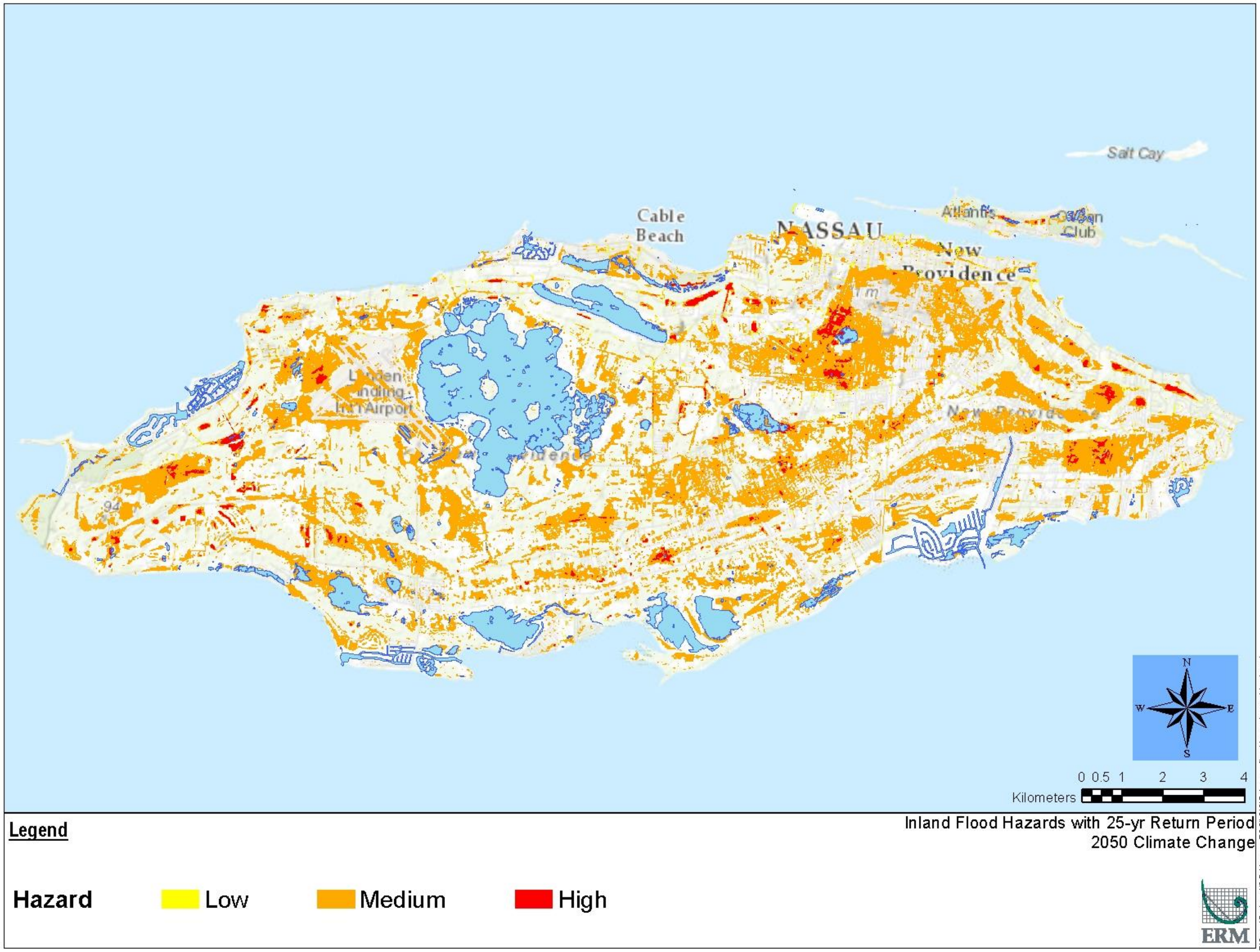


Figure A1- 29: Inland flooding for a 25-year return period with 2050 climate change

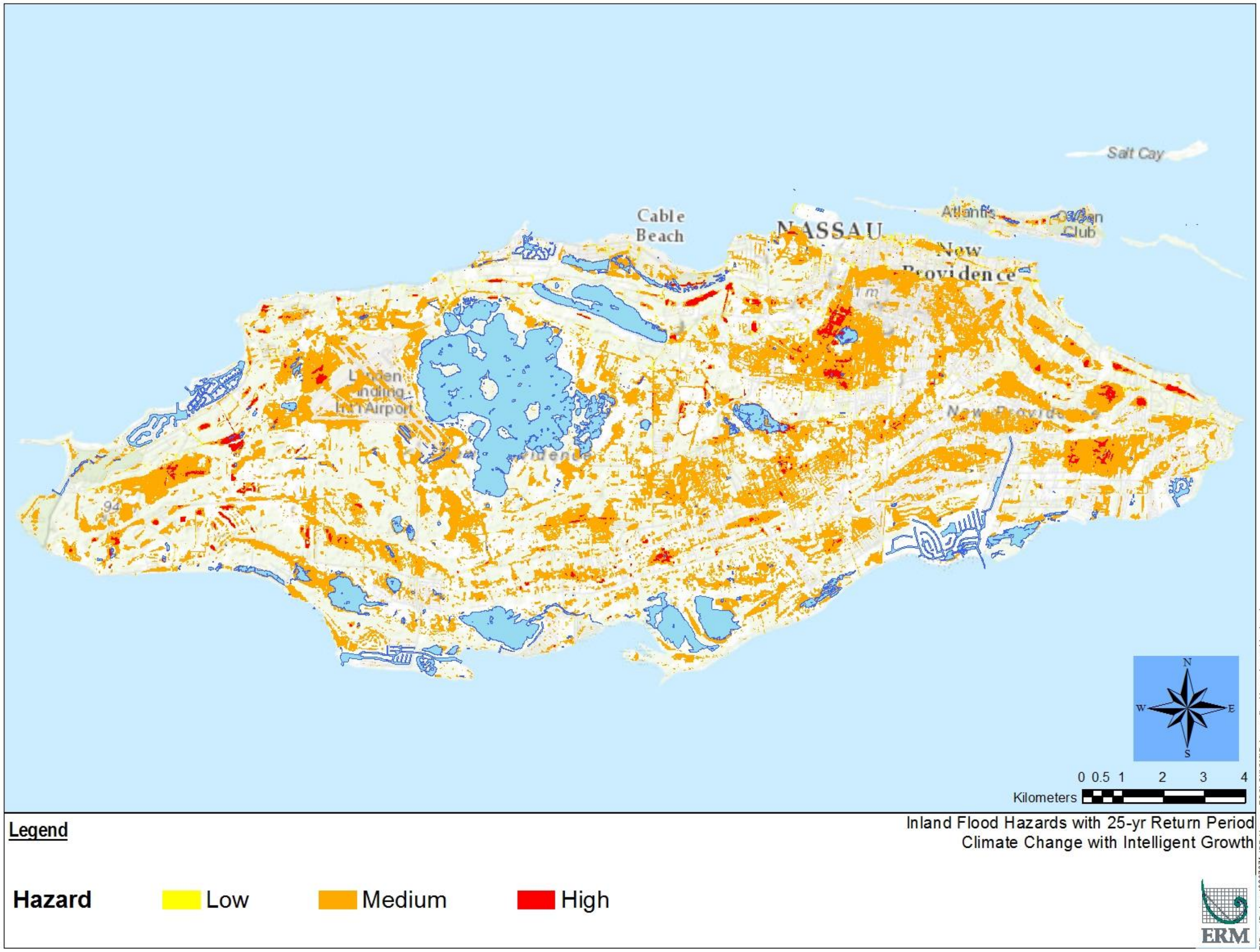


Figure A1- 30: Inland flooding for a 25-year return period with 2050 climate change and intelligent growth

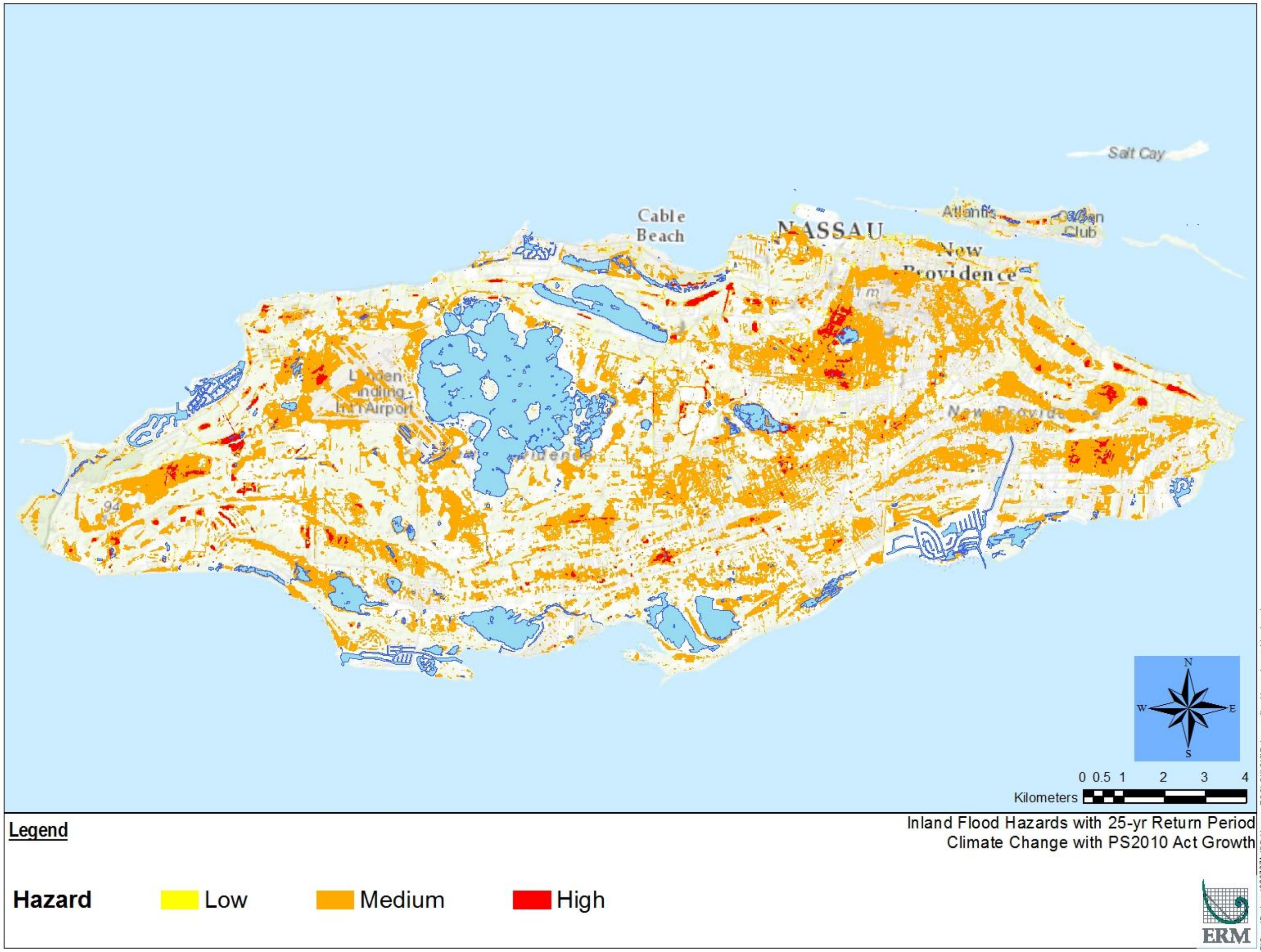


Figure A1- 31: Inland flooding for a 25-year return period with 2050 climate change and Business-As-Usual growth

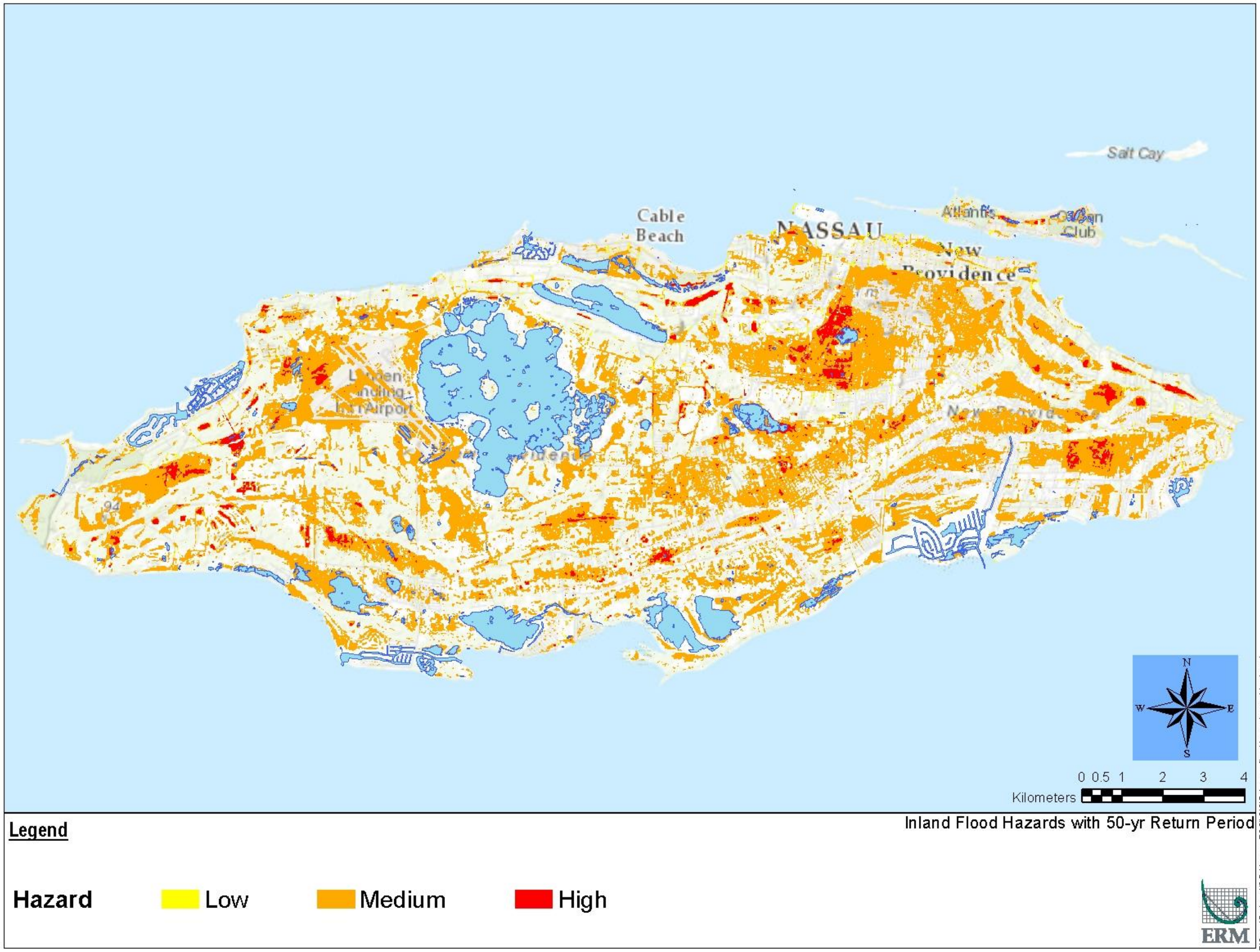


Figure A1- 32: Inland flooding for a 50-year return period under baseline conditions

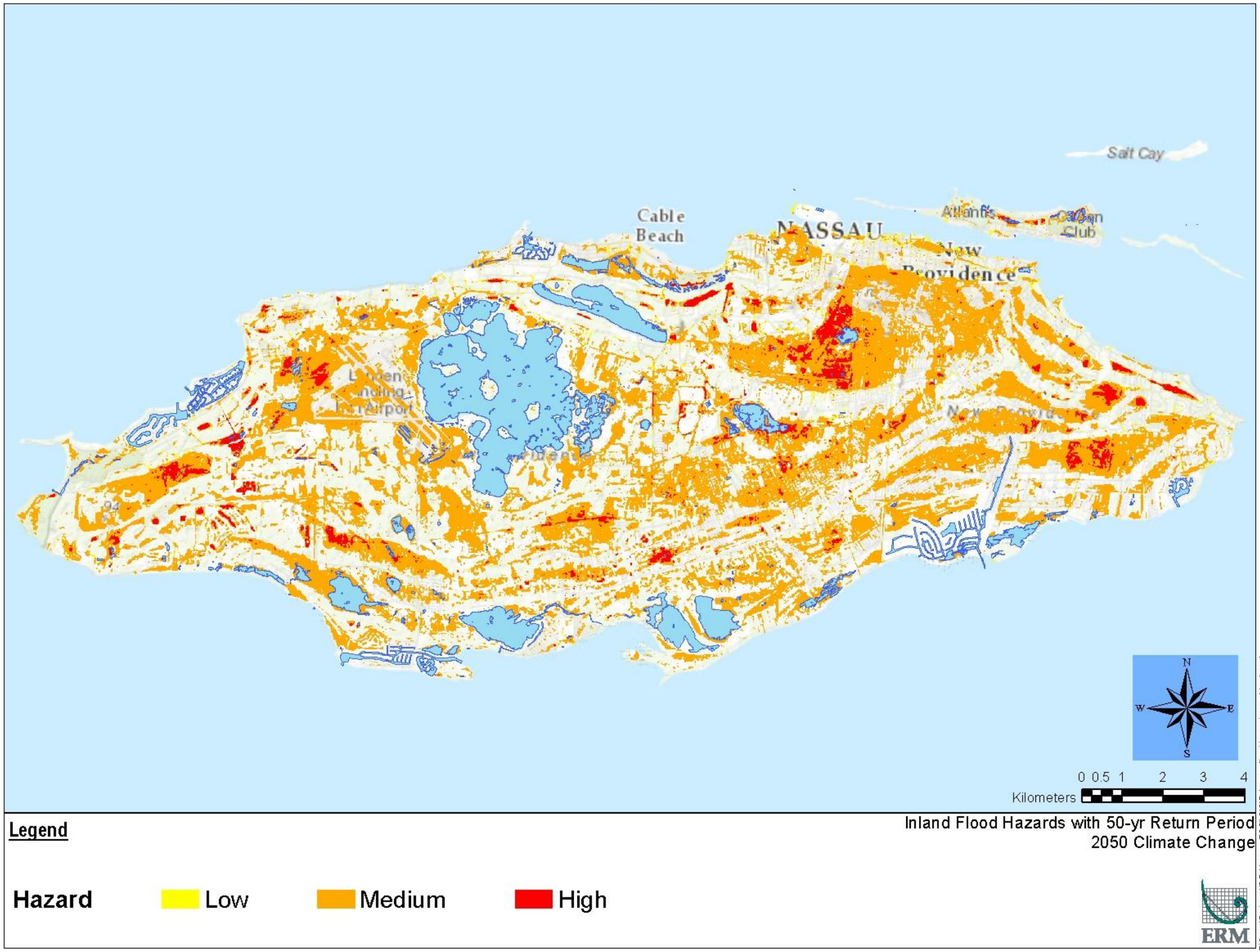


Figure A1- 33: Inland flooding for a 50-year return period with 2050 climate change

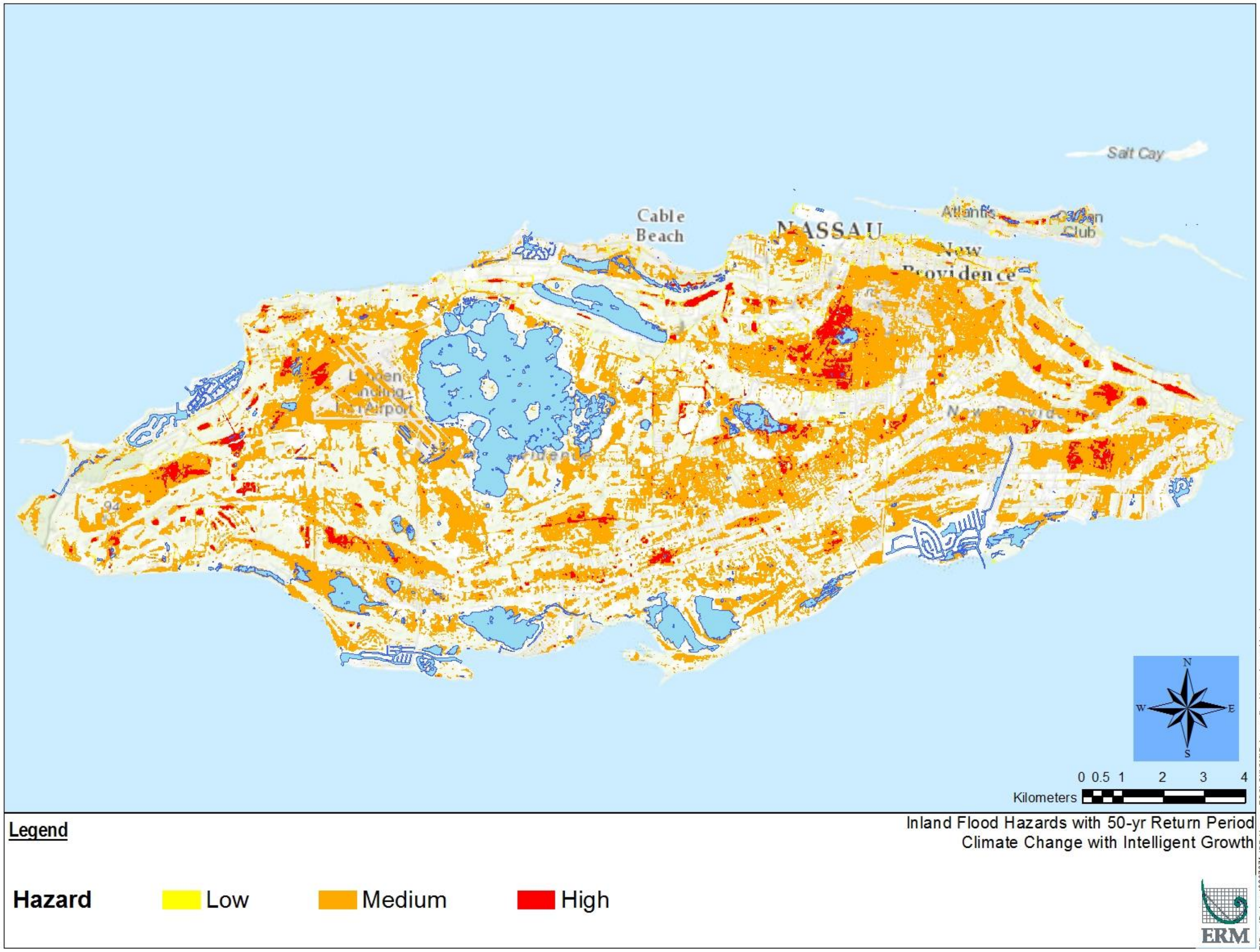


Figure A1- 34: Inland flooding for a 50-year return period with 2050 climate change and intelligent growth

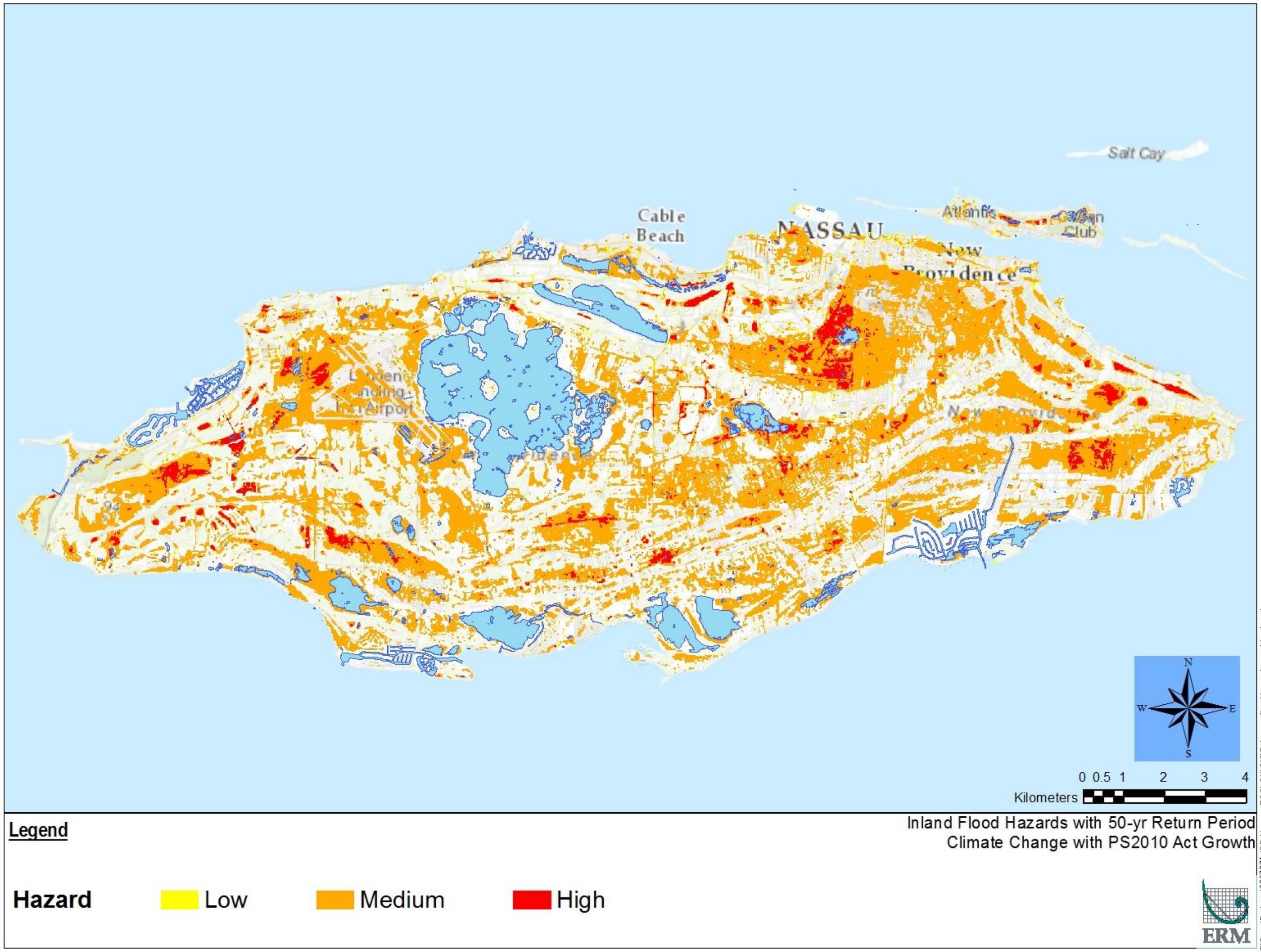


Figure A1- 35: Inland flooding for a 50-year return period with 2050 climate change and Business-As-Usual growth

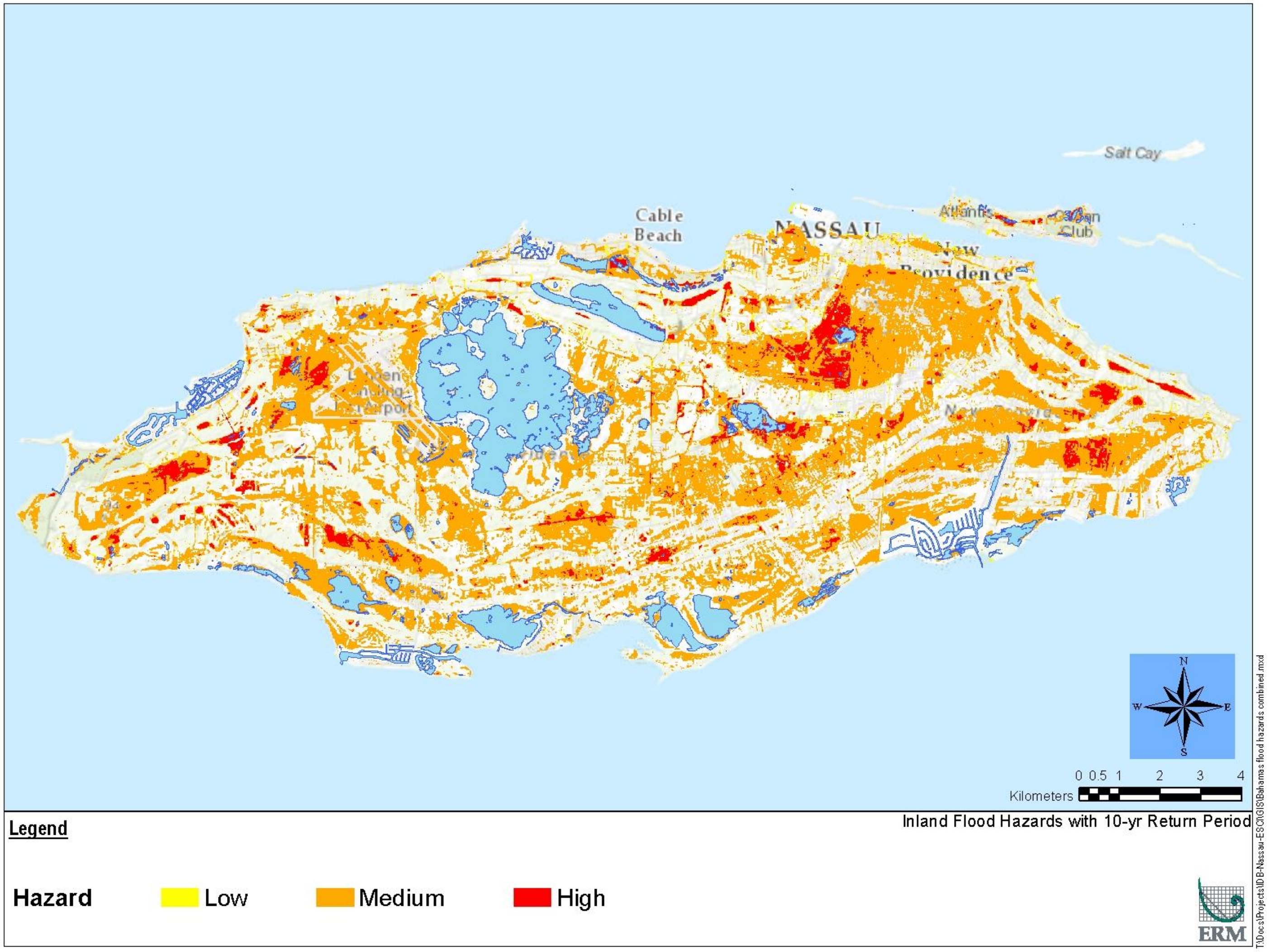


Figure A1- 36: Inland flooding for a 100-year return period under baseline conditions

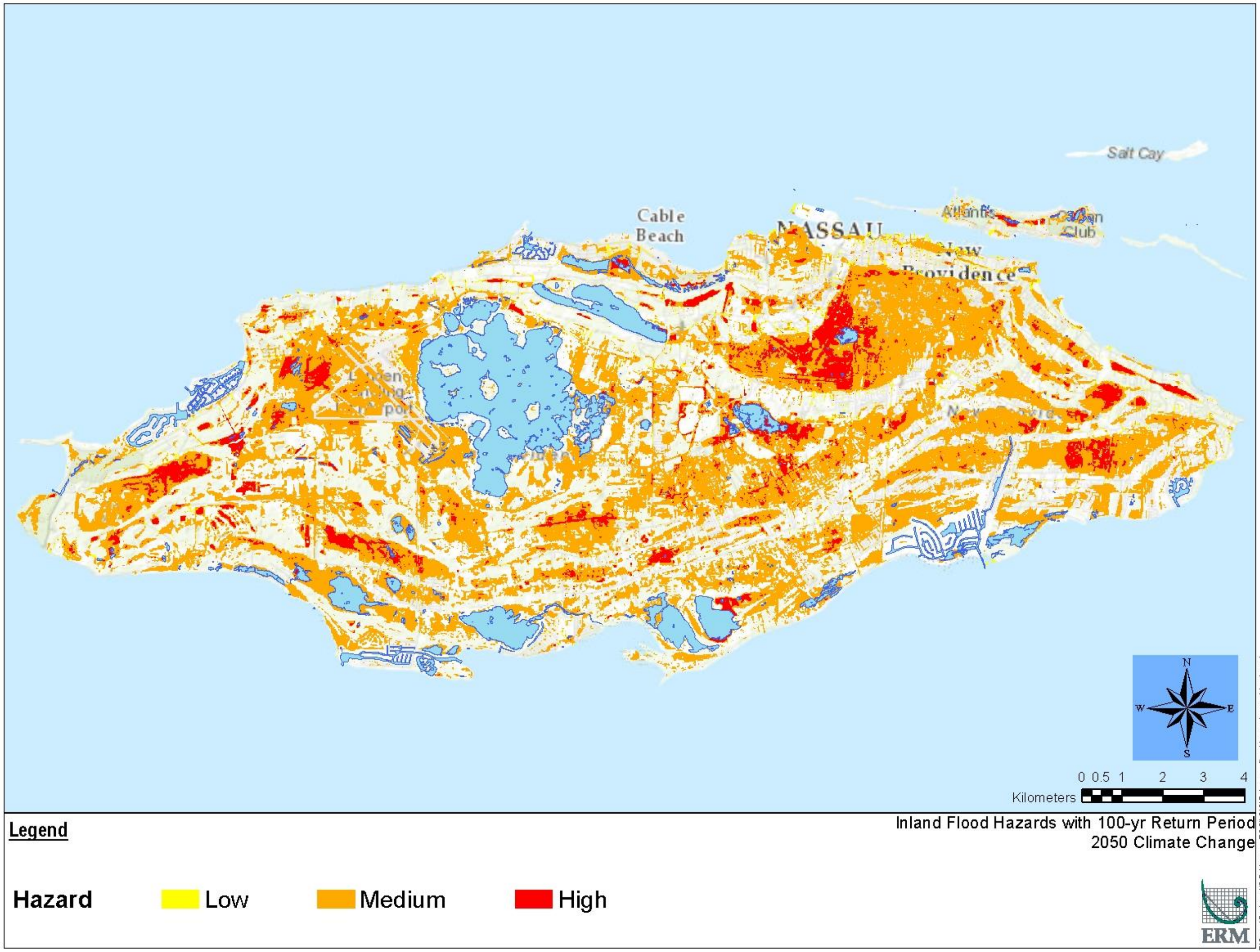


Figure A1- 37: Inland flooding for a 100-year return period with 2050 climate change

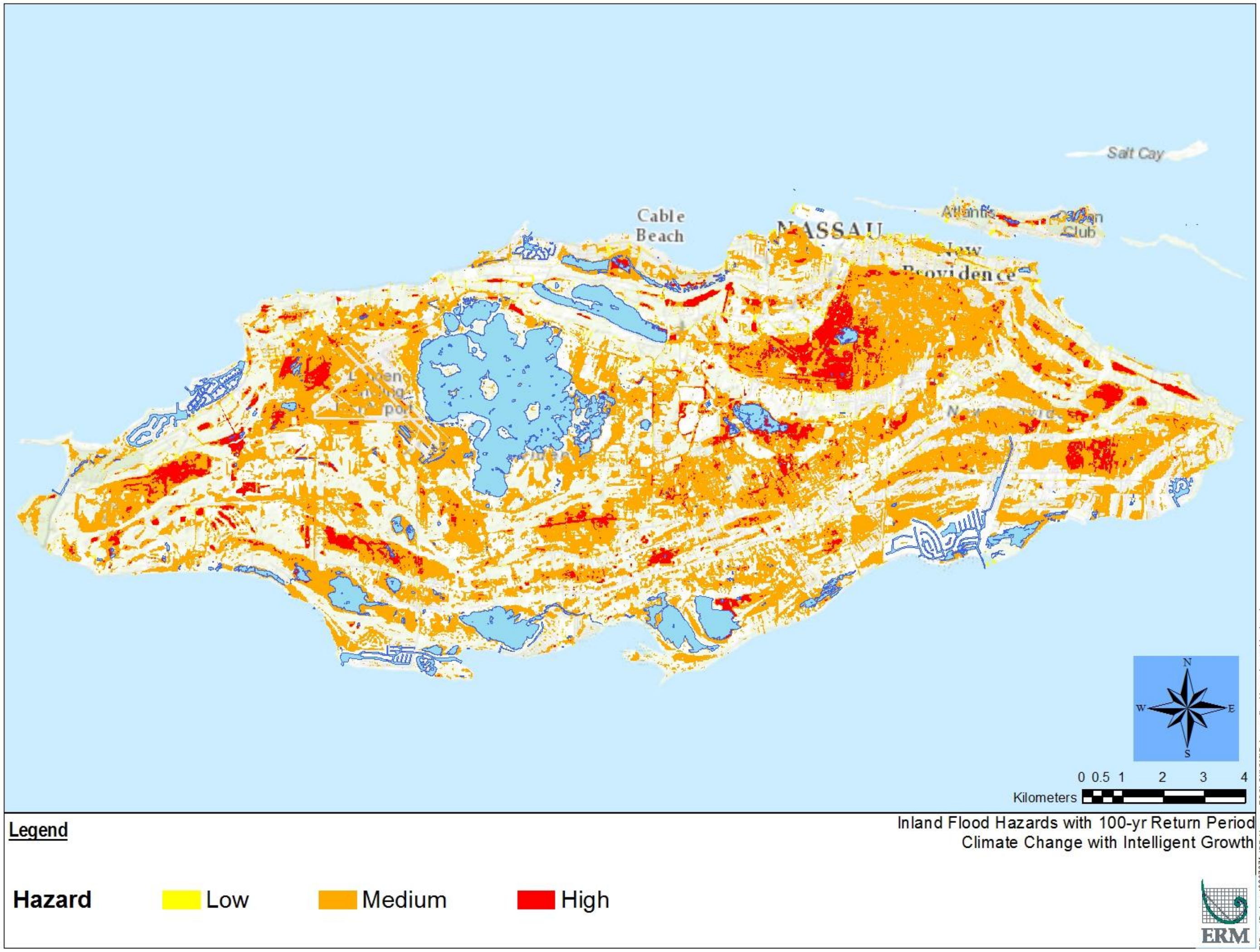


Figure A1- 38: Inland flooding for a 100-year return period with 2050 climate change and intelligent growth

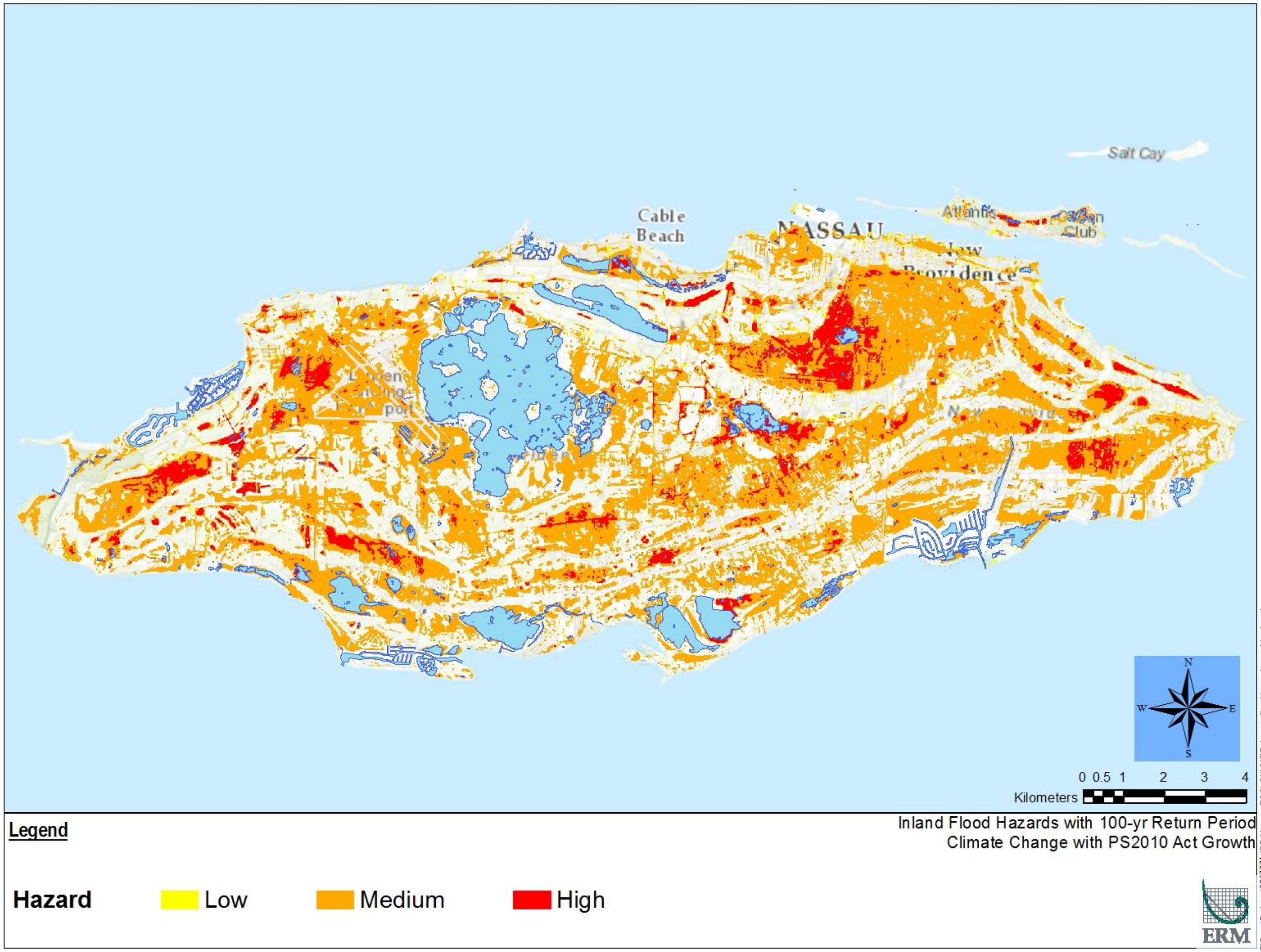


Figure A1- 39: Inland flooding for a 100-year return period with 2050 climate change and Business-As-Usual growth

A1.6 Groundwater Salinization

The third hazard evaluated in New Providence and Paradise islands is groundwater salinization (or seawater intrusion). This is the migration of seawater into the freshwater aquifer. Generally, groundwater salinization occurs in an unconfined aquifer that contacts the sea at the shoreline and the freshwater, which is less dense than seawater, floats as lenses above the seawater (USGS 2000). Since the groundwater sources in New Providence and Paradise islands are affected by salinization, the Government of Bahamas uses Reverse Osmosis (RO) treatment techniques for desalination and supplements or replaces groundwater sources (USACE, 2004).

Groundwater resources in New Providence and Paradise islands also include fresh, brackish, saline, and hypersaline waters found in the near and deep subsurface of the islands and in permanent and ephemeral water bodies. These groundwater resources are mainly affected by rainfall, geology, orientation and shape of surface and subsurface limestone (Maul and Cant, 2013). According to Cant and Weech (1980), there are nine aquifers in New Providence Island with a total area of 70.8 km^2 (see Table A1-14). The recharge of these aquifers primarily depends on the quantity and distribution of precipitation, the type of vegetation, and the permeability of surface materials comprised by limestone rock (USACE, 2004).

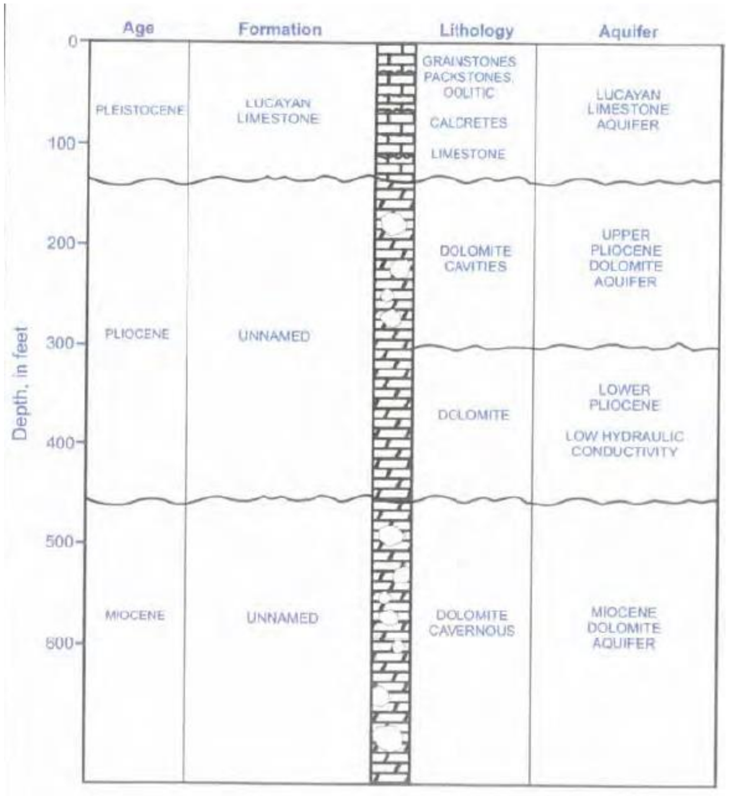
The aquifers in New Providence Island are Pleistocene-aged Lucayan Limestone which is comprised of poorly-stratified, oolic limestone (Pierson 1982). Figure A1-40: shows a generalized hydrogeology of New Providence Island including the approximate location of the Lucayan Limestone aquifer. According to EIA-Albany (2005), hydraulic conductivity values have been reported between 2.5 and 59.3 meters per day (m/day) with an average of 37.5 m/day from in-situ measurements.

Table A1- 14: Capacity of Aquifers Located in New Providence

Aquifer[a]	Approximate Volume (m^3)	Maximum lens thickness (m)	Average thickness (m)
Blair and Pinewood Gardens	7,450,000	11.0 (36 ft)	7.6 (25 ft)
East of Sea Breeze	222,000	7.0 (23 ft)	6.1 (20 ft)
South Beach	4,406,000	7.3 (24 ft)	6.1 (20 ft)
Golden Gates	616,000	6.7 (22 ft)	6.1 (20 ft)
Blue Hills Ridge	6,229,000	11.3 (37 ft)	7.6 (25 ft)
Prospect to Grants Town	8,727,000	9.1 (30 ft)	7.6 (25 ft)
Cow Pen Road	493,000	7.6 (25 ft)	6.1 (20 ft)
South Lake Killarney	3,489,000	7.6 (25 ft)	6.1 (20 ft)
Western New Providence	88,816,000	15.2 (50 ft)	9.1 (30 ft)

m^3 = cubic meters; m = meter; ft = feet.

Source: Adapted from Cant and Weech, 1980



Source: EIA-Albany, 2005

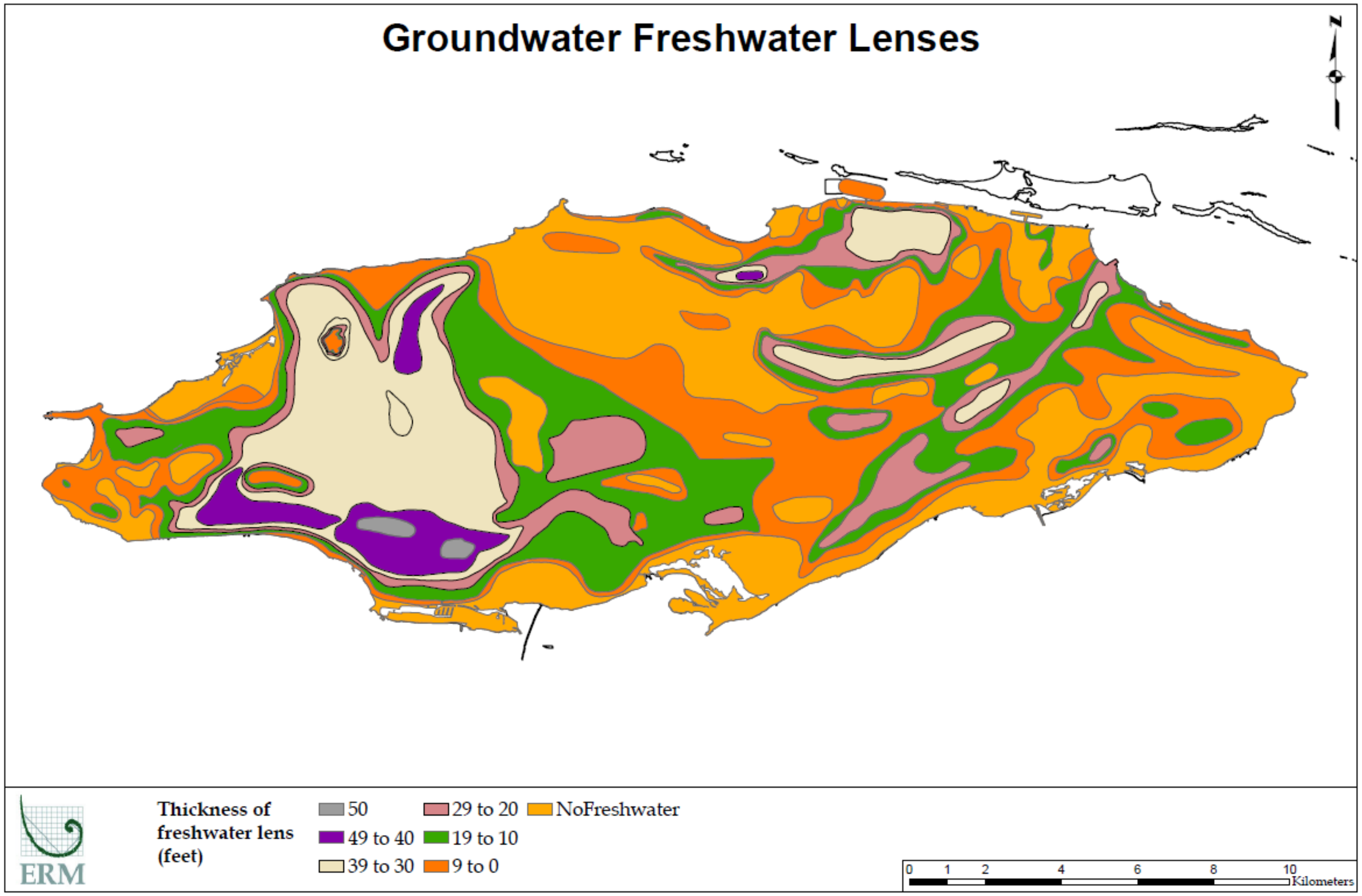
Figure A1- 40: Generalized hydrogeology of New Providence Island

The main source of freshwater in New Providence Island comes from freshwater lenses located below surface. These lenses float above the saline and brackish waters under the islands surface because they are less dense than saltwater. Depths where these lenses can be found range between shallow depths (within a few meters) and extend to approximately 33.5 m (see Figure A1-41). In some cases, these freshwater lenses are known as blue holes when they are uncovered to the surface (Cant 1986). The water table elevation is assumed to be less than one meter above sea level (asl) in New Providence and the water table reaches a maximum elevation of 1.2 m asl (Cant 1996; Diamond, 2011). Flooding occurs when the water table is raised by the topography of the island (ridges or hills) that channel or concentrate runoff. The raised water table usually lasts for two or three weeks returning to a normal level as a result of increased coastal discharge (Cant 1996).

Since these freshwater lenses are located close to the surface, they are susceptible to be exploited or damaged by salt intrusion, principally in residential areas or within larger developments. Cant (1996) observed salt intrusion in the island, particularly in harbors, and that the problem keeps increasing. Natural phenomenon such as storm events or natural erosion within the limestone rock can also produce changes in the orientation, size or shape of the freshwater in specific areas (Cant 1986). Other factors affecting the freshwater lenses in New Providence are associated to the increase of population by the operation of septic tanks; illegal dumping; generation of industrial wastes; use of fertilizers, fungicides and herbicides in agriculture; and leakage or spillage from underground fuel storage tanks (Cant, 1996; Cant, 1997; SENES 2005).

In addition to groundwater salinization, groundwater resources in NPI are prone to natural and anthropogenic contamination given the nature of freshwater resources (high water table), soil, climate and geology (low-lying limestone) of NPI as well as the limited wastewater disposal network. Swamps and/or marshes are often used for waste disposal and untreated domestic wastes and effluents are directly discharged to groundwater, representing one of the main threatens to groundwater resources in NPI.

Among all the threats for groundwater in NPI described above, the analysis conducted for this study only includes a high level evaluation of groundwater salinization vulnerability. Methods and results of our approach are described in Appendix A2 *Assets Exposed, Impacts and Losses*.



Source: Adapted from The UNDP/Bahamas Government Groundwater Studies in New Providence 1976-1984

Figure A1- 41: Thickness of freshwater lenses in New Providence Island

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Appendix A2: Assets Exposed, Impacts and Losses

Emerging and Sustainable Cities Program - Nassau

Environmental Resources Management

Appendix A2: Assets Exposed, Impacts, and Losses

A2.1 Characteristics of Assets Exposed

Introduction

The inventory of exposed assets involves understanding the distribution of people, buildings, and infrastructure that may be affected by natural phenomena. Exposed assets are buildings and infrastructure that are susceptible to damage given some hazard. Assets can be residential, commercial, and industrial buildings, institutions such as hospitals and schools, or infrastructure such as roads and bridges, electrical systems, and telecommunication systems. Other potential exposed assets include:

- Urban buildings
- Urban infrastructure (e.g., roads, bridges)
- Rural infrastructure
- Natural and regional infrastructure
- Human exposure

Examples of exposed assets in New Providence and Paradise islands (NPI) are shown in Figure A2-1 and A2-2..

Source: ERM, site visit December 2015

Figure A2- 1: Administrative building, example of exposed assets

Source: ERM, site visit December 2015

Figure A2- 2: Houses and streets, example of exposed assets

Building Inventory Assessment

In Nassau, there was insufficient detailed information to carry out a site specific assessment of all buildings, and therefore an inventory of buildings and property values were conducted through rapid field assessments and a review of geospatial databases to estimate the number and distribution of assets in the New Providence and Paradise Island (study area). From the data review and mapping process, a table of average property values of a single unit/building for each land use was constructed and is provided in Table A2-1 by considering prices from the Bahamas Real Estate Association. Mapping the land use and property values provided a basis for classifying buildings, and the geographical distribution of average property values is presented in Figure A2-3.

Table A2- 1: Estimated land use property values for the study area

Land use	Mean value per property unit in US Dollars	Land use	Mean value per property unit in US Dollars
Informal	$100,000	Low Density Residential (LDR)	$500,000
Agriculture	$100,000	Unprotected Forest	$100,000
Industrial	$1,000,000	Mixed Dwelling Agriculture	$125,000
Airport	$1,000,000	Protected Forest	$100,000
Commerce (C)	$1,000,000	Protected Wetland	$100,000
High Density Residential (HDR)	$125,000	Recreational (parks and manicured grass like traffic circles)	$500,000
Medium Density Residential (MDR)	$250,000	Golf	$1,000,000
Cultural Heritage (CH)	$1,000,000	Tourism (T)	$10,000,000
Institutional	$10,000,000	Unprotected Wetland	$100,000
Luxury (L)	$10,000,000	Vacant Vegetation	$100,000
Beach or Waterfront Park	$1,000,000		

Population Exposure Assessment

In addition to buildings and infrastructure, exposed assets include human exposure. Information on the geographical distribution of population density was analyzed with geographic information systems (GIS). A map of the population density throughout the study area (New Providence and Paradise Island) is shown in Figure A2-4 and population density by district is presented in Table A2-2. New Providence comprises a range of population densities, from low on the western end (<500/km^2), to high within the city (>4500/km^2). There is also a correlation between the property values and the population density. Less dense, more disperse areas with larger property boundaries tend to have higher property values. The exception is the downtown area which is dense but also has high property values due to the commercial and tourism buildings in those areas.

Table A2- 2: Population and density by district

District	Population (2010)	Population Density 1/km^2
Sea Breeze	10671	1954
Bamboo Town	10380	3198
Blue Hills	13062	1307
Carmichael	8489	4105
Clifton	9323	158
Elizabeth	13233	3538
Englerston	11076	6334
Farm Road	9967	5505
Fort Charlotte	8292	1966
Fox Hill	9603	2397
Garden Hills	11257	2165
Golden Gates	7682	4941
Golden Isles	8345	349
Kennedy	9179	4866
Killarney	9977	211
Marathon	8531	2296
Montagu	9897	1203
Mount Moriah	8345	1759

District	Population (2010)	Population Density $1/km^2$
Pinewood	8715	6255
South Beach	9744	1361
St Anne	8741	1290
St Cecelia	9494	5804
St Thomas More	10450	3312
Bain And Grants Town	8743	3835
Yamacraw	7716	1999

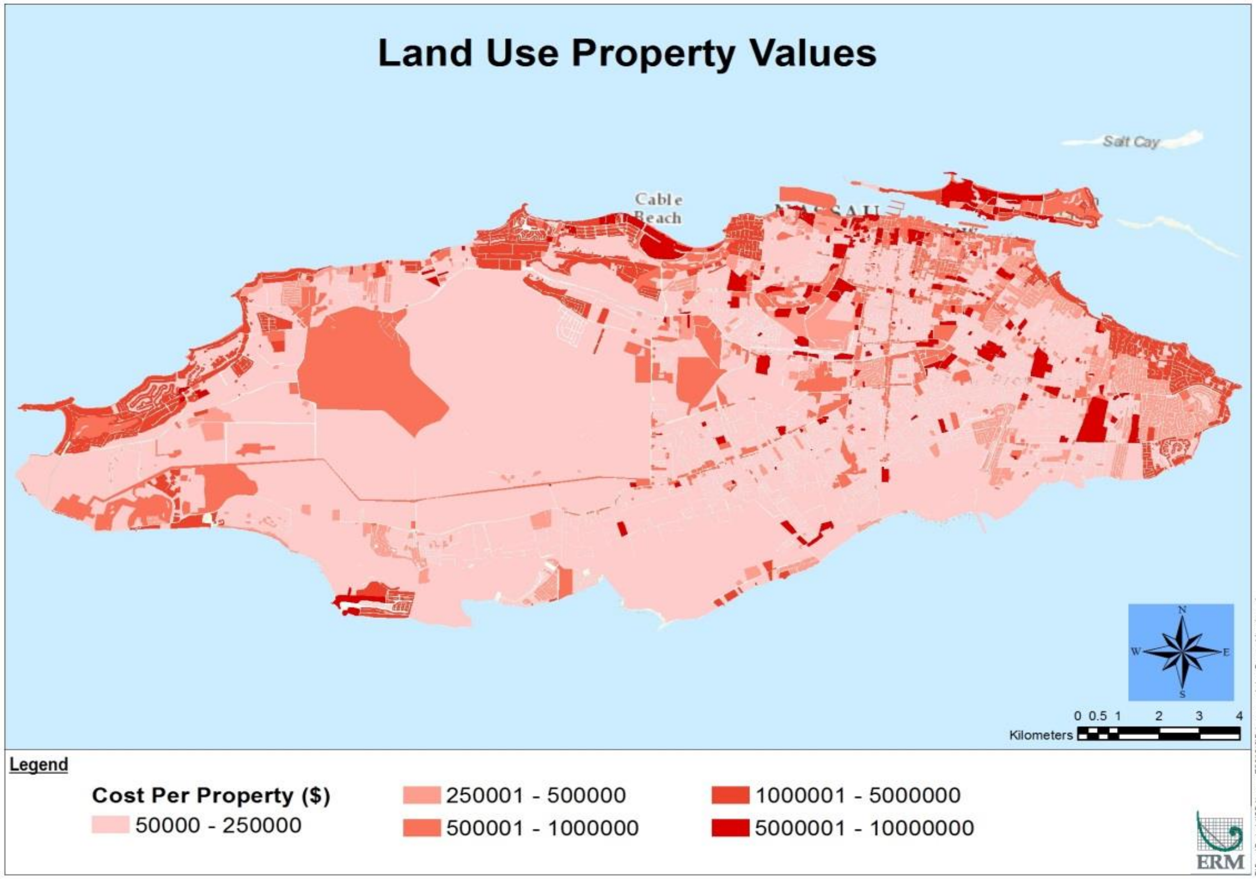

Figure A2- 3: Land use property values in US dollars estimated for New Providence and Paradise Island

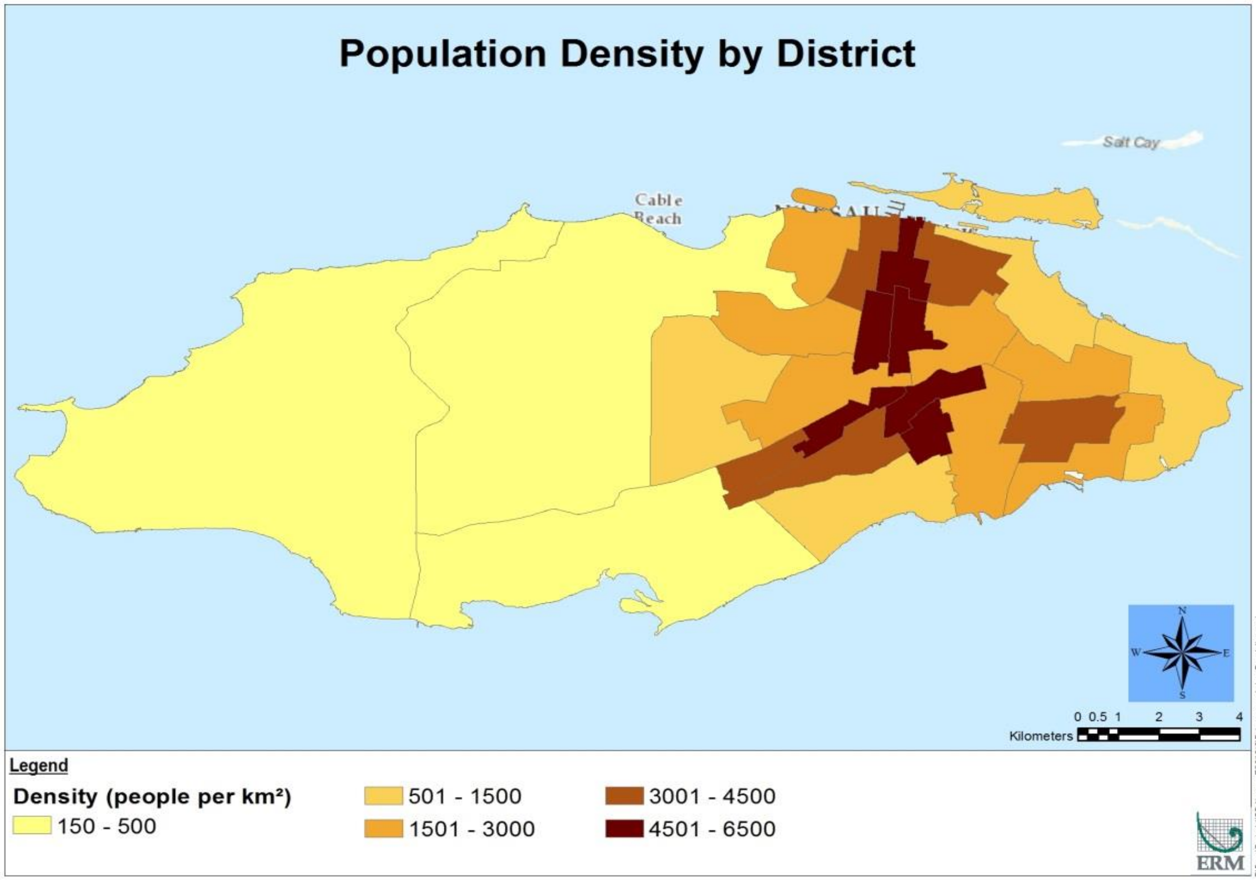

Figure A2- 4: Population density by district

A2.2 Impacts and Losses

Approach

This section presents an estimate of the risk associated with each hazard. The findings can be used to support local and regional planners in understanding the potential impacts of each hazard and allow a comparison of hazards by quantifying potential impacts.

The application of risk assessment methodology has resulted in an *approximation* of risk. These estimates should be used to understand relative risk from hazards and potential losses; however it is important to understand that uncertainties are inherent in any loss estimation methodology, arising in part from incomplete scientific knowledge concerning natural hazards and their effects on the built environment. Uncertainties also result from approximations and simplifications that are necessary for a comprehensive analysis (such as abbreviated inventories, and model parameters such as precipitation data or economic parameters).

Risk Metrics

The economic loss results presented here use indicators of *Probable Maximum Loss (PML)* and *Average Annualized Loss (AAL)*. PML provides an estimate of losses that are likely to occur due to a single hazard. *AAL* is the estimated long-term value of losses to assets in any single year. The *AAL* is the summation of event losses (L_i) and event occurrence probabilities (P_i) for all stochastic events in a loss model and is expressed as:

$$Average\ Annual\ Losses = \sum_i P_i L_i$$

The use of annual losses approach has two primary benefits that include: 1) the ability to assess potential losses from all future disasters; and 2) provides an objective means to evaluate mitigation alternatives.

Risk Mapping

The risk metric described above can be used to provide an understanding of the spatial extent of losses and help to identify and prioritize the urban areas or localities that are under risk. The street light indicator methodology shown in Figure A2-5, where colors on the map coincide with the level of risk, has been used to map risk:

Figure A2- 5: Street light risk indicator

By mapping risk, stakeholders have a better understanding of where potential losses will be the highest and where monies should be allocated for risk reduction. All the areas and exposure categories that have a high and very high risk should be automatic choices for risk reduction measures.

A2.3 Coastal and Inland Flooding Risk

Estimated probable losses were determined from the exposed assets and flood hazards. Estimations were made for either the economic losses from property damage or for the risks posed to human health. Exposed assets are based on the distribution of properties and populations, as described in earlier sections (see *section* Building Inventory Assessment).

Flood modeling was used to calculate the probabilities of occurrence of hazards and the flood hazard magnitudes. A detailed description of the flood modeling is provided in *Appendix A1-Hazards Profiles* of this report. Inland and coastal flood hazards due to extreme rainfall events were determined across New Providence and Paradise islands. Events included the 10-, 25-, 50-, and 100-year return period storms. As described in *Appendix A1 – Hazards Profiles*, the hazards are classified as no hazard, low, medium, and high.

To determine property damage, a vulnerability index was estimated based on five grouped land use type and hazard. The economic vulnerability index (EVI) ranges from 0% to 100%, where 0% is no damage, and 100% is a total loss. Table A2-3 shows the EVI assigned to each of the five grouped land use categories and hazard levels in New Providence and Paradise islands. A definition of the hazard levels is provided in Table A1-10 and *Appendix A1 – Hazards Profiles.*

Table A2- 3: Economic Vulnerability Index by land use and hazard

Grouped Land use	Land Uses from Table A2-1	Hazard			
		none	low	medium	high
Residential	Informal, High Density Residential (HDR), Medium Density Residential (MDR), Luxury (L), Beach or Waterfront Park, Low Density Residential (LDR)	0%	25%	50%	100%
Commerce	Commerce (C), Cultural Heritage, Institutional, Recreation, Golf, Tourism (T)	0%	15%	45%	100%
Industry	Industrial	0%	15%	40%	100%

Infrastructure	Airport	0%	25%	55%	100%
Agriculture	Agriculture, unprotected forest, Mixed Dwelling Agriculture, Protected Forest, Protected Wetland, Unprotected Wetland, Vacant Vegetation.	0%	30%	65%	100%

Source: Adapted for New Providence and Paradise islands from Huizinga, 2007

Estimated Probable Losses

With the EVI calculated from the land use and hazard rating for each return period, the economic risk to properties can be mapped. Maps shown in Figures A2-8 through A2-23 were created from the combined inland and coastal flood modeling to determine the highest risks due to both hazards. Maps show US dollar (USD) values which indicate the highest probable damage to properties within a given area. Using the EVI maps and an inventory of buildings as exposed assets in the study area, *PML* for each event and the *AAL* were calculated. The *PML* is shown in the loss exceedance curves in Figure A2-6, and in Table A2-4. Loss exceedance curves per grouped land uses are shown from Figure A2-7 to Figure A2-11. A comparison of the climate change *PML* to the baseline conditions and to the climate change with intelligent growth is given in Table A2-4.

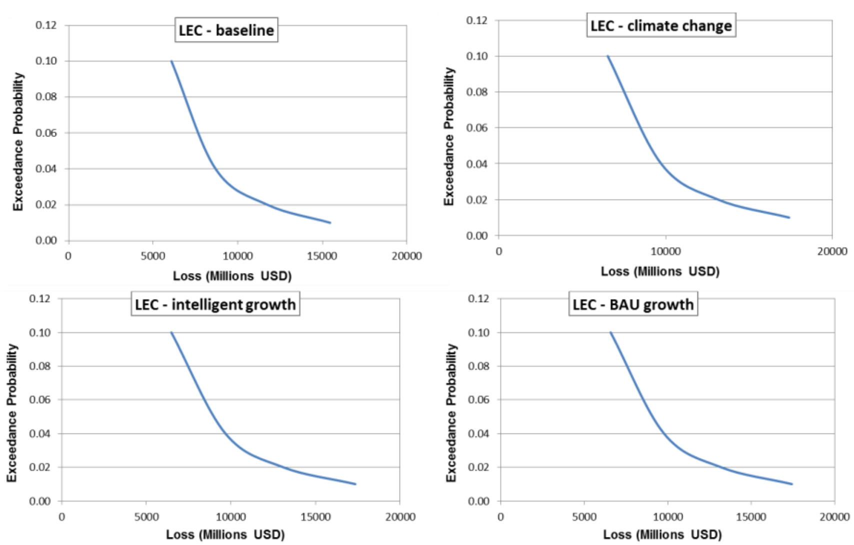

Figure A2- 6: Loss exceedance curves for inland and coastal hazards

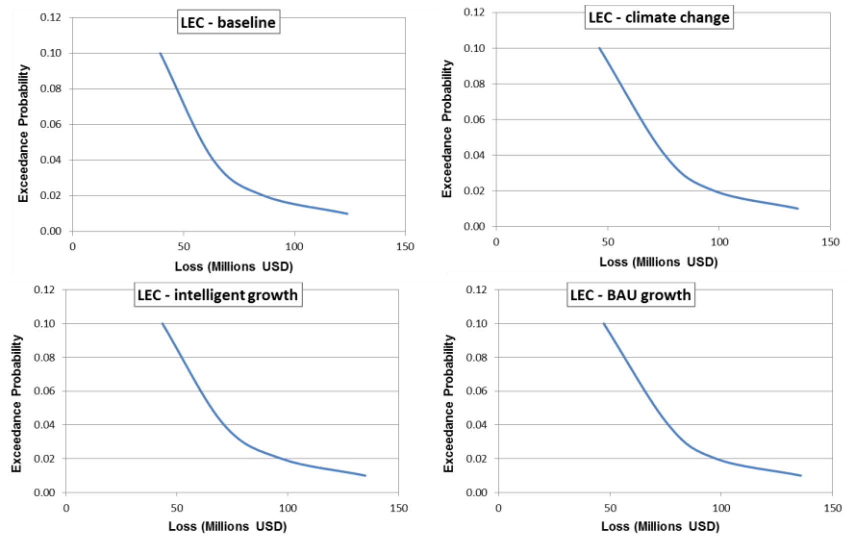

Figure A2- 7: Loss exceedance curves for inland and coastal hazards-Agriculture

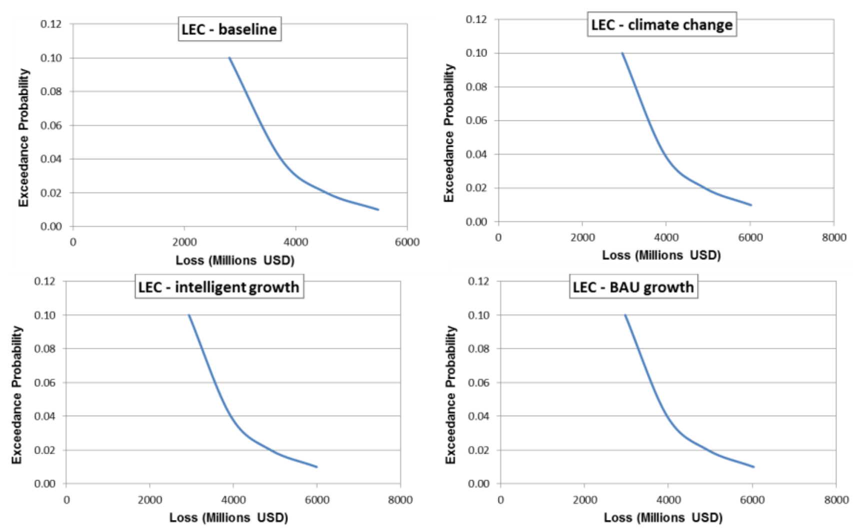

Figure A2- 8: Loss exceedance curves for inland and coastal hazards-Commerce

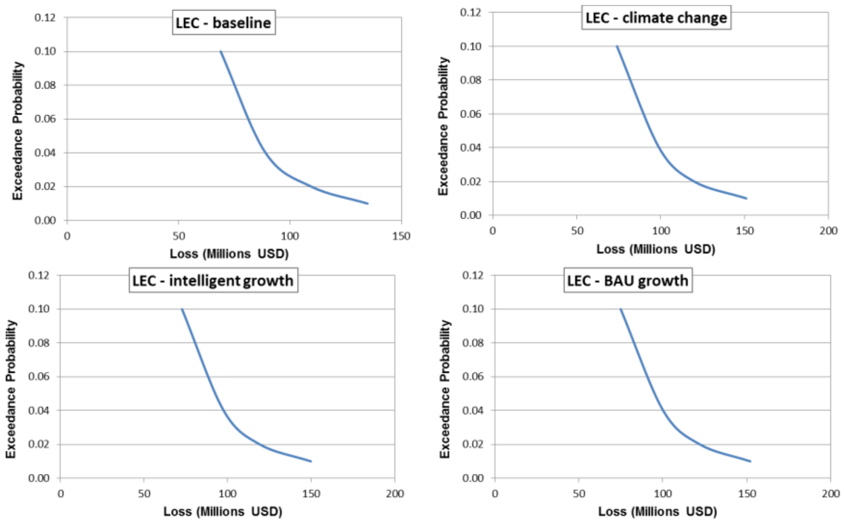

Figure A2- 9: Loss exceedance curves for inland and coastal hazards-Industry

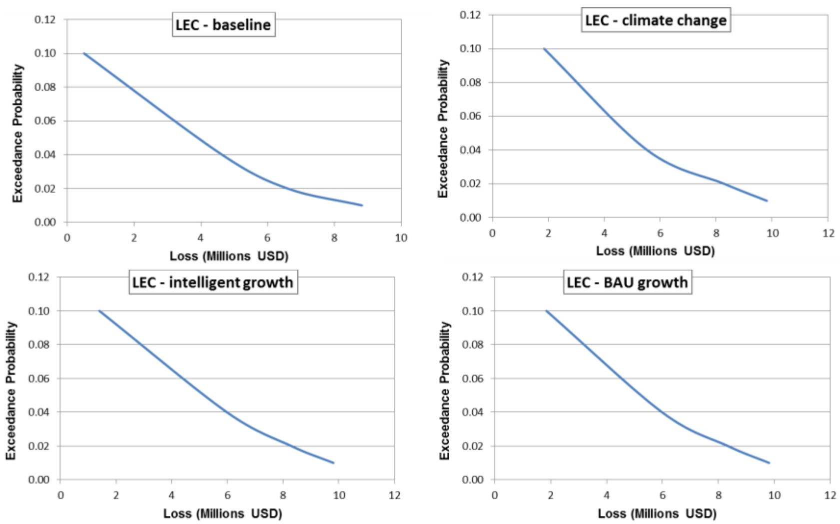

Figure A2- 10: Loss exceedance curves for inland and coastal hazards-Infrastructure

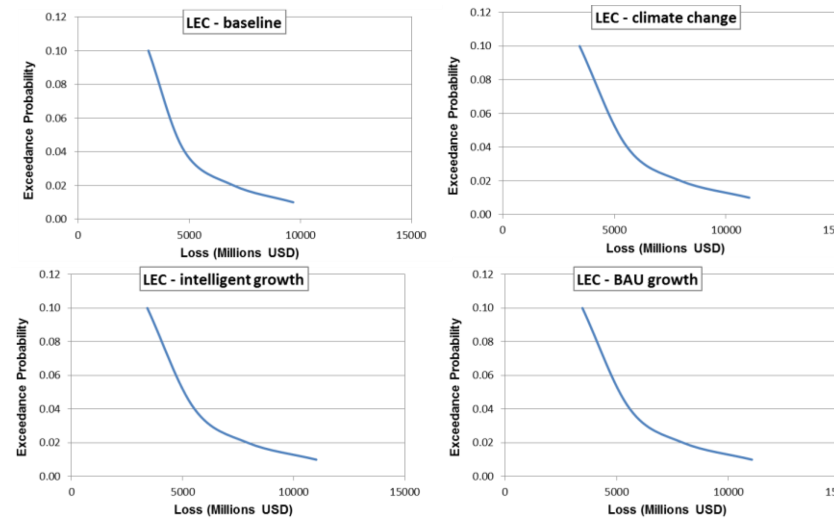

Figure A2- 11: Loss exceedance curves for inland and coastal hazards-Residential

Table A2- 4: Probable maximum losses (PML) in millions USD$ for baseline, climate change, intelligent growth, and Business-As-Usual scenarios

	Return Period			
Scenarios	**100-year**	**50-year**	**25-year**	**10-year**
Baseline	15,453	11,762	8,686	6,075
Climate Change	17,398	13,152	9,735	6,530
Intelligent Growth	17,349	13,089	9,674	6,476
Business-As-Usual (BAS)	17,425	13,181	9,766	6,568

The PML values, shown in Table A2-4, indicate that land use changes represent the main driver to exacerbate losses associated to flooding hazards in NPI. These results also suggest that reductions on PML are expected for the Intelligent Growth compared to the BAS urban growth in NPI.

Table A2- 5: Change in PML due to climate change 2050, and comparison to Business-As-Usual (urban growth) and intelligent growth

Scenarios	Return Period			
	100-year	50-year	25-year	10-year
Climate change vs. baseline PML	12.6%	11.8%	12.1%	7.5%
Business-As-Usual vs. baseline PML	12.8%	12.1%	12.4%	8.1%
Intelligent growth vs. baseline PML	12.3%	11.3%	11.4%	6.6%

Loss Exceedance and Average Annual Losses

An estimate of the total *AAL* for New Providence and Paradise islands (NPI) for both inland and coastal flooding is USD $1.3 billion under baseline conditions and USD $1.5 billion under climate change conditions. These estimates consider only the direct impacts or damages to property. Indirect impacts such as losses from a decrease in tourism require further economic analysis. For comparison, the PreventionWeb results list an *AAL* for storm surge only throughout the country of Bahamas as USD $1.3 billion (UNISDR, 2015).

Population Risks

A population vulnerability index (*PVI*) was assigned based on hazard ratings. The index ranges from 0 to 1 where 0 indicates that danger to persons is very low or non-existent, and 1 indicates a high or very high danger to persons, as provided in Table A2-6. Population risk is then calculated as the population density multiplied by the *PVI* (Equation 1). A scale of the population risk was assigned ranging from very low to very high. The scale, provided in Table A2-7, is based on a Gaussian distribution where each category is above or below the mean risk by a number of standard deviations.

- Moderate risk is between -0.5 to +0.5 standard deviations of the mean risk for a 100-year event;
- High risk is +1.5 to +2.5 standard deviations above the mean;
- Very high risk is +2.5 to +3.5 standard deviations above the mean;
- Low risk is -1.5 to -2.5 standard deviations below the mean; and
- Very low risk is -2.5 to -3.5 standard deviations below the mean.

Areas with a very low risk are least affected by inland and coastal flooding, moderate areas are average (i.e. what most people will encounter), and very high risk areas are heavily impacted. Maps of the population risk for the 10-, 25-, 50-, and 100-year return periods are shown in Figure A2-29 through Figure A2-44.

Equation 1 Population risk

$$Population\ Risk = PVI * Population\ Density$$

Table A2- 6: Population vulnerability index (PVI) by hazard

Hazard	PVI
None	0
Low	0.25
Medium	0.50
High	1.0

km^2 = square kilometers

Table A2- 7: Population risk ratings for risk maps

Population risk (persons in danger per km^2)	Risk
0 - 350	Very Low
351 - 1050	Low
1051 - 1760	Moderate
1761 - 2461	High
2461 - 5505	Very High

km^2 = square kilometers

The approach used for this study presented the following limitations:

- Damage to properties was assessed based on the flood depth and velocity, and the type of land use. Damages were applied uniformly within each land use, without considering building age or construction.

Improved construction methods, such as a raised foundation, can reduce damages to a building.

- Population risks have been evaluated on an average district-wide basis. The population distribution within a district varies considerably, with some areas of high population density, and other areas where there is no population.
- Risks do not indicate fatality or the type of injury that may occur. It does not consider people moving to higher ground or avoiding flooded areas. Therefore, estimates of the population risk are considered a conservative estimate of danger to persons, and are most useful in indicating the relative danger that can occur across different areas of New Providence and Paradise Island.

In conclusion, areas of very high risk occur due to the most severe flooding and are concentrated in central parts of Nassau where there is low lying ground, many buildings, and a high population density. Much of the western side of New Providence Island is a low or very low population risk due to the low population density. Because population density is assigned for each district, the population risk within a neighborhood of the district can be greater than the average risk across the district. A district may have an overall low density, but a neighborhood within it with a higher density. To show the relative abilities of persons to replace the property damaged in a flood, an additional map (see Figure A2-12) was created for the 100-year return period event that combines the property and population risks. In addition, economic losses will be largely impacted (an increase of 8-13%) by climate change. Land use changes, either increases or decreases in urbanization, can affect the flood losses, although to a lesser extent than climate change.

The following equation were used to define combined risk levels shown in Figure A2-12:

Equation 2 Combined risk

$$Risk = \frac{Hazard}{3} * [Density]/[PropertyValue]$$

Where:

- Hazard equal to
  - 1 is considered low;
  - 2 is considered medium; and
  - 3 is considered high.
- Risk between:
  - 0.000011 – 0.001311 is considered very low
  - 0.001312 – 0.004811 is considered low
  - 0.004812 – 0.013249 is considered medium
  - 0.013250 – 0.020453 is considered high; and
  - 0.020454 0.044037 is considered very high

Figure A2-4 shows the population density while Figure A2- 3 shows property values used to generate the combined risk map shown in Figure A2-12
The following ranges were used to define combined risk levels:

- Very low = 0.000011 – 0.001311
- Low = 0.001312 – 0.004811
- Medium = 0.004812 – 0.013249
- High = 0.013250 – 0.020453
- Very High = 0.020454 0.044037

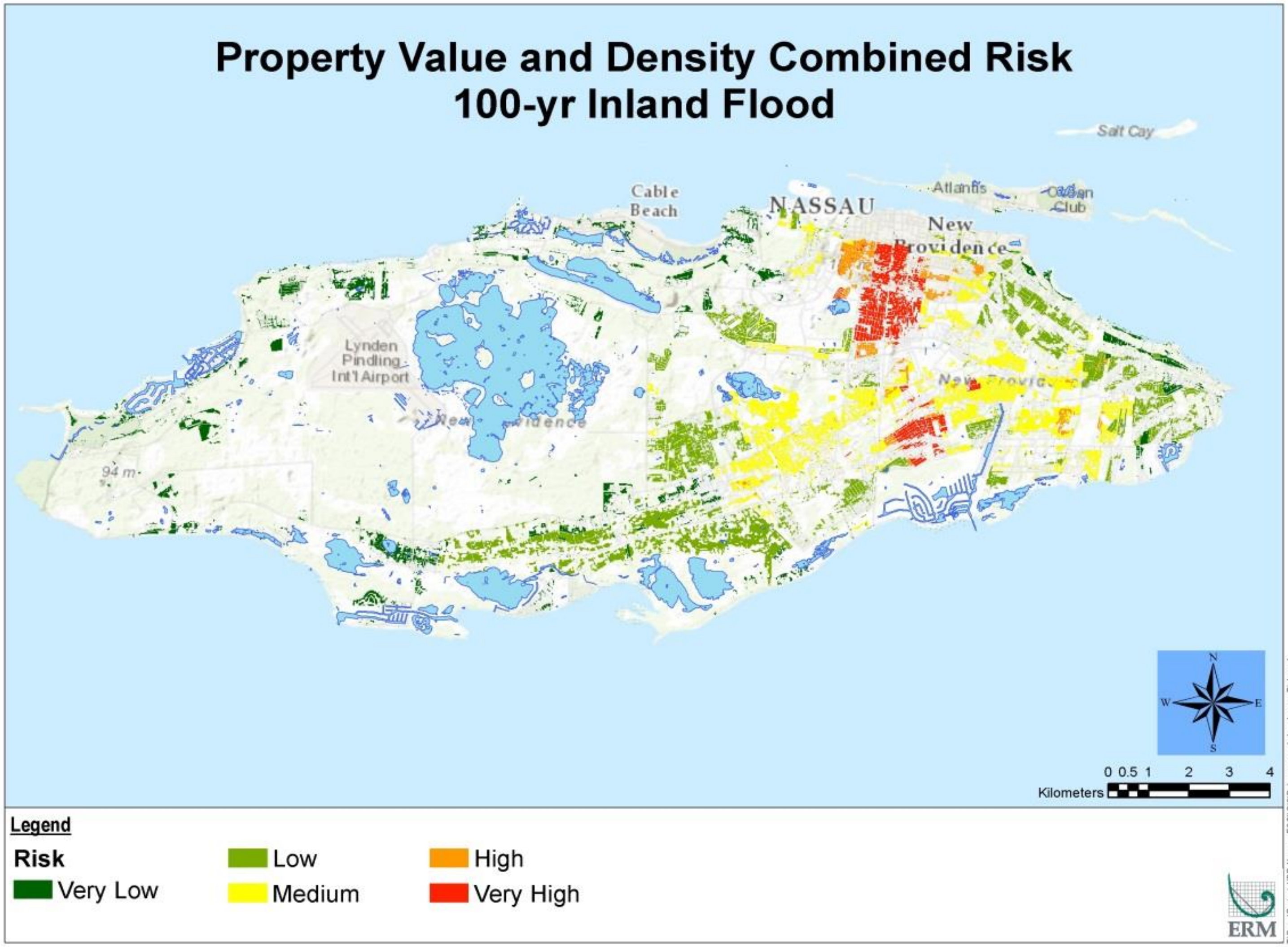

Figure A2- 12: Combined population and economic risk for a 100-year return period inland flood

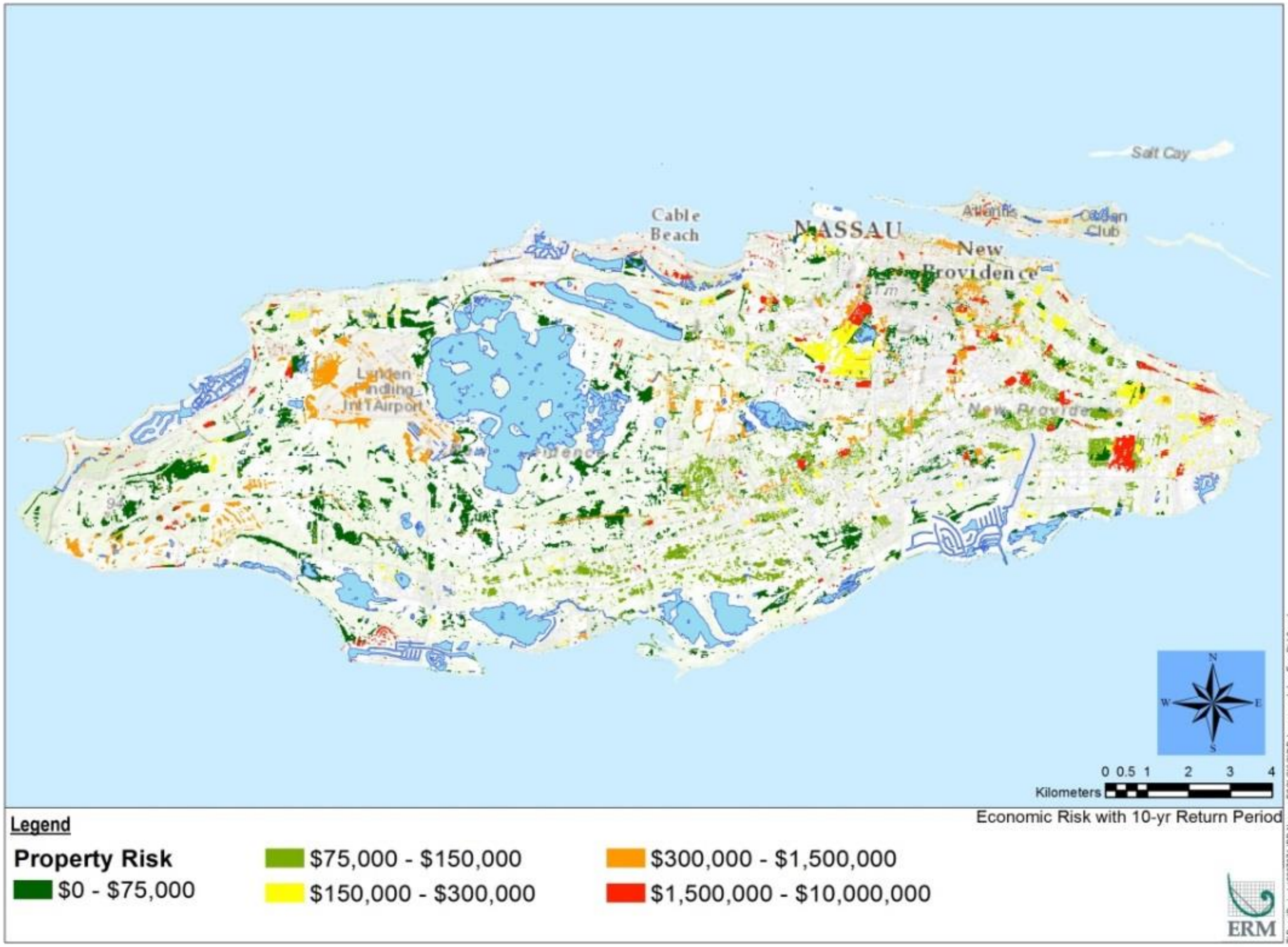

Figure A2- 13: Economic risk with a 10-year return period under baseline conditions

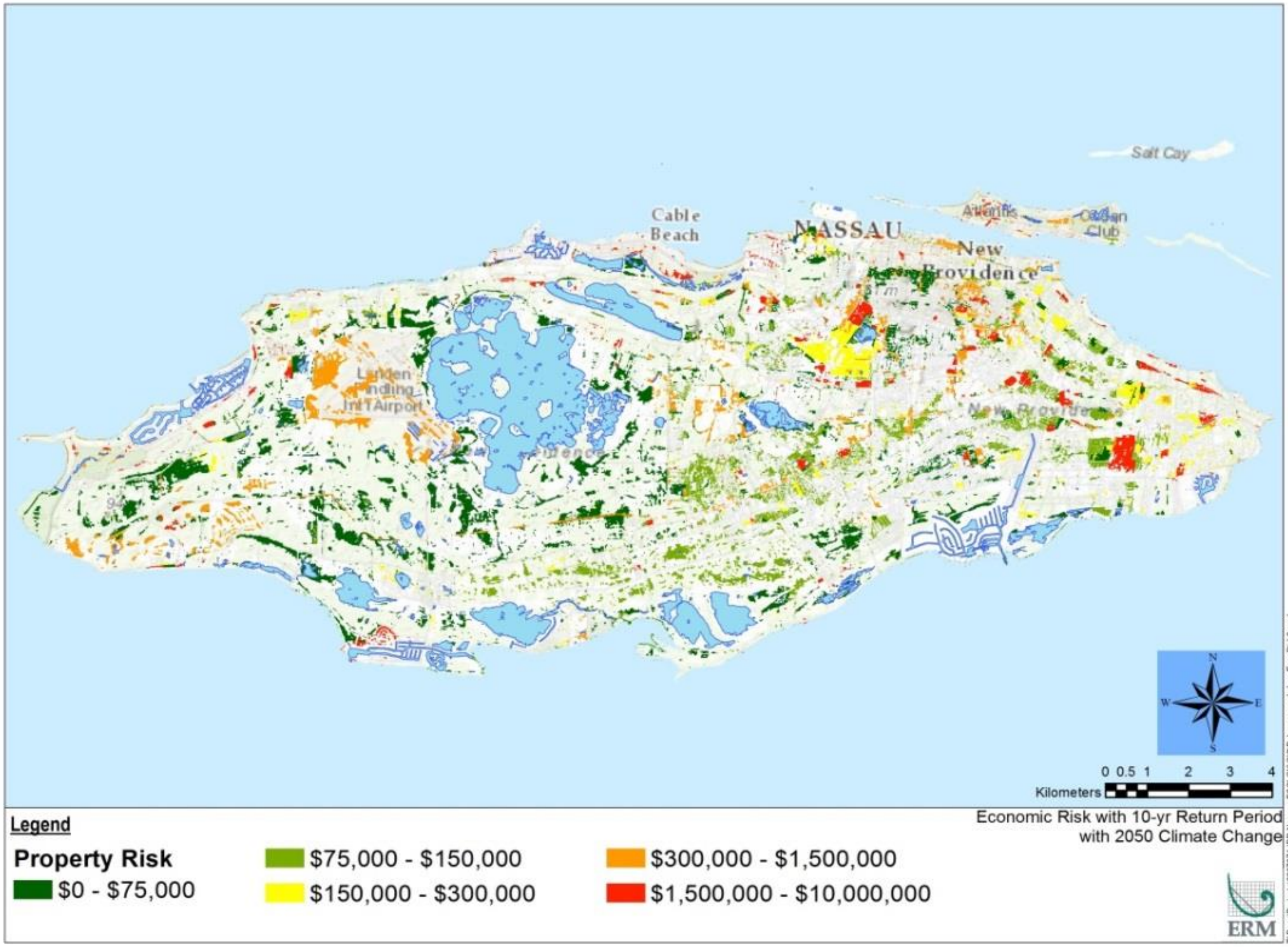

Figure A2- 14: Economic risk with a 10-year return period and with 2050 climate change

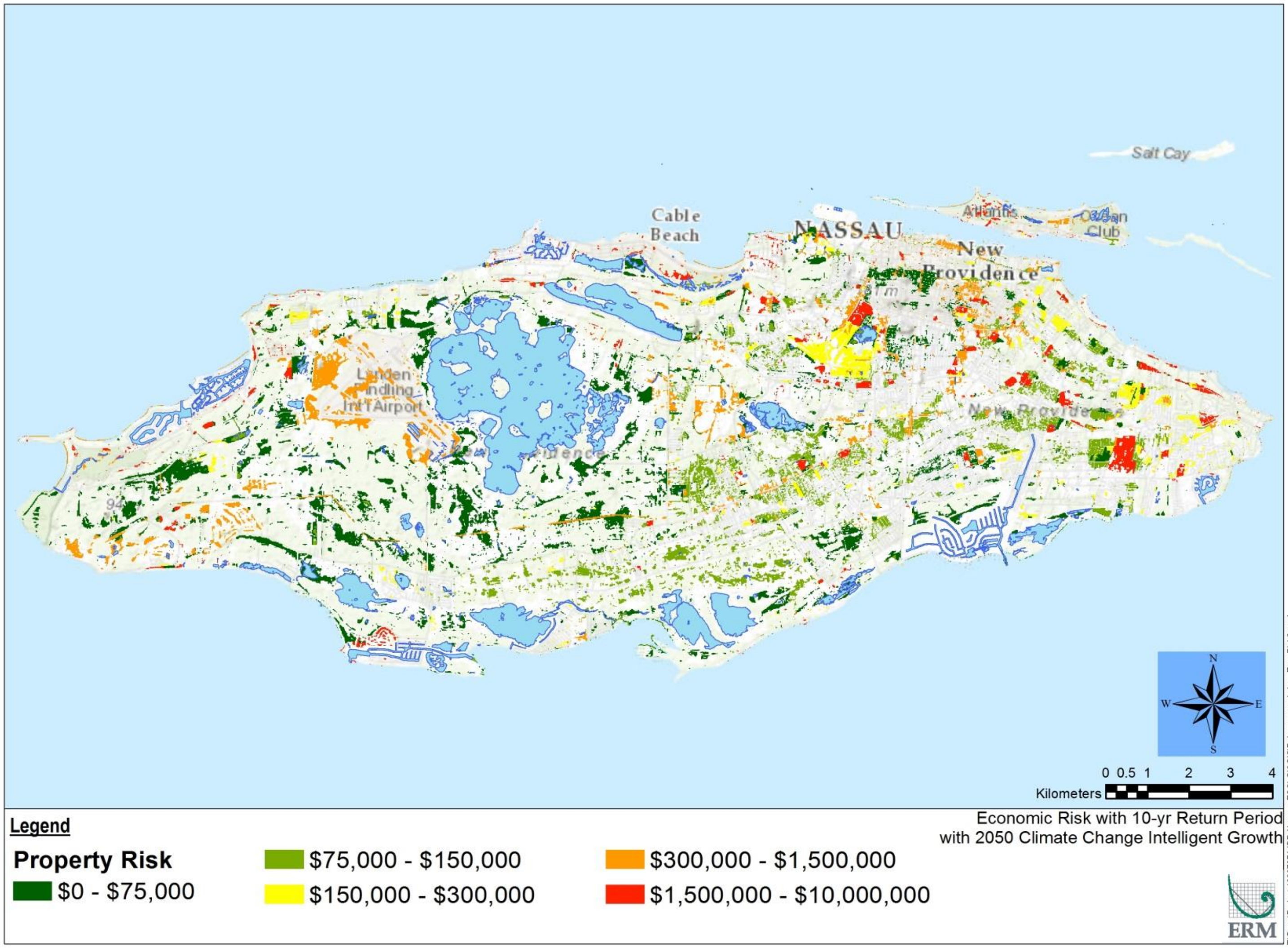

Figure A2- 15: Economic risk with a 10-year return period and with 2050 climate change and intelligent growth

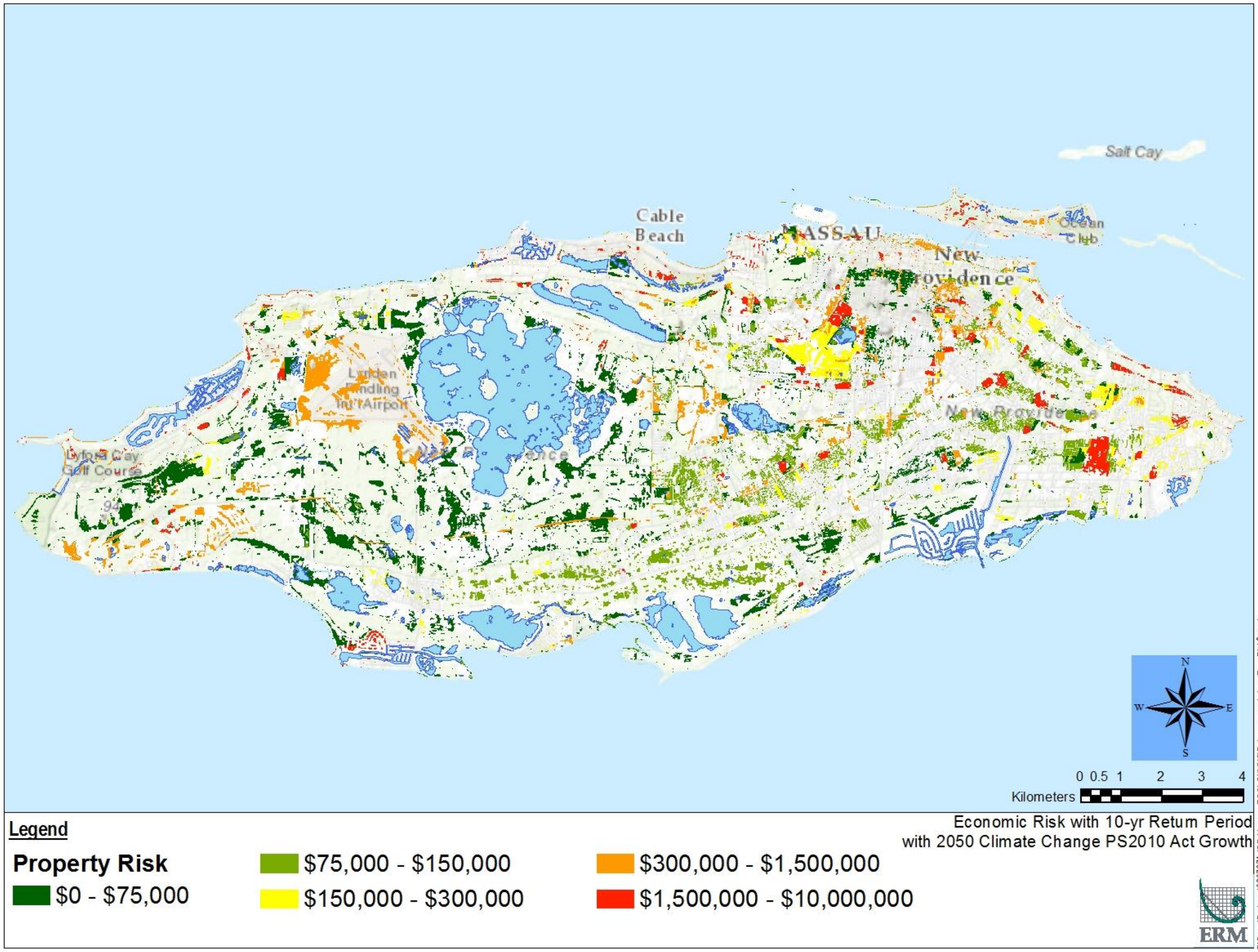

Figure A2- 16: Economic risk with a 10-year return period and with 2050 climate change and Business-As-Usual growth

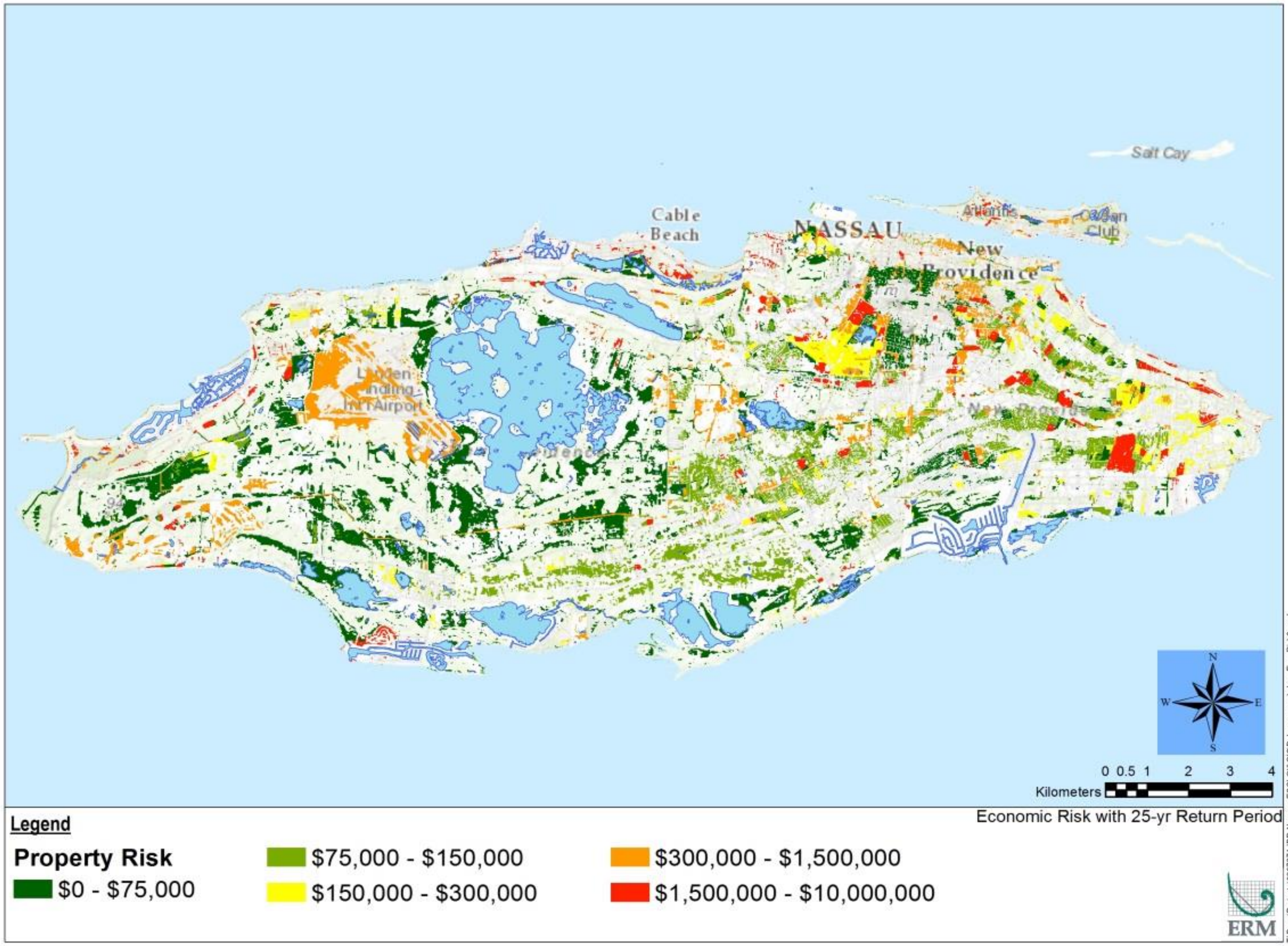

Figure A2- 17: Economic risk with a 25-year return period under baseline conditions

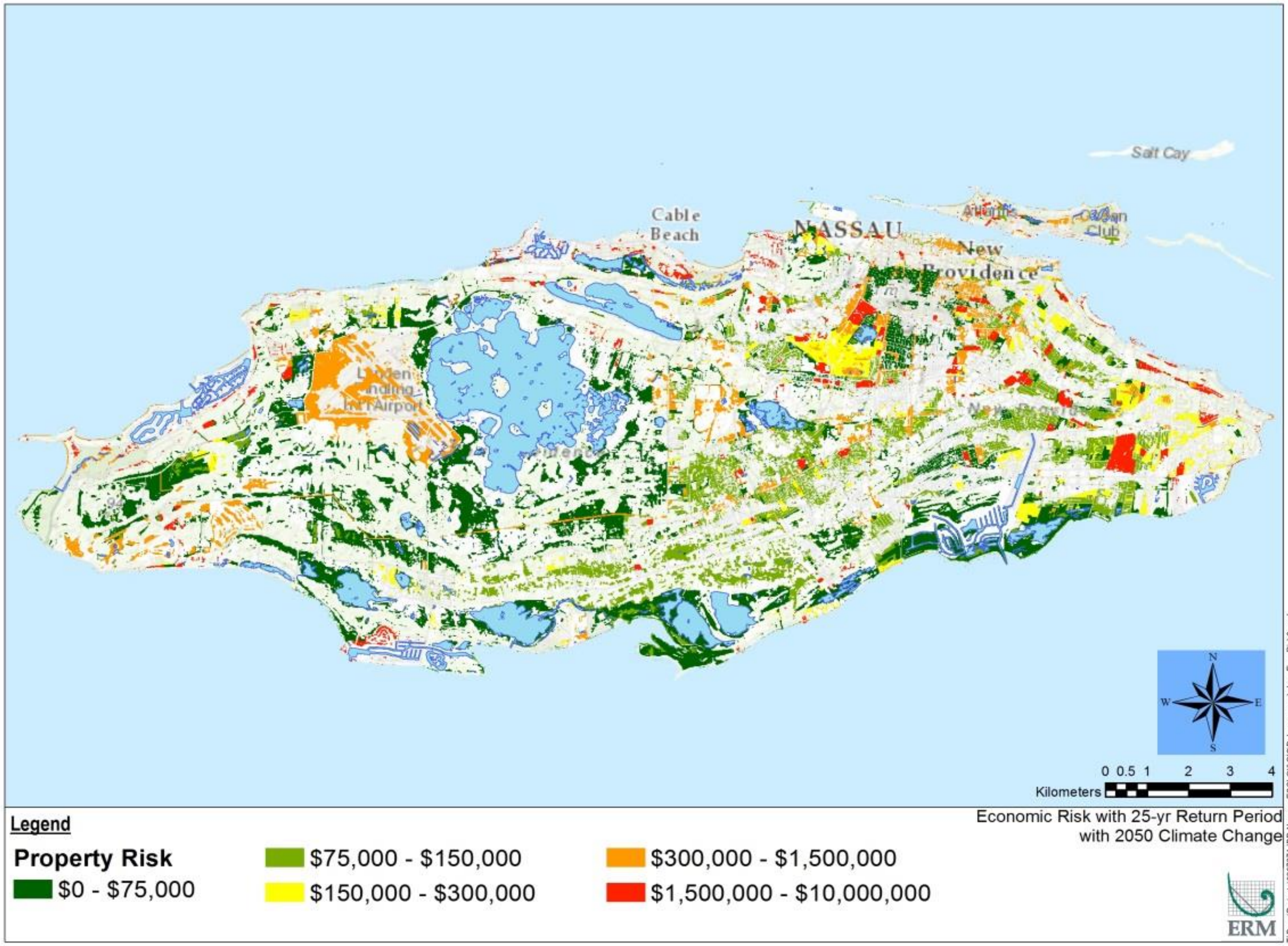

Figure A2- 18: Economic risk with a 25-year return period and with 2050 climate change

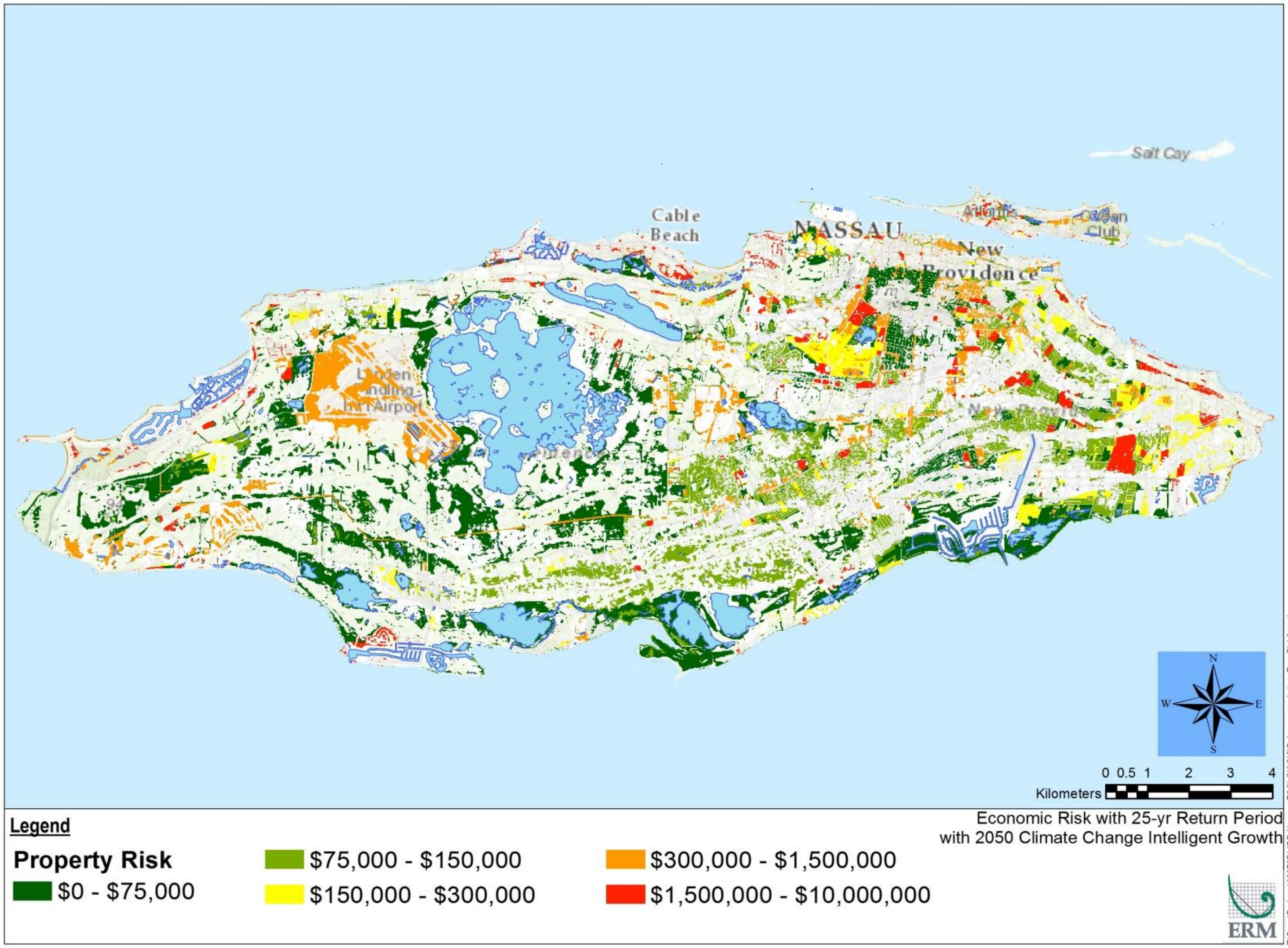

Figure A2- 19: Economic risk with a 25-year return period and with 2050 climate change and intelligent growth

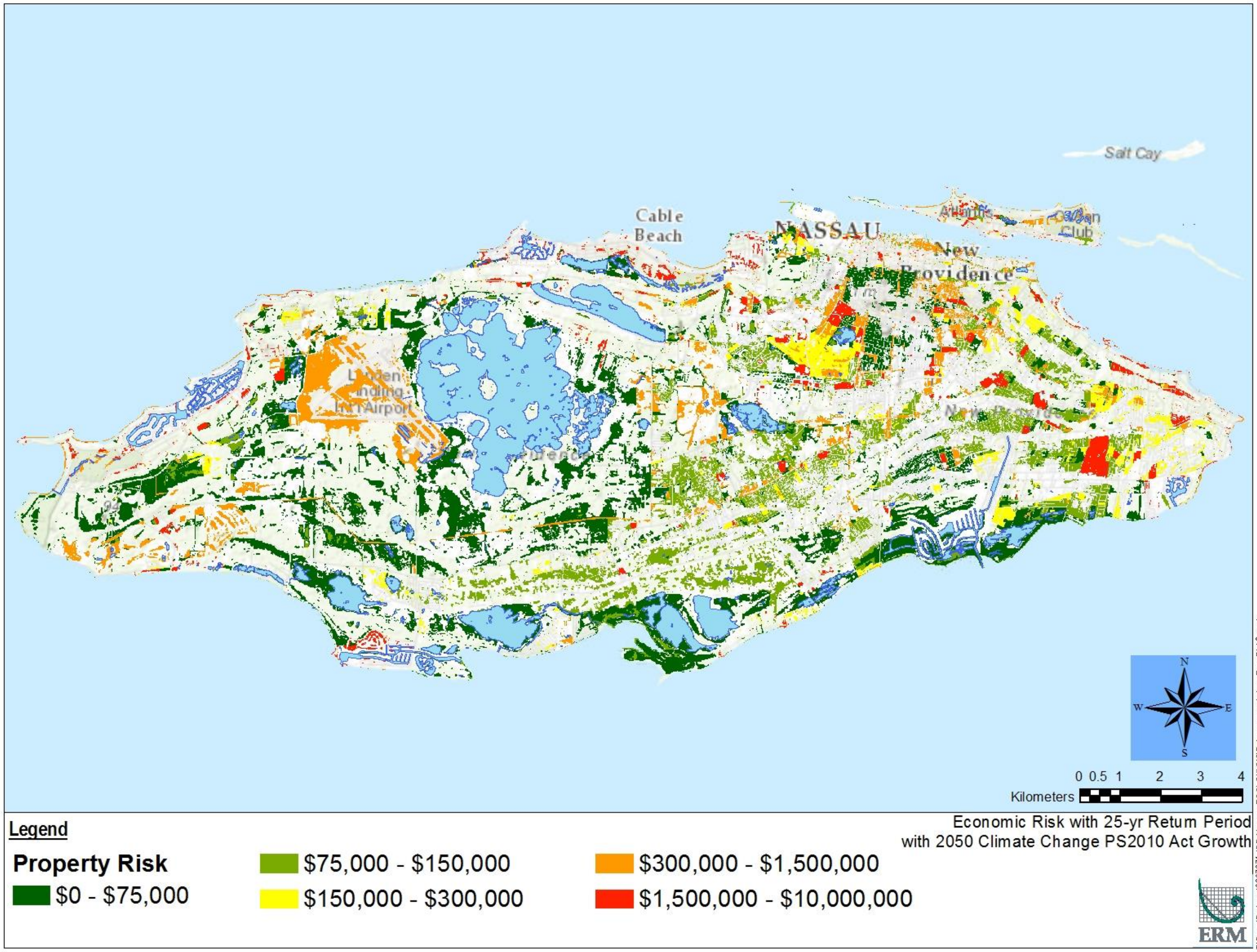

Figure A2- 20: Economic risk with a 25-year return period and with 2050 climate change and Business-As-Usual growth

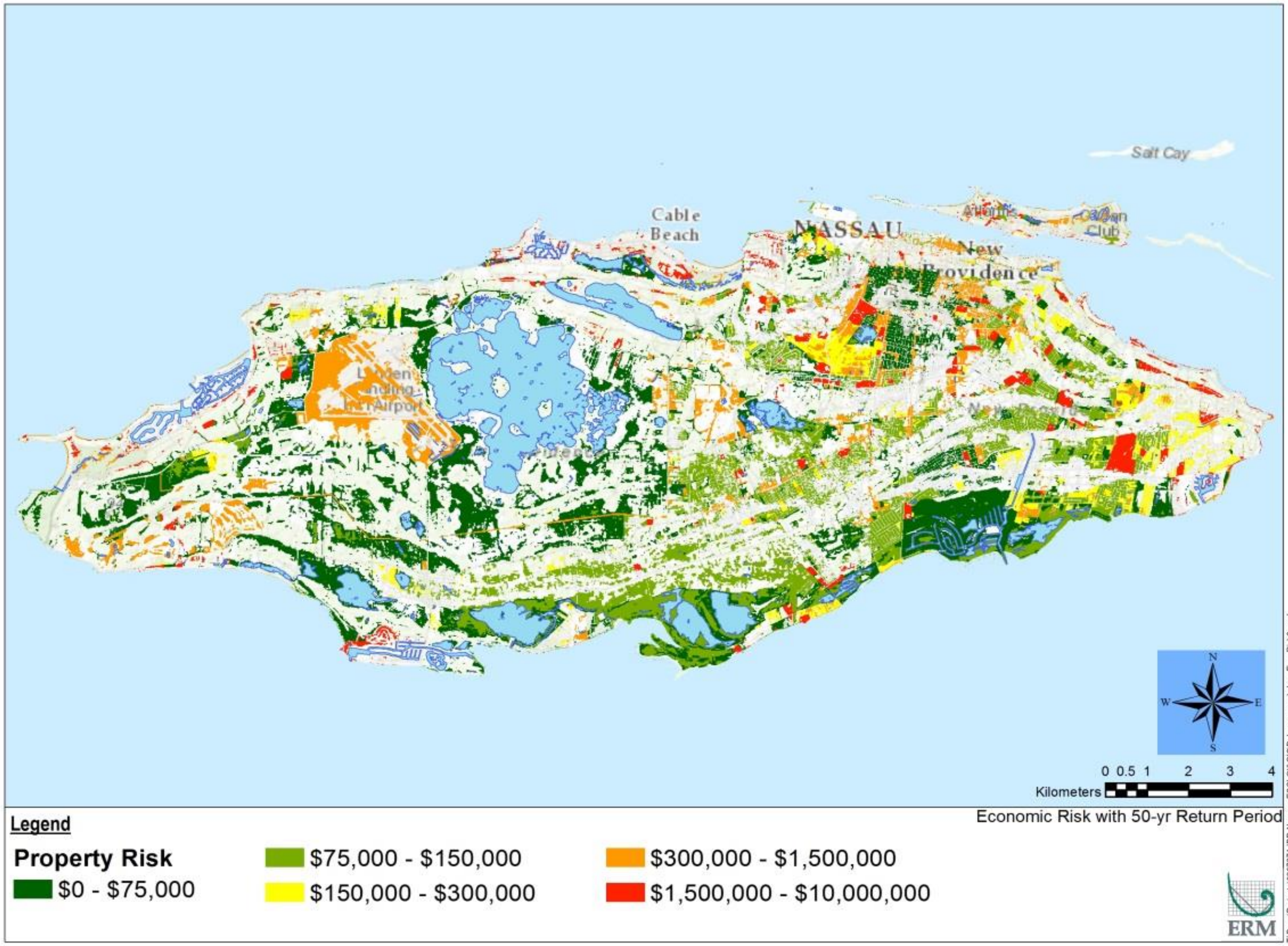

Figure A2- 21: Economic risk with a 50-year return period under baseline conditions

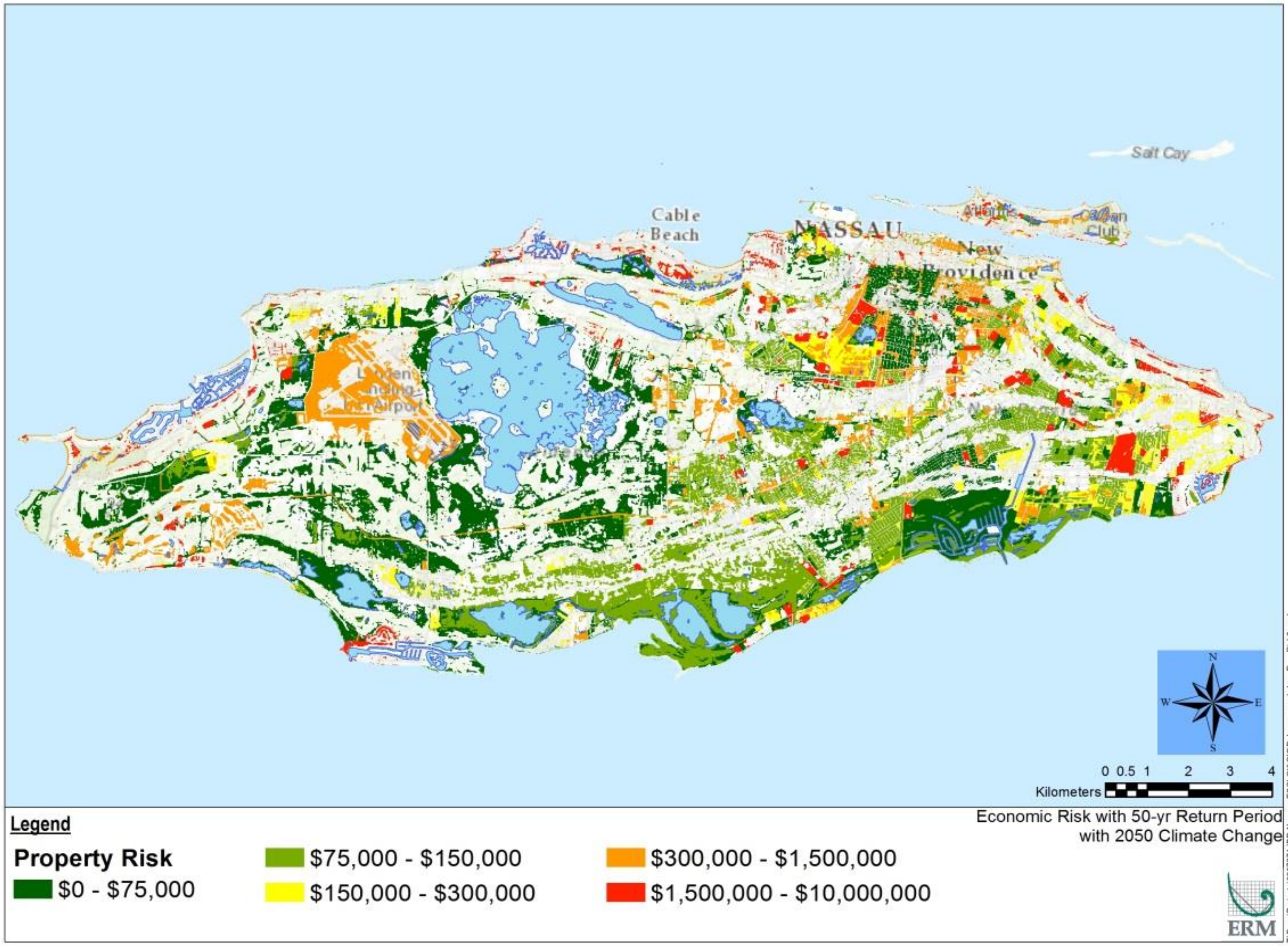

Figure A2- 22: Economic risk with a 50-year return period and with 2050 climate change

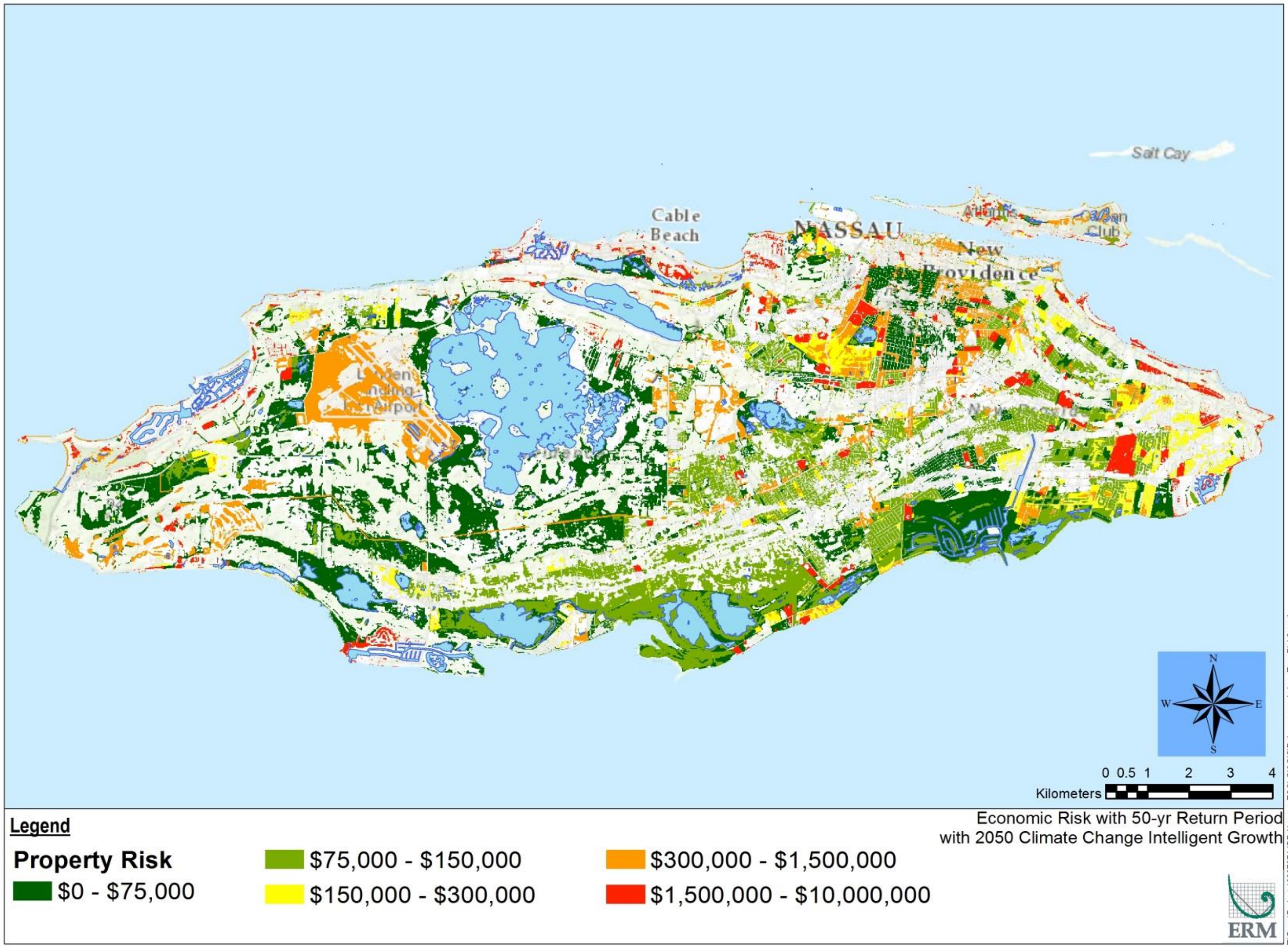

Figure A2- 23: Economic risk with a 50-year return period and with 2050 climate change and intelligent growth

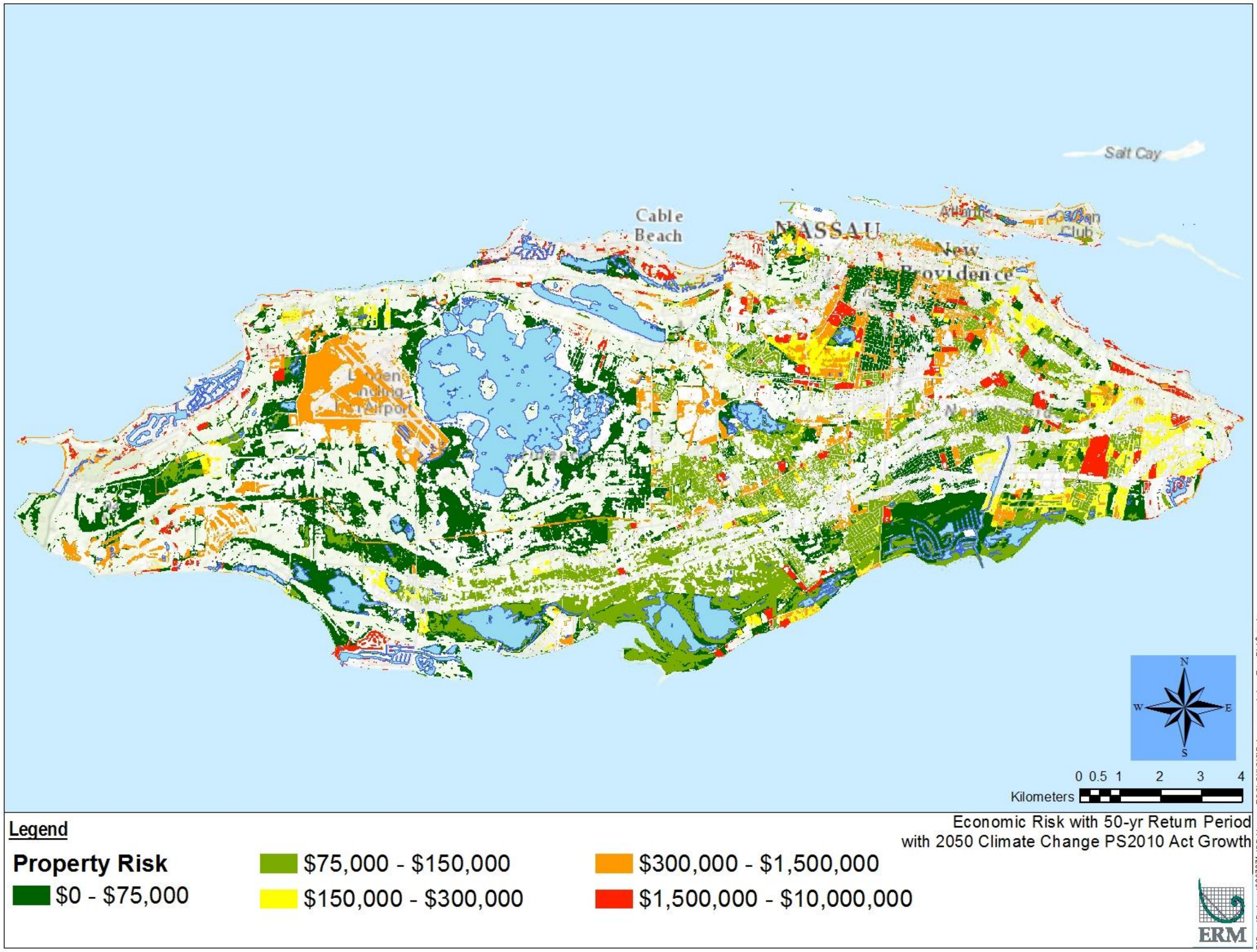

Figure A2- 24: Economic risk with a 50-year return period and with 2050 climate change and Business-As-Usual growth

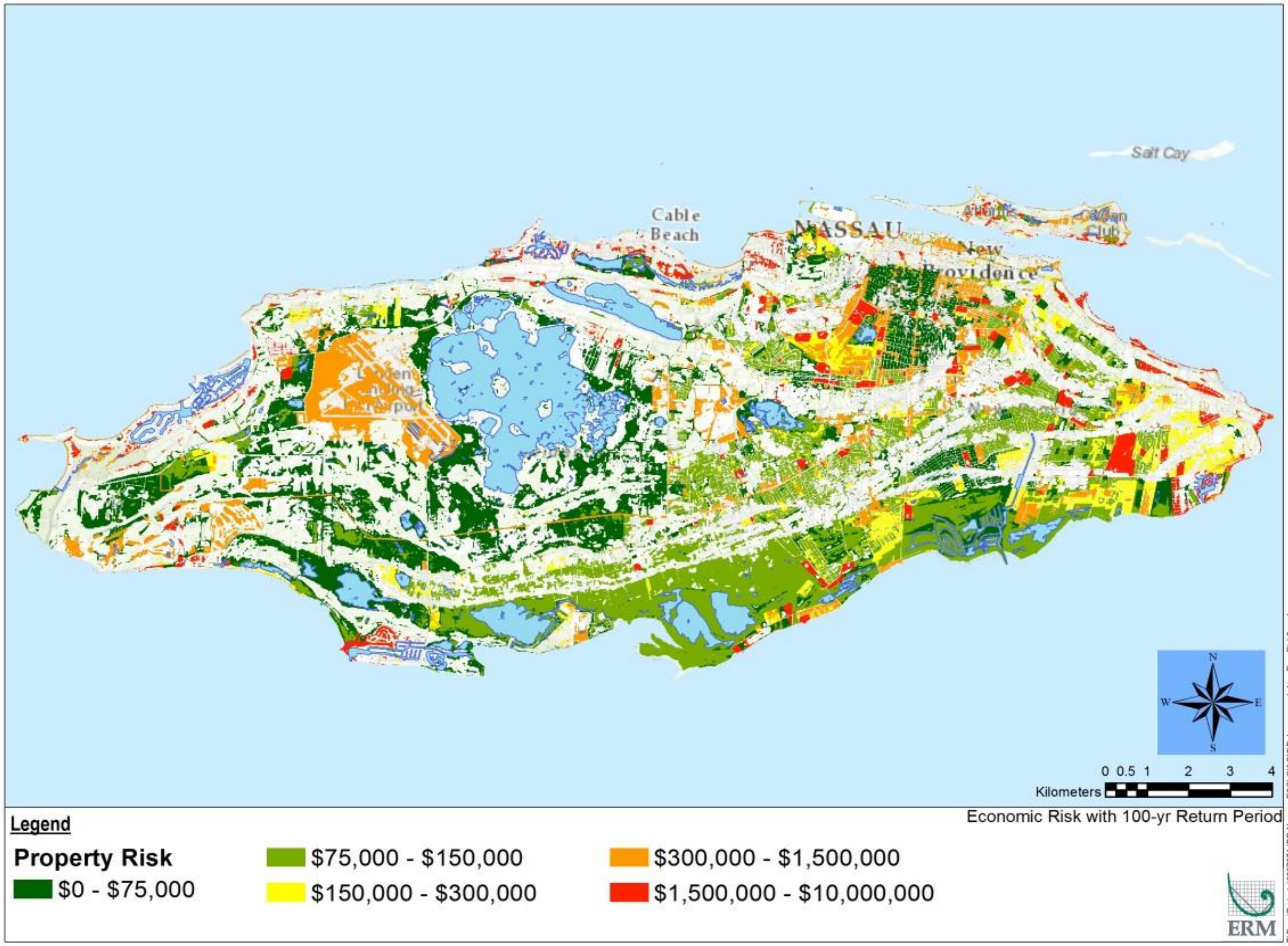

Figure A2- 25: Economic risk with a 100-year return period under baseline conditions

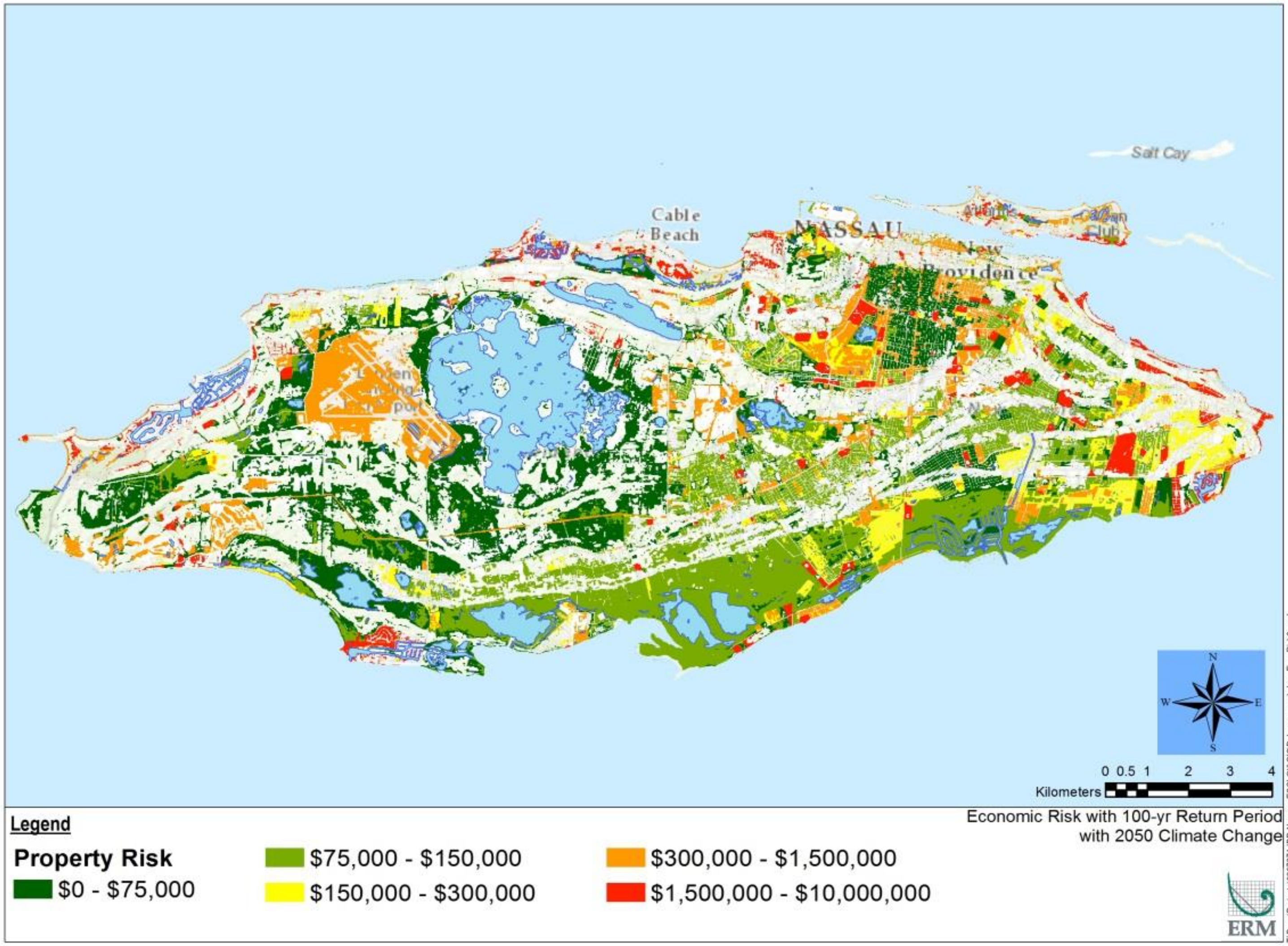

Figure A2- 26: Economic risk with a 100-year return period and with 2050 climate change

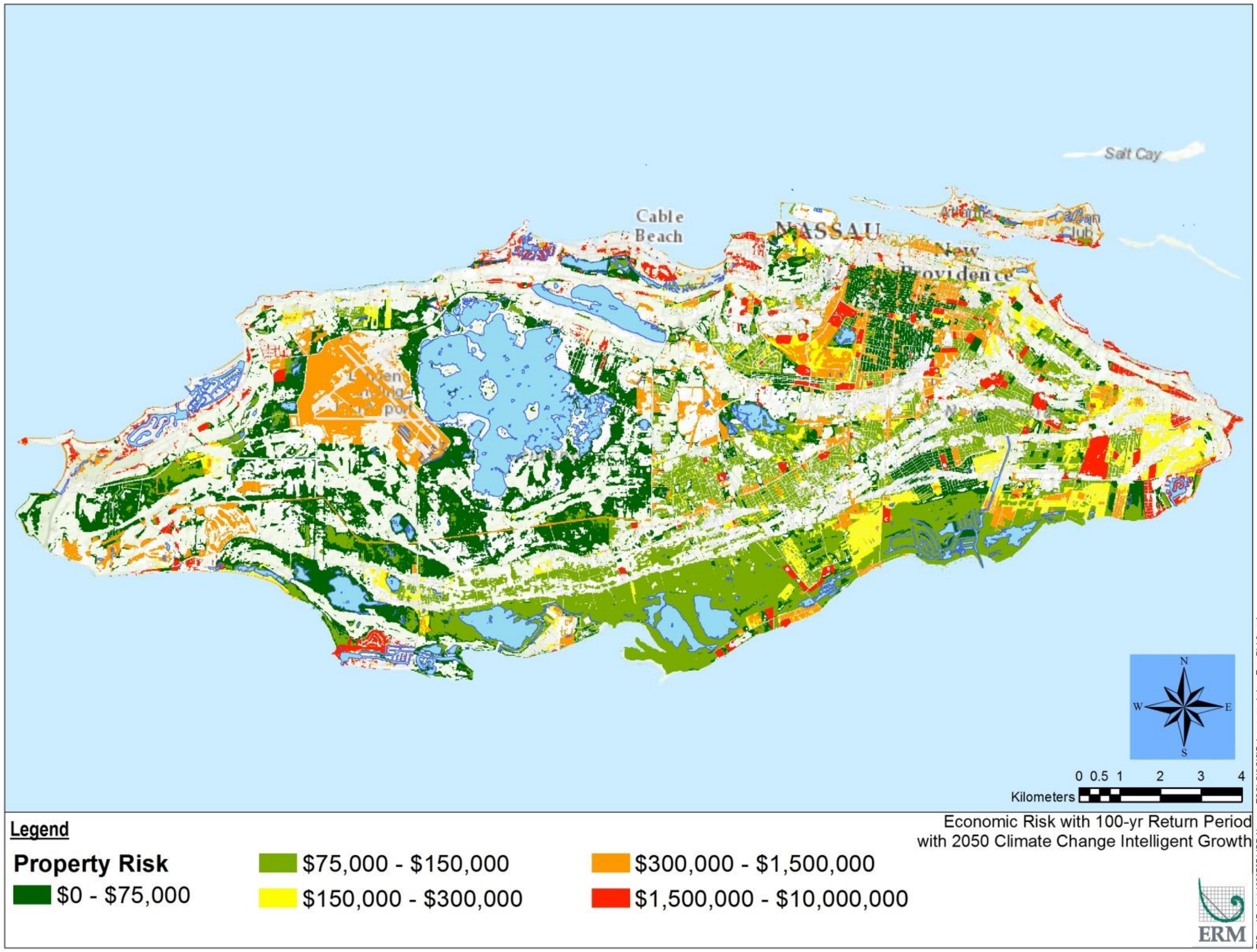

Figure A2- 27: Economic risk with a 100-year return period and with 2050 climate change and intelligent growth

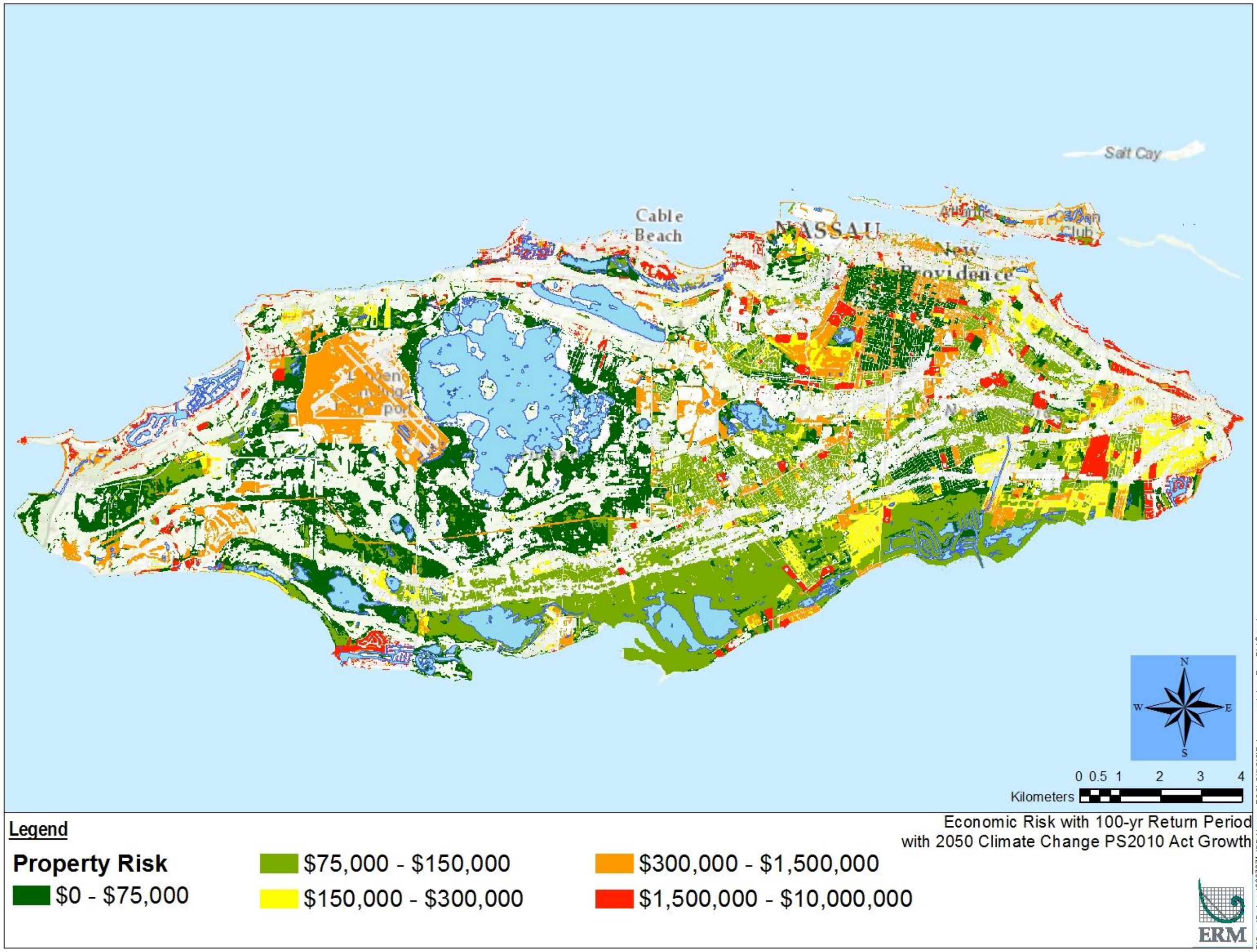

Figure A2- 28: Economic risk with a 100-year return period and with 2050 climate change and Business-As-Usual growth

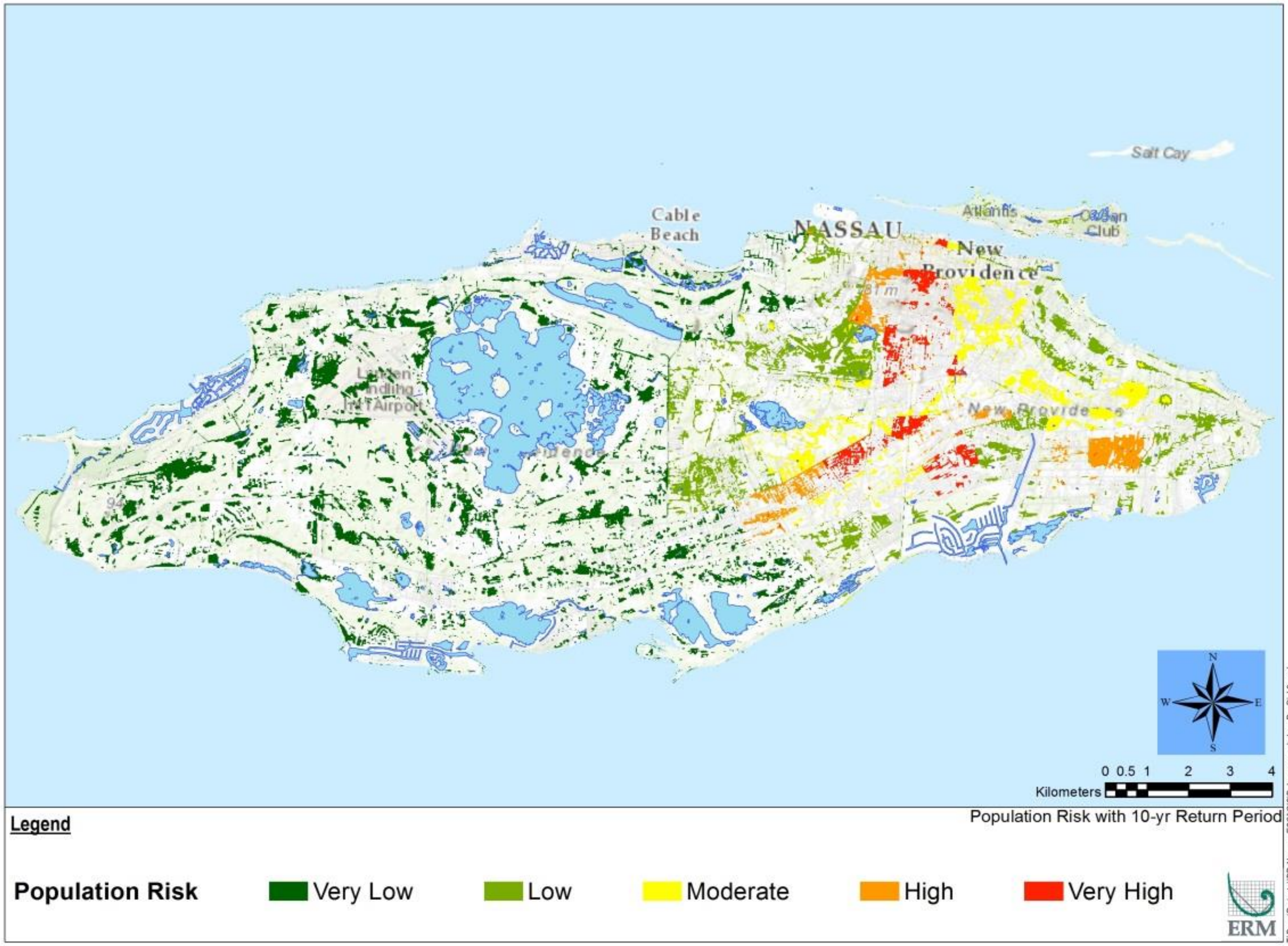

Figure A2- 29: Population risk with a 10-year return period under baseline conditions

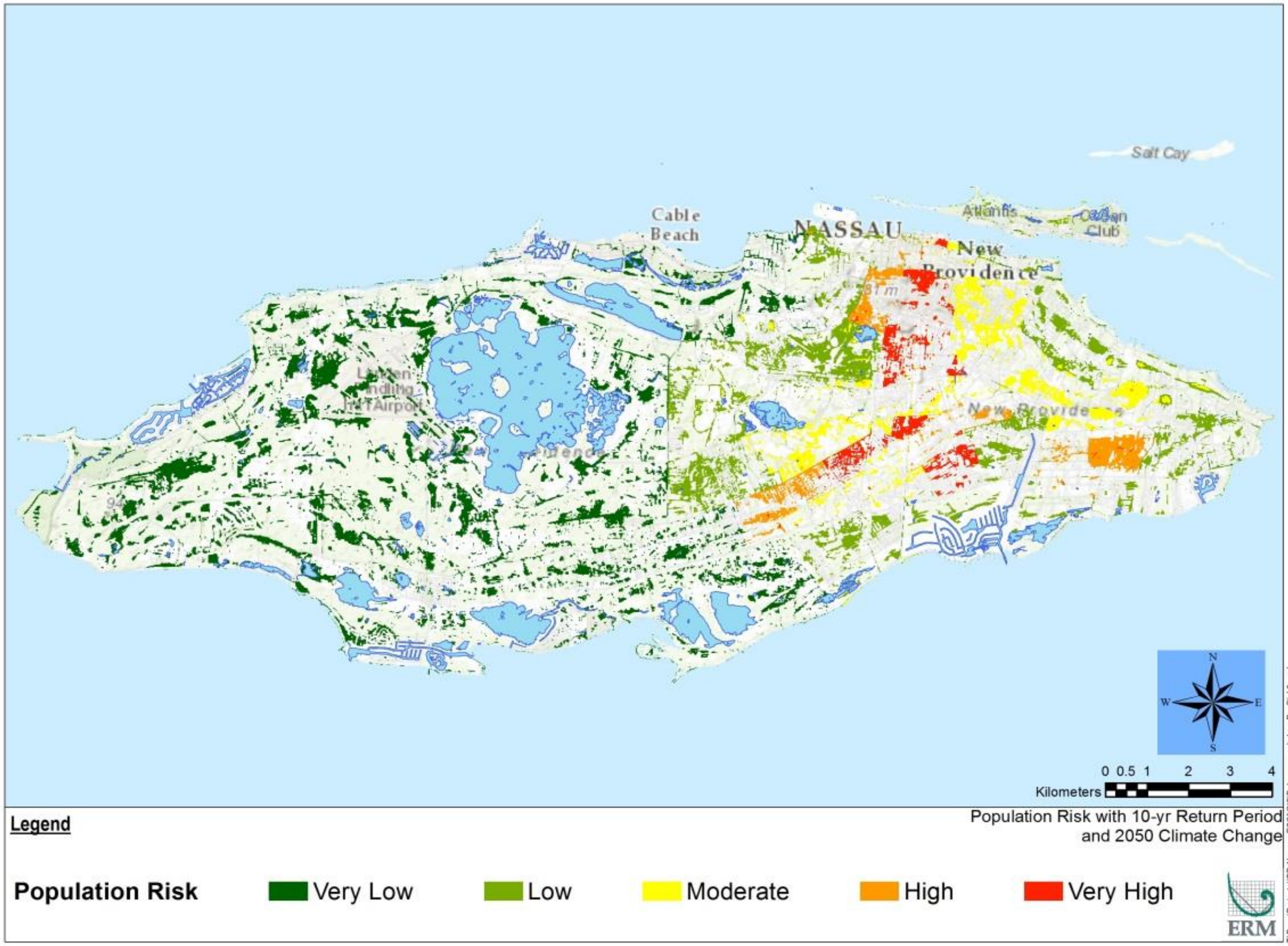

Figure A2- 30: Population risk with a 10-year return period and with 2050 climate change

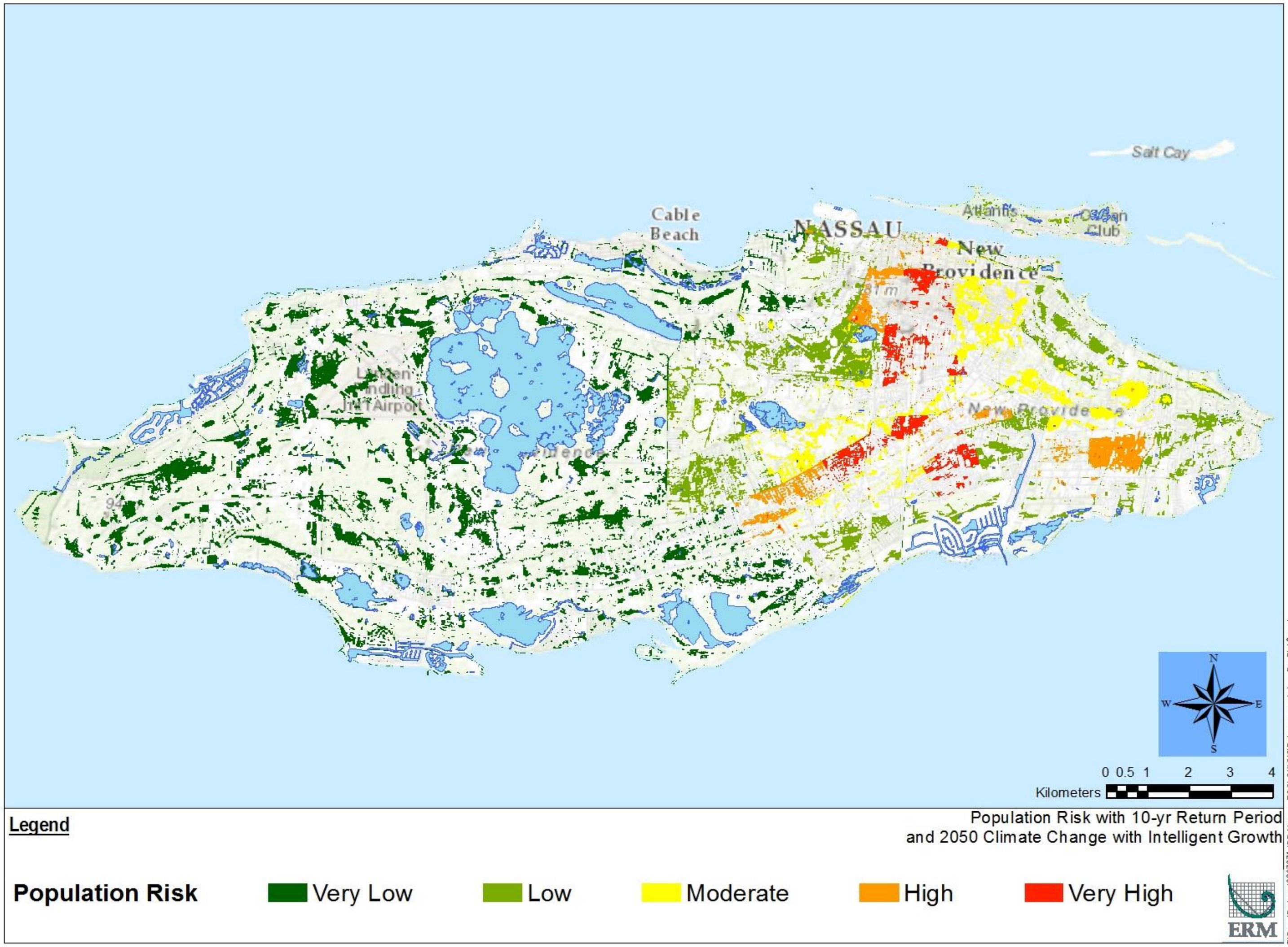

Figure A2- 31: Population risk with a 10-year return period and with 2050 climate change and intelligent growth

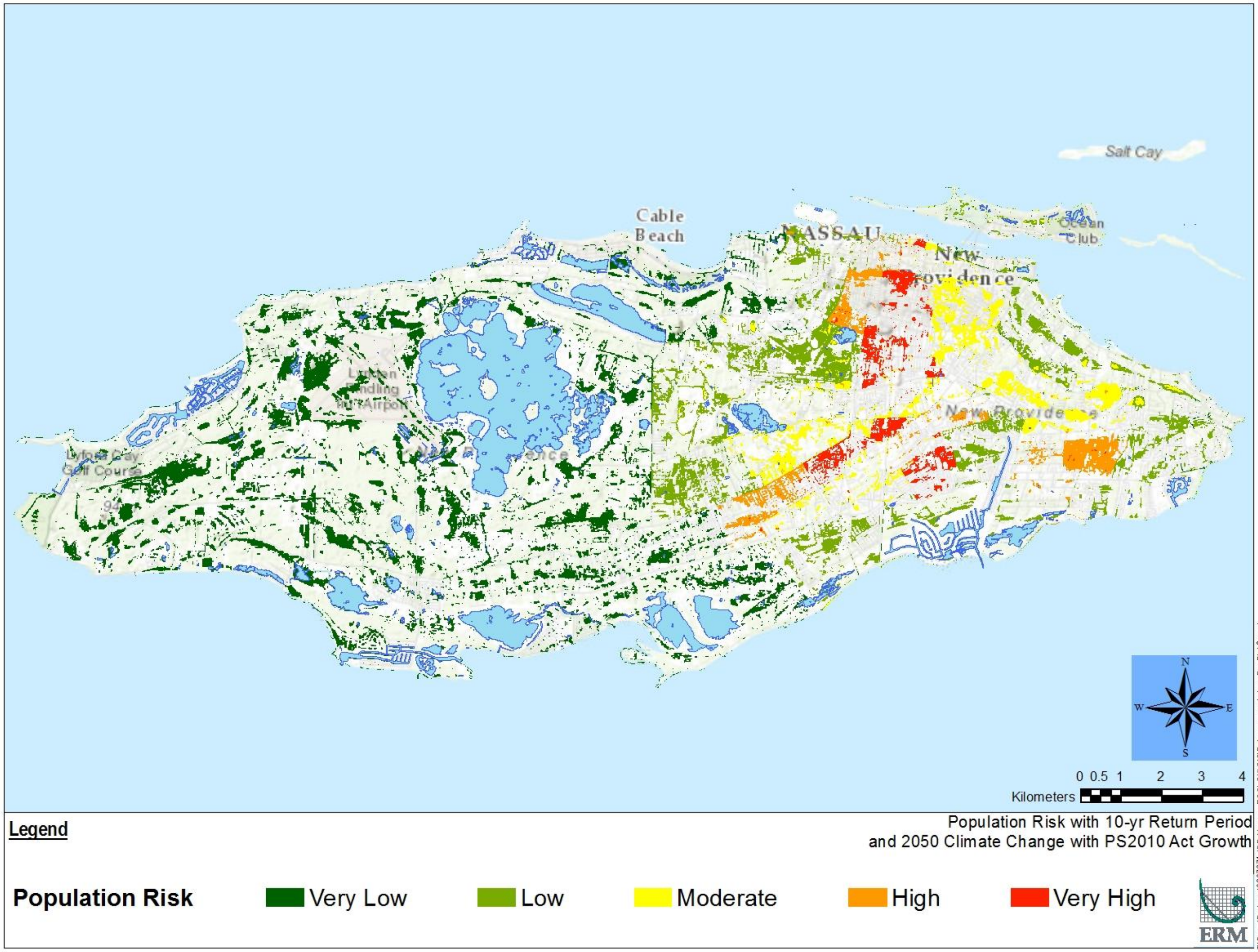

Figure A2- 32: Population risk with a 10-year return period and with 2050 climate change and Business-As-Usual growth

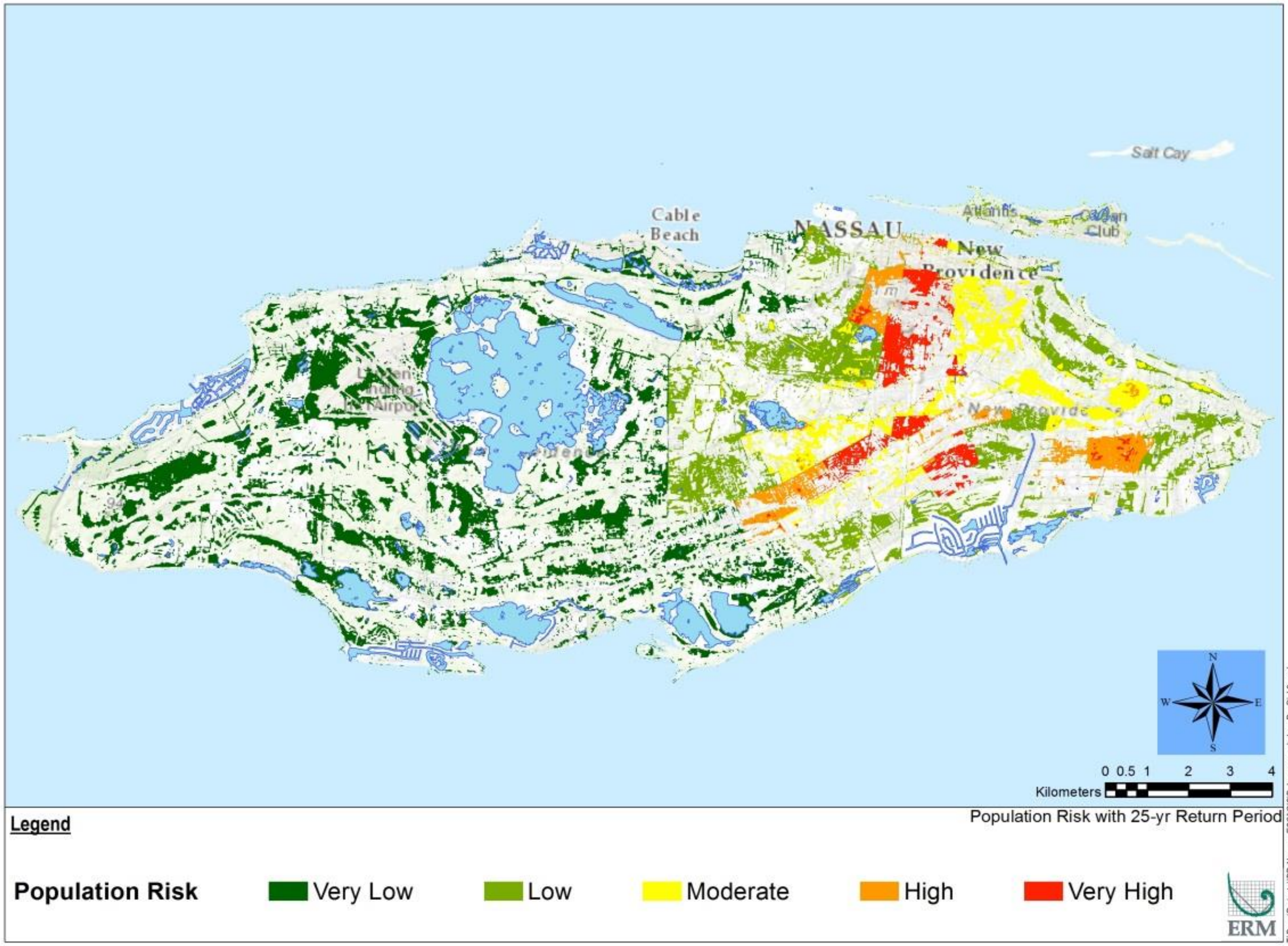

Figure A2- 33: Population risk with a 25-year return period under baseline conditions

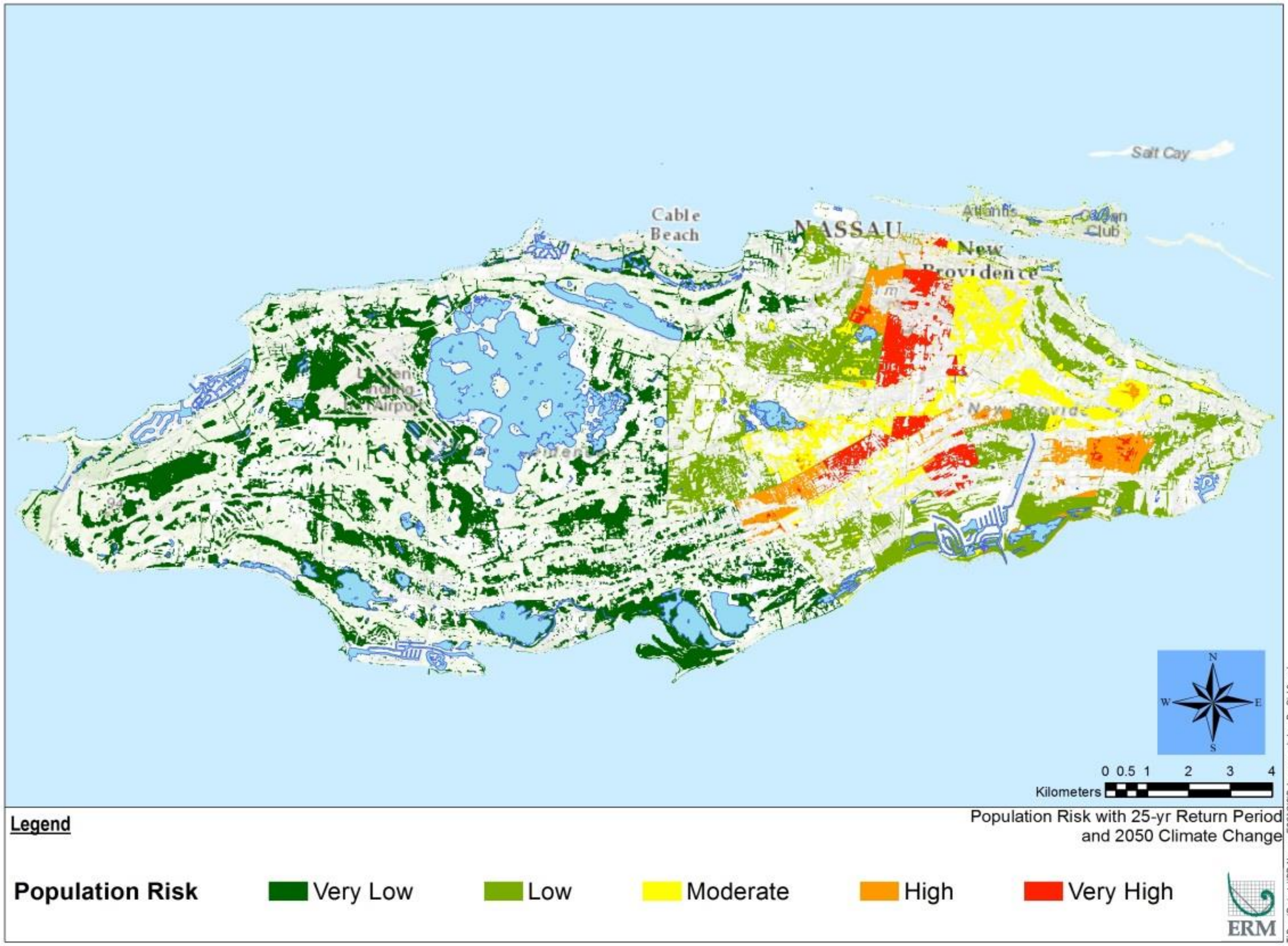

Figure A2- 34: Population risk with a 25-year return period and with 2050 climate change

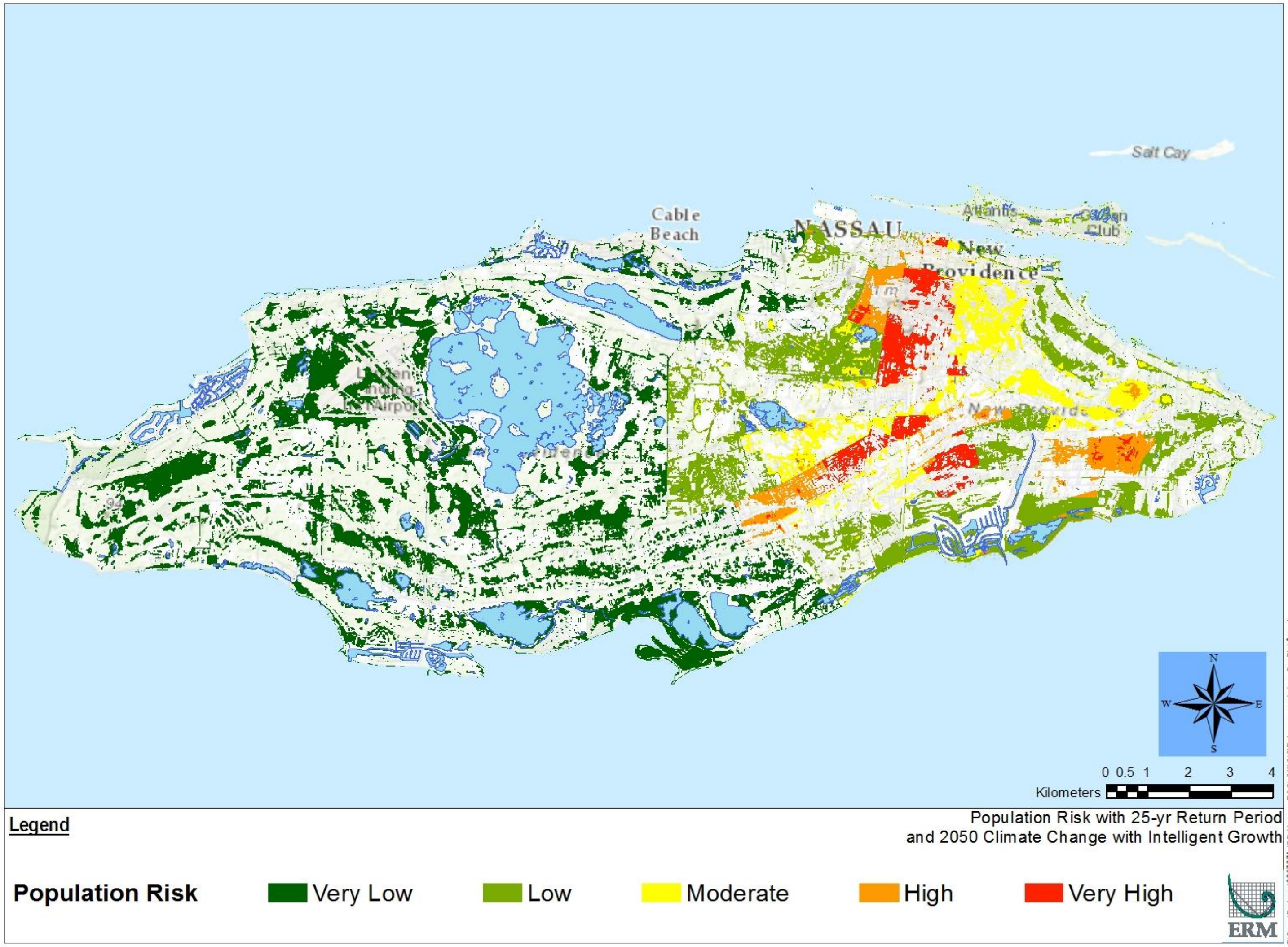

Figure A2- 35: Population risk with a 25-year return period and with 2050 climate change and intelligent growth

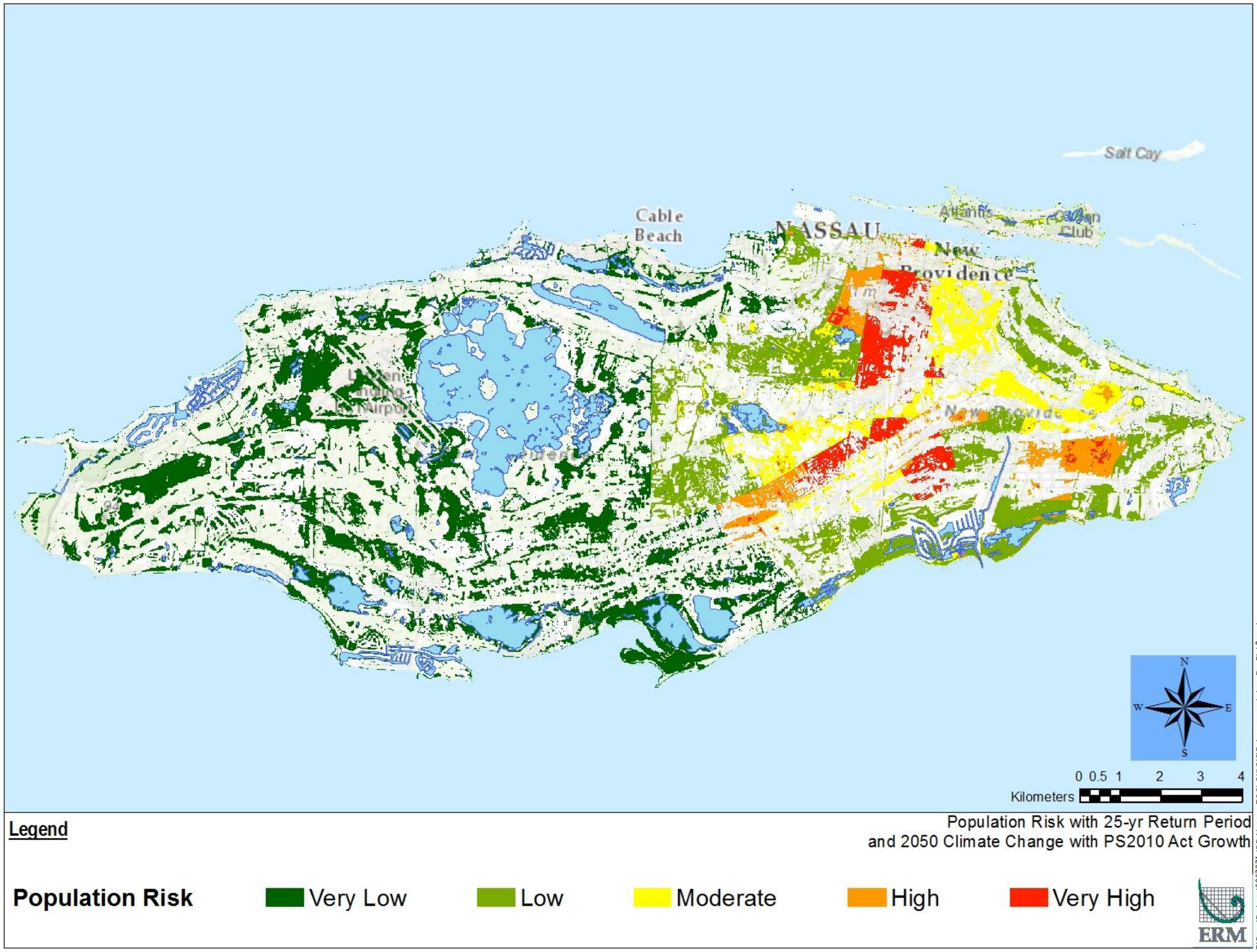

Figure A2- 36: Population risk with a 25-year return period and with 2050 climate change and Business-As-Usual growth

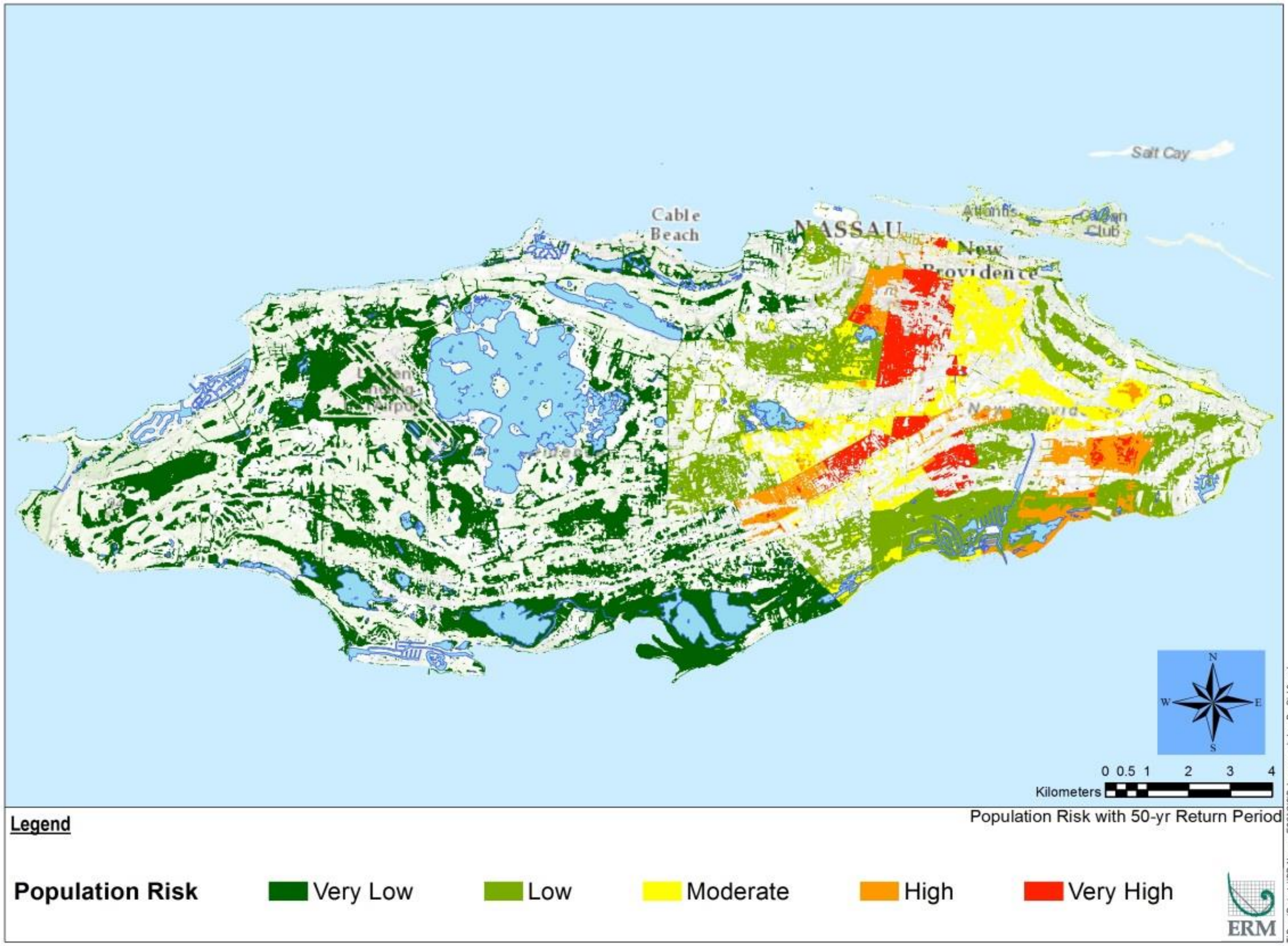

Figure A2- 37: Population risk with a 50-year return period under baseline conditions

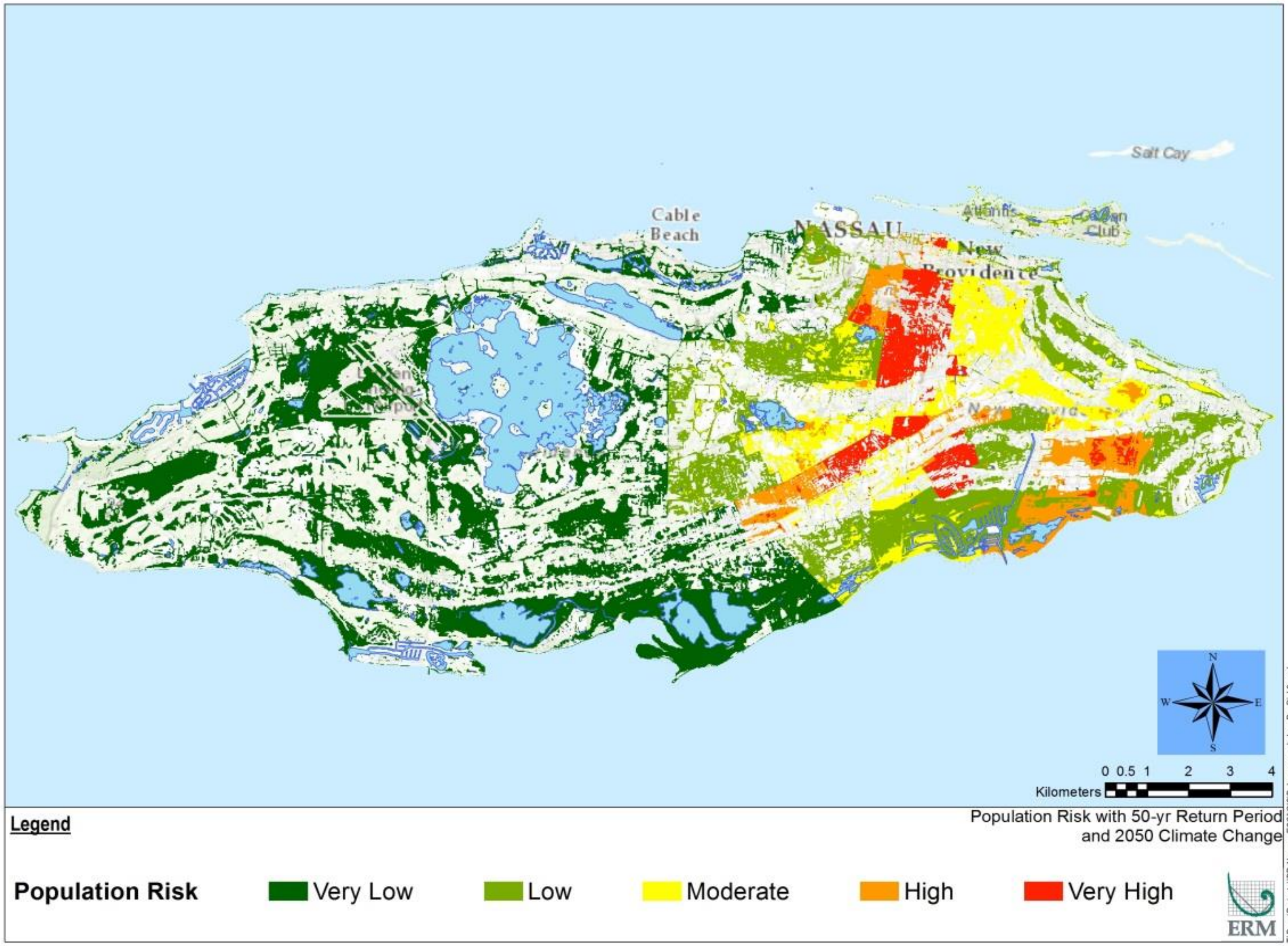

Figure A2- 38: Population risk with a 50-year return period and with 2050 climate change

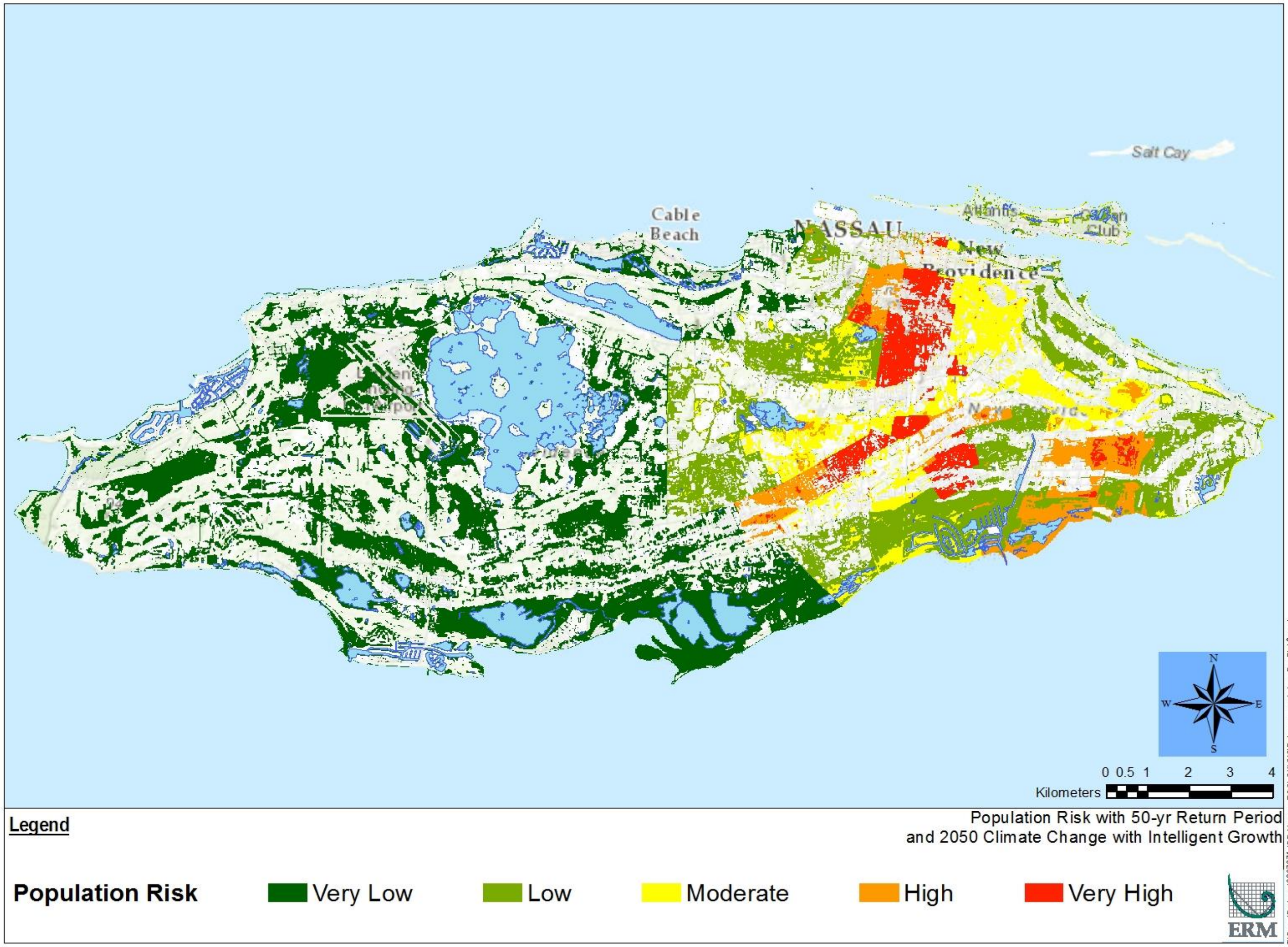

Figure A2- 39: Population risk with a 50-year return period and with 2050 climate change and intelligent growth

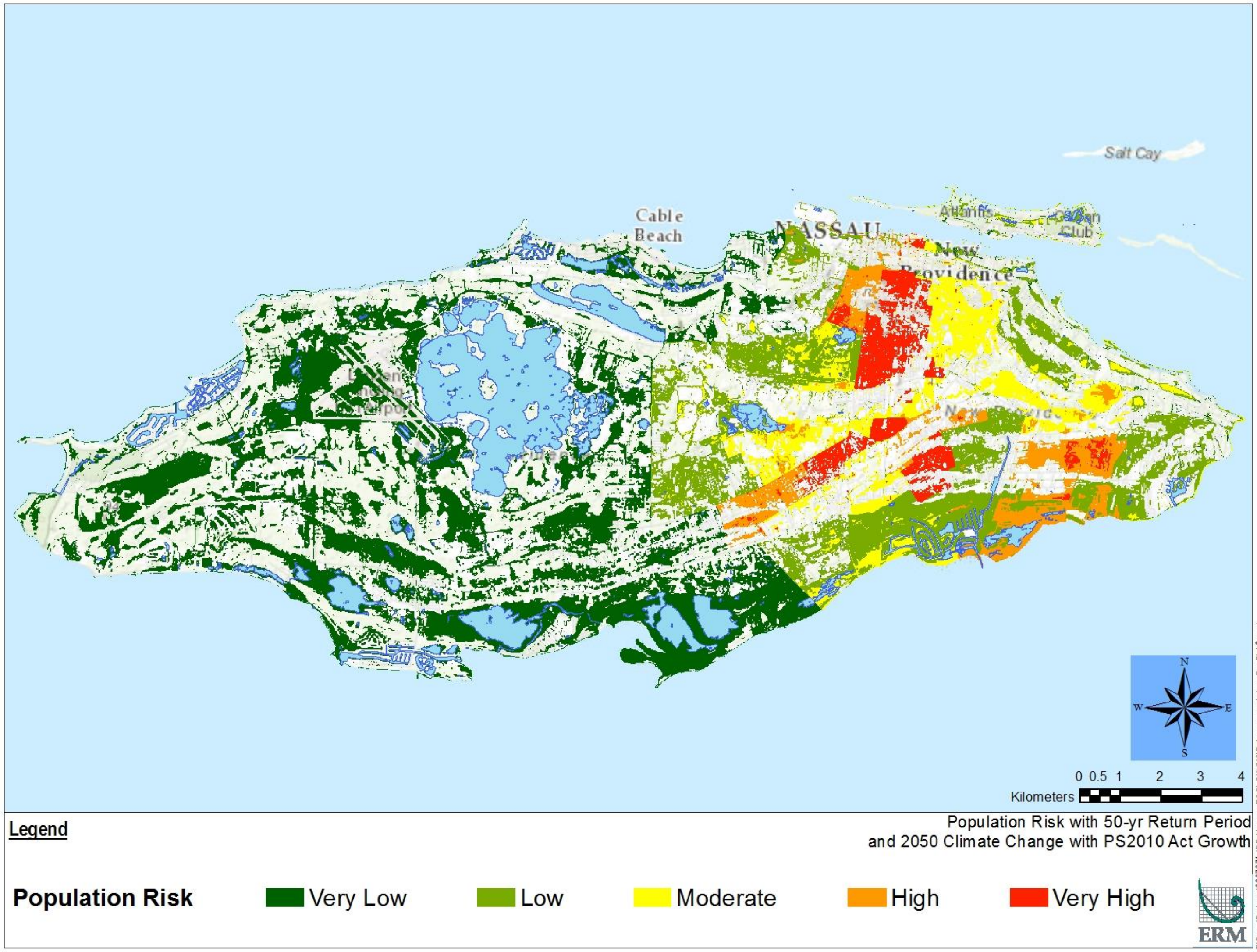

Figure A2- 40: Population risk with a 50-year return period and with 2050 climate change and Business-As-Usual growth

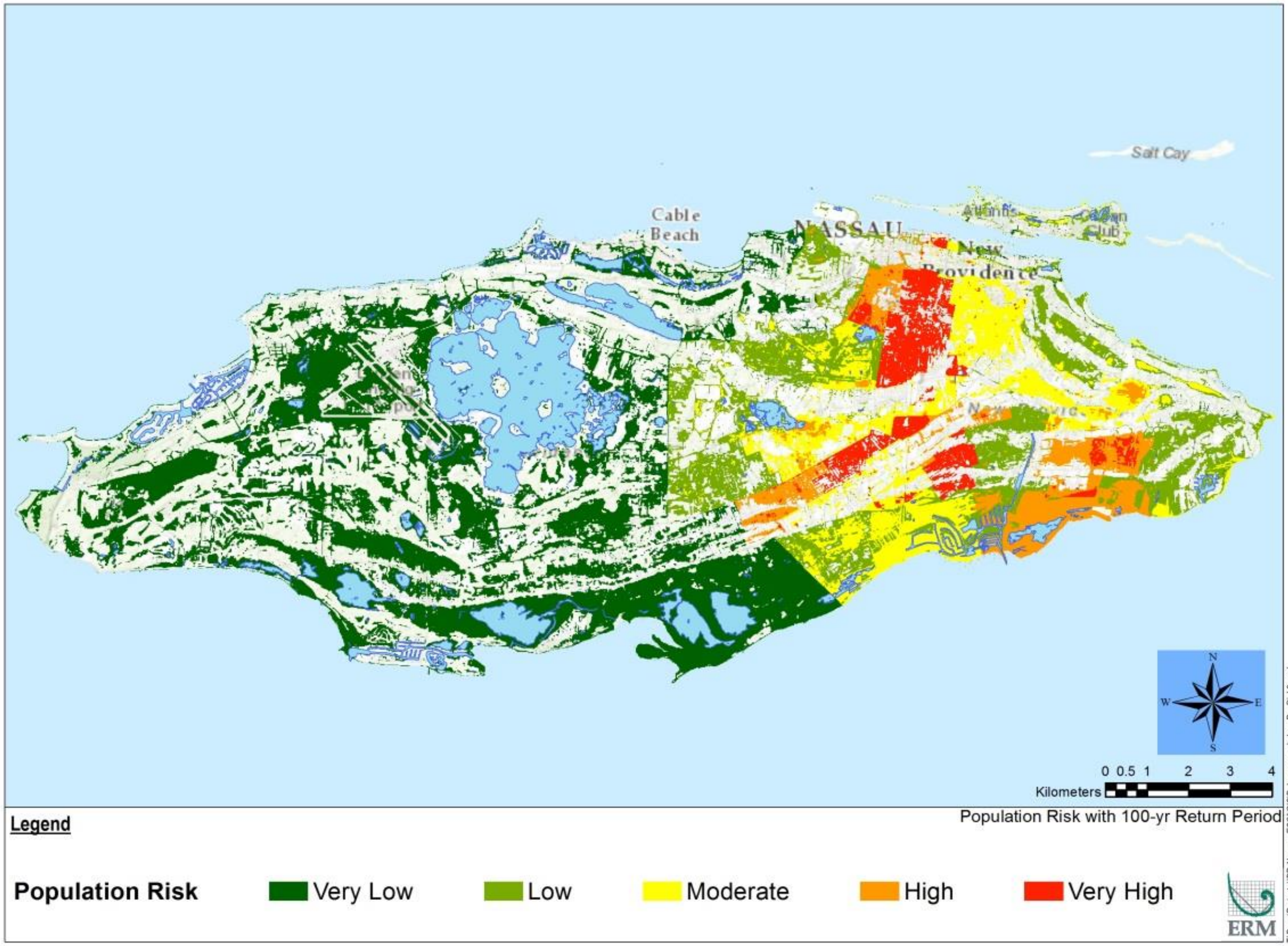

Figure A2- 41: Population risk with a 100-year return period under baseline conditions

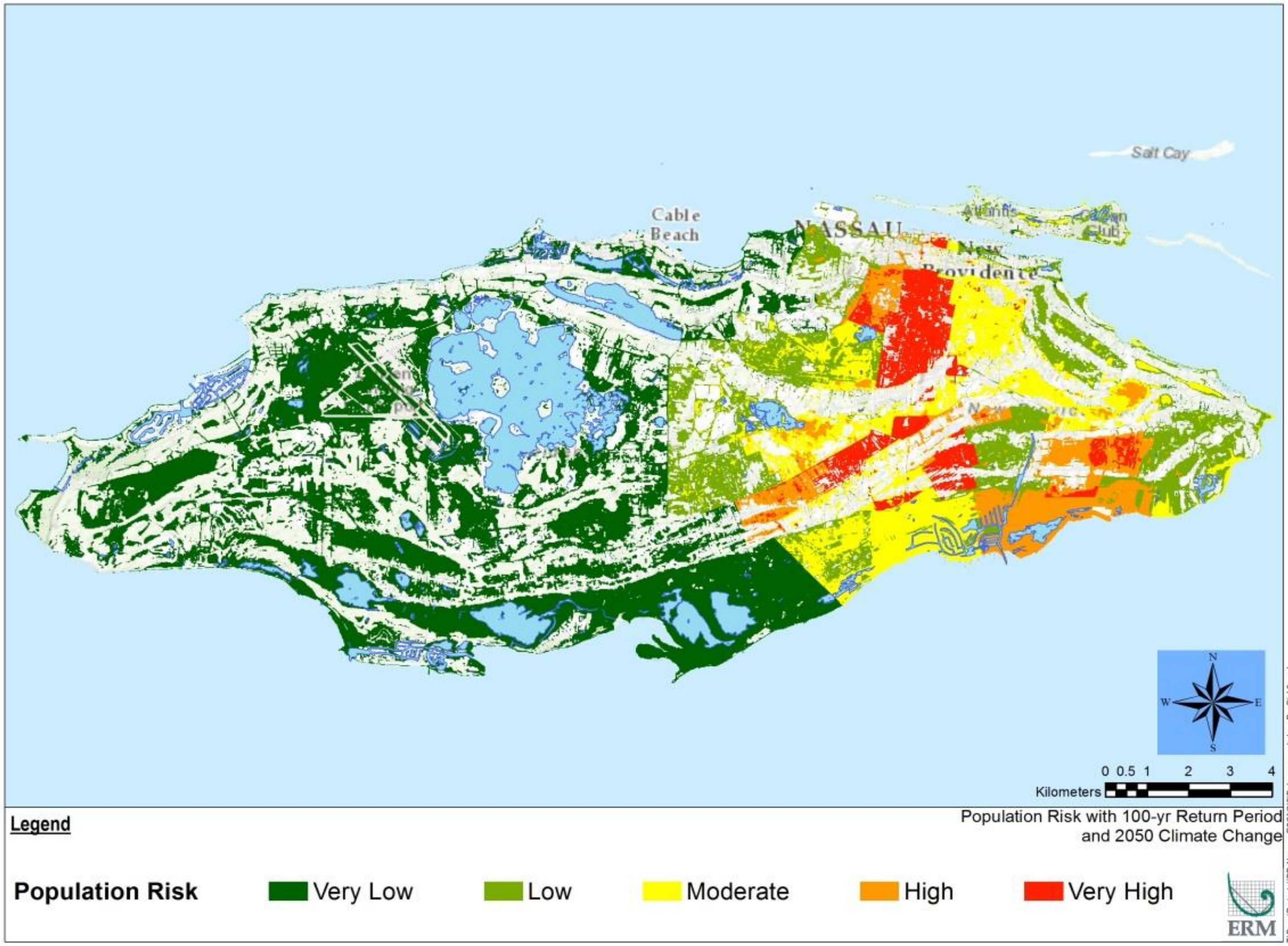

Figure A2- 42: Population risk with a 100-year return period and 2050 climate change

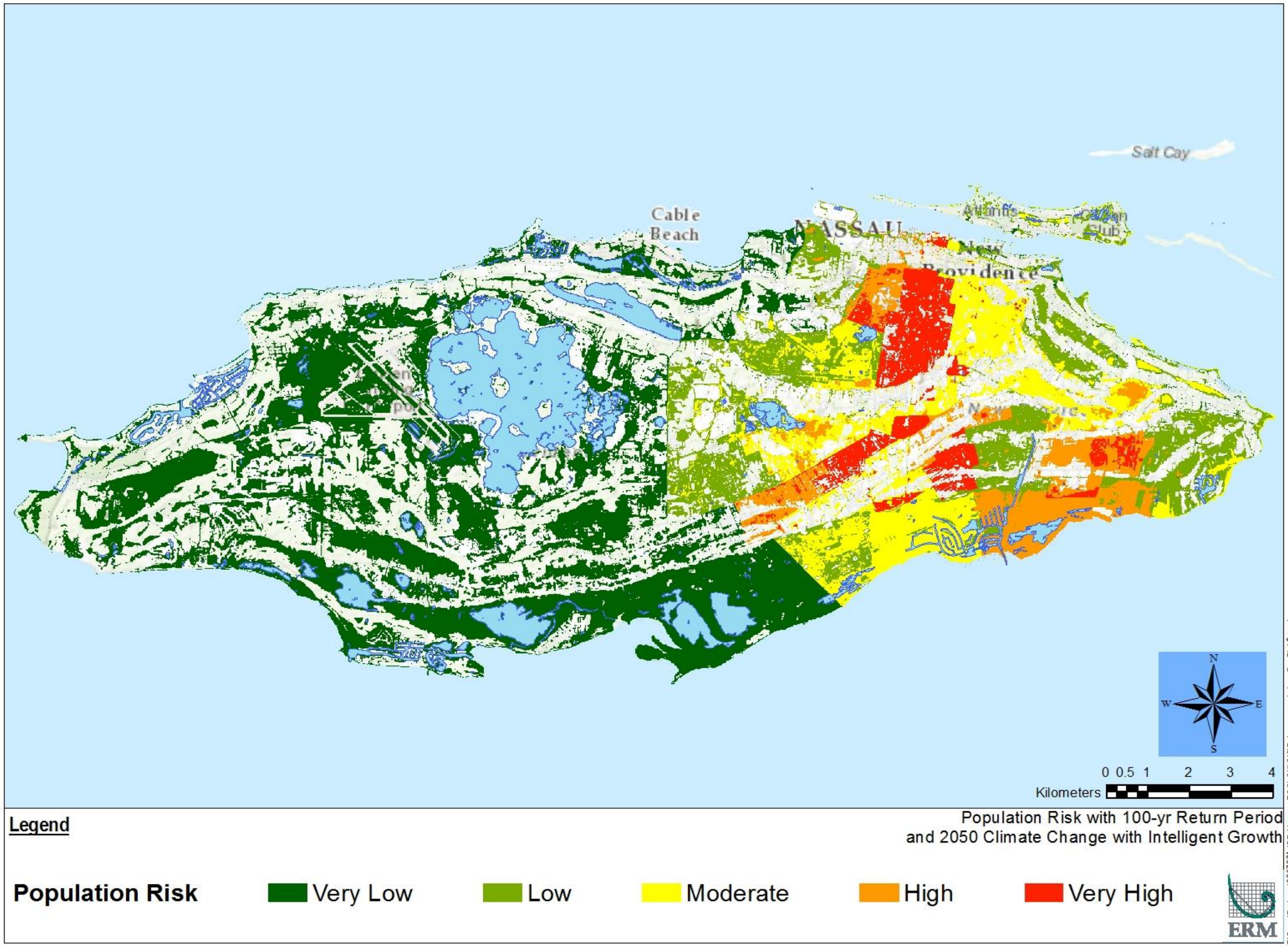

Figure A2- 43: Population risk with a 100-year return period and with 2050 climate change and intelligent growth

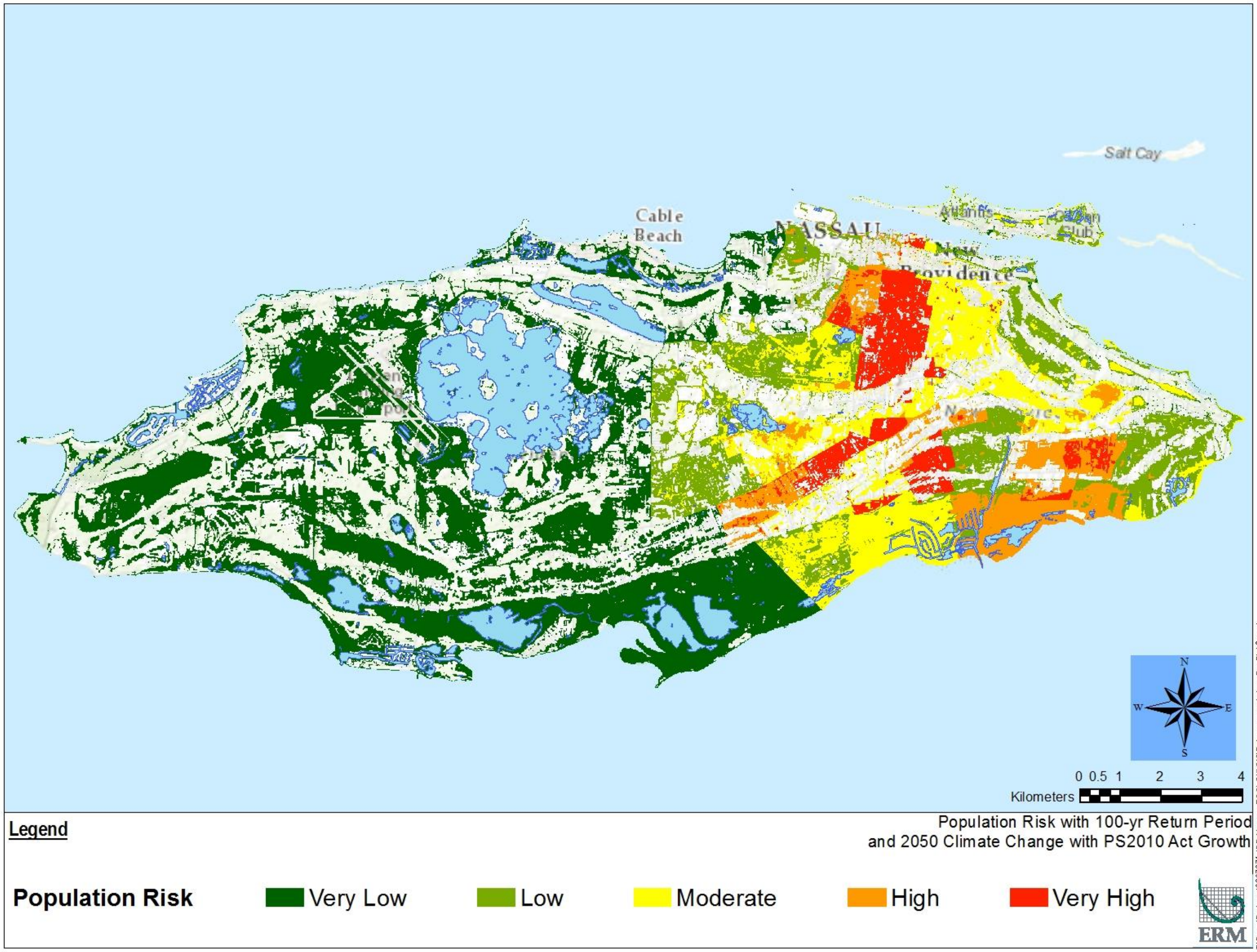

Figure A2- 44: Population risk with a 100-year return period for Business-As-Usual growth Plus 2050 climate change Scenario

A2.4 Groundwater Salinization

Among all the threats to groundwater in New Providence and Paradise Island described in *Appendix A1-Hazards Profiles*, the analysis conducted for this study only includes a high level evaluation of groundwater salinization vulnerability. The fresh water lens is a publicly available good with low barriers to access and finite supply but it is being overexploited to an extent where it is no longer available in some areas, and may pose health risks in many others in NPI (CASTALIA, 2010). Methods and results of the approach used in this study are described below.

Groundwater salinization vulnerability

Groundwater vulnerability assessments are based on indices and are typically used to map the vulnerability of groundwater to contamination. The most used index methods are DRASTIC (Aller et al., 1987) and GOD (Foster, 1987). According to Liggett and Taiwar (2009), index methods are easy to implement, inexpensive to produce, use readily available data, and often produce categorical results. These methods also evaluate vulnerability spatially over large regions and can illustrate the vulnerability of the water table or uppermost aquifers in a region. Index methods are appropriate to generate regional-scale screening tools that can be used by decision-makers, and for prioritizing focus areas and level of site assessments. However, these traditional groundwater vulnerability index methods are challenging to apply in the case of seawater intrusion vulnerability investigation because the processes leading to the migration of the freshwater-saltwater interface are different to the processes leading to the migration of a contaminant such as fertilizers or pesticides from the land surface through to the subsurface and into an aquifer. However, either the DRASTIC or GOD index method could be modified to include other parameters of relevance to conduct a seawater intrusion assessment. One of these modified methods is GALDIT, which considers the most important factors controlling seawater intrusion in coastal aquifers (Lobo-Ferreira et al., 2005).

For this study, the GALDIT index method was used to assess groundwater vulnerability salinization for aquifers located in the New Providence and Paradise islands. The acronym GALDIT is formed from the parameters used within this index-based assessment method:

- **G**roundwater Occurrence;
- **A**quifer hydraulic conductivity;
- Groundwater **L**evel relative to sea level;
- **D**istance of site from seawater;
- **I**mpact of exiting status of saltwater intrusion in the area; and
- **T**hickness of the aquifer which is being mapped.

According to Lobo-Ferreira (2005) the GALDIT factors are measurable parameters for which data are generally available from difference sources without detailed reconnaissance. Each factor is assigned a relative weighting and a rating. The weightings are pre-determined with values ranging between 1 and 4 while ratings values vary from 1 to 10. A local index of vulnerability is calculated by multiplying each rating by their weighting and adding all six products. The indices range between 13 and 130.

The equation for determining the GALDIT index is:

$$\frac{\sum_{i=1}^{6}\{(W_i)\}}{\sum_{i=1}^{6} W_i} = GALDIT - Index$$

where:

W_i is the weight of the i^{th} indicator and R_i is the importance rating of the i^{th} indicator.

Table A2-8 presents the range of weights and ratings for GALDIT while Table A2-9 shows the GALDIT vulnerability classification for different GALDIT-index.

Table A2- 8: GALDIT's Weights and Ratings

Indicator	Weight	Indicator Variables and Importance Rating
Groundwater occurrence/Aquifer type	1	Confined aquifer (10); Unconfined aquifer (7.5); Leaky confined aquifer (5); Bounded Aquifer – recharge and/or impervious boundary aligned parallel to the coast (2.5).
Aquifer Hydraulic Conductivity (m/day)	3	>40 m/day (10); 10-40 m/day (7.5); 5-10 m/day (5); and <5 m/day (2.5).
Height of ground water **L**evel above mean sea level (m)	4	<1.0 m (10); 1.0-1.5 m (7.5); 1.5-2.0 m (5); and >2.0 m (2.5).
Distance from shore/High Tide (m)	4	<500 m (10); 500-750 m (7.5); 750-1000 m (5); >1000 m (2.5).
Impact status of existing seawater intrusion ratio of $Cl/[HCO_3^{-1} + CO_3^{2-}]$	1	>2.0 (10); 1.5-2.0 (7.5); 1.0-1.5 (5); and <1.0 (2.5).
Aquifer thickness (saturated) in meters	2	>10 (10); 7.5-10 (7.5); 5.0-7.5 (5.0); and <5.0 (2.5).

m/day = meters per day; m = meters.

Source: Adapted from Lobo-Ferreira, 2005

Table A2- 9: Adapted GALDIT Vulnerability Classes

GALDIT – Index Range	Vulnerability Classes
>8.0	High
7.5 to 8.0	Moderately High
5 to 7.5	Moderate
<5	Low

Source: Adapted from Lobo-Ferreira, 2005

For this study, the importance ratings for the six indicators required by GALDIT was assigned to determine the vulnerability classes for each of the seven lenses located in New Providence Island (Table A2-10). The selection of the importance ratings was based on the available groundwater data described above and description of the indicators shown in Table A2-9.

Figure A2-45 shows a map with vulnerability indexes for groundwater salinization in New Providence and Paradise Islands. The results indicate that groundwater presents high vulnerability to salinization based on GALDIT index method. These vulnerability classes criteria shown in A2-9 considers existing physicochemical conditions and location of NPI's aquifers.

Table A2- 10: GALDIT's Weights and Ratings for New Providence Groundwater Vulnerability Analysis

Feature	Weight	Selected Importance Ratings						
		Area 1 - No freshwater	**Area 2 (-9 to 0 ft)**	**Area 3 (-19 to -10 ft)**	**Area 4 (-29 to -20 ft)**	**Area 5 (-39 to -30 ft)**	**Area 6 (-49 to -39 ft)**	**Area 7 (<-50 ft)**
Groundwater occurrence/Aquifer type	1	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Aquifer Hydraulic Conductivity (m/day)	3	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Height of ground water **L**evel above mean sea level (m)	4	10	10	10	10	10	10	10
Distance from shore/High Tide (m)	4	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Impact status of existing seawater intrusion ratio of $Cl/[HCO_3^{-1} + CO_3^{2-}]$	1	10	10	10	10	10	10	10
Aquifer thickness (saturated) in meters	2	2.5	2.5	5	7.5	10	10	10
Vulnerability		**7.7** Moderately High	**7.7** Moderately High	**8.0** Moderately High	**8.3** High	**8.7** High	**8.7** High	**8.7** High

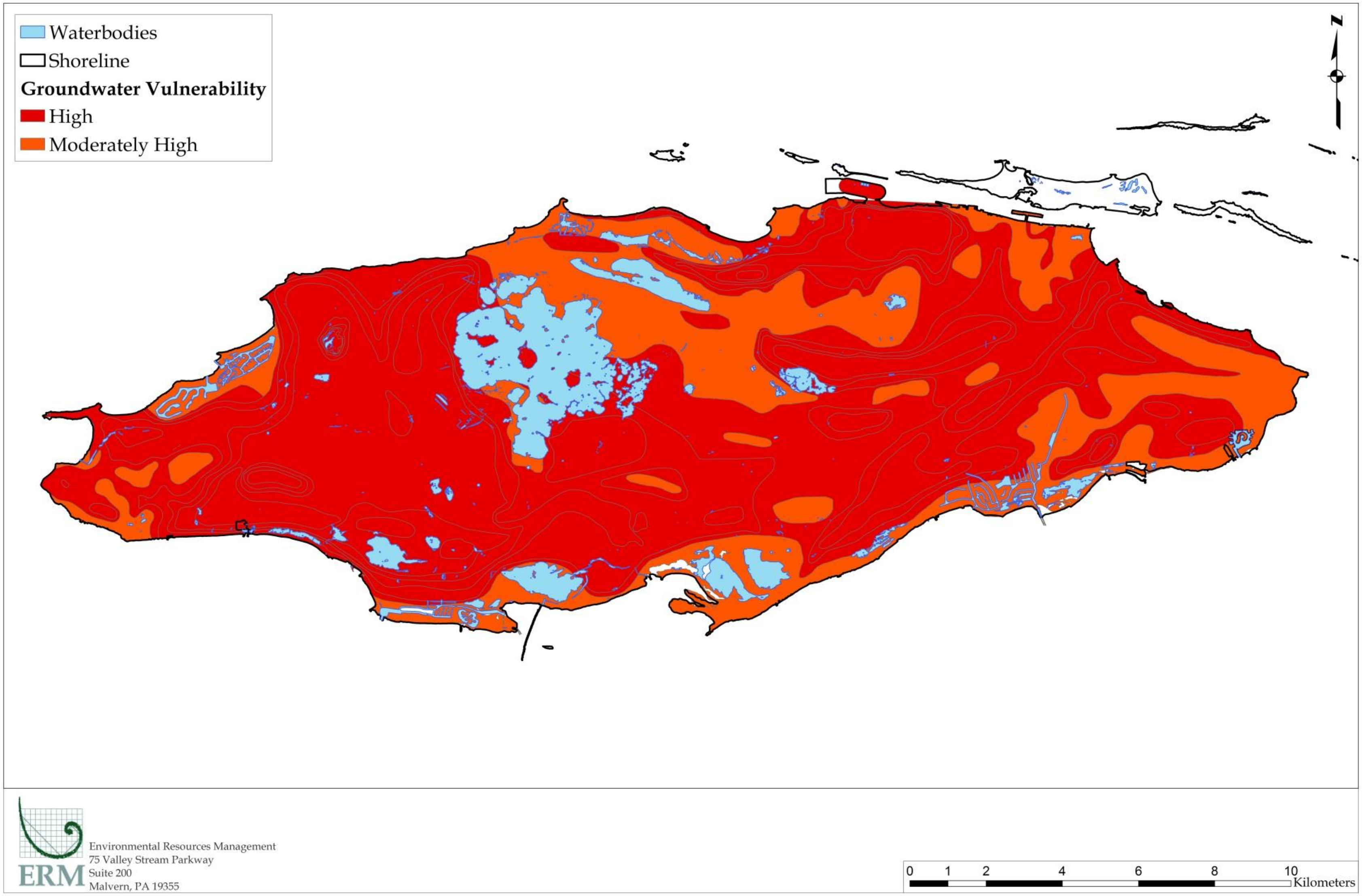

Figure A2- 45: Groundwater salinization vulnerability map of New Providence

Climate Change Effects on Fresh Groundwater Availability

The objective of this section is to evaluate how existing and future water consumption demands and climate change would affect fresh groundwater supply in New Providence and Paradise Island.

This section includes an evaluation of how aquifers in New Providence have been historically treated and how the projected reduction of precipitation and increase in population for the 2050 horizon would affect freshwater availability and demand in New Providence and Paradise islands. To conduct this assessment, ERM used historical monthly precipitation for the 1951-2015 period from the rain gauge located at the Nassau International Airport (see Figure A2-46); area and volume of the New Providence aquifers (71 km^2 and 120.4 cubic million meters), water consumption per capita; and estimated volumes of desalinated or barged water. Figure A2-47 shows results from the New Providence aquifer calculation used to evaluate the historical changes in groundwater availability. The color lines shown in Figure A2-47 indicate the changes in the following three variables:

- *Water availability (Precipitation):* This variable is calculated from monthly historical precipitation, infiltration, and aquifer area;
- *Water use:* This variable depends on population, including seasonal population fluctuations, and estimated water consumption from other sectors (i.e., agriculture, industrial); and
- *In-Out:* This is the difference between water availability and water use.

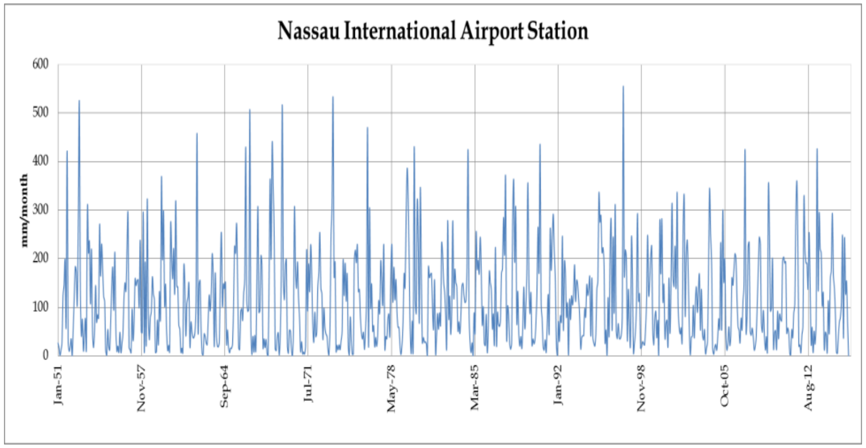

Figure A2- 46: Monthly precipitation at Nassau International Airport Station, 1951-2015

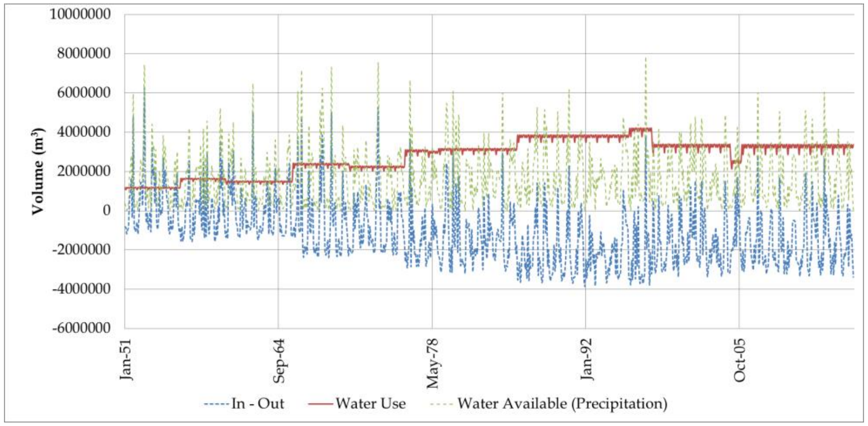

Figure A2- 47: New Providence aquifer calculation

The effects of future climate change on the New Providence aquifer were also evaluated. For this, reductions in precipitation up to 20% (see Table A1-2 in Appendix A1 *Hazards Profiles*) projected for New Providence were used for this assessment and results indicate that climate change would exacerbate the current lack of fresh groundwater combined with increases in water demands from future population growth.

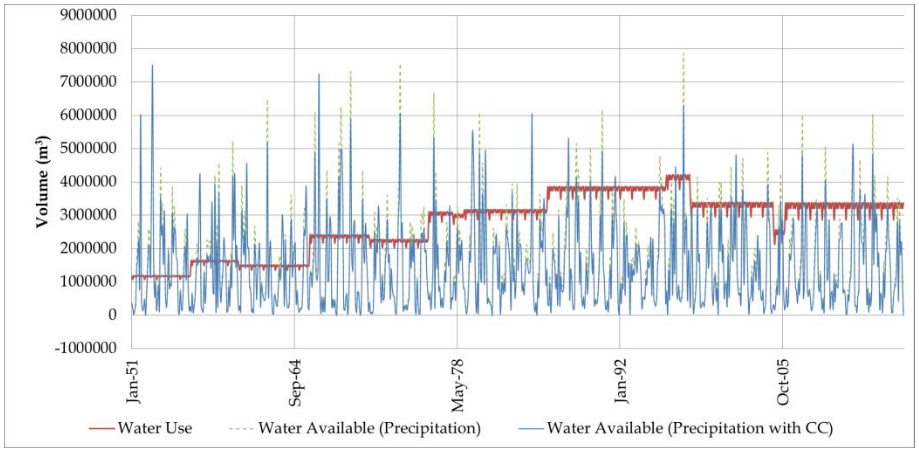

Figure A2- 48: Comparison of estimated water availability with and without Climate Change for the New Providence aquifer

As described above, the aquifers of New Providence are already affected by salinity intrusion and projected SLR has the potential to exacerbate this hazard. However, the economic development of New Providence and Paradise Island, particularly for tourism, depends on the availability of potable water (Caribbean Environmental Health Institute, 2006). This is why since 1961 the Government of Bahamas has implemented technology for desalination of seawater mainly through the use of Reverse Osmosis (RO). Other alternatives such as rainwater harvesting and bringing water in from neighboring islands (barging) have been evaluated but the cost of desalinated water in New Providence is comparable to the cost of barging water, and presents higher quality and sustainability. According to the Water and Sewerage Corporation (WSC), potable water supply for New Providence and Paradise Island completely depends on desalination process. The marginal cost of abstracting groundwater is approximately equal to the cost of the current desalination practice (a minimum of about USD$1.00 per one thousand gallons) based on a study conducted by CASTALIA (2010) in which recommendations for updating the regulatory framework for the water and sanitation sector in The Bahamas are provided. Continuing abstracting groundwater to meet water needs for NPI, results in a not environmental and socio-economical practice. It is estimated that there may be approximately 40,000 wells just on New Providence and metering, billing and collecting volumetric fees from these users would be restrictively high and most likely be beyond the capacities of the Bahamian government. It is recommended that the Government of Bahamas offers subsidies in areas where the fresh water lens is being overexploited to households or business that are using private wells that choose to switch to piped supply.

In addition to groundwater salinization, groundwater contamination, principally due to uncontrolled use of disposal of untreated wastewaters (domestic and industrial), represents another source of pollution for groundwater. Contamination of groundwater in NPI is produced by natural and anthropogenic activities such as severe weather (hurricanes and tropical storms); solid waste; sewerage (pathogens and nitrates);agriculture (pesticides, fertilizers, fungicides); coastal construction; landfills (leachate); tourism; residential; service and distribution services (release of toxic chemicals and oils); underground fuel storage tanks (leakage or spillage);and water extraction (SNC, 2014; The Bahamas National Report, 2016).

Even though, the scope of this work does not include the study of groundwater contamination, it is important to highlight groundwater resources in NPI are extremely vulnerable and prone to pollution. It is recommended to design and implement a Master Water Resources Management Plan that must be synchronized with Waste Management and Development Plans for NPI in order to preserve and restore (within the possible) the groundwater resources of NPI.

A2.5 References

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Appendix A3: Risk Reduction Assessment

Emerging and Sustainable Cities Program - Nassau

Appendix A3: Risk Reduction Assessment

A3.1 Introduction

This appendix was prepared based on results obtained from the hazard and risk assessment conducted for New Providence and Paradise Islands (see *Appendix A1* and *Appendix A2*). By considering these results, a series of general risk reduction recommendations were prepared and five mitigation strategies were explored in more detail through a cost-benefit analysis. The selection of these five adaptations considered outcomes from the workshops conducted in February 2016 in Nassau with key stakeholders, previous studies related to climate change vulnerability (i.e, SNC, 2014), and the Bahamian National Policy for the Adaptation of Climate Change (NPACC, 2005). The main objective of the NPACC is:

"to foster and guide a national plan of action, formulated in a coordinated and holistic manner, to address short, medium and long-term effects of Climate Change, ensuring to the greatest possible extent that the quality of life of the people of The Bahamas and opportunities for sustainable development are not compromised"

Below is a list of adaptations options, discussed and shared during the February 2016 workshop. These adaptations are candidates to be implemented in New Providence and Paradise Islands (NPI) to reduce risks associated to inland flooding, coastal flooding, and/or groundwater salinization.

Inland Flooding

- Education and awareness of conservation measures;
- Adapted construction and design regulations, zoning;
- Reforestation and land use planning;
- Low Impact Development (LID) such as roof gardens, porous pavement, bio-swales;
- Prevent development in low-lying areas exposed to flooding under existing and future conditions;
- Property protection;
- Provide adequate drainage ahead of new developments;
- Implement flood protection measures to existing developments by stipulating Codes and Requirements such as minimum platform levels;
- Improve drainage in flood prone areas by continually increasing drainage capacity and elevating assets in low-lying areas.

Coastal Flooding

- Install/update early warning systems;
- Restrict development along the coast;
- Restore/protect coastal buffer zones and natural environment, mangroves, similar features;
- Develop a hurricane preparedness and evacuation plan;
- Design and implement a coastal management plan;
- Prohibit excavation of canals, waterways and areas below the water table;
- Protect/nourish beaches and coastal dune formations;
- Adopt appropriate physical planning policies that will protect infrastructure from storm surges;
- Review, update and enforce building codes, especially in areas prone to high risk coastal flooding.

Groundwater Salinization

- Implement Reverse Osmosis (RO) technologies (desalinization) or alternative sources of drinking water. RO is currently used in The Bahamas;
- Consider offering subsidies in areas where fresh water lenses are being overexploited to households or business that are using private wells that choose to switch to piped supply;
- Perform hydro-census of all wells and septic systems;
- Improve sewage system, avoid using sink holes, swamps, and marshes as dump sites;
- Plan and implement a comprehensive public education program to prevent groundwater pollutions and increase conservation;
- Control rock and sand mining activities below water table;
- Prohibit excavation of canals, waterways and areas below the water table.

This appendix highlights the approach followed for a risk reduction assessment and introduces and conducts a scenario analysis for five selected adaptation strategies in high risk areas to provide an estimate of the costs and benefits. The risk reduction assessment mainly comprises all activities, including structural and non-structural measures, to avoid (prevent) or to limit (mitigate) adverse effects of hazards.

Outlining the benefits of risk reduction in terms of reduced damages and other associated benefits can help in decision making for allocating limited resources for investment in risk reduction. A Benefit Cost Analysis (BCA) is used to assess the likely costs and benefits of risk reduction measures.

The terms "mitigation alternatives" and "what if analysis" were used interchangeably to indicate options that can be taken forward for more detailed engineering analysis and specific implementation. Table A3-1 provides a list of five possible adaptations recommended for the seven Nassau Inland Adaptation Zones (NIAZs) identified for New Providence (see Figure A3-1). These areas should also be addressed comprehensively, through a master flood adaptation program. This is essential for the sustainability of NPI. Details of these NIAZs are included in section 13 of the Urban Growth Study. The five adaptations were specifically designed to address the hazards analyzed in this study for NPI.

Figure A3- 1: Seven Nassau inland adaptation zones (NIAZs)

Table A3- 1: List of Adaptations for New Providence and Paradise islands

Natural hazard	Adaptation Scenario
Inland flood	Upgrade urban drainage infrastructure
Coastal flood	Mangrove protection at the southern shoreline
Inland flood	Green infrastructure (green roofs in urban areas)
Coastal flood	Protection of coastal flooding and erosion
Inland and coastal flood	Property protection

The risk assessment that was conducted for New Providence and Paradise islands (NPI) provides the basis to assess the benefits and costs of possible adaptation measures. The risk assessment considers hazards, exposure, and vulnerability to buildings, infrastructure, and society. The overall approach followed for the BCA is shown in Figure A3-2 and considers the various benefits expected from strategies and the corresponding costs involved.

The risk metrics (annual average loss-AAL), developed for this study, were used to identify and prioritize areas or localities that are under risk. Next, the risk (loss) was analyzed after a particular adaptation option is implemented. The benefits of adaptation are then estimated by taking the difference between direct and indirect losses with and without the proposed adaptation. The benefits were estimated at present value (PV) of future (recurring) benefits considering the life of the asset that is being proposed. The costs of adaptation were also estimated including the cost of structural interventions, setting up systems, recurring maintenance costs, etc.

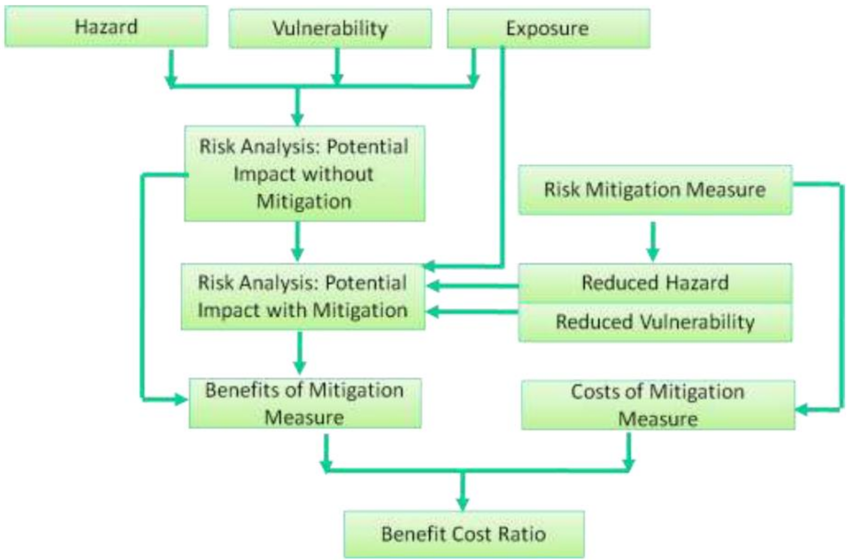

Figure A3- 2: Benefit cost analysis flowchart

A3.2 General Approach

ERM's general approach to evaluate BCA for five proposed adaptations included the use of information from the deterministic hazard and risks assessments results derived earlier in this study (see *Appendix A1- Hazards Profile* and *Appendix A2-Assets Exposed, Impacts and Losses*). The base case risk metrics (AAL) were used to identify areas or neighborhoods which are likely to benefit from the proposed adaption improvements.

The benefits to the area of interest are calculated by comparing the base case (AAL) and the AAL with the adaptation options in place. Cost benefit ratio measures the costs incurred and the benefits accrued from a policy or action.

The adaptation reduction benefit (B_{IR}) is calculated as

$$B_{IR} = X_{without} - X_{with} \qquad (1)$$

Where

- B_{IR} is the adaptation reduction benefit
- $X_{without}$ is the expected damage or economic impact without the project
- X_{with} is the expected damage or economic impact with the project

The Benefits include reduced losses to buildings in the seven identified NIAZs (see Figure A3-1) due to the improvement of the proposed adaptations. The benefits due to the reduction in losses are estimated as the difference between present values of future flood AAL with the adaptation and AAL without the adaptation. Since these benefits accrue over the life of the project, it is important to discount them to a present value so that benefits accruing at different times can be made comparable.

The benefits are estimated as present value of future recurring benefits considering the life of the system, which is the minimum time the system will be functional (i.e., 20 years). The present value of the future benefits is estimated as:

$$PV = C_o \frac{(1+d)^t - 1}{d\,(1+d)^t} \qquad (2)$$

Where

- PV is Present Value
- C_o is Cost (average annual loss)
- d is discount rate (we assumed 3% for this study)
- t is time in years (i.e., 20 years).

The benefit cost ratio (BCR) is computed by taking a ratio of present value of all benefits due to the adaptation and the total costs of the adaptation.

$$BCR = \frac{\sum Present\ Value\ of\ Benefits}{\sum Costs\ of\ Adaptation} \qquad (3)$$

Details of the five adaptations proposed for NPI are described below including estimated costs and BCR.

A3.3 Adaptation Option No. 1: Upgrade Urban Drainage Infrastructure in Downtown Nassau

Nassau Inland Adaptation Zone 6 and Zone 7 (see Figure A3-1) were selected to demonstrate how improvement to urban infrastructure can be used to effectively mitigate damage and reduce costs due to inland flooding. The example was identified to address the problem of excessive stormwater runoff and inefficient conveyance of that water to the ocean or to groundwater. The increasing urbanization and impervious cover and inadequate stormwater infrastructure result in urban flooding. Only a small portion of Nassau is serviced with formal water and sewer infrastructure, as discussed in the Urban Growth Study. We propose a development of additional storm sewers, inlets, manholes, and catch basins to alleviate the localized flooding, a programmatic clearing of existing sewer infrastructure, and to discharge the storm water into the ocean or to groundwater. The proposed project will benefit 9.6 square kilometers (km^2) in Nassau (see Figure A3-3). The estimated length of new sewer lines which run underneath roads is about 150 km. Sewer lines and tide gates at the point of discharge in to the port (ocean), or pumping stations to inject storm water to groundwater, are not included in costs of the proposed upgrade.

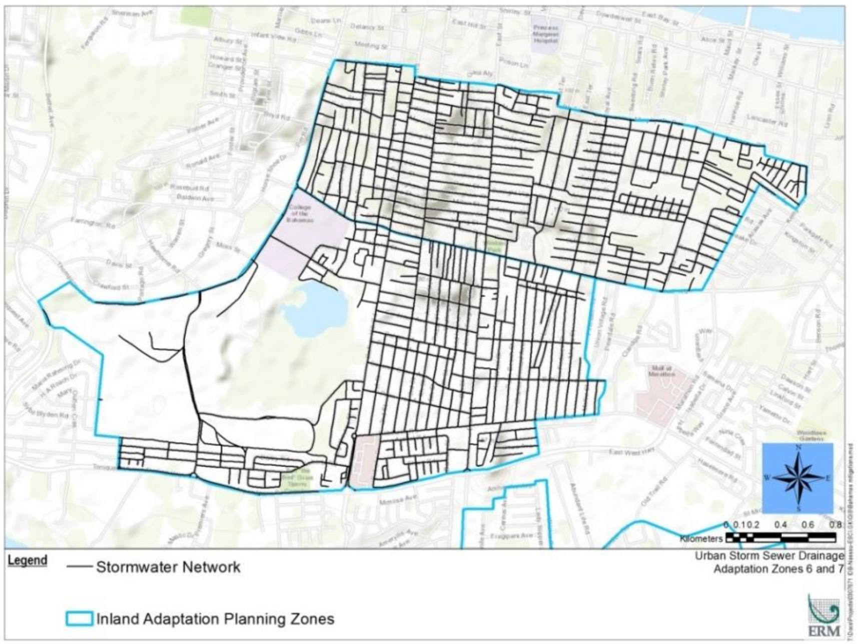

Figure A3- 3: Urban storm sewer drainage

As described above, various benefits and costs are considered in the cost benefit analysis to estimate the cost benefit ratio. The proposed urban drainage system is expected to benefit a large area of Nassau, and reduce flood losses to various exposure sectors.

Costs: Total costs were estimated according to methods and values given by Heaney (2002). Costs include concrete pipes sized 0.3048 m, 0.9144 m, and 1.524 m. It was assumed that 80% of the distance will have 0.3048 m branch pipes, 10% will have 0.9144 m trunk pipes, and 10% will have 1.524 m trunk pipes. Table A3-2 provides the costs per kilometer of different size pipes, trenches, and manholes, adapted from Heaney (2002).

Table A3- 2: Cost estimates of urban drainage system

Item	Cost (2016 USD $/km)
Manholes	47,244
12" Pipe	74,173
36" pipe	351,496
60" pipe	693,071
Trenching for 12" pipe	39,543
Trenching for 36” pipe	142,677
Trenching for 60” pipe	277,181

It was assumed that the urban drainage network will be installed along the same paths as roads. In total, Zone 6 has 74 km of roads, and Zone 7 has 76 km of roads. The total cost was calculated from the length of the system and the cost per kilometer, and is estimated to be USD $21.2 million for Zone 6 and USD $21.6 million for Zone 7.

Benefits were estimated by assuming a loss reduction of 50% of the AAL within both zones. The loss reduction may be even higher provided that the storm water system is designed to handle a 100-year event.

The costs, benefits, and present values for the urban drainage systems are provided in Table A3-3. The base case is the status quo, losses without adaptation.

Table A3- 3: Benefit-cost analysis of urban drainage system in Nassau (in millions USD$)

Particular	Details	Base Case	Adaptation
Basis	Life, Years	20	
	Growth factor	14.9	
Flood AAL	Inland Adaptation Zone 6	80.6	40.3
	Inland Adaptation Zone 7	145	72.3
Present value of future losses	Inland Adaptation Zone 6	1,201	600
	Inland Adaptation Zone 7	2,154	1,077
Costs	Zone 6 Urban Drainage System		21.2
	Zone 7 Urban Drainage System		21.6
	TOTAL COST		**42.8**
Present value of Benefits	Inland Adaptation Zone 6		600
	Inland Adaptation Zone 7		1,077
	TOTAL BENEFIT		**1,677**
Benefit Cost Ratio	Benefit Cost Ratio		**39**

Base Case: The results from base case analysis of the deterministic risk assessment were used to establish this scenario. The results from the defined beneficiary urban area suggest that AAL for buildings due to floods is USD $225 million. The present value (PV) of future flood AAL to buildings in the base case is estimated over 20 years to be USD $3,355 million.

Benefit Cost Ratio of adaptation: Since the total cost of construction of the upgrade is estimated to be USD $42.8 million, the total PV of the benefits with the proposed upgrades is estimated to be USD $1,677 million.

Considering the total benefits of USD $1,677 million against the total costs of the adaptation USD $42.8 million, the BCR for this adaptation is 39. Considering the satisfactory BCR of this adaptation, this adaptation may be taken forward for possible planning, pre-feasibility study.

A3.4 Adaptation Option No. 2: Protection of Mangroves at the South Shore

Mangrove destruction on the south shore of New Providence Island has been a growing concern. An increasing population and urbanization have encroached on the south shore environment. The changed land use and vegetation can have an effect on the hazard potential and vulnerability at parts of the south shore. Restoration and protection of existing mangroves is proposed as an adaptation to reduce coastal flooding. An example of this type of adaptation implemented in The Bahamas is the Mangrove Restoration in Bonefish Pond National Park (Dahlgren, 2013). Figure A3-4 presents the proposed locations where Mangrove protection/restoration could be implemented.

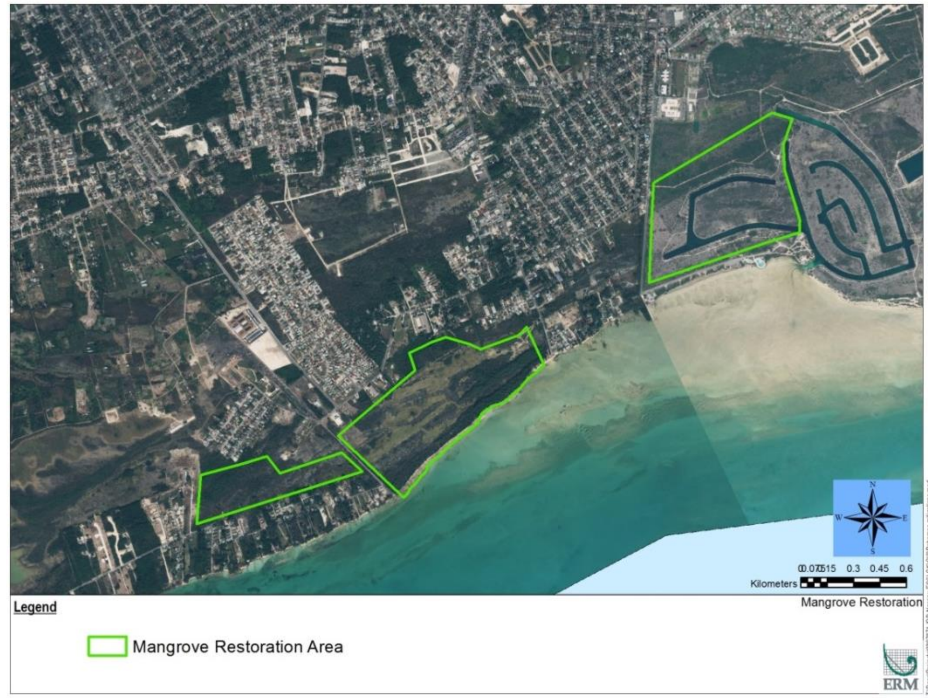

Figure A3- 4: Potential beneficiary area for mangrove protection

Natural features like Mangroves help to absorb large volumes of advancing water, and as a result, have a dissipating effect on wave energy. In this regard the mangrove forests at the southeast of New Providence are important for mitigating the effects of coastal flooding and erosion. It is proposed to reforest an area of approximately 1.2 km^2 of Mangroves at the southeast coastal sector of New Providence (see Figure A3-4). With the reduced flood inundation, it is expected the risk of flooding in the area of interest (at southeast coast of New Providence) will also be reduced. Probabilistic risk assessment results derived earlier in this study were used to estimate the reduction in risk and overall benefits (losses avoided). The base case risk metrics (AAL) have been used to identify the area of interest which may be benefited (approximately 2.95 km^2).

Costs: The costs of this measure include the costs of planting and conservation of mangrove trees. The project cost for implementing this measure in an area of approximately 1.2 km^2 is estimated at USD $11.8 million considering a unit cost of USD $10 million per km^2 based on values reported in literature (i.e., King and Bohlen, 1994; Lewis III, 2016). The costs are assumed one-time investments with expected benefits spread over the life of the system. The life of the system has been taken as 50 years.

Benefits: For this project, a portion of the direct tangible benefits of a flood damage reduction is expected as inundation decreases. The benefits include reduced losses to buildings due to the mangrove protection. The benefits due to the reduction in losses for various sectors (as shown in the equation No. 1 above) are estimated as the difference between present values of future flood AAL with the adaptation and AAL without the adaptation. Since these benefits accrue over the life of the project, it is important to discount them to a present value so that benefits accruing at different times can be made comparable.

The life of the system is usually considered as the minimum time period in which the system will be functional. Though, the average life of the mangrove is generally more than 50 years, but the benefits starts with the complete maturity of the plants and established of renewed ecosystem cycle in the area. Hence, in this case the life of the system is taken as 50 years.

The outcome of the PV (see equation No. 2) is the present value of future benefits over time (considered as the life of the system). The total present values of benefits with the proposed adaptation action is USD $105.3 million.

Table A3-4 lists the values used in the adaptation evaluation of mangrove protection. The base case is the status quo, losses without adaptation.

Table A3- 4: Benefit cost analysis of m Mangrove protection in southeast of New Providence (millions USD$)

Particular	Details	Base Case	Adaptation
Basis	Life, Years	50	50
	Growth factor	25.7	25.7
Flood AAL	Economic Risk	13.6	9.6
Present value (PV) of future losses	Economic Risk	351	245.7
Costs	Cost of Mangrove Protection/restoration		**11.8**
	TOTAL COST		
Present value of Benefits	TOTAL BENEFIT		**105.3**
Benefit Cost Ratio	Benefit Cost Ratio		**8.9**

Benefit Cost Ratio of adaptation: Since the total cost of planting/preserving mangroves is estimated to be USD $11.8 million, the total PV of the benefits with the proposed mangrove protection is estimated to be USD $105.3 million.

The benefit cost ratio (BCR) is computed by taking a ratio of PV of all benefits due to the adaptation and the total costs of the adaptation (see Equation No. 3). Considering the total benefits of USD $105.3 million against the total costs of the adaptation USD $11.8 million, the BCR for this adaptation is 8.9. A BCR greater than 1.0 suggests that the benefits outweigh the costs of the adaptation and that the adaptation is a positive investment. Considering the satisfactory BCR of this adaptation, it may be taken forward for possible planning, pre-feasibility study.

A3.5 Adaptation Option No. 3: Green Roofs in Urban Areas

Green roofs are considered green infrastructure that are interconnected network of open spaces and natural areas, such as greenways, wetlands, parks, forest preserves and native plant vegetation that naturally manages stormwater and reduces flooding risk (Center for Neighborhood Technology, 2008). Other green infrastructure includes bio-retention, and porous pavement, among others. Benefits associated with the use of green infrastructure include reduction of flooding, mitigation and adaptation to climate change, and supply of freshwater[8].

Nassau Inland Adaptation Zones (NIAZs) from 1 to 7 (see Figure A3-4) were selected to demonstrate how green roofs can be used to effectively mitigate damage and reduce costs due to inland flooding. The example was identified to address the problem of excessive stormwater runoff. In general, institutions such as hospitals and schools are good candidates for building green roofs. However, further designs would be needed to determine the most feasible locations of green roofs. The increasing urbanization and impervious cover and inadequate stormwater infrastructure result in urban flooding combined with the limited availability of open spaces in the island. Based on these conditions, we propose the use of green roofs as an alternative to alleviate the localized flooding. The proposed project may benefit approximately 21 km^2 in Nassau (see Figure A3-4) if the NIAZs are only considered. The estimated area for installing green roofs within the seven Nassau NIAZs is about 3.7 km^2. For this analysis, we assumed that only 10% of the 3.7 km^2 of roofs from houses located within the seven NIAZs will be candidates to implement green roofs.

Costs: Total costs are based on values obtained from different Green roof companies[9],[10] and EPA (2015). Costs include installation (USD$269/$m^2$) and annual maintenance (USD$17/$m^2$/year).

It was assumed that the green roof will be installed in 10% of the roofs located within the seven NIAZs. The total cost was calculated from the estimated roofs areas and the cost per m^2, and was estimated to be approximately USD $218 million for the seven NIAZs.

Benefits were estimated by assuming a loss reduction of 30% of the AAL within the seven NIAZs. The costs, benefits, present values for the green roofs systems are provided in Table A3-5. The base case is the status quo, losses without adaptation.

Table A3- 5: Benefit-cost analysis of green roofs in Nassau (in millions USD$)

Particular	Details	Base Case	Adaptation
Basis	Life, Years	20	20
	Growth factor	14.9	14.9
Flood AAL	Inland Adaptation Zone 1 to 7	419.1	293.4
Present value of future losses	Inland Adaptation Zone 1 to 7	6,235	4,364
Costs	Green Roofs		218
	TOTAL COST		**218**
Present value of Benefits	Inland Adaptation Zone 1 to 7		1,870
	TOTAL BENEFIT		**1,870**
Benefit Cost Ratio	Benefit Cost Ratio		**9**

Base Case: The results from base case analysis of the deterministic risk assessment were used to establish this scenario. The results from the defined beneficiary urban area suggest that AAL for buildings due to floods is approximately USD $419 million. The present value of future flood AAL to buildings in the base case is estimated over 20 years to be USD $6.2 billion.

Benefit Cost Ratio of adaptation: Since the total cost of construction and maintenance of the green roofs is estimated to be USD $218 million, the total present value of the benefits with the proposed adaptation is estimated to be USD $1,870 million.

Considering the total benefits of USD $1,870 million against the total costs of the adaptation USD $218 million, the BCR for this adaptation is 9. Considering the satisfactory BCR of this adaptation, this adaptation may be taken forward for possible planning, pre-feasibility study.

[8] http://www.gsa.gov/portal/mediaId/167839/fileName/Cost_Benefit_Analysis.action

[9] http://www.royalgrass.com/artificial-grass/green-roof
[10] https://www.renewableenergyhub.co.uk/how-do-green-roofs-work.html

A3.6 Adaptation Option No. 4: Protection of Coastal flooding and erosion

Coastal flooding and erosion along the shores of New Providence Island have been a growing concern. Encroaching population and urbanization practices have increased the susceptibility of damage from coastal flooding and erosion. Ongoing climate change and sea level rise (SLR) will increase the uncertainty and the risk of larger damages. A coastal management plan is proposed to mitigate the effects of coastal flooding and erosion along the shores of New Providence Island.

A coastal management plan is developed to provide for sustainable protection, conservation and management of the coastal zone. The following activities are proposed:

- *Activities on the coast* to interrupt the excessive fluctuations of the coast due to erosion and accretion, and protect against coastal flooding. These activities involve the construction of hard- or soft-engineering structures in order to prevent excessive erosion. Typical hard-engineering structures include: seawalls and ripraps for small coastal protection near houses and urban areas, and breakwaters and groins for larger coastal protection projects. Typical soft-engineering structures include: beach nourishment and beach drains. The costs these structures are reported in Table A3-6.

- *Activities on the land* to stabilize the near-shore environment against wind and water erosion, and to enhance dune-building processes. These activities can be proposed to enhance the coastal protection and habitat. Typical activities on land involve the strengthening, protection and construction of landforms such as sand dunes or erosion control structures. The cost of these operations varies widely depending on the length and width of the area to be managed. A typical cost range per dune revegetation can be set at USD$3 to USD$300 per lineal meter.

Table A3- 6: Typical cost of hard- and soft- engineering structures for coastal protection

Structure type	Structure	Total cost
Hard-engineering	Seawalls (riprap excluded)	$1600 - $4000 per lineal meter
	Riprap	$4200 - $6400 per cubic meter
	Breakwater	$3300 - $9800 per lineal meter
	Groins	$1600 - $6600 per lineal meter
Soft-engineering	Beach nourishment	$160 - $500 per lineal meter
	Beach drainage	$70 - $300 per lineal meter

The proposed adaptation is expected to benefit a large area of New Providence Island, and provide for sustainable protection, conservation and management of its coastal zone. Figure A3-5 shows the potential coastal areas where this proposed adaptation can be applied.

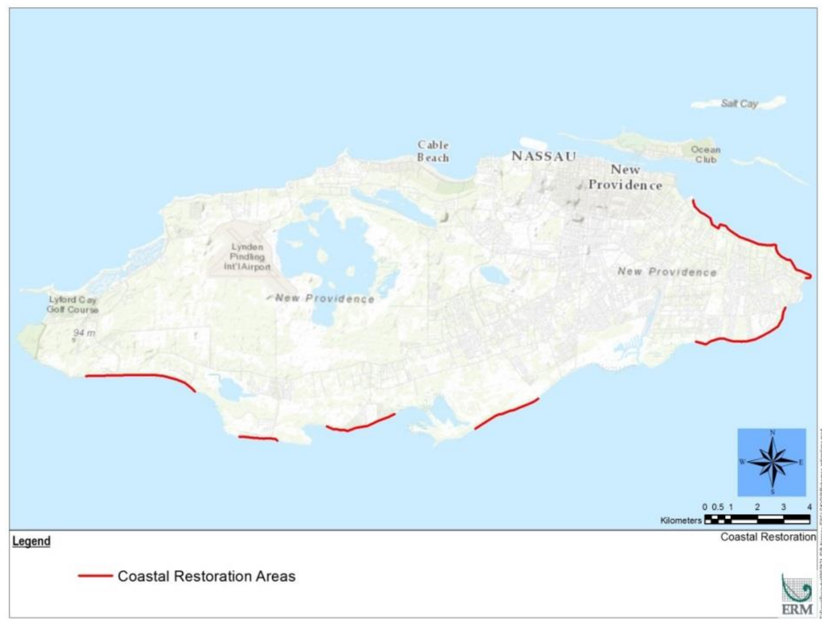

Figure A3- 5: Potential coastal restoration areas

Costs: Total costs are based on values shown in Table A3-6 and do not include costs associated with labor and maintenance. The total cost is estimated to be approximately USD $72.9 million for the coastal areas shown in Figure A3-5.

Benefits were estimated by assuming a loss reduction of 30% of the AAL within coastal zones. The costs, benefits, present values for the proposed adaptation are provided in Table A3-7. The base case is the status quo, losses without adaptation.

Table A3- 7: Length and costs of coastal flooding structures for selected areas (in millions USD$)

Particular	Details	Base Case	Adaptation
Basis	Life, Years	20	
	Growth factor	14.9	
Flood AAL	AAL for coastal flooding restoration areas	101.8	71.2
Present value of future losses		1,514	1,060
Costs	Cost of Groins		40.5
	Cost of Seawalls		32.4
	TOTAL COST		**72.9**
Present value of Benefits			
	TOTAL BENEFIT		**454**
Benefit Cost Ratio	Benefit Cost Ratio		**6.2**

Base Case: The results from base case analysis of the deterministic risk assessment were used to establish this scenario. The results from the defined beneficiary urban area suggest that AAL for buildings due to coastal floods is approximately USD $101.8 million. The present value of future flood AAL to buildings in the base case is estimated over 20 years to be USD $1.5 billion.

Benefit Cost Ratio of adaptation: Since the total cost of construction of infrastructure for coastal protection is estimated to be USD $72.9 million, the total present value of the benefits with the proposed adaptation is estimated to be USD $454 million. Considering these total costs and PV of the benefits, the BCR for this adaptation is 6.2 and this adaptation may be taken forward for possible planning, pre-feasibility study.

A3.7 Adaptation Option No. 5: Property Protection

In order to protect buildings and communities, properties can be protected through means of barriers such as berms, flood proofing, or Invisible Flood Control Walls (IFCW) (Flood Control America, 2014). Ideally, these protecting structures are integrated into the existing landscape and buildings to minimize negative aesthetics, or even improve the aesthetics of properties. Berms and levees are embankments made of earthen, concrete, or other materials to hold back flood waters. Flood proofing is a method of upgrading existing structures with materials and methods that reduce the building's vulnerability to flooding (see Figure A3-6). Floodproofing includes waterproofing walls and floors, interior drainage systems and pumps, flood shields, and closures which seal openings such as windows on a permanent or temporary basis, i.e. when flooding occurs (FEMA 1986). Most temporary flood shields are constructed of metal (primarily steel and aluminum) (FEMA 1986).

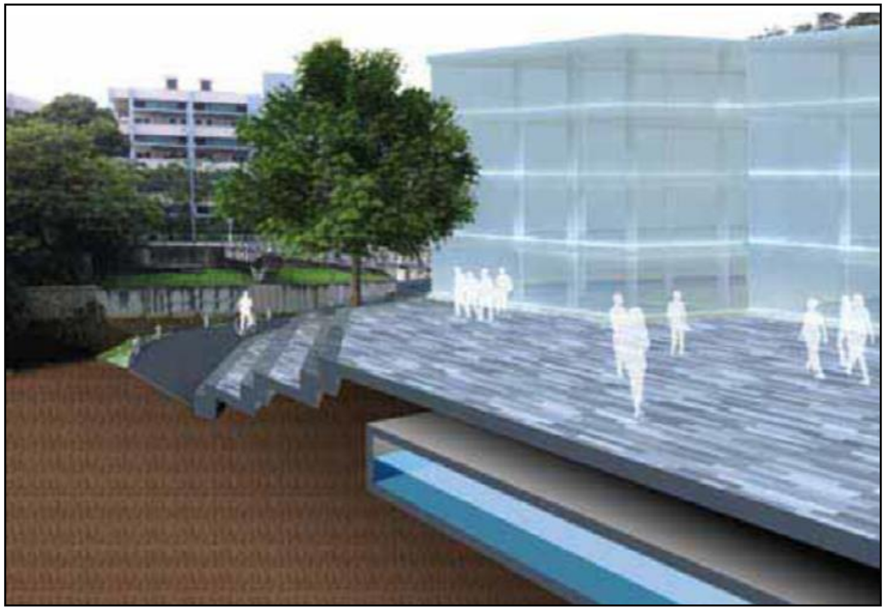

Figure A3- 6: Example of floodproofing a building with an interior drainage system

An IFCW (see Figure A3-7) can be installed around structures which cannot be raised or relocated, and would experience floods in spite of other adaptation measures. The IFCW, a product of Flood Control America (2014), is a removable wall that is erected only during the threat of a flood. Patented, twenty-foot sealed, interlocking, hollow aluminum planks stack on top of a sill plate integrally constructed on a permanent concrete foundation. Intermediate posts provide additional support. Flood barriers may also provide secondary benefits such as reducing inflow to the sewer system. A floodwall has the advantage of preventing floodwaters from reaching the structure and protecting surrounding areas from inundation. However, floodwalls may also be cost prohibitive, require maintenance, or affect local drainage, possibly creating or worsening flood problems for others (FEMA, 2007).

Figure A3- 7: Invisible Flood Control Wall

Several institutional buildings in Nassau were identified as high flood risk with high economic and/or societal value. These buildings are the best initial candidates for property protection. The first institutions are Her Majesty's Prison and the Sandilands Rehabilitation Centre. This location is susceptible to both inland and coastal flooding, would incur economic losses if damaged, and has high societal value. Unique to prisons and hospitals is the difficulty of evacuating people in the event of a natural disaster. A combination of earthen berms and IFCWs could be placed around the prison and center in conjunction with existing security measures. Because of the size of the property and available open space, flood barriers around the entire perimeter could be infeasible, and this property would also benefit from green infrastructure discussed above such as detention basins. The location of potential flood barriers is presented in Figure A3-8. If this or other properties are chosen for implementation of the adaptations, further designs would be needed to determine the most feasible locations of floodwalls or floodproofing.

The second set of institutions are the CV Bethel Senior High School, South Beach Public Library, and the South Beach Clinic. This area is at risk of flooding from 50-year and 100-year coastal storm surges at depths up to 2 meters. Permanent and IFCW protection around the perimeter could protect these key buildings. The third and fourth structures are the Bahamas Academy along Marshall Road, and the Antol Rogers High School. Both areas are at risk due to 50-year and 100-year coastal flooding. Other buildings throughout Nassau may benefit from flood proofing, berms, or IFCWs. In general, institutions such as hospitals and schools are good candidates for building specific flood protection. This list identifies the buildings which are at the highest risk and could gain the greatest benefit from adaptations. The location of potential flood barriers is presented in Figures A3-8 to A3-10.

Figure A3- 8: Property protection flood barriers at Her Majesty's Prison and Sandilands Rehabilitation Centre

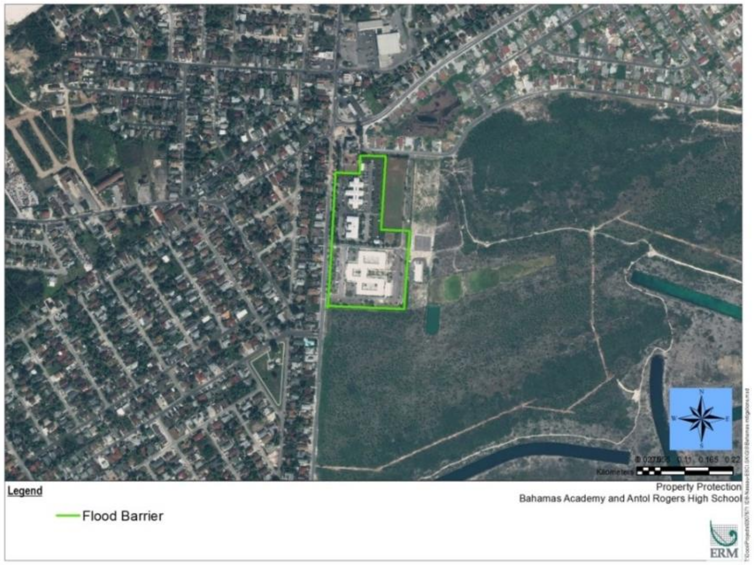

Figure A3- *9*: *Property protection flood barriers at CV Bethel Senior High School*, South Beach Public Library, and the South Beach Clinic

Figure A3- 10: Property protection flood barriers at Bahamas Academy and Antol Rogers High School

A cost-benefit analysis of implementing flood control barriers was conducted for the above locations. The costs include construction of permanent or semi-permanent (IFCW) walls to protect buildings.

Costs were estimated based on FEMA (2007). In most areas, a 2-meter floodwall will be sufficient, and the cost is approximately $640 per linear meter (FEMA, 2007). The length of floodwalls for each example area and the total costs are provided in Table A3-8.

Benefits are estimated based on the property values assessed in *Appendix A2*, at $10,000,000 per institutional property, and the AAL from coastal and inland flooding.

Table A3- 8: Length and costs of floodwalls for selected properties

Building	Length of floodwall (m)	Total cost (USD $)
Her Majesty's Prison and Sandilands Rehab	1530	979,080
CV Bethel Senior High School, South Beach Public Library, and the South Beach Clinic	1051	672,187
Bahamas Academy	438	279,910
Antol Rogers High School	531	339,725

Results of the cost benefit analysis for property protection of seven institutions are presented in Table A3-9. The total cost of flood barriers will be USD $2.27 million, and the total benefit will be USD $48 million, and the BCR for this adaptation is 21. Considering the satisfactory BCR of this adaptation, this adaptation may be taken forward for possible planning, pre-feasibility study.

Table A3- 9: Property protection cost benefit analysis (in millions USD$)

Particular	Details	Base Case	Adaptation
Basis	Life, Years	20	20
	Growth factor	14.9	14.9
Flood AAL	Total AAL for 7 properties	6.5	3.2
Present value of future losses		96	48
Costs	Total costs for floodwalls		2.27
	TOTAL COST		**2.27**
Present value of Benefits			
	TOTAL BENEFIT		**48**
Benefit Cost Ratio	Benefit Cost Ratio		**21**

A3.8 References

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