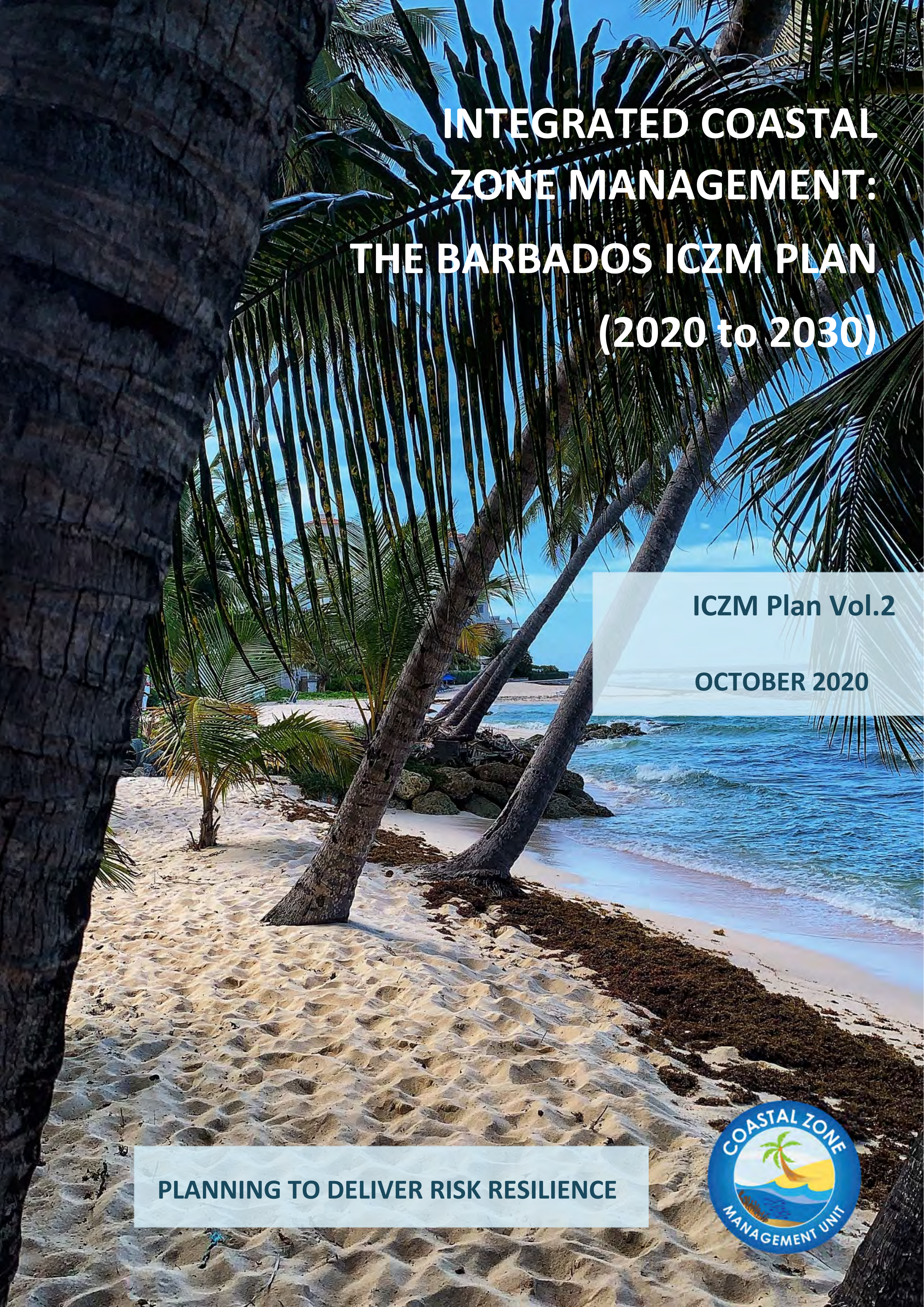

INTEGRATED COASTAL ZONE MANAGEMENT: THE BARBADOS ICZM PLAN (2020 to 2030)

ICZM Plan Vol.2

OCTOBER 2020

PLANNING TO DELIVER RISK RESILIENCE

COASTAL ZONE MANAGEMENT UNIT

INDEX

(OCTOBER 2020)

INDEX

ACRONYMS

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ACRONYMS

AAL	Average Annual Loss
BBMP	Barbados Beach Management Plan
BIO	Biodiversity Conservation and Coastal Habitat Restoration
BM	Beach Management
BMS	Barbados Meteorological Service
BNSI	Barbados National Standards Institute
BSS	Barbados Statistical Service
BTA	Barbados Tourism Authority
CBMP	Carlisle Bay Marine Park
CCA	Climate Change Adaptation
CCU	Climate Change Unit
CDEMA	Caribbean Disaster Emergency Management Agency
CI	Construction and Maintenance of Coastal Structures
CRMP	Coastal Risk Management Programme
CZM	Coastal Zone Management
CZMA	Coastal Zone Management Area
CZMU	Coastal Zone Management Unit
DEM	Department of Emergency Management
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
EbA	Ecosystem-based Adaptation
ED	Enumeration District
EEZ	Exclusive Economic Zone
EI	Emerging Issues
EPA	Environmental Protection Area
EPD	Environmental Protection Department

ESIA	Environmental and Social Impact Assessment
FPMR	Folkestone Park and Marine Reserve
GHG	Greenhouse gases
GoB	Government of Barbados
GSI	Geological Survey Investigation
HWM	High Water Mark
ICZM	Integrated Coastal Zone Management
IDB	Inter-American Development Bank
IDD	Disaster Deficit Index
IMP	Integrated Monitoring Programme
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LEC	Loss Exceedance Curves
MAP	Marine Protected Area
MMA	Marine Managed/Management Area
MMABE	Ministry of Maritime Affairs and the Blue Economy
MPW	Ministry of Public Works
MSP	Marine Spatial Planning
NAP	National Programmes of Action
NCC	National Conservation Commission
NCRIPP	National Coastal Risk Resilience Platform
NGO	Non- Governmental Organisation
NHCA	National Heritage Conservation Area
NOP	National Ocean Policy
PA	Public Awareness and Stakeholder Participation
PADO	Professional Association of Dive Operators
PDP	Physical Development Plan

PIU	The Public Investment Unit
R	Research
R2R	Ridge-to-Reef
RCP	Representative Concentration Pathway
REE	Non Living Resource Exploration and Exploitation
S	Development Planning and Setbacks
SANDS	Shoreline and Nearshore Data Systems
SAP	Strategic Action Plan
SIDS	Small Island Developing States
SLR	Sea Level Rise
SWOT	Strengths, Weaknesses, Opportunities and Threats
TCDPO	Town and Country Development Planning Office
WHO	World Health Organization

FOREWORD
(OCTOBER 2020)

FOREWORD

Our coast has immense value and is integral to the lives of Barbadians. All of its 97 kilometres (60 miles) are beautiful, diverse and productive. Barbados' coast has a special national heritage that comprises a range of different natural features which include cliffs, mangrove swamps, tide pools, beaches and low lying coral rock platforms. However, few people appreciate the incredible opportunities that it offers to improve the well-being of current and future generations. Our coast provides:

- **Goods and services** essential to meeting basic needs and improving the quality of life of all Barbadians. It provides food, a place to live, work and relax, and a gateway to the world via the Bridgetown Port.
- **Economic opportunities** for improving Barbados' development prospects, including tourism, fishing and a range of recreational business-related opportunities.

Maintaining the diversity, health and productivity of our coast is central to realising and sustaining these economic and social benefits. Doing so requires an understanding of the wider coastal system. Our coast is:

- **A complex natural system.** Many interactions take place there. It is the meeting place of the land and sea – where freshwater and seawater mix; the venue for high energy and change - where tides, currents, winds and waves shape and reshape the shoreline and the backdrop for rich landforms and resources (living and non-living) such as coral reefs, beaches, sand dunes, mangroves, seagrasses, wetlands, rocky headlands and rivers. The coast also nurtures diverse life-forms including turtles, marine mammals, fish, seabirds and a range of coastal plants, all of which make up varied ecosystems. It is therefore rich in natural resources.
- **A natural heritage, which must be carefully managed**. It is a public asset that supports a variety of human activities and is subject to intense and growing demands. However, coastal resources are finite, and vulnerable to over-use, degradation and importantly, climate change. Ongoing coastal erosion and sea level rise all make implementation and preservation of lateral beach access challenging. In fact, the coast can also be an unforgiving place, where inappropriate planning decisions can expose human life and property to high risks. In spite of this, it nonetheless offers enormous opportunities for future development in Barbados.

According to historical records, global average sea surface temperature has increased by 1 degree Celsius since the 1850s as indicated by the Intergovernmental Panel on Climate Change (IPCC). Small Island Developing States (SIDS) such as Barbados are therefore likely to be impacted by factors including coastal erosion, flooding, tidal variations and tropical storms/hurricanes that are exacerbated by climate change. The growing population and economic development will simply create more pressure on land use and the natural resources along the coastal zones. We therefore need to protect the natural assets for the benefit of our coastal communities and in order to achieve economic prosperity in the future.

Coastal management in Barbados has undergone a significant evolution over the past 35 years placing the island at the forefront of ICZM related best practice across the Caribbean, and contributing to a thriving coastal tourism industry that continues to remain at the core of the country's economy. Despite this, a more modern coastal management delivery model is now required if Barbadians are to realise and sustain goods and services and development opportunities that the coast provides. The Government of Barbados (GoB) is committed to adopting a new strategy in order to better implement a climate and disaster risk resilient related ICZM approach which places an improved emphasis on adaptation strategies that provides the optimum response to factors that are exacerbated by climate change. This new delivery model seeks to introduce improved coastal risk understanding and procedures into infrastructure and non-structural adaptation measures that are designed to increase resilience to climate induced coastal hazards whilst embracing ICZM principles and lessons from international best practice.

Implementing risk resilient ICZM is not a simple task, but given the potential, it is a task well worth undertaking. To achieve this, and through implementation of this Plan, there is a concerted effort, through public organisations in tandem with civil society, to promote the following:

- **A more co-ordinated and integrated coastal management approach.** The various human uses of coastal resources are inter-dependent. These uses affect each other and the overall benefits that can be gained from the coast. Co-ordinated and integrated management is needed to ensure that the positive benefits of different human uses are realised in the interests of all Barbadians. Our coast should therefore be managed in a holistic way as a **system,** not as a range of distinct sectors.
- **More efficient, effective and co-operative governance**, based on partnerships between Government, civil society and the private sector. Current legal and institutional arrangements for coastal management are complicated and fragmented. Risk resilient ICZM capacity needs to be built to achieve the development potential of the coast. Proactive guidance is needed to promote a visionary, practical and focused management process that fosters self-regulation and shared responsibility for our special coastal heritage.

The above shall facilitate implementation of this updated ten-year ICZM Plan (2020 - 2030), which represents a mandatory requirement under the Coastal Zone Management Act (currently under revision). There are two (2) Volumes to the Plan:

- Volume 1: Integrated Coastal Zone Management – The Barbados Policy Framework (2020 to 2030);
- Volume 2: Integrated Coastal Zone Management – The Barbados ICZM Plan (2020 to 2030).

It should be emphasised that these two Volumes have been developed in consultation with all stakeholders to enhance understanding about the risks associated with climate change and development pressures around the coastal zones in Barbados. The Plan takes into consideration existing studies that focus on coastal hazards relating to overtopping, sea level rise, cliff stability and flooding along the Barbadian shoreline. Presently, the Ministry of Maritime Affairs and the Blue Economy (MMABE), through the Coastal Zone Management Unit (CZMU) intervenes in association with other partners during extreme events and executes various coastal management efforts to combat such hazards.

This updated Plan provides the guidance that was previously lacking with regards to appropriate long-term ecosystem-based interventions that may be combined with the existing strategies to deal effectively with known coastal hazards. Such measures will help to build coastal resilience and capacity within developmental planning decision making within the newly defined coastal zone management area (CZMA) whilst in addition seeking to reduce future coastal risks and encouraging sustainable coastal economic development for communities by supporting the promotion of healthy coastal ecosystems.

The Plan is therefore an important milestone for Barbados. It will provide not only a framework for all coastal management initiatives but also an opportunity for stakeholders to become more aware of the seriousness of climate change and the developments affecting our nation. The clock is ticking and the race has begun. As one of the world's smallest nations, and through implementation of this Plan, we are tackling climate change and all of its issues head on.

PART A

(OCTOBER 2020)

PART A: SETTING THE SCENE FOR RISK RESILIENT ICZM

A1. INTRODUCTION

Coastal management is of critical importance to the people, economy and environment of Barbados. The coastal resources and ecosystems, distributed along 97 km of shoreline, provide both opportunities for enjoyment in addition to offering tremendous benefits for the economy and employment opportunities for all Barbadians. The tourism sector for example, which is mainly based around beach and marine activities, accounted directly for 13% of the total GDP in 2017 whilst its indirect contribution is estimated at 40% of total GDP (WTTC, 2018). Despite this, most economic activities that rely on the coast (including tourism, urban development and fisheries and new emerging sectors), all exert significant pressures on valuable coastal resources and ecosystem services. Additionally, as the country's population continues to grow, the demand that this places on coastal resources increases considerably.

Barbados currently finds itself confronted with the reality of facing global climate change and adapting to the increased risks that this brings. The coast in particular is becoming more exposed to tropical storms and hurricanes whilst being increasingly susceptible to beach and cliff erosion either from specific short-term events or from long-term coastal processes. Regional projections, for example, suggest that climate change is increasing the disaster risk profile of Barbados, especially when issues such as the effects of sea-level rise (SLR) are taken into account.

The complexity of coastal processes, the development of new and competing land uses activities, the existence of diverse stakeholder interests and the new emerging issues, including climate change, all now require a comprehensive and integrated approach towards managing the coastal zone in Barbados. In tandem with this, there is a global acceptance that Integrated Coastal Zone Management (ICZM) and Disaster Risk Management (DRM) in coastal areas are totally entwined and they constitute a sole approach to ensure the sustainable and resilient management of the coast.

ICZM IN BARBADOS

Harnessing and sustaining the development potential of the coast will require a significant change in thinking about how to plan and manage land use development processes. To facilitate this change, proactive ICZM planning, supported by latest knowledge on climate change needs to be integrated into new guidelines, legislation, regulations and advisories to help improve awareness to the public, private and civil society sectors to support the achievement of long-term climate compatible development within the coastal zone.

To date, the Government of Barbados (GoB) through the Coastal Zone Management Unit (CZMU), has made significant advances in ICZM, including tangible achievements in coastal erosion control, coastal resource conservation, institutional strengthening and capacity building. Guidance for the management of coastal uses, development and regulation along the coast of Barbados, up to now, has been addressed within the original ICZM Plan and Policy Framework (Halcrow 1998a, 1998b and 1998c). However, the new challenges facing Barbados, including climate change and DRM, require a new way of thinking, culminating in an update to these 1998 plans and policies (i.e.: this revised Volume 2 Plan).

This updated ICZM Plan (2020) adopts an integrated DRM and Climate Change Adaptation (CCA) approach towards supporting effective coastal planning by incorporating the latest results from an Inter-American Bank (IDB) funded programme named the "Coastal Risk Assessment and Management Program (CRMP)" and a supporting tool entitled the "National Coastal Risk Information and Planning Platform (NCRIPP)" which was undertaken and developed by the CZMU between 2011 and 2020. The CRMP has supported the analysis of the current and future key issues for facing coastal management delivery in Barbados by collecting new scientific information in addition to gathering stakeholder concerns, observations and suggestions. Through the CRMP, new policy goals, priorities and updated management guidelines and implementation procedures are provided (to support public agencies and private individuals) to help with ICZM Plan implementation. Two separate volumes have been produced that legally comprise the ICZM Plan:

- Volume 1: ICZM – The Barbados Policy Framework (IHCantabria, 2020), that describes ICZM policy outcomes and goals.
- Volume 2: ICZM – The Barbados ICZM Plan (this document), that provides detailed guidance on general themes relevant for activities within the Coastal Zone Management Area (CZMA) at the national and Sub Area level, to support and advise on how all sectors and the wider society in Barbados can achieve climate and disaster risk compatible development.

Coupled with the proposed revisions to the CZM Act (2020), foundations for the sustainable use and promotion of climate-resilient development within the legally defined CZMA of Barbados are now formalized.

A1.1. Purpose and Structure of the Plan

> **PURPOSE OF THE ICZM PLAN**
>
> The purpose of this Plan is to provide detailed guidance for the management of coastal resources, uses, development and regulation along the coast of Barbados that embraces current and future climate and disaster related risks.

This Volume 2 (of the ICZM Plan) is divided into five separate Parts:

- PART A: SETTING THE SCENE FOR RISK RESILIENT ICZM: introduction to the Plan and its vision, and description of the characteristics of the coast, based on the last existing baseline and risk assessment studies performed by the GoB.
- PART B: IDENTIFICATION OF PRIORITIES: identification of issues and challenges to be faced and definition of policy goals for ICZM.
- PART C: NATIONAL GUIDANCE: guidance on general themes that are relevant to support decision making within the defined CZMA. These guides include sub-sections on current status, implications, management guidance and supporting actions at a national scale.
- PART D: SUB-AREA GUIDANCE: action brief for each Sub Area of the Barbados CZMA, tabulating issues and likely implementation pathways highlighting recommended lead (and supporting) agencies, timeframes and links to relevant government policy as appropriate.
- PART E: IMPLEMENTATION: key requirements for the implementation of the ICZM Plan with sections on approval processes, supporting implementation strategies, financial considerations as well as monitoring and evaluation procedures.

A1.2. Geographic Scope of the Plan

THE COASTAL ZONE MANAGEMENT AREA AND THE ZONE OF INFLUENCE

The principle of "Island System Management", which recognizes the need for the management of terrestrial and coastal resources together, as well as the International Union for Conservation of Nature initiative entitled "Reef to Ridge", is relevant for the protection of natural resources and environmental awareness. This is particularly important as Barbados possesses a unique coastal character that is strongly influenced by prevailing coastal dynamics. The focus, in relation to protection of coastal resources and to reduce climate and disaster related risk, falls within a legally defined CZMA whereby planning permission may only be granted if applications are consistent with the policies set out in this ICZM Plan (Vols.1 and 2). Two different geographical areas are hereby defined within this ICZM Plan (Figure A.1.):

- The **CZMA**, a core area where human activities can directly impact upon coastal resources or where land is exposed directly to coastal hazards. The CZMA represents the geographical scope of this ICZM Plan.
- The **Zone of Influence** (ZoI) represents the surrounding space to the core area (both inland and offshore), where activities or events could indirectly affect the integrity of coastal resources identified within the core area.

Figure A.1. Updated CZMA and ZoI.

As stated within the Planning and Development Act (2019), any new development proposal that is identified within the CZMA, shall have regard to the provisions and guidelines set out in the ICZM Plan. That means that the CZMU will advise all statutory authorities on all relevant policies, regulations and advisories that may apply within the CZMA. Regarding the Zone of Influence, the role of the CZMU will be to raise awareness to public and, private sectors, civil society and the general public of the implications and impacts of any proposed activity or future development on the integrity of coastal resources that may currently be taking place or where future consideration of an activity is raised. This can specifically include any impacts anticipated from strategic and national plans or developments proposals submitted (see Part C, Section C5). Through specific coordination and collaboration mechanisms, the CZMU shall continue to be involved towards supporting and contributing to existing collaborative partnerships and forums that may exist now or in the future (see Sections 1.4 and 1.5) that may help develop joint initiatives to promote the conservation and sustainable exploitation of coastal resources within the defined core CZMA or ZoI.

A1.2.1. The Coastal Zone Management Area

THE CZMA

The CZMA constitutes the geographic limits of this ICZM Plan, updating the inland and offshore limits originally established within 1998 ICZM Plans for the Atlantic and Caribbean Seas (Halcrow 1998). The delineation of the CZMA of Barbados is based on a sound technical and scientific analysis of the coastal zone.

The first step undertaken to re-define the CZMA was to analyse international definitions of similar "zones" adopted. The analysis deduced that any precise delimitation of a coastal area should be based on the specific characteristics of any specific country and the respective inland and offshore limits that are influenced by the climate or disaster related hazards of relevance to that nation. The methodology applied adopted a spatial multi-criteria analysis (MCA) approach that the two key coastal issues facing the GoB, namely: (a) the effective management and sustainable use of coastal resources and (b) hazards and associated coastal risks derived from a changing climate. Specific criteria and variables were selected that consider and embrace Islands Systems Management (ISM). Each coastal resource (defined under the CZM Act) and climate/disaster related hazard (McCue, 2018) were analysed through the adoption of the following principles:

- *Guarantee the continuation of physical and environmental processes*. That is, to secure the natural functioning of dynamic coastal processes and protect sensitive coastal ecosystems.
- *Guarantee the continuation of sustainable socio-economic activities*. This focuses on ensuring the economic activity impacts consider the importance of sustainable coastal resource management.
- *Guarantee coherence in governance mechanisms*. This principle calls for the need for institutional coordination and harmonization of governance mechanisms including plans, policies, regulations and laws.
- *Mainstreaming coastal risk understanding into coastal planning*. This addresses the prevention and/or reduction of the effects of coastal hazards by ensuring their consideration within all sector strategies.

- *Mainstreaming adaptation to climate change strategies into coastal planning*. This focuses on integrating adaptation strategies into ongoing policy and planning processes, such as the Physical Development Plan (PDP 2017) or other sectoral strategies or relevance.

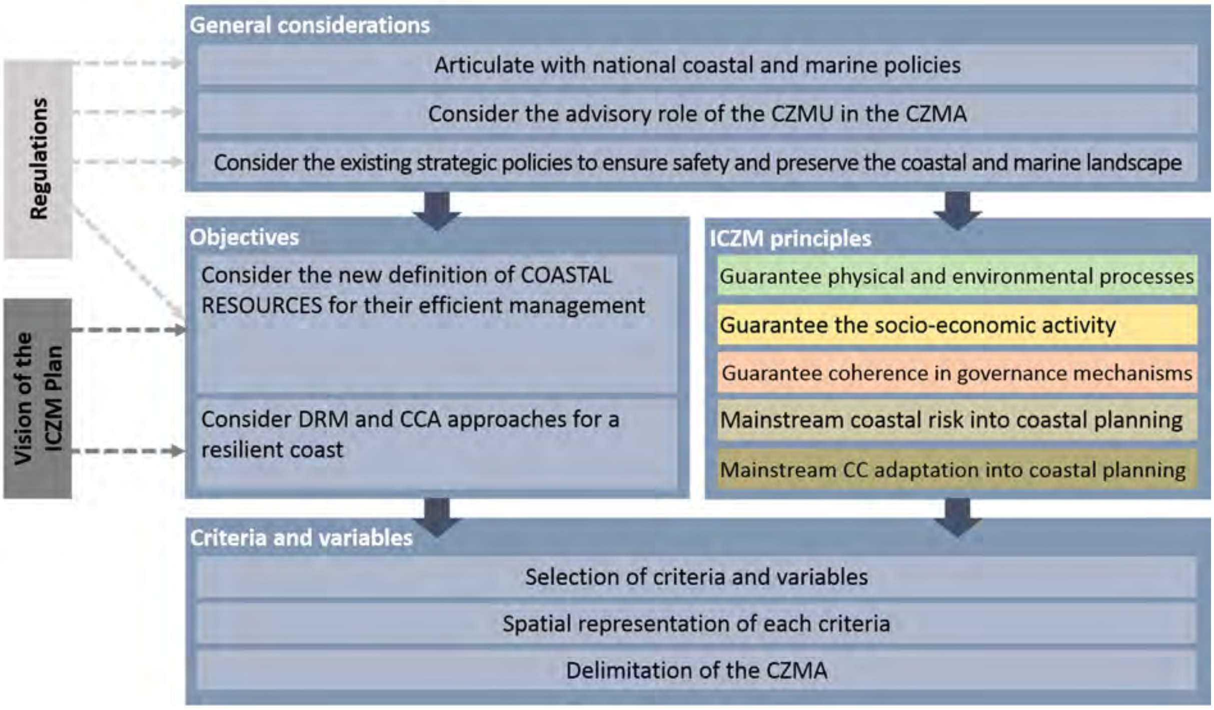

Figure A.2. Conceptual framework for the definition of the CZMA.

By adhering to these considerations and principles, Table A.1 and Table A.2 present the set of spatial criteria used to delineate the limits of the CZMA.

Category	Criteria for Each Coastal resource
Beaches	Initiation of sediment transport (calculated as -10 m bathymetric contour)
	Storm surge flooding area (T= 100-years)
	Areas of adjacent auxiliary facilities directly related to beaches (including beach accesses, adjacent recreational areas and lifeguard facilities)
	Areas of the current mapped resource defined by the competent agency
Sand dunes	Total extension of the primary dune
	Areas of the current mapped resource defined by the competent agency
Surf zone	Wave shoaling and surf zone (calculated as -140 m bathymetric contour), including sand reserves
	Beach areas
Coastal cliffs and caves	Initiation of sediment transport (calculated as -10 m bathymetric contour)
	Inland boundary of the recommended setback - cliff collapse (T=100-years)
Wetlands	Connection area between wetland and coastal waters
	Areas defined as a wetland by the competent agency
Coral reefs	Limit depth related to shallow-water coral reef ecosystems presence estimated as the -150 metres bathymetric contour)
	Areas of the current mapped resource defined by the component agency
Algal and seagrass beds	Areas of the current mapped resource defined by the competent agency
Places of environmental interest	Total extension of the planned and current marine reserves
	Areas with endangered and protected species, including turtle nesting sites, mangroves, Walkers Quarry restoration area and coastal woodlands

Category	Criteria for Each Coastal resource
	Areas of the current mapped resource defined by the competent agency
Places of landscape interest	Coastal areas of outstanding aesthetic value, including (i) the wave shoaling and surf zone (calculated as the -140m bathymetric contour), and (ii) coastal landscape protection areas defined under the PDP(2017) and the CZMU, and the National Park landscape (200m buffer from the coastline)
	Coastal rural areas of medium aesthetic value (100 m buffer from the coastline) in rural areas defined by the (PDP)
Places of geological interest	Areas with coastal and marine geological and geomorphological formations of outstanding value
Cultural resources	Lighthouses
	Historic locations including HARP gun, screw dock, old coastal forts, selected archaeological areas and monuments and prehistoric sites
	Include historic architecture – UNESCO sites
	Fishing landing sites
	Underwater Cultural Heritage
	Areas of the current mapped resource defined by the competent agency
Coastal infrastructure	Initiation of sediment transport (calculated as the -10m bathymetric contour)
	The area occupied by coastal infrastructures, including port and marina areas, coastal defences, outfall and intakes and defence areas
	Include coastal infrastructures related to socio-economic activities: fishing landing sites and reef fishing sites; power generating plants, etc.
	Areas of the current mapped resource defined by competent agency: marine and port restricted areas
Existing regulations	Minimum 30m setback distance established by PDP (2017)

Table A.1. Criteria for the delimitation of the CZMA addressing coastal resources.

Category	DRM/CCA Criteria
Hazardous areas - NCRIPP	Storm surge flooding area (T=100-years)
	Areas affected by coastal erosion
	Tsunami flooding area (T=100-years)
	Setback recommendation for cliff erosion collapse (T=100-years)
Hazardous areas – IPCC SLR scenario	Estimated flooding area (storm-surge and tsunami) considering the SLR projection as the principal effect of climate change considering RCP 8.5 in the year 2100 (IPCC,2019)
T: return period. RCP: Representative Concentration Pathways, defined as a greenhouse gas concentration trajectory adopted by the IPCC.	

Table A.2. Criteria for the delimitation of the CZMA addressing DRM and CCA.

The new CZMA (Figure A.3) extends around the entire coastline of Barbados, with landward and seaward limits of variable widths. These are defined as follows:

- **Landward Limit:** the landward limit embraces the above criteria and includes key terrestrial coastal habitats such as beaches, cliffs, wetland, and mangroves, areas of importance for endangered species, places of environmental and geological interest, areas of outstanding landscape value, cultural resources linked to the coast, coastal infrastructures; and those areas exposed to coastal hazards (storm surge, tsunami, coastal erosion and cliff collapse), considering long-term scenarios of SLR. This landward area also covers the minimum 30m setback from the High Water Mark (HWM) established by the PDP (2017). It is defined by specific coordinate points (longitude, latitude) each being 50m apart.

- **Seaward Limit:** this contains key marine resources and habitats (coral reefs, algae and seagrass beds, etc.); protected and restricted marine areas; areas of outstanding seascape value; and the surf zone where active sediment transportation influences beach profile shape (i.e.: the nearshore "closure depth" contour).

Figure A.3. The Coastal Zone Management Area.

A1.2.2. Sub Areas of the CZMA

The CZMA is divided into a series of "Sub Areas", as originally defined within the 1998 ICZM Plan, that reflect specific Barbadian coastal characteristics and risk exposure variances. These were based on the legal and administrative framework, physical (mainly coastal geology), geomorphological and human (mainly land use patterns) characteristics. They continue to embrace these criteria set in 1998, but importantly, they have now been updated to better reflect the improved understanding of coastal hazards, vulnerabilities and climate/disaster risks that have more recently been studied, monitored and witnessed since 1998 to the present day.

A total of eight Sub Areas are defined, five of them are located in the Atlantic coast (Sub Areas 1, 2, 3, 4 and 5) and the other three are located in the Caribbean coast (Sub Areas 6, 7 and 8) (see Figure A.12):

- *Sub Area 1: South Point to Kitridge Point*. This covers the south-east coast and comprises lengths of cliff top with existing settlements that over recent years are increasingly being sub-divided (low levels of occupancy). This is an extensive and commercially undeveloped urban land reserve that is also an important recreation area. The nearshore environment is dominated by the presence of Cobblers Reef. It also commands high landscape value. Beach and cliff erosion are the most significant risks experienced in this Sub-Area.

Figure A.4. Sub Area 1.

- *Sub Area 2: Kitridge Point to Conset Point.* The land use in this Sub-Area is characterised by small scale agricultural holdings and the settlements of Sealy Hill, Whitehaven and Bayfield. Some parts are subject to new developments that may cause conflict with local community perspectives and views. Due to the topography of the Sub Area, it experiences reduced direct coastal risks related to climate change (i.e.: storm surges, coastal flood inundations etc).

Figure A.5. Sub Area 2.

- *Sub Area 3: Conset Point to the Choyce*. This Sub Area covers most of the coastline of the Barbados National Park. There is more topographical variety in Sub Area 3 when compared to the other Sub Areas. It consists of sloping areas between the main escarpment and the coast and is quite heavily eroded. With low density, the economic activities are diverse: residential, tourism, agriculture and fisheries, and sand extraction. The Sub Area commands high potential for tourism development and recreational activities. Regarding coastal risks, storm surge inundation may prove a future issue due to its shallow topographic slope gradients.

Figure A.6. Sub Area 3.

- *Sub Area 4: The Choyce to North Point*. North Point lies to the north of the island at the boundary between the Caribbean and Atlantic coasts. This coastline is predominantly exposed to high swells, waves and winds and displays a fairly barren cliff-top landscape. Apart from the main settlement of Rockfield, there is limited built development. Locations such as River Bay and Pico Tenerife are popular for recreation (cliff walks etc). Beach erosion and cliff collapse, however, are coastal risks that are most pertinent within this Sub Area.

Figure A.7. Sub Area 4.

- *Sub Area 5: North Point to Maycocks Bay*. Being mainly undeveloped, the landscape within this Sub Area is dominated by cliff top related coastal vegetation. The main coastal risk relates to geotechnical issues that includes cliff collapse.

Figure A.8. Sub Area 5.

- *Sub Area 6: Maycocks Bay to Batt´s Rock*. This extends along the leeward west coast of the island. Land use immediately adjacent to the coast is principally influenced by tourism related development/infrastructure combined with residential areas that include the commercial centres of Speightstown and Holetown. As it is exposed to wind and swell waves, coastal hazards within this Sub Area mainly are linked to storm surge related events.

Figure A.9. Sub Area 6.

- *Sub Area 7: Batt´s Rock to Needham´s Point*. This Sub Area is predominantly south-west facing. Land use is dominated by the footprint of Bridgetown and hence supports the highest population density anywhere in the island. The key coastal embayment feature is the sheltered area of Carlisle Bay whose southern boundary (Needham´s Point) in included within a proposed Marine Protected Area (MPA). The area is exposed to coastal hazards including storm surge, swell events and potentially tsunami as a consequence of the low lying topography and shallow coastal hinterland slope that occurs within the Sub Area.

Figure A.10. Sub Area 7.

Figure A.11. Sub Area 8.

- *Sub Area 8: Needham´s Point to South Point.* This Sub Area extends along the south coast of the island and includes Oistins Bay. It is principally a residential area although there are also sections immediately adjacent to the coast that have more of a tourism focus. The regional centre of Oistins is an important focal settlement for fisheries-related activities. Due to the shallow coastal hinterland slope (especially adjacent to Needham's Point), the Sub Area is exposed to medium level risks that are associated with storm surges whose impacts may be exacerbated by SLR.

Other key characteristics relating to the natural and socio-economic setting, and developmental opportunities and constraints of these Sub Areas are described in more detail within Part D of this ICZM Plan.

Figure A.12. Sub Areas of the CZMA.

A1.3. Vision Statement

The vision of the ICZM Plan embraces the original version established in 1998 though, for completeness, was reviewed for possible alteration following a national process of consultation with interested and affected parties during 2018 and 2019. A series of visioning and issue identification workshops were held, involving over 200 participants, from more than 30 organizations. These events, under the guidance of the CZMU, provided the foundation from which the national vision was developed.

> **VISION**
>
> *"A coast and marine area to be proud of, which is valued, appreciated and safeguarded as places to live, work, use and relax; places where economic activity and the use of resources are sustainable, hazard resilient and adaptive to climate change, and where the natural environment is protected and enhanced to keep its essential and unique place in the Barbadian heritage and economy."*

The vision seeks to provide a clear statement of intent for the ICZM Policy Framework (Vol. 1). It expresses the GoB's intention to enhance the capacity of current and future generations to realise their human potential within the context of maintaining diverse, healthy and productive coastal resources and ecosystems.

A1.4. Legal and institutional framework for risk-resilient ICZM in Barbados

A1.4.1. New and Existing Legislation, Regulations and Government Policy relevant to ICZM

Many elements of GoB policy and legislation are relevant to activities taking place in and around the coast. The primary legislative instruments which are relevant to ICZM in Barbados are the following:

- proposed revisions to the CZM Act (2020) to help update and supersede the existing CZM Act (Cap. 394A 1998)[1];
- Planning and Development Act (2019);
- Marine Pollution Control Act (1998);
- Fisheries Act (Cap. 391) L.R.O 1995;
- Barbados Territorial Waters Act (Cap. 386) L.R.O. 2002;
- Marine Areas (Preservation and Enhancement) (Barbados Marine Reserve Regulations) 1981 and other provisions within the current CZM Act that currently pertain to management of restricted areas by the National Conservation Commission (NCC) of the Ministry of the Environment and National Beautification (MENB).

The proposed revisions to the CZM Act (2020), if considered, will create the essential foundation for the implementation of risk resilient ICZM in Barbados as it mandates the CZMU to prepare an ICZM Plan and an order delimiting a CZMA. This Plan, by convention in Barbados, includes the elucidation of an ICZM Policy Framework (Volume 1) that is in keeping with other national policies. Provision for

[1] This draft legislative Bill update has been produced though no formal consultation has been carried out to date.

describing the boundaries of the CZMA is also included in the proposed revisions to the CZM Act (2020). Whilst it will not provide details of the plan, nor exact boundaries of the CZMA, these aspects are included in the ICZM Plan (see Annex 1) and referred to within the revised CZM Act. The Plan will come into force after the receipt of Ministerial approval (see Part E). The CZM Act will include a legal requirement to review the ICZM Plan every 10 years. The key steps in implementing the Plan are shown in Figure A.13.

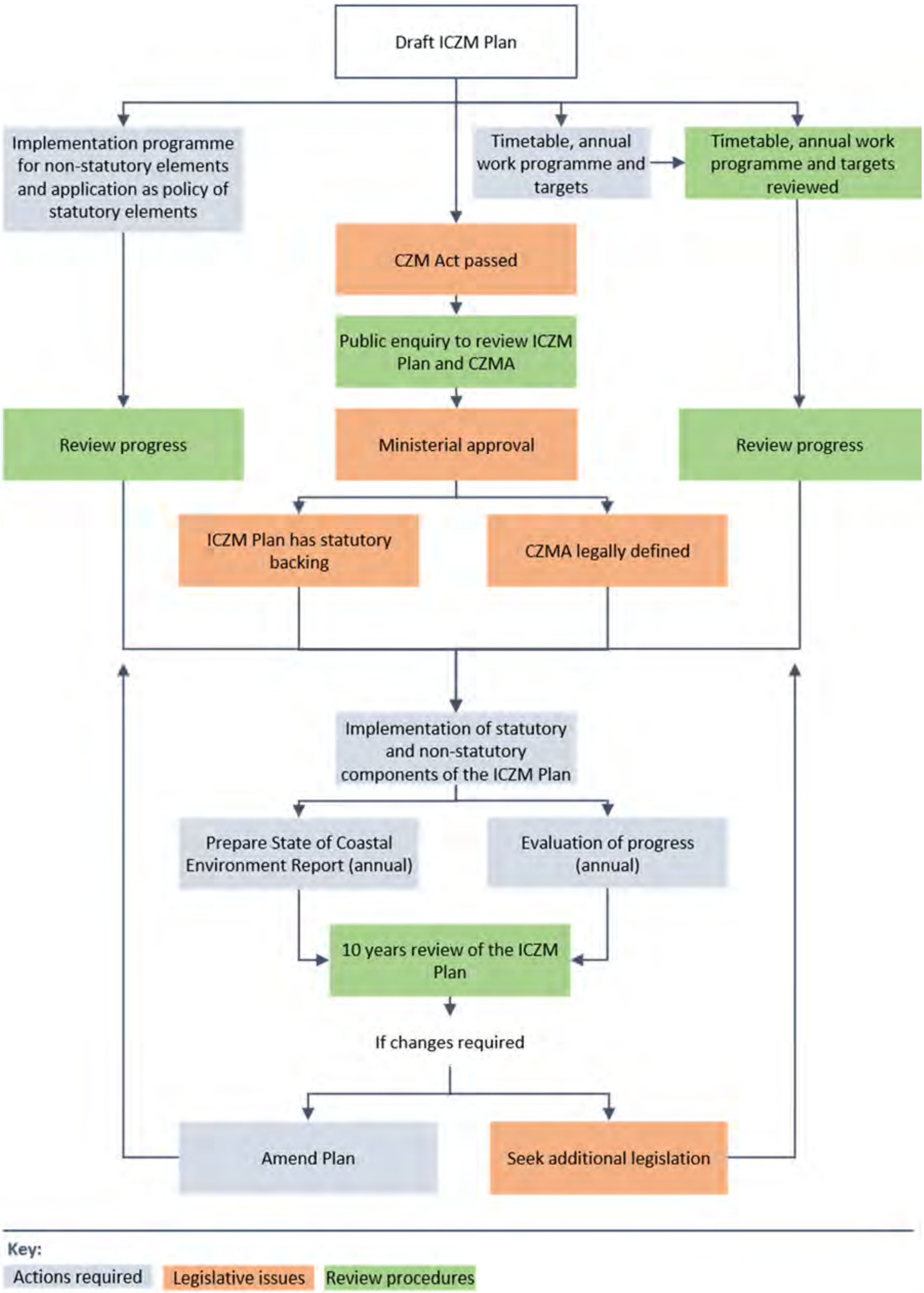

Figure A.13. Key stages in the Barbados ICZM process. (Source: adapted for Halcrow, 1998a).

To support implementation of this ICZM Plan, a series of National Guidance advisories are prepared (see Part C), ranging from coastal engineering, beach management and new emerging issues facing the CZMA of Barbados. In addition to this, and at the core of this ICZM Plan (and replicated within the proposed revisions to the CZM Act (2020)), is that public outreach and engagement remains a pivotal aspect to ensure successful implementation of this ICZM Plan. In addition to the gathering of social data to inform coastal resource management decision making, the importance of message communication (outreach) is vital. To this end, Part C focuses specifically on how this should be delivered by all stakeholders (see National Guidance C.10).

In addition, a new set of draft regulations has been designed to accompany the proposed revisions to the CZM Act (2020) as follows:

- Regulation 1: Coastal Zone Management Regulations 2020;
- Regulation 2: Special Marine Areas (Preservation and Enhancement) Regulations, 2020
- Regulation 3: Draft Aquarium Trade Regulations, 2020
- Regulation 4: Coral and Coastal Organisms Protection Regulations 2020

A new separate piece of legislation is being prepared to support the proposed revisions to the CZM Act (2020). The Open Beaches Bill (2019) is designed to declare and affirm the right of the public to access, use and enjoy the beaches of Barbados and to secure the interest of the public by partially altering the common law doctrine of accretion. Within this Bill, the public right to beaches will be subject to any other law related to environmental management and in particular beach protection and to public safety, health, order and the regulation of trade. This Bill will play a supporting role to assist CZMU in their coastal planning efforts. The Crown, acting through the Director of the CZMU (see draft Regulation 1 above), shall continue to have the right and authority to construct groynes, breakwaters, and sediment trapping devices or any other structures which are specifically designed to cause accretion of land or to prevent erosion of land.

Government agencies undertaking primary risk resilient ICZM functions are shown in Table A.3.

Primary or Secondary ICZM Function	Agency Responsible	Key Partner Implementation Agencies	Legislation	Future Delivery of Risk Resilient ICZM – likely actions
Primary Function 1: Preparation and revision of Coastal Management Plans: • Inventory of coastal resources (data collection, etc.) • Coastal management strategies • Standards of new development • Allocation of resources between competing use • Coordination with other development plans • Stakeholder engagement	CZMU *(Ministry of Maritime Affairs and the Blue Economy)*	TCDPO; Ministry of Finance, Economic Affairs and Investment; Environmental Protection Department; Drainage Division; Fisheries Division; Department of Emergency Management National Conservation Commission Natural Resources Department, (Energy Division)	Proposed revisions to the CZM Act (2020)	Need to ensure that new status of coastal resources is undertaken as part of the "State of the Coast" reporting strategy. In addition important that new hazard risk profile findings are presented into this updated CZM Plan as well as being reflected and inculcated into a new set of national applicable monitoring and evaluation indicators (M&E) that will help to demonstrate institutional and GoB progress against the SDG13 and the Sendai Framework. Tsunami and storm surge hazard mitigation measures, articulated within the updated ICZM Plans, need to be embraced within future developmental policy and planning decision making (applications) that consider evacuation routes/setback guidance (i.e.: new standards, etc.).
Primary Function 2: Control of development in Coastal Zone Management Area: • Environmental and Social impact assessment • Inspection • Consultation to Town & Country Planning Office • Compliance and enforcement • Review design of any coastal projects • Data collection on stakeholders • Stakeholder engagement	TCPDO, CZMU	Environmental Protection Department Drainage Division Soil Conservation Unit Fisheries Division Barbados Water Authority Ministry of Finance, Economic Affairs and Investment; National Conservation Commission Natural Resources Department, (Energy Division) Natural Heritage Department) All government Departments linked to any aspect of developmental control within the defined CZMA.	Planning and Development Act (2019) Proposed revisions to the CZM Act (2020) Tourism Development Act (2002)	Planning system is currently not specifically climate-resilient. Impetus for GoB to adopt through advisories and protocols, designed and prepared by key agencies (e.g.: DEM and CZMU) are required. Implementing Standard Operating Procedures (SoPs), building codes (not formalised) and the like to advice on climate-resilient adaptation measures for existing and future infrastructure (with advisories for retrofitting where suitable) may be needed. The development or expansion of any activity in the CZMA and of any facilities associated with them will continue to need and involve CZMU supervision through the development control process and some will trigger an environmental impact assessment (EIA). CZMU needs to play an enhanced role in the planning development control arena with total support from TCDPO. This could be undertaken through the setup of complimentary "Standing Committees" on specific topics, similar to the approach adopted by DEM

Primary or Secondary ICZM Function	Agency Responsible	Key Partner Implementation Agencies	Legislation	Future Delivery of Risk Resilient ICZM – likely actions
				whereby sector-specific sub DRM teams are chaired by specific sectors. CZMU to consider ways of improving two-way communication between themselves and relevant stakeholders so that an early understanding of any large development project that may be attracted to Barbados is considering climate resiliency into early design ideas.
Primary Function 3: Beach erosion and accretion control (coastal maintenance): • Monitoring programs, sampling measurement and data collection • Database building Stakeholder engagement	CZMU Ministry of Transport , Works and Maintenance	Ministry of Tourism and International Transport Barbados Tourism Investments Inc Department of Emergency Management Barbados Meteorological Service The Research and Planning Unit Barbados Statistical Service National Conservation Commission	Proposed revisions to the CZM Act (2020)	Need to set up a series of "transition hand over" phases (advisories) to other organisations to take responsibility for management and maintenance of structures/assets etc. Where possible, there is a need to reduce the cost of outsourcing skills to private companies with regards to core activities that may be undertaken by the CZMU such as maintenance of coastal assets, setting up new databases etc.
Primary Function 4: Research and its regulation: • Internal research programs • Approval and monitoring of external programs through stakeholder engagement • Compliance and enforcement • Supporting data collection programmes	CZMU and Fisheries Division	Ministry of Finance, Economic Affairs and Investment Environmental Protection Department The Research and Planning Unit Barbados Statistical Service National Conservation Commission Natural Resources Department, (Energy Division) Natural Heritage Department) Barbados Agricultural Development and Marketing Corporation	Proposed revisions to the CZM Act (2020) Fisheries Act (2004)	Creation of an implementable policy on Knowledge Management (KM) so that all key information developed (via various consultancies) can be used for improved implementation of the ICZM Plan for GoB especially regarding monitoring and evaluation and compliance/enforcement-related issues. Creation of a clear "conditions of sale" as well as "information sharing" policies on the coastal related data is required. CZMU could potentially add "marine climate services" to their technical portfolio to help the Barbados Meteorological Service (BMS).
Primary Function 5: Coastal Resources protection and monitoring: • Monitoring and data collection (sampling, etc.) • Coral reef/ wetland/mangrove/seagrass database creation	CZMU Fisheries Division	Ministry of Finance, Economic Affairs and Investment Environmental Protection Department Drainage Division Fisheries Division Barbados Water Authority Ministry of Tourism and International Transport Sanitation Service Authority Ministry of Transport and Works	Proposed revisions to the CZM Act (2020)	Creation of an outreach strategy that clearly communicates agency mandates and roles with regard to reef conservation. This should dilute any confusion over responsibilities and delivery expectations linked to various statures, regulations and laws (i.e.: the proposed revisions to the CZM Act (2020), NCC Act and Fisheries Act, etc.).

Primary or Secondary ICZM Function	Agency Responsible	Key Partner Implementation Agencies	Legislation	Future Delivery of Risk Resilient ICZM – likely actions
• Setting and enforcing protection standards • State of the Coast Reporting • Education and Outreach • Stakeholder engagement		Department of Emergency Management Barbados Coast Guard Barbados Statistical Service National Conservation Commission Natural Resources Department, (Energy Division) Natural Heritage Department Royal Barbados Police Force Barbados Agricultural Development and Marketing Corporation		There is also no formal reporting system is currently in place to capture coral reef health statistics as part of a "state of the coast" reporting system. There is a need to formalise a new reporting function to assess progress against a nationally agreed set of bio-indicators as well as SDG 14.
Primary Function 6: Marine water quality testing: • Monitoring and data collection programs • Sampling and analysis • Database building • State of the Coast Reporting • Interpretation and assessment of results and trends • Identification of critical water quality characteristics for specific environments • Establishment of appropriate standards (both ambient and point of discharge) • Enforcement of water quality standards through stakeholder engagement	EPD CZMU	Government Analytical Services Drainage Division Soil Conservation Unit Fisheries Division Barbados Water Authority Ministry of Tourism and International Transport Sanitation Service Authority Ministry of Transport and Works Barbados Statistical Service National Conservation Commission	Marine Pollution Control Act (1998)	There is no formal reporting system is currently in place to capture environmental statistics or "state of the coast" information. There is a need to formalise a new reporting function progress against a nationally agreed set of bio-indicators (for wetlands, mangroves, seagrasses as well as coral reefs) in addition to SDG 13 and 14 national reporting support.
Primary Function 7: Coastal Engineering and Shoreline Management: • Monitoring and data collection • Coastal construction and maintenance • New materials for beach recharge • Enforcement of prohibition, conditions of approval where permitted	TCDPO CZMU	Drainage Division Soil Conservation Unit Sanitation Service Authority Ministry of Transport and Works Department of Emergency Management Barbados Meteorological Service National Conservation Commission	Planning and Development Act (2019) Proposed revisions to the CZM Act (2020)	A national Coastal Engineering Guide ("How to Guide") needs to be prepared that embraces the new NCRIPP data with a summary "White Paper" disseminated to all GoB Ministries and new developers (including TCDPO as an annex to the existing EIA ToR Guideline). New technical guidance on (for example) flood retention basins, flood conveyance and ecosystem-based adaptation advisories and practices and use of quarried sands for beach recharge should be developed that

PRIMARY OR SECONDARY ICZM FUNCTION	AGENCY RESPONSIBLE	KEY PARTNER IMPLEMENTATION AGENCIES	LEGISLATION	FUTURE DELIVERY OF RISK RESILIENT ICZM – LIKELY ACTIONS
• Support to promote ecosystem-based adaptation techniques • Stakeholder engagement				consider new engineering support advice within the Coastal Zone Management Area. Importantly, no building regulations are enshrined in law at present, where these do exist they are in need of update to become climate resilient (to better embrace latest climate model predictions of precipitation rates for better calculate culvert diameters for roads). Internally, infrastructure specifications do already exist (written by MTW) for roads and culvert designs and these are communicated to contractors as required. These need to better acknowledge the more recent climate prediction and risk analysis work recently carried out by CZMU through the NCRIPP project.
Primary Function 8: Development and management of marine parks, reserves and beach accesses: • Identification of potential marine reserves and parks • Establishment and operation • Beach Management Standard setting (ISO13009) through stakeholder engagement • Data collection on beach users	NCC	CZMU TCDPO Ministry of Finance, Economic Affairs and Investment Environmental Protection Department Drainage Division Soil Conservation Unit Fisheries Division Ministry of Tourism and International Transport Barbados Tourism Investments Inc Department of Emergency Management Barbados Meteorological Service Barbados Tourism Investment Inc. (BTI) Barbados Tourism Authority Barbados Hotel and Tourism Association	Proposed revisions to the CZM Act (2020) Planning and Development Act (2019) National Conservation Commission Act	Creation of a new International Standard for Beaches (ISO13009) – with NCC as the lead implementer under the management of the Barbados Standards Bureau. The service provided by CZMU would be as supporting coordinator. The new Special Marine Areas Regulations (2020),once endorsed, may be used to help identify and manage new marine reserves/parks etc.
Supporting Function 1: Coordination and enforcement: • Ensuring that primary coastal management functions are carried out through stakeholder engagement • Ensuring that all coastal management functions are	CZMU TCDPO	CZMU Government Analytical Services Ministry of Finance, Economic Affairs and Investment Environmental Protection Department Drainage Division Soil Conservation Unit Fisheries Division	Proposed revisions to the CZM Act (2020) Marine Pollution Control Act (1998)	The CZMU should consider multi-disciplinary approaches whereby the actions are delivered by other partners, though CZMU may spearhead the action if required and if necessary to promote the need. Improving public outreach of CZMU to the public is important and should continue to be improved upon

Primary or Secondary ICZM Function	Agency Responsible	Key Partner Implementation Agencies	Legislation	Future Delivery of Risk Resilient ICZM – likely actions
coordinated through stakeholder engagement		Barbados Water Authority Ministry of Tourism and International Transport Barbados Tourism Investments Inc. Sanitation Service Authority Ministry of Transport and Works Department of Emergency Management Barbados Meteorological Service Barbados Coast Guard The Research and Planning Unit Barbados Statistical Service National Conservation Commission Natural Resources Department, (Energy Division) Natural Heritage Department) Barbados Police Force Royal Barbados Police Force Customs Division, Barbados Agricultural Development and Marketing Corporation Barbados Tourism Investment Inc. (BTI) Barbados Tourism Authority Barbados Hotel and Tourism Association		coupled with improve education to all sectors of society on risk resilient ICZM measures.
Supporting Function 2: Provision of legislation and regulations: • Identify needs for legislation and regulations • Timely drafting and submission to Parliament of the Minister for consideration	Chief Parliamentary Counsel Solicitor General's Chambers		N/A	Proposed revisions to the CZM Act (2020) encourage improved enforcement powers to the CZMU to help remove poor coastal designed structures. This should help to climate proof the current planning system and to help with regulatory enforcement. Recommend new specific M&E guidance or models are set up to comply with the latest Sendai Framework Priorities/Targets/Indicators. CDEMA encouraged to support a consistent approach to determine this approach for Caribbean Nations.

Table A.3. Government agencies undertaking primary risk resilient ICZM functions.

A1.4.2. The legal and institutional framework for physical planning in the CZMA

The CZMU is one of several agencies within the Ministry of Maritime Affairs and the Blue Economy (MMABE) with responsibility for supporting GoB with regards to advice on physical planning within the defined CZMA. The CZMU remains as the national focal agency for ICZM and coastal planning advisories in Barbados and is responsible for undertaking, in conjunction with others, a series of primary and secondary functions for risk resilient ICZM (see Table A.3) and in liaison with others concerning all other (non-primary) ICZM functions that are not embraced under the proposed revisions to the CZM Act (2020). It therefore works in partnership with other agencies of government and acts as the key development advisors to the Town and Country Development Planning Office (TCPDO) who have the absolute authority for granting permission for all developments in Barbados and hence within the CZMA to help implement the ICZM Plan.

The TCDPO is responsible for enforcing the Land Boundaries Act (1980) and the more recent Planning and Development Act (PDA 2019[2]) as it relates to all lands within the limits of the territorial waters of Barbados which includes the newly defined limits of the CZMA. The PDA (2019) underpins the approach that applies to this ICZM Plan, as well as the wider process of developmental planning in Barbados.

Importantly for ICZM delivery, the PDA (2019) expresses the requirement for public participation towards achieving the purposes of the Act which was a requirement that was absent from the original Town and Country Planning (Cap. 240). The new PDA (2019), which shall be delivered through a range of internal administrative Sections, importantly provides for a Planning and Development Board (the "Board") whose requirements pertaining to the operation and members of that Board, are definitively expressed within the PDA (2019) with regards to engagement and public participation. The Board is a body corporate with perpetual succession and a common seal and is responsible for the implementation of the policies framed by the Minister. This is relevant to the implementation of this ICZM Plan as the CZMU's role and responsibility (as a key member of this Board) will be to specifically to advise the TCPDO on the granting of permissions for development within the CZMA plus to ensure that all relevant supporting agencies undertake their roles to implement the policies and adopt the guidelines set out within the ICZM Plan.

These supporting agencies (with specific reference to physical planning in the CZMA) that are important in delivering aspects of ICZM (primary or secondary functions) include the following:

- Environmental Protection Department (EPD) implementing the Marine Pollution Control Act 392A (1998) to address water quality matters on land and at sea[3];
- Drainage Division (within the Ministry of Transport, Works and Water Resources - MTWM) on matters relating to the effective management, monitoring and enforcement of drainage structures as necessary relative to the Prevention of Floods Act (1951) and the Highway Act;
- Soil Conservation Unit (through the Soil Conservation Scotland District Act (1998) on matters regarding the stability of land within the Scotland District area;
- Fisheries Division on matters regarding fisheries and aquaculture/mariculture projects,

[2] Anticipated to be a Statutory Instrument in 2020

[3] The Environmental Management Act is not yet enshrined in law. However, elements of the Act are being implemented nationally by EPD though it has no legal authority to enforce or prosecute any known offenders and instead the EPD's regulatory authority remains bound by the Health Services Act (1969),

- Barbados Water Authority on groundwater and water supply matters, under the Underground Water Control Act (1953) and the Barbados Water Authority Act (1980);
- Ministry of Tourism and International Transport on coastal tourism-related issues;
- Barbados Tourism Investments Inc. on matters that help identify investment opportunities and service providers;
- Sanitation Service Authority on matters relating to the Mangrove Pond Beautification Programme and to ensure refuse collection and street cleaning within the CZMA;
- Ministry of Transport, Works and Maintenance (MTWM) on matters relating to sustainable transport and infrastructure works strategy.

Supporting Committees (in addition to the Planning and Development Board) that help implement physical planning related activities include the Barbados Hotel and Tourism Association committees that exist on various topics including conservation and beach management.

A1.4.3. The legal and institutional framework for Disaster and Climate Risks

This ICZM Plan is designed to enable the GoB to respond successfully to the challenge of improving institutional governance on DRM and CCA issues. To support disaster and climate mainstreaming, the approach seeks to inculcate CCA and DRM within longer-term adaptation action planning. Key paradigm shifts in governance arrangements, though this ICZM Plan, seek to better embrace aspects of risk identification, prevention and mitigation and financial risk management for preparedness and response and recovery under the CZMU's mandate (under the legislative powers set within the proposed revisions to the CZM Act (2020)).

Key stakeholders to support implementation include (amongst others) the following:

- Department of Emergency Management (DEM) who seeks to implement the Emergency Management Act (2006) and the Emergency Powers Act, Cap. 161 (2006-20) to help promote and institutionalize the practice of appropriate preventative and mitigation measures for all possible hazards, as well as the development and maintenance of effective national and sectoral warning, response and recovery plans.
- Barbados Meteorological Service (BMS)[4] who are responsible for monitoring marine conditions in the country (within the context of meteorological data forecasting needs) and maintaining a database of weather data including stream flow data valuable for use in flood mapping and early warning system implementation.
- Barbados Coast Guard which represents the maritime division of the Barbados Defence Force with responsibilities for patrolling Barbados' territorial waters as well as drug interdiction and humanitarian and life-saving exercises.
- The Public Investment Unit (PIU)[5] who provides assistance, advice and guidance to line ministries, which have direct responsibility for project planning and implementation, including advice on DRM (ex-ante services).
- The Research and Planning Unit provides expert policy and technical advice based on a sound framework for economic and social planning (including DRM) through the conduct of economic

[4] Within the Ministry of Agriculture and Food Security
[5] Within the Ministry of Finance and Economic Affairs

and social research, policy analysis, rational economic and social planning, technical cooperation, coordination and the compilation and analysis of statistical information.

- Barbados Statistical Service (BSS) has a mandate (under the Statistics Act) to collect, compile, analyse, abstract and publish reliable and timely information relating to the social, economic and general activities or conditions of the inhabitants of Barbados. BSS works with DEM to assist on damage assessment work after natural disaster events. BSS also relies heavily on CZMU to provide specific data to support this plus also baseline maps of the coast (LiDAR, etc.).

Existing committees and their respective roles include the Cabinet approved multi-stakeholder National Climate Change Committee (NCCC) which recently transformed into the Climate Change Unit (CCU) tasked with producing the 2nd National Communication on Climate Change (2018). In addition, the Technical Standing Committee on Coastal Hazards is a scientific Standing Committee comprising of representatives from both GoB and private sector all working on DRM initiatives to reduce hazards along the coast, such as tsunamis, storm surge, winter swells, erosion, sea-level rise and oil spills. There may be a future need for all stakeholders, under the advisory role

of CZMU, to support in the production and subsequent Summary Reports and/or "White Paper" publications plus other supporting actions as identified in Table A.3 that include functions including (amongst others) capacity support enforcement support and future regulation recommendations, etc.

A1.4.4. The legal and institutional framework for coastal resource protection

Coastal resources (including greater emphasis on wetlands, mangroves and seagrass beds amongst others) have been granted specific attention within the proposed revisions to the CZM Act (2020) to ensure their consideration (in tandem with coral reefs) is granted with reference to how they may be affected/ impacted by CCA/DRM. Specific attention is also given to all land, water, minerals/nodules and offshore aggregates found on or under the seabed and living (and non-living) resources associated with the shoreline, water column, and marine areas of Barbados, including beaches, shore cliffs, seascapes and other resources of aesthetic value, coral reefs, coral rubble, algal beds, seagrass beds, sand dunes, mangroves, other wetlands and other ecosystems found along the shore together with the flora and fauna found in these areas.

The CZMU Director has a key role to notify all relevant agencies of the need to consult CZMU if they are seeking to undertake any activities, or make decisions, that may affect coastal resource health and integrity. The legal requirement to consult, contained in Section 33(3) of the existing CZM Act (1998), and retained within the proposed revisions to the CZM Act (2020) therefore represents an important legal tool to help deliver this approach (with support from a range of organisations – see Table A.3). A new routine process for communicating research findings, plus the assessment of the status of coastal resources, is to be adopted in the form of an annual "State of the Coast" report that is a requirement set out within this ICZM Plan and linked to revised legislation such as the proposed revisions to the CZM Act (2020). This shall be supplemented with publications (including "White Papers" as appropriate) to help clarify the range of roles that coastal resources play in Barbadian society.

Supporting organisations with specific reference to the protection of coastal resources within the CZMA, whom are important in delivering ICZM and in partnering to produce the "State of the Coast" reports include the following:

- Environmental Protection Department (EPD) implementing the Marine Pollution Control Act 392A (1998) to address water quality matters on land and at sea[6];
- National Conservation Commission (within the MENB) who are mandated (under the National Conservation Commission Act 1982) to carry out a number of functions related to the provision of services to the public and the protection and enhancement of the marine and terrestrial environment as well as regulatory functions as described in its Act. NCC also represents an important and integral agency towards the delivery of beach management related activities in Barbados.
- Natural Resources Department (NRD), (Energy Division) within the Prime Minister's Office (PMO) whose role is to support the promotion and development of all local natural resources (on-shore and within the Barbados EEZ), in an economically and environmentally sustainable manner.
- Natural Heritage Department (NHD) works with the NCC (the enforcers of regulations) to implement the Marine Areas (Preservation and Enhancement Act – 1976) and the Marine Areas (Preservation and Enhancement – Barbados Marine Reserve Regulations - 1981) to promote the conservation of special and unique biomes through effective management of a network of terrestrial and MPAs.
- Fisheries Division who are responsible for implementing the Fisheries Act (1993) and to provide support on fisheries planning and management (including sports fisheries) with the Fisheries Resource Management Section (of this Division) providing scientific information for planning and implementing measures for fishery management and development, including catch and effort statistics; biological, social and economic information, fisheries management measures and aquaculture and mariculture services. Fisheries Regulations (1998) may be made under the Fisheries Act (1993) on all aspects of fisheries and related activities, including limiting catches and protecting species such as coral shells, ornamental fish, lobsters, conchs and sea-eggs. The Act also requires licensing of vessels and fishermen and makes provisions for resource management plans ("fisheries schemes").
- Soil Conservation Unit implements the Soil Conservation (Scotland District) Act (1998) which include interventions to implement the extensive re-vegetation of the Scotland District with a large variety of vegetation including fruit trees.
- Barbados Coastal Guard and Police Force has responsibilities for patrolling Barbados' territorial waters as well as drug interdiction and humanitarian and life-saving exercises. They support CZMU with regards to local enforcement of the Shipping (Watersports) Regulations (2004) and beach byelaws (set by NCC authority) plus also the adherence to speed controls within marine protected areas (e.g.: Folkestone Marine Park and Carlisle Bay Marine Park).
- Barbados Agricultural Development and Marketing Corporation (BADMC) established by a legislative act (Cap. 254) in 1993 and help with undertaking water quality monitoring of groundwater for irrigation purposes.
- Barbados Port - MMABE has responsibility for the Barbados Port Inc., a private company of which the Government of Barbados holds 100 percent shares.

[6] The Environmental Management Act is not yet enshrined in law. However, elements of the Act are being implemented nationally by EPD though it has no legal authority to enforce or prosecute any known offenders and instead the EPD's regulatory authority remains bound by the Health Services Act (1969),

- Maritime Division (MMABE) - responsible for advising the Minister on program-related policy formulations and implementation and the management of the legislative/regulatory, supervisory and monitoring framework, including relevant international conventions that govern matters relating to shipping, seafaring, and safety at sea and the prevention of marine pollution.

Existing committees and their respective roles include the National Oil Spill Response Committee (chaired by the EPD) who coordinate activities including training on shoreline oil spill response and clean up techniques.

A1.5. Relationship of the ICZM Plan to other plans

The updated PDP (2017) is the primary planning instrument within Barbados for establishing the use of land, and the environment and conservation policies that will apply within these designations. The PDP is supported by a number of other plans that provide national guidance on specific elements of natural resource management and development, namely:

- The ICZM Plan (this document plus Volume 1 ICZM Policy Framework);
- Barbados National Strategic Plan (NSP 2005-2025);
- Draft National Climate Change Policy Framework (NCCPF) (2012);
- Country Document for Disaster Risk Reduction (DEM 2014);
- Tourism Master Plan (2014-2023);
- The Environmental Management Plan (1998);
- Barbados Growth and Development Strategy (2013 – 2020)
- Barbados Oil Spill Contingency Plan (2013);
- Fisheries Management Plan (2004 to 2006);
- Barbados National Biodiversity Strategic Action Plan (2002)

There are cross-references between the various planning documents. In the updated PDP (2017) for example, it is stated that the ICZM Plan abide to the *Natural Heritage System* approach and in return, all decisions on coastal development, conservation, and management in the CZMA are to be informed by the latest technical data and analysis available to the CZMU and that the ICZM Plan will implement the PDP policies for Open Spaces that occur within the CZMA (Section 2.2.2 – Natural Heritage System: Coastal Zone Management sub-section).

Reflecting this synergistic approach, Section 4.4 of the PDP (OS3 – Coastal Landscape Protection) defines the limits of Coastal Landscape Protection Zones from Salt Cave Point to Conset Bay (south and east coasts) plus from Archers Bay to Maycocks Bay (north-west coast) whereby the inland limit is defined by the CZMA boundary. In addition, Section 4.8 of the PDP (2017) refers to "Shore Access Points" and the importance of maintaining access to the sea for emergency vehicles and maintenance vehicles for coastal structures. In a similar vein, the objectives for the Barbados National Park have been used to guide the coastal management programme for the stretch of coast which falls within the proposed National Park (see Section 4.2.8 of the updated PDP 2017). Additional information on links such as these are given in the national guidance in Part C of this ICZM Plan. These links will need to be maintained when any of these related plans and policies are reviewed (see Figure A.14). The Planning and Development Board (as set out within the PDA (2019)) shall assist with this process[7].

Consistency of approach, in line with the updated PDP (2017) and the PDA (2019)[8] (Sections 1.4 and C5.1 of this ICZM Plan), remains paramount throughout the effective life of this ICZM Plan. These also provide the opportunities to support delivery of an improved environmental impact assessment (EIA) process for the country. This opportunity is supported through existing planning processes with the Director of the CZMU currently identified (within the PDA 2019) as a key member of the Planning and Development Board which is an obligatory channel of cooperation and communication relating primarily to physical development and planning.

Links between the different legal provisions are subsequently essential to ensure ICZM delivery and success as all aspects of ICZM in Barbados involve aspects of environmental management. Consequently, in addition to the proposed revisions to the CZM Act (2020) (see Section 1.5), the PDA (2019) and the Marine Pollution Act (1998), the entire legal framework is important to the implementation of the ICZM Plan. New legislation is being prepared in the form of the Open Beaches Bill (2019) with provisions to help facilitate ICZM delivery. Pending developments to formalise a "Sustainable Ocean Based Economy (SOBE)" for Barbados shall also require close integration with this ICZM Plan and supporting sectoral strategies within the coming years.

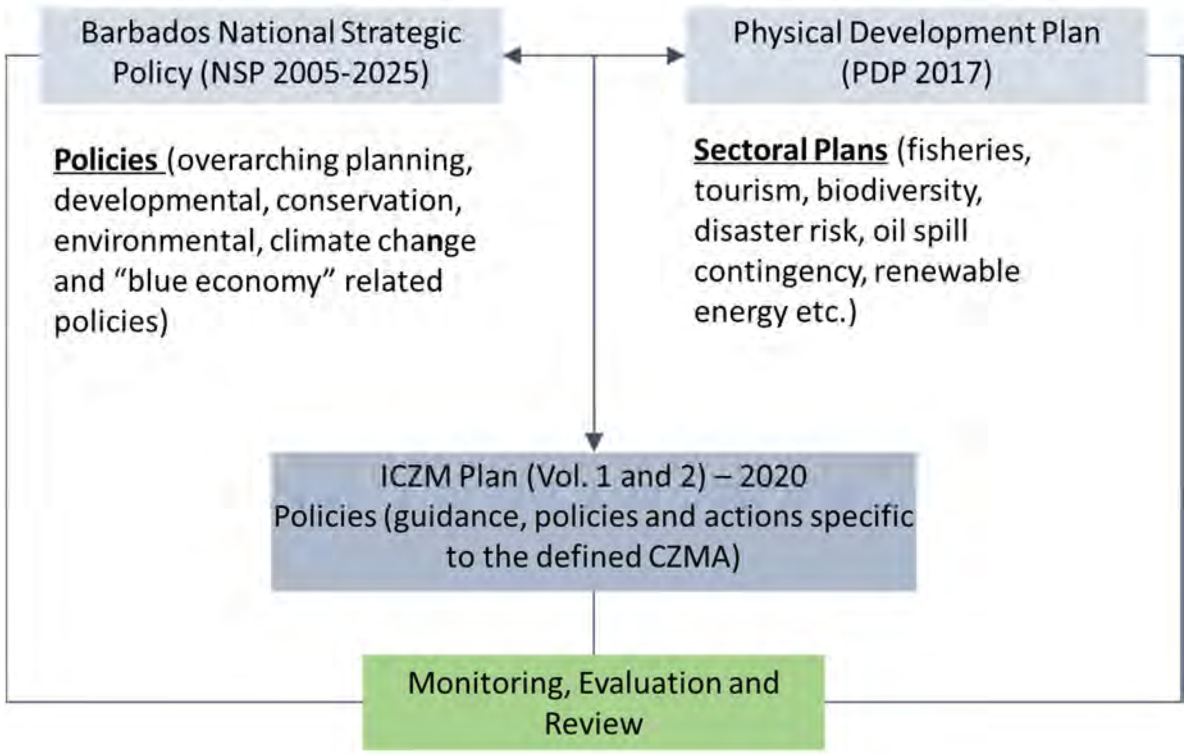

Figure A.14. Links between key planning documents which support this ICZM Plan.

[7] The Planning and Development Board is a body corporate with perpetual succession and a common seal. The Board is responsible for the implementation of the policies framed by the Minister.
[8] Accepted by both Houses of Parliament by January 2019. Currently it underpins the approach that applies to ICZM as well as the process of national physical planning and development. It is anticipated that this legislative instrument will be effected as a Statutory Instrument.

A2. CHARACTERISTICS OF THE CZMA

The description of the coastal characteristics -including the natural environment, the people and economy and the risks derived from natural and anthropogenic processes- is presented in this section. The information provided has been extracted from the numerous baseline studies and risk assessments developed by the CZMU during last years (see Annex 2), mostly within the CRMP (IDB funded programme – undertaken by Baird 2015-2018). These baseline studies have been integrated within the NCRIPP, which is a software tool to provide planners and other government groups with a manner to assess and mitigate risk.

A2.1. The natural environment

A2.1.1. Physical environment

Climate

Barbados is the most easterly of the islands of the Lesser Antilles, located at 13º 4’ North latitude and 59º 37’ longitude, which determines the island climate.

The climate is tropical and oceanic, hot and humid all year round, with an average and homogeneous (without severe seasonal or daily changes) temperature of 26.8 ºC. The island enjoys two weather seasons: the wet season, which coincides with the Atlantic hurricane season (from June to November), and the dry season, with an average rainfall range of 39 mm per month. During the wet season, most of the rainfall is derived from tropical waves that lead to downpours or thunderstorms with monthly average rainfall ranges from 160/170 mm.

Geology and geomorphology

The coastline length of Barbados is about 114 km of which approximately 59 km are coralline limestone cliffs (Golder, 2016), mainly located along the southeast, east and north coasts (Figure A.15). Approximately 86% of the land area is capped by coralline limestone rocks, overlying uplifted sea-bed sediments and weak/poorly consolidated Tertiary rocks of Eocene.

Cliffs have been classified into five main types (Golder, 2017; Figure A.16 and Figure A.32) based on rock strength, type, modes of failure and geological composition. Total lengths of each type classified around the island are:

- Type A - about 11 km.
- Type B - about 19 km.
- Type C - about 19 km.
- Type D - about 5 km.
- Type E - about 6 km.

Coralline cliffs exist around the majority of the coastline of Barbados, except for Scotland District. According to Golder (2017), between the predominant cliff areas along the west and south coasts (Sub Areas 6, 7 and 8, Figure A.15), about 21 km length of the coastline consists of calcareous beach sand. Moreover, along the east part of the island, approximately 13 km of primary silica (quartz) sand beaches occur at or near the base of the exposed sloping Tertiary sediments/weak rocks of the Scotland District.

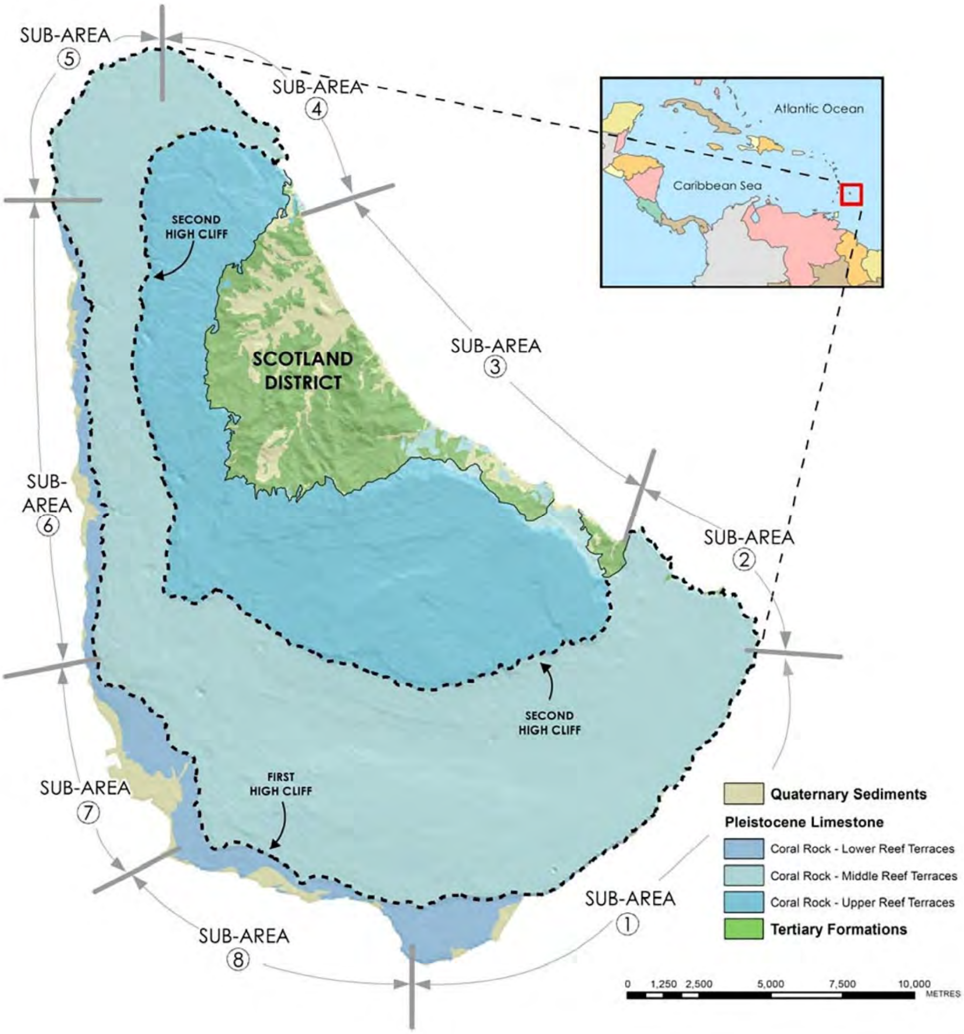

Figure A.15. Sub-areas of the Geotechnical surveys Investigation developed by Golder Associates (Source: Golder, 2017).

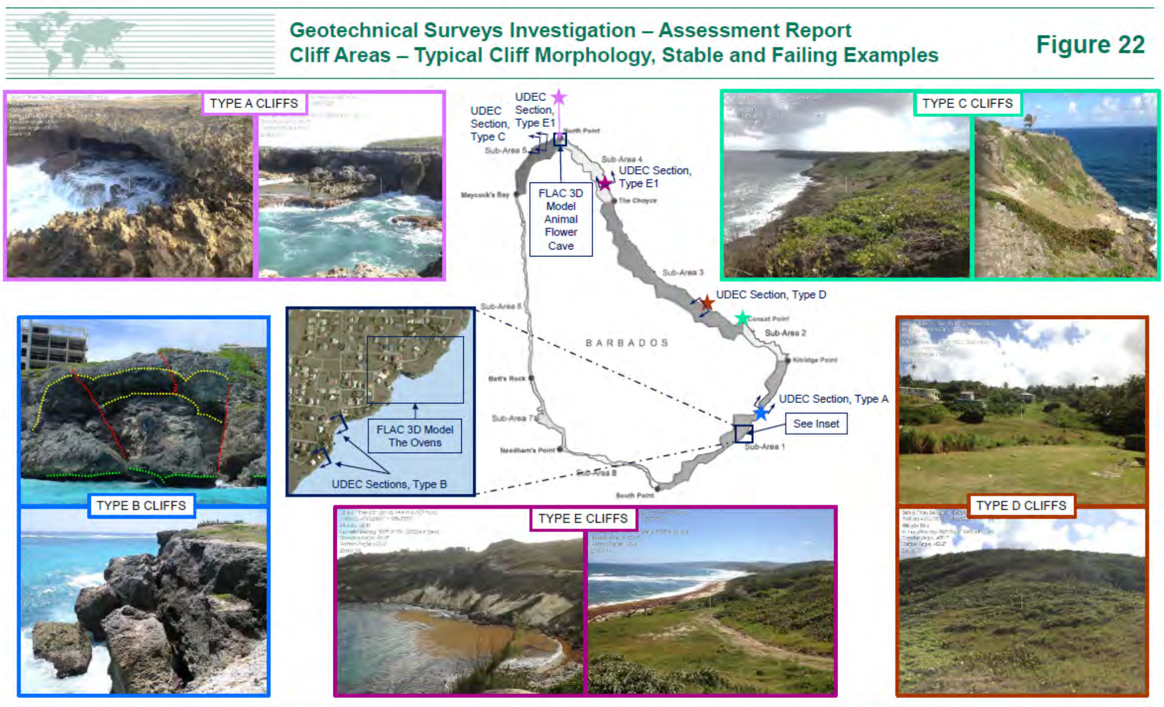

Figure A.16. Examples of the five types of cliffs (Golder, 2017).

Nearshore dynamics

Nearshore dynamics in Barbados are related to the interface between the sea and the land. These dynamics are complex systems that evolve in time and produce changes between them. The more important nearshore dynamics for the ICZM of Barbados are sea level, current circulation, waves, sediment transport, and coastal stability.

Sea level

Sea level movement is composed of two different processes: the rise of sea level due to astronomical tides and the rise of sea level due to atmospheric surges.

Barbados, as in the majority of the Caribbean Sea, presents mixed semidiurnal tides, this magnitude is well-know and it is possible to be predicted accurately. However, the prediction of surges is more difficult because of the intertitles derived from atmospheric processes. Commonly this magnitude is calculated subtracting the astronomical tide from the instrumental register of sea level in areas protected of the short waves, as bays or behind breakwaters in ports.

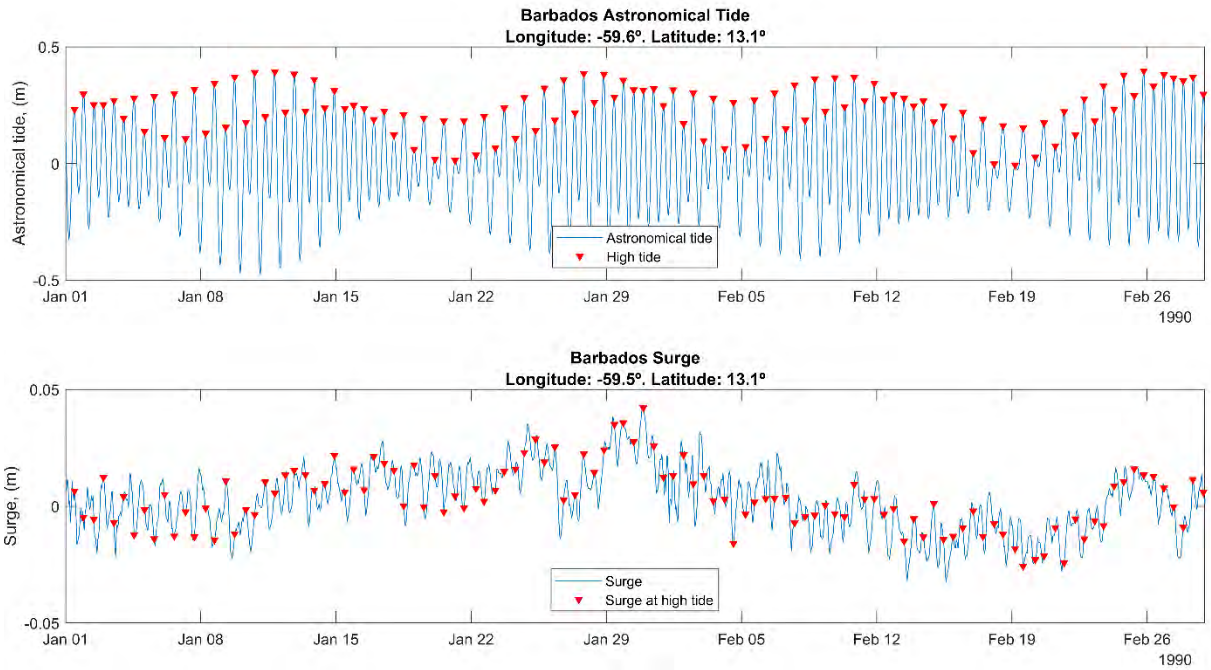

Figure A.17. Astronomical tide and atmospheric surge obtained from reanalysis databases.

Sea level monitoring is performed in Barbados using two tide gauges, one at Port St Charles and another one at Bridgetown Port.

Current circulation

Barbados is subjected to both south and north equatorial currents. The north equatorial current flows east to west at a latitude of 10° to 20°.

Barbados is subjected to both south and north equatorial currents. Moreover, the influence of the Orinoco and Amazon Rivers are also influencing the pattern of currents around the island. As a result, the dominant oceanographic currents in Barbados are from the southeast towards the northwest but the important variability of these processes usually needs the use of numerical modeling to obtain specific results in nearshore scales. Barbados has carried out an important effort in the study of nearshore current circulation during the last years as part of the CRMP. Consequently, Barbados implemented, calibrated and validated an island-wide model to perform the downscaling of the regional currents to local scale using several intermediate numerical domains.

Waves

Wind-generated waves at the sea surface play a major role in many engineering and environmental issues, both in the open ocean and coastal zones, providing a significant contribution to coastal sea level extremes and subsequent flooding. They are also a key factor in determining rates of coastal erosion and sediment budgets. At the open sea, they represent a major hazard for any offshore operation or structure or to maritime transportation and shipping activity. Therefore, changes in wave climate are of central importance for almost all aspects of coastal and offshore activities.

Barbados is affected primarily by waves generated by the following:

- NE Trade Winds;
- North Atlantic Ocean Swells;
- Hurricane and Storm Activity.

Illustration of these three mechanisms of wave generation and their relative direction of approach to the island is presented in Figure A.18.

Figure A.18. Wave Generation Mechanisms for Barbados. (Source: Baird and Associates, 2003).

Long period swells originate from storm activity in the North Atlantic and propagate to the shoreline of Barbados. These waves impact in first instance the north-east and east coasts but also, due to their long periods (12 seconds and greater), tend to wrap around westerly affecting the west coast, and easterly affecting the complete east coast and in last instance the south coast of the island.

The North East trade winds result from the pressure gradient that exists due to rising air at the equator. These trade winds that blow within the vicinity of Barbados cause locally generated seas.

Hurricanes and storms form over tropical waters (between 8° and 20° latitude) in areas of high humidity, light winds, and warm sea surface temperatures (typically 26.5°C or greater). These conditions usually prevail in the summer and early fall months of the tropical North Atlantic and North Pacific Oceans and for this reason, hurricane 'season' in the northern hemisphere runs from June through November. These systems typically form east of Barbados and travel west, generally passing north of the island.

Wave data has been collected in Barbados starting over 30 years ago. Much of the older data are either not available, have inadequate documentation, use older technologies, and/or are very limited in duration. The more consistent and reliable data generally commence in the late 1990s. Wave data provides one of the primary driving forces in the CRMP and also is an important part of the development carried out in the NCRIPP.

In the last years, new data measurements from CRMP has been used to calibrate and validate island-wide modeling to obtain a comprehensive reanalysis of the wave climate in Barbados. The location of the instruments used during the Nearshore Wave Study (NWS) and the island-wide domain used for the regional downscaling are presented in Figure A.19. As a result, NWS concludes that the model would compare well during some periods and then poorly during another period when the offshore waves were similar. The conclusion was that currents were playing a large role in the wave transformations into the more sheltered areas (such as the SW coast).

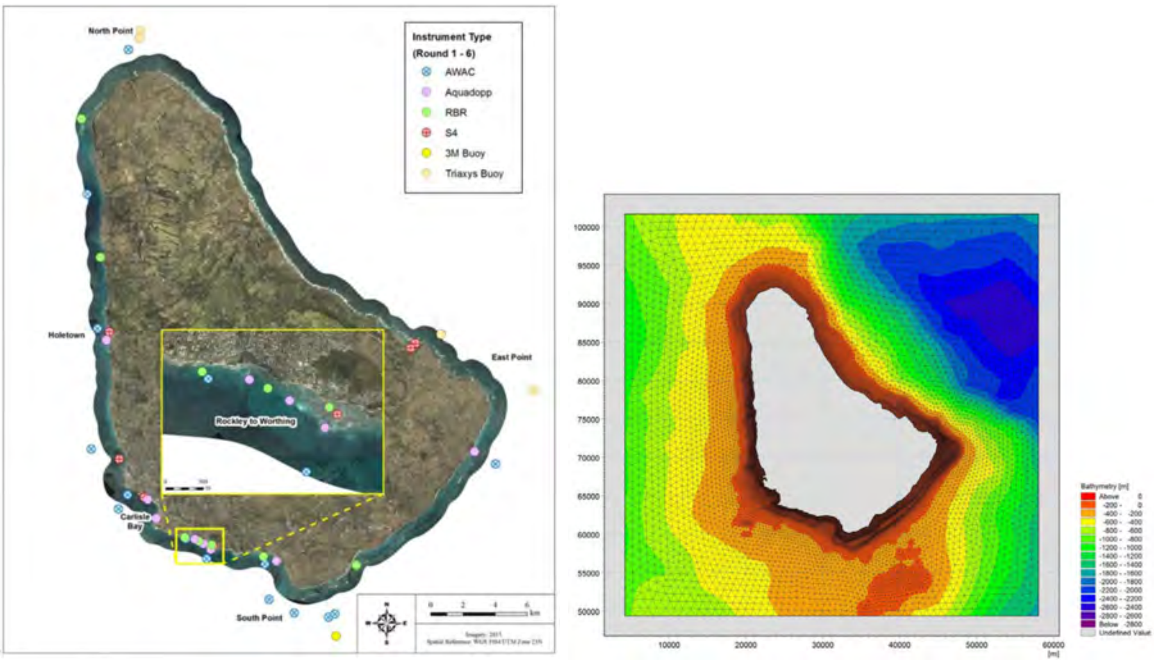

Figure A.19. Location of Wave Measurement Equipment during NWS and Nearshore Wave Model Domain (Source: Baird, 2016).

Sediment transport and coastal stability

Sediment transport and coastal stability are important issues related to the physical environment of the coast of Barbados because of the important use of the beaches on the island. Sediment transport is a complex process in which many factors are involved such as currents, waves, reefs, sediment availability, sand supply, man-made structures.

To enhance the understanding of these processes, a numerical model was developed as part of the CRMP to adopt an integrated sediment budget approach that incorporates the balance between beach building and beach eroding parameters on a multi-decadal scale to assess the impact of SLR. The key sediment budget components for a typical beach in Barbados include: 1) carbonate sediment supply from local underwater habitats such as corals, 2) profile response to storm events (driven by cross-shore sand transport) under different sea levels, and 3) alongshore sediment supply as a result of the gradient in longshore sediment transport (reach-based difference between incoming and outgoing alongshore transport).

Carbonate sand supply, from local underwater habitats such as corals, is one of the major components contributing to the beach sediment budget (Baird, 2016b).

Longitudinal transports were calculated and results confirm some of the previous works carried out in local scales like the predominance of a longitudinal transport from Bottom Bay to North Point at the Atlantic coast. However, at the south part of Bottom Bay, the net annual longitudinal transport goes to the south-west until it reaches Carlisle Bay where longitudinal transports in both directions are significantly balanced. As an example, longitudinal sediment transport patterns at 2m depth are presented in Figure A.20.

The sediment budget model indicated that the most sensitive locations to SLR are those where the beach is prevented from migrating landward during SLR by an existing hard barrier at the back of the beach. As a result, the beach becomes narrower and steeper and loses its ability to preserve a reservoir of sand for temporary storm loss. Furthermore, beach overtopping or over-washing events would increase resulting in sand (and water) being washed across roads or properties behind the beach. Beaches on the southwest and west coasts of Barbados are susceptible to coastal squeeze (e.g. Sandhurst Main, Drill Hall, the southern reach of Carlisle Bay, Fitts Village, Folkestone and Heywoods South) due to the manmade structures along the densely populated shoreline. North Point is also susceptible to coastal squeeze, due to the steep rocky coastal cliff located at the back of the beach.

Following the CRMP Shoreline Change Study (Baird, 2015c), the majority of the eroding coast (natural) shoreline is located between Sandy Lane and the Cement Plant on the west coast. The only segments of accreting coast (natural or engineered) are located north and south of the Port in Bridgetown (Figure A.21). The majority of the southwest coast is classified as stable coast (engineered), while the entire north shore is coastal cliff. The Scotland District is dominated by dynamically stable coast in the north and coastal cliffs in the south. The east and southeast coasts feature coastal cliffs with isolated pocket beaches that are generally stable.

When aggregated for the entire island, some important trends for the coast of Barbados emerge. First, 8% of the coastline is eroding, while only 2% features an accretion rate. The coastal cliffs represent 48% of the island, while 8% of the coast has been classified as artificial coast. The northern half of the Scotland District features the only coast classified as dynamically stable (natural) but it is a large segment and represents 9% of the shoreline of the island.

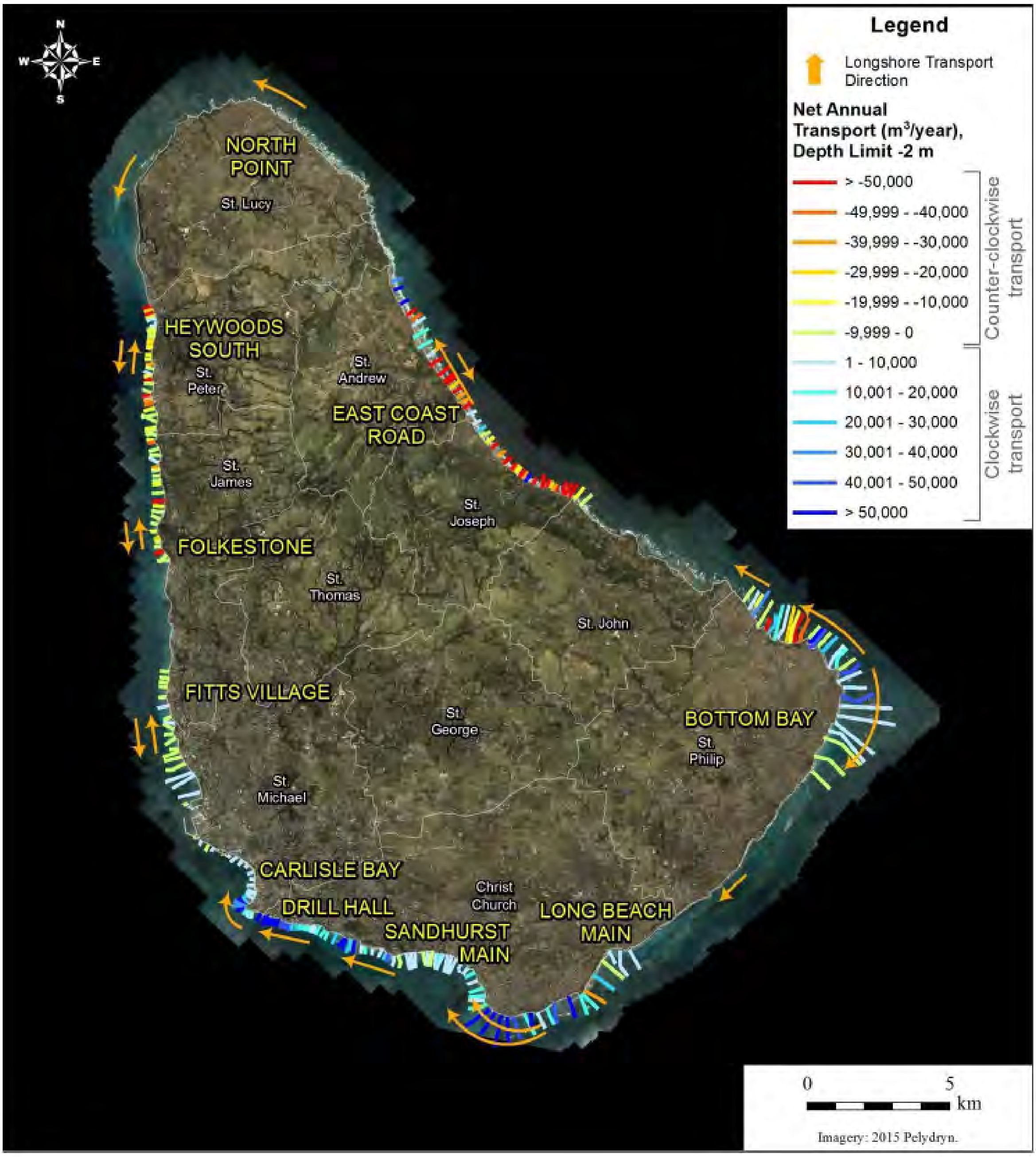

Figure A.20. Sediment transport patterns around the coast of Barbados (Source: Baird, 2016).

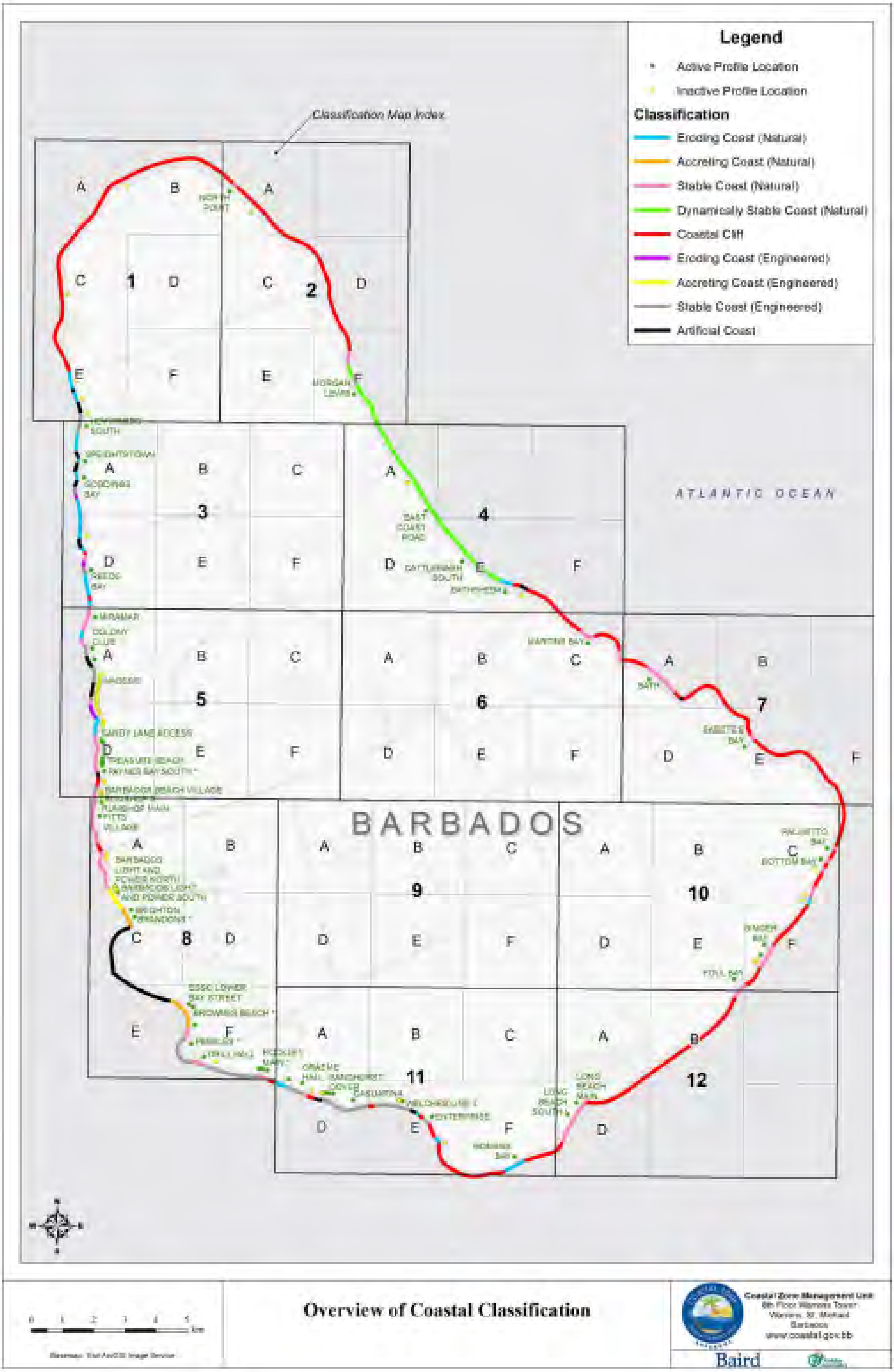

Figure A.21. Overview coastal classification due to their coastal stability (Baird, 2015).

Water quality

The quality of the marine water is fundamental to the maintenance and functioning of the coastal ecosystems as well as human health. According to the ICZM Plan for the Caribbean Coast (Halcrow, 1998b), in Barbados, terrestrial discharges are the main source of pollutants in the marine environment and the main transport mechanisms are surface water runoff, groundwater discharge and direct discharge or dumping.

A review of historical data shows that poor water quality has been characteristic of the south and west coasts of Barbados due to nutrients, which have been identified as a key stressor affecting the health of the coral reefs (Baird, 2015b). During the 1992/93 sampling program nutrient (nitrate and phosphate) and bacteria levels already exceeded threshold levels on most of the west and southwest coasts. On the other hand, the Atlantic coastal area showed low levels of contaminants in both terrestrial and coastal waters (Halcrow, 1998a), and therefore, a better quality than the Caribbean area of Barbados.

Agricultural practices and residential wastewater disposal have been identified as a significant source of nutrient contamination in both surface waters and groundwater (Baird, 2015b). It is important to note that surface water discharges depend on seasonal rainfall, but groundwater discharges are continuous and generates the largest nitrogen lead to coastal waters. This study also indicates that removal of wastewater inputs and improved agricultural practices could reduce groundwater nitrogen loads by approximately 60%. This would significantly improve nearshore water quality, not only with respect to nutrients, but also by reducing other contaminants associated with residential and agricultural wastewater.

A2.1.2. Biological environment

Coastal habitats

Barbados shows a rich biodiversity of coastal habitats and ocean life. Nevertheless, habitat loss is an on-going challenge to biodiversity conservation in Barbados. During colonial times, substantial vegetation was cleared for agricultural purposes, building materials and firewood. More recently, vegetation loss has resulted primarily from land clearing to facilitate residential development, the largely ad-hoc urbanization process and the construction of tourism sector developments, such as hotel and golf course facilities.

Some of the natural coastal habitats present in Barbados are: Beaches, sand-dunes and sandy bushlands, Sea Cliffs and Sea Rocks, Gullies, Coastal Wetlands, Tidepools and Coral Reefs.

Beaches, sand dunes and sandy bushlands

Beaches are characterized by xerophytic (a plant that needs very little water) and halophytic vegetation (a salt tolerant plant that grows in soil of waters of high salinity), although windward and leeward dunes show some specific differences. According to the Barbados National Biodiversity Strategy and Action Plan (BNBSAP, 2002), within the beaches on the windward coast the sandy bush-lands, sometimes referred to as dry thorn scrub communities with cacti and other prickly shrubs, often appear to be a further development of the *Coccoloba* association of the dunes. The leeward beaches are relatively narrow and, where they have not been cleared for coastal development, are backed by trees and shrubby undergrowth.

On the other hand, there are some pebble beaches, characterized by pebbles, boulders and a reef flat extended from the beach seaward for several meters. These pebble beaches are found at Cattlewash, Edgewater, Glenburnie, 3 Boys Rocks and Tent Bay (St. Joseph), which were described in the study of Lewis (1960) and this information has been no update since then.

Sea Cliffs and Sea Rocks

Sea cliffs are characterized by a sparse plant life, that is restricted to halophytes species, which occur in the crevices. At the tops of these cliffs, grasses and shrubs are usually abundant.

It is important to note the presence of three rare cliff species: *Heliotropium microphyllum* (lesser Antillean endemic) found only at River Bay, St Lucy; *Strumpfia maritima* (Caribbean-wide sp), which is found only near Gemswick to Foul Bay, and Barbados Cinnamon found at Pico Tenneriffe, the only location on island where it has been found.

Gullies

The gullies are landforms created by running water, eroding sharply into soil, typically on a hillside. They are predominant features in the island, running in all directions from the higher elevations to the sea. Today, these gullies tend to have a large and mature collection of native ferns, climbers, shrubs and trees in Barbados (BNBSAP, 2002).

Coastal wetlands

Mangroves communities mainly compose the scrub vegetation in the coastal Barbados swamps. The largest mangrove area in Barbados is placed in Graeme Hall Swamp (30 ha) that includes both natural and man-made water bodies (BNBSAP, 2002), with the largest remaining area of red mangroves (*Rhizophora mangle*) and white mangroves (*Laguncularia racemosa*).

The mangrove forests of Barbados also include the species *Conocarpus erectus*, which is limited to Chancery Lane (Carrington, 1991).

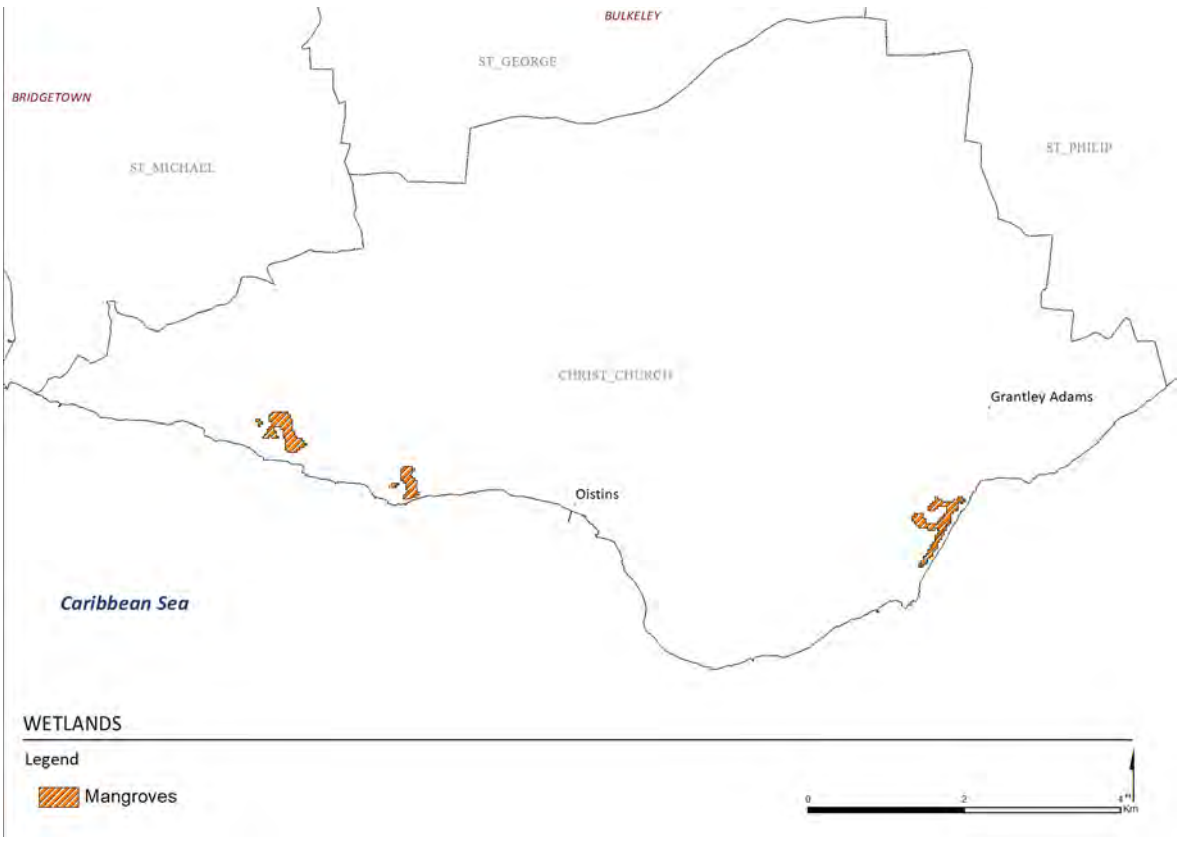

Figure A.22. Mangrove's distribution in Barbados (Source: CZMU).

Another wetland coastal habitat are the seagrass beds. Four species of seagrasses have been reported for Barbados: *Thalassia testudinum*, *Syrungodium filiforme*, *Halodule wrightii* and *Halophila* sp (Delcan, 1994; Vermeer, 1997).

Tidepools

Tidepools are present along the north, east and south-east coast of Barbados. Tidepools act as nursery habitat (Mahon and Mahon, 1994) and recruitment issue (Halcrow, 1998b) for some reef fish.

Coral reefs

The coral reefs are a great ecological value of Barbados (Figure A.23). This habitat provides shelter, feeding and breeding grounds, recruitment sites and nursery grounds for multiple marine organisms. Moreover, coral reefs show several socio-economic impacts such as their medicinal properties, the associated white sand that act as source of beach nourishment, recreational and educational values to both visitors and locals, and the climate services provided for coastline protection from erosion. The majority of wave attenuation on fringing reefs is due to wave breaking on the reef crest (approximately 80 to 90%), while the live coral canopy on the reef flat accounts for an additional 10 to 20% of the wave attenuation (Baird, 2015). Despite their importance, more than 70% of coral reefs in the Caribbean are under immediate threat from anthropogenic stressors and climate change (Jackson et al., 2014).

According to the BNBSAP (2002), the total area covered by the bank reefs in Barbados is estimated at 4.9 km^2, while the fringing reefs cover 1.4 km^2. The fringing reefs generally have three distinct zones: back reef, reef flat, and the spur and groove zone, while the bank reefs are characterized by a narrow crest and steep landward and seaward slopes.

Figure A.23. Distribution of coral reefs in Barbados (Source: CZMU).

Endangered species

The major threats to biodiversity in Barbados are habitat loss and fragmentation, but also a long history of alien species introduction (BNBSAP, 2002). Some of these introduced species are the mongoose (*Herpestes javanicus*), cane toad (*Bufo marinus*) and wild sage (*Lantana*).

The Lesser Antilles has approximately 2100 species of indigenous plants, but only about 700 of these indigenous plants are hosted by Barbados. According to Cohall (2014), the intense cultivation of sugar led to the disappearance of many indigenous plants. Nevertheless, Barbados preserves two endemic species: broom weed (*Phyllanhus andersonii)* and *Metastelma barabdense*. Broom weed is found in several gullies, but *Metastelma barabdense* has not been seen for, at least, 20 years.

The IUCN Red List of Threatened Species lists eight critically endangered species of fauna in Barbados: the Altantic Goliath Grouper (*Epinephelus itajara*), Elkhorn Coral (*Acropora palmata*), Eskimo Curlew (*Numenius borealis*), Hawksbill Turtle (*Eretmochelys imbricata*), Smalltooth Sawfish (*Pristis pectinata*), Staghorn Coral (*Acropora cervicornis*) and Warsaw Grouper (*Epinephelus nigritus*).

On the other hand, the Barbados leaf-toed gecko (*Phyllodactylus pulcher*), a species unique to the island, was declared extinct until a small colony was rediscovered in 2011. Nowadays, the estimated number of adult Barbados leaf-toed geckos remaining in the wild is 250.

Natural protected areas

Barbados shows different types of natural protected areas: National Park, Natural Heritage Conservation Areas (features and locations that are important to the natural heritage of the island) and Coastal Landscape Protection Zones (coastal areas with a natural character and unique physical attributes), as well as a variety of coastal/beach parks and open spaces (see annex Figure A.24).

The National Park (Scotland District; Figure A.25) is the base of the Barbados System of Parks. It encompasses a wide range of land use activities, from forestry and conservation to tourism, settlements, sugar production and other extraction activities. The National Park is an IUCN Category 5 Protected Landscape/Seascape. Therefore, the aim of this protected area is to preserve and sustain important landscapes/seascapes and the associated nature conservation and other values created by interactions with humans through traditional management practice.

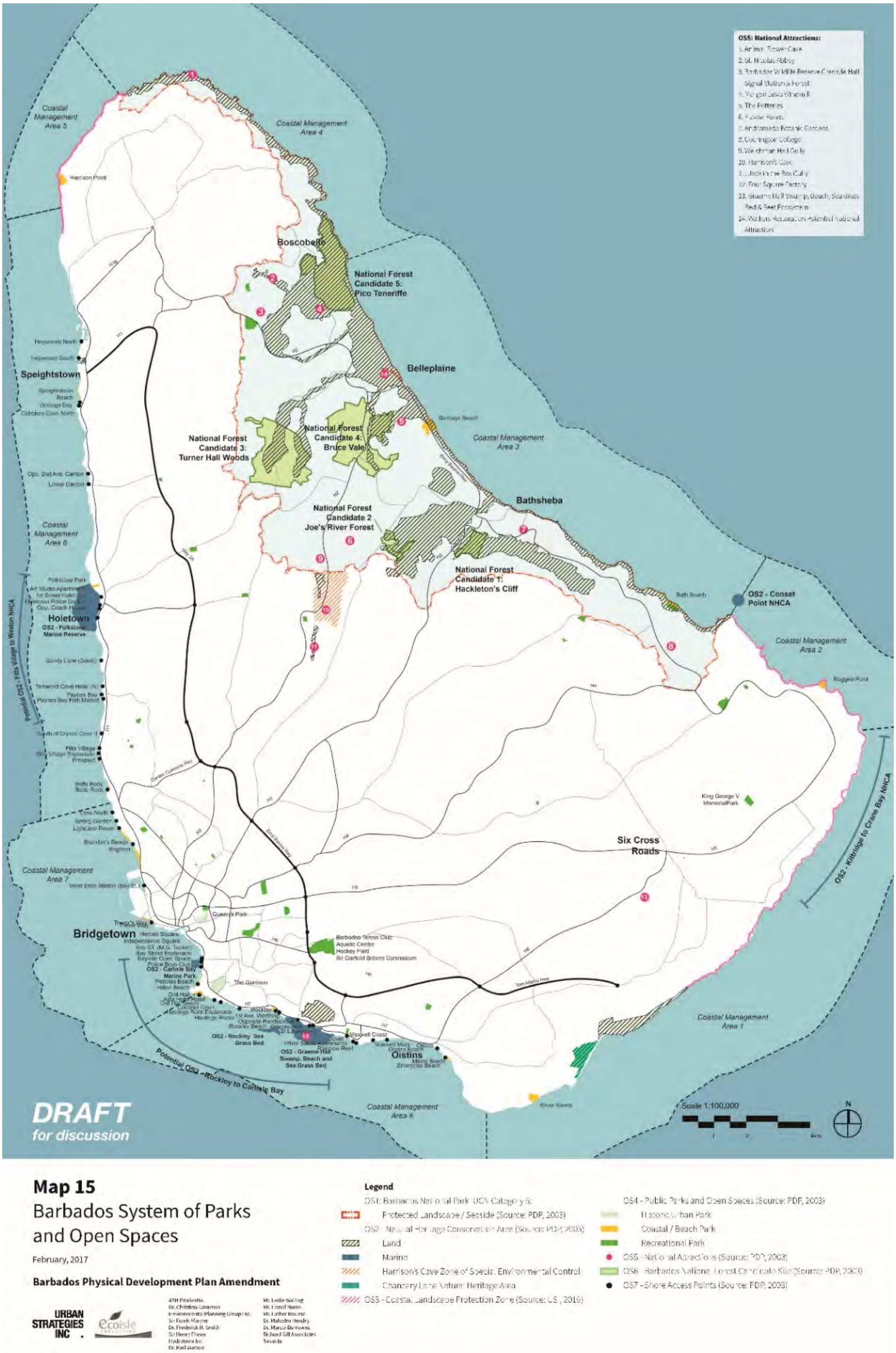

Figure A.24. System of Parks and Open spaces in Barbados. (Source: PDP, 2017).

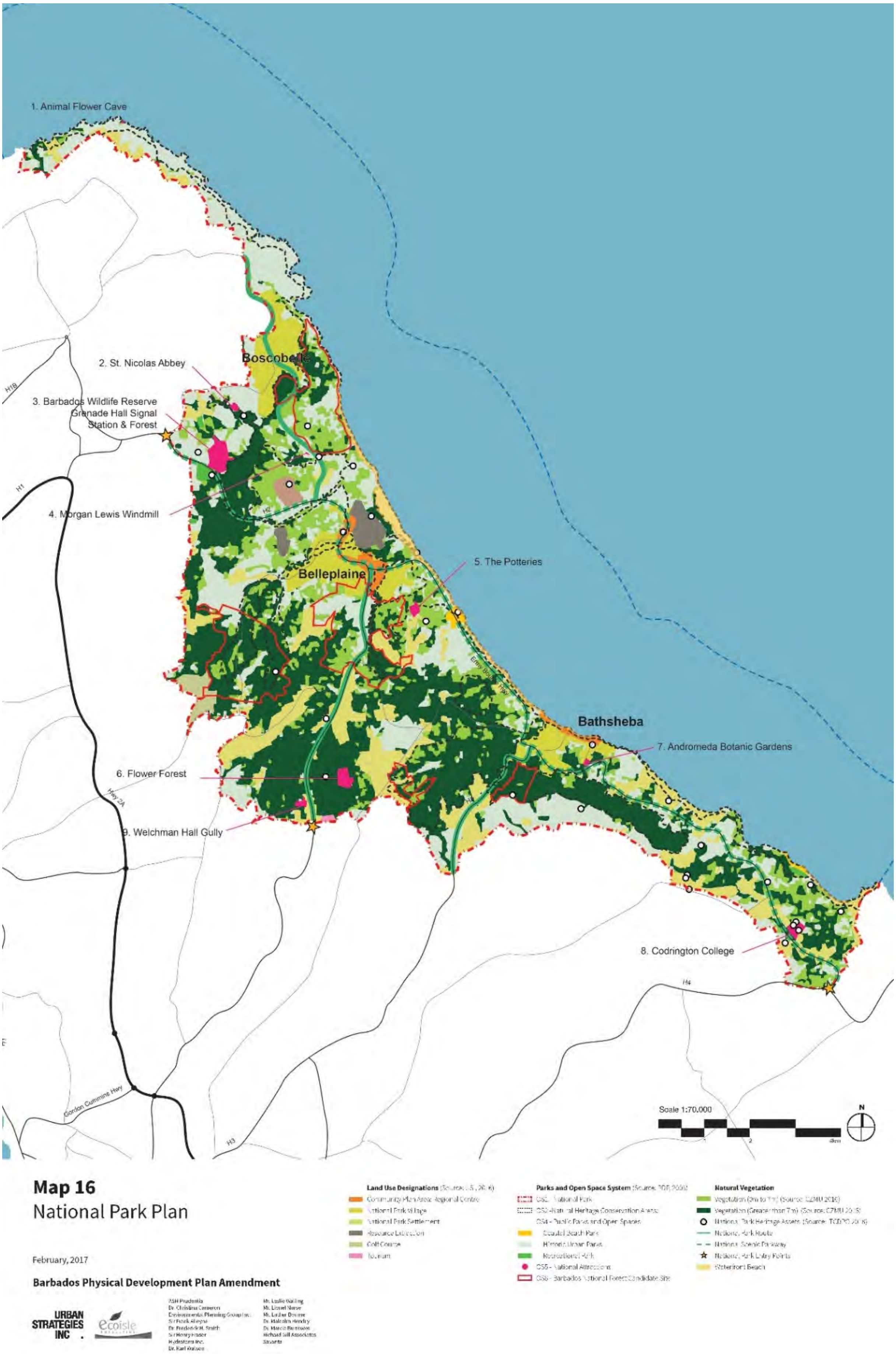

Figure A.25. Settlement Structure Map. (Source: Barbados Physical Development Plan Amendment 2017).

The Natural Heritage Conservation Areas are sensitive or unique ecosystems, both within and outside of the National Park, which require protection from development and intensive recreational development. According to the PDP (2017), there are two categories of Natural Heritage Conservation Areas: land and marine.

The Land Natural Heritage Conservation areas include: Graeme Hall Swamp and Beach; Heywoods Mangrove Swamp; Chancery Lane Swamp; Harrison Cave Special Study Area; Welchman Hall Gully; Jack in the Box Gully; as well as the Heritage Conservation Areas of the Natural Park (all of the coastal beaches, dunes and cliffs, including Morgan Lewis and Walkers Beach and St. Lucy Cliffs; Hackleton's Cliff and Woods, Turners Hall Woods, Cattlewash Woods, Joe's River Forest, Boscobelle Woods; Long Pond and Green Pond; The Green River, Joe's River, Bruce Vale River systems; The Savannahs complex; and Chalky Mount.).

The Marine Natural Heritage Conservation Areas include: Graeme Hall Beach, Sea Grass Bed and Reef Ecosystem; Carlisle Bay Marine Management Area; Rockley Breakwater; Kitridge to Crane Bay; Conset Point; and Folkestone Marine, which was the first marine protected area in Barbados (1981).

On the other hand, two coastal landscape protection zones have been designated in Barbados: the zones extend from Salt Cave Point to Conset Bay (along the southeast and east coasts) and from Anchers Bay to Maycock's Bay (along the northwest coast). These areas contain significant habitat and contribute to the appearance and function of the coastal areas of Barbados (Barbados Physical Development Plan, 2017).

A2.2. People and economy

A2.2.1. Demography

Barbados is one of the world's most densely populated islands in the world (about 660 persons per square km). With a surface of 439 km^2, the island's population is about 293.000 (index mundi, 2018), with a median age of 39 years. According to 2010 census, ethnic groups constitute the following percentages of Barbadian population: 92.68%: black; 3.49%: white; 2.67%: mixed; 0.99%: East India 0.05%: Chinese; 0.03: Arab; and 0.09%: other.

Population densities showed in Figure A.26 evidence high values at the coast, mainly around the four coastal community cores (Speightstown, Holetown, Bridgetown, and Oistins) with densities over 3000 people per square km. Moreover, the entire urban corridor proposed in Draft PDP (2017), located along the west, south and south-east coast, concentrates most of the population of the island.

On the other hand, the interior areas present the lowest densities, under 1000 people per square kilometer. Also, densities under 1500 people per square km are presented at the east coast, where National Park is located and where the wildest character of the Barbadian coast is still conserved.

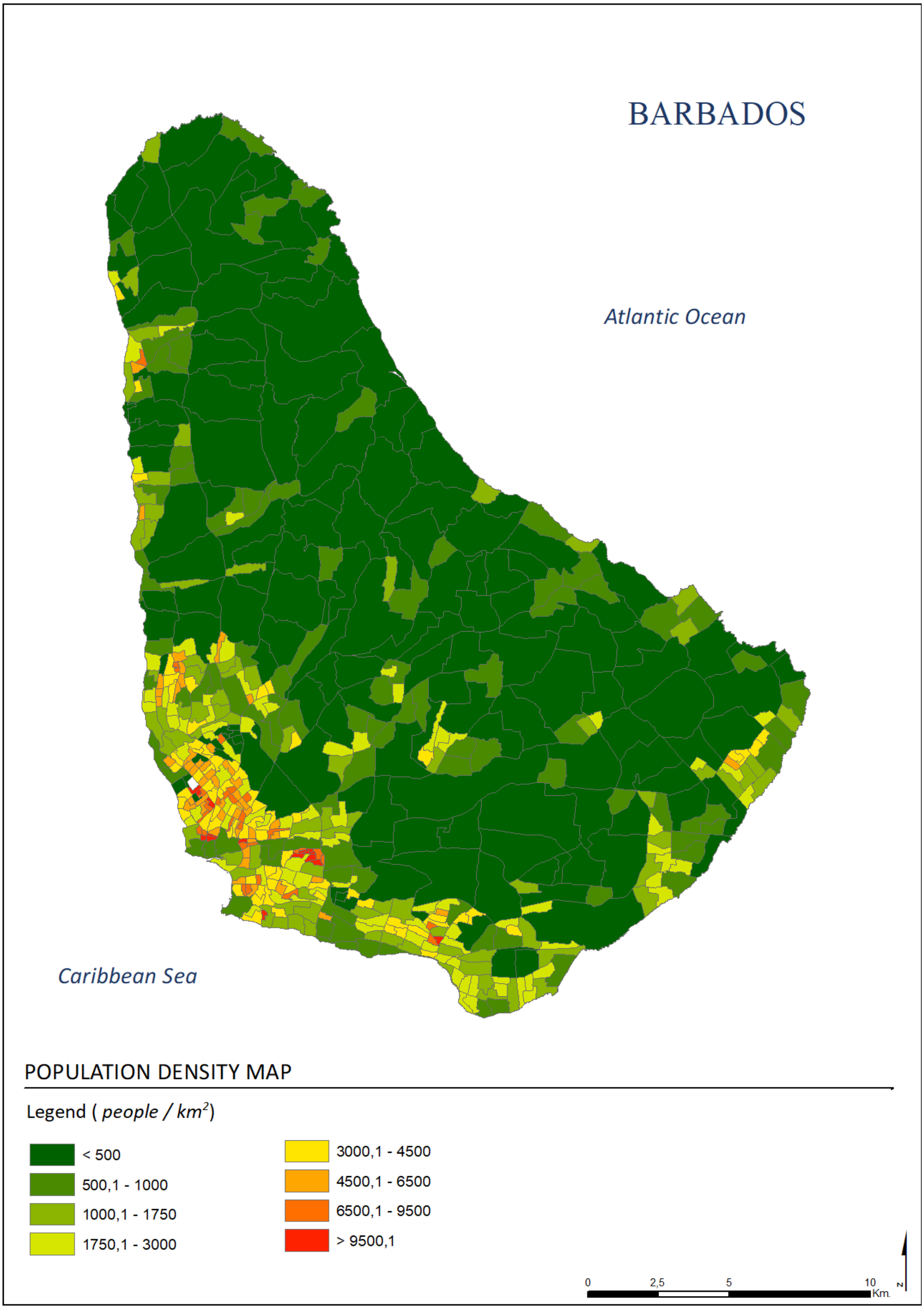

Figure A.26. Population density map of Barbados.

A2.2.2. Land-use

The Barbados Revenue Authority (BRA) define the usage of the 121940 parcels of land that are included in the BRA Tax Database. It is important to note that the BRA data represents the number of properties but does not provide an indication of the size of these properties or total area. While it does show the development of infrastructure types in Barbados.

It is important to note that over 25% of the population and much of the infrastructures lie within a risk zone about 2 km of the flood plain in coastal line. Accordingly, the west and south coasts have always been the preferred site for settlement in the Caribbean area because of the calm waters, natural harbors and gentle slopes (ICMPCCB, 1999). Consequently, there is no agricultural land in these coastal areas. On the other hand, within the Atlantic coast, there are also differences along the coast. The southeast is predominantly residential, while the east coast has little built development, with large areas of important natural and heritage resources. On the north and northwest coasts, the land use is predominantly agricultural (ICMPACB, 1998).

In recent times, although much of the landscape have been transformed from natural ecosystems into agricultural ecosystems (NBSAP, 2002), the land under agricultural production is declining through the demand for land for settlements and tourism development (hotels and golf areas).

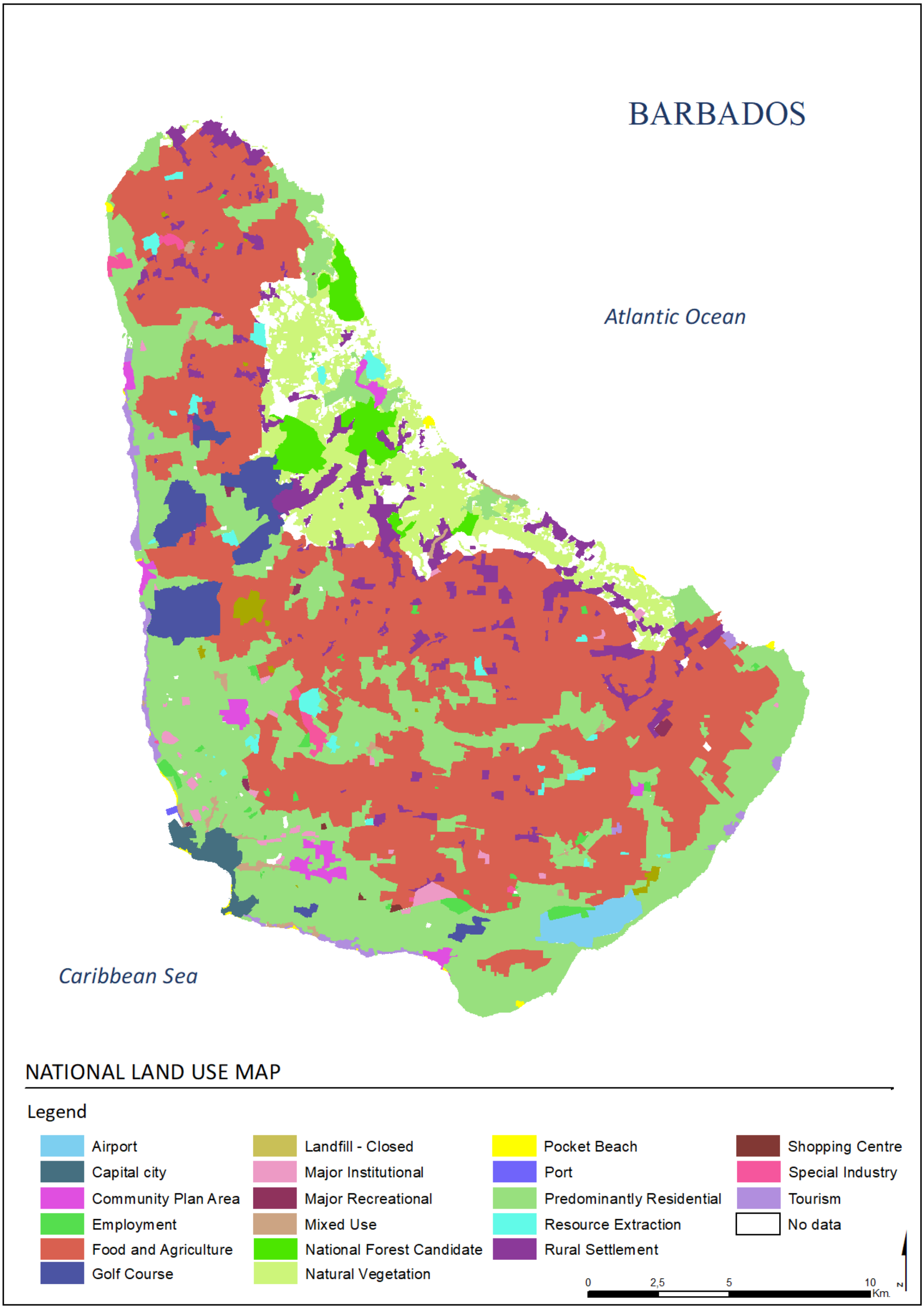

Figure A.27. Land use Map.

A2.3. Risks in the CZMA

The NCRIPP, being a key component of the CRMP, was a multiphase project that involved investigation of hazards, vulnerability and risk for assets and inhabitants in Barbados. The first phase of the project focused on analysing the following hazards: hurricane winds, storm surge, rainfall-induced flooding, coastal erosion, seismic, landslides, tsunamis and oil spills at sea; climate change was examined as part of this study and was not considered to be a separate and distinct hazard on its own but is certainly a contributing factor to some of the above hazards. The second phase of the project involved assessing the vulnerability of assets to the above hazards. Vulnerability was classified on both exposure to the hazards, as well as susceptibility to the hazard. The third phase of the project involved calculating financial damage resulting from the assessed hazards. Risk is computed for multiple hazards at various return periods for a range of assets.

This section presents a summary of the studies conducted. The text presented has been extracted from the Final Hazard Report (Baird, 2017), Final Vulnerability Report (Baird, 2017b), Revised Draft Risk Report (Baird, 2018b) and the Hazard Risk Atlas (Baird, 2018). These reports include the most updated information on disaster risk management in Barbados.

A more detailed description is provided for those hazards and related risks that area considered "core issues" for the CZMU: storm surge, coastal erosion (beach and cliff), and tsunami.

A2.3.1. NCRIPP Hazard assessment

This section presents the major results of the NCRIPP Hazard Assessment, the first phase in the overall assessment of hazards, vulnerability and risk for assets and inhabitants in Barbados. The NCRIPP study examines natural hazards (hurricane winds, storm surge, shoreline erosion, rainfall-induced flooding, tsunamis, landslides and seismic hazards) and one anthropogenic hazard (marine oil spills). The effects of climate change are also considered (where appropriate) to define hazards both in the present day and in the future.

Desktop studies and numerical modelling were performed to estimate these hazards. Details on the methodology used and results obtained are presented in the Final Hazard Report and a series of hazard maps. Hazards related to coastal processes which are core issues for the CZMU are also presented in the Sub-Areas maps (Part D).

Climate change impacts on hazards

A summary of climate trends is presented in Annex 3 and is based on the report titled "Historical Trends and Future Climate Change: Barbados" prepared by the Climate Studies Group at the University of West Indies (UWI) in Mona, Jamaica., completed for the NCRIPP study.

Air temperatures, rainfall, hurricane winds, and sea levels are the climate parameters considered, including regional trends and variability in Barbados. Finally, the climate parameters are discussed in terms of their effects on the following NCRIPP-defined hazards:

- Wind/hurricanes
- Landslides
- Storm surge
- Tsunamis
- Coastal erosion

- Coastal and inland flooding

Other hazards considered in the NCRIPP that were not deemed to be significantly impacted by climate change, included earthquakes, and oil spills. That is not to say that some minor linkage to these hazards is not theoretically possible, but climate change does not contribute in a definable manner, considering the overall accuracy and uncertainty in defining these hazards.

A brief summary of the findings, as included in the NCRIPP report, is provided in Annex 3, where GCM refers to general climate models while RCM refers to regional climate models. Input to the various GCMs and RCMs include various "scenarios" with respect to global economic activity, population growth, energy usage and greenhouse emissions. The table presented in Annex 3 was produced before the publication of the Special Report on the Ocean and Cryosphere in a Changing Climate, in September 2019. In this report, the sea level rise projections indicate higher values than previous IPCC reports. Major conclusions from this report related to SLR are presented after Table A.4.

Sea level rise projections – IPCC 2019.

Sea level continues to rise at an increasing rate. SLR by 2100 is projected to be faster under all scenarios, including those compatible with achieving the long-term temperature goal set out in the Paris Agreement. Table A.4 presents the projected Global Mean Sea Level (GMSL) for RCP 2.6 and 8.5. RCP -Representative Concentration Pathway- is a greenhouse gas concentration (not emissions) trajectory adopted by the IPCC. Four pathways were used for climate modelling and research for the IPCC Fifth Assessment Report (AR5) in 2014. The pathways describe different climate futures, all of which are considered possible depending on the volume of greenhouse gases (GHG) emitted in the years to come.

RCP	Increase in meters relative to (1986-2005), central values and the 5%-95% *Likely range (66%-100%)*	
	2081- 2100	2100
2.6	0.39 (0.26–0.53)	0.43 (0.29–0.59)
8.5	0.71 (0.51–0.92)	0.84 m (0.61–1.10)

Table A.4. GMSL projections for RCPs 2.6 and 8.5. Source: IPCC 2019.

Mean sea level rise projections are higher by 0.1 m compared to the IPCC Fifth Assessment Report AR5 under RCP8.5 in 2100, and the likely range extends beyond 1 m in 2100 due to a larger projected ice loss from the Antarctic Ice Sheet (medium confidence).

Extreme sea level events that are historically rare (once per century in the recent past) are projected to occur frequently (at least once per year) at many locations by 2050 in all RCP scenarios, especially in tropical regions (high confidence). The increasing frequency of high-water levels can have severe impacts in many locations depending on exposure (high confidence).

Hurricane winds

Barbados is located at the south-eastern edge of the Atlantic hurricane region and has an overall low frequency of close tracking hurricane intensity events. It is more common that severe storms, which may have damaging winds, high rainfall and cause coastal impacts, to be below hurricane strength in the vicinity of Barbados.

Between 1979 and 2015, a total of 27 Category 2 (or stronger) hurricanes tracked within 500 km of Barbados. NCRIPP study focused on defining the long-term wind hazard from CAT 2+ events, including defining the regional scale spatial and temporal wind characteristics that will drive associated wave and storm surge impacts.

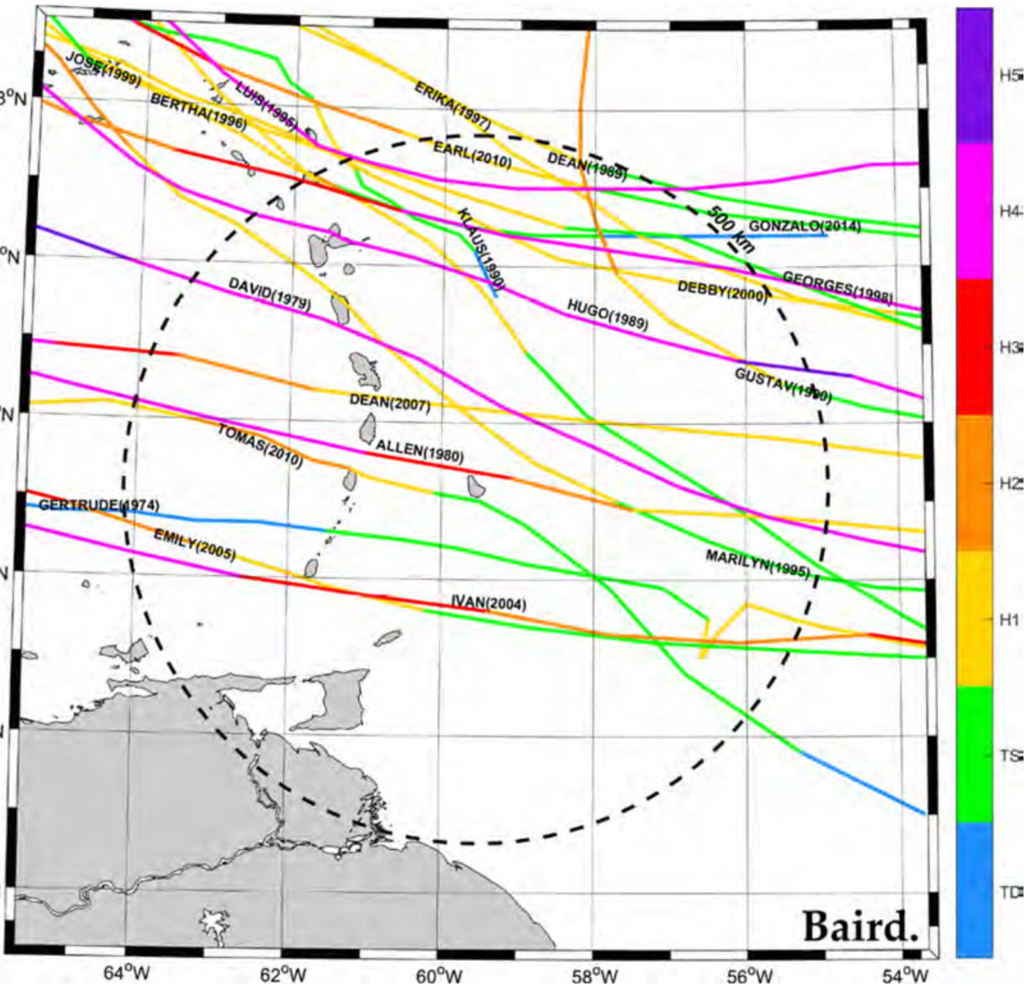

Figure A.28. Track / Intensity Plot for 19 Selected Events within 500 km (Best Track data set). (Source: Baird, 2017).

The resulting recommended wind speeds, obtained by Monte Carlo analyses, are provided in Table A.5. Therefore, this information is used in other NCRIPP studies to produce long-term records of hurricane wind fields. The 1,000-year event data set that has been produced provides a large random assessment of hurricane tracks and intensities. This large data set reduces the spatial banding that can occur in short data sets and evens out the “chance” of some regions from encountering or missing strong storms due to the relatively short duration of the reliable track data sets.

	Return period (years)		
	20	50	100
10 min wind speed (10 m)	23.7 m/s	29.4 m/s	<33.1 m/s
3 sec gust wind speed (10 m)	33.9 m/s	42 m/s	47.3 m/s

Table A.5. Recommended hurricane wind values from Monte Carlo analysis.

Storm surge

Storm surge is a significant natural hazard to coastal regions in Barbados. It is a type of coastal flooding caused by the passage of tropical storms and hurricanes or distant swell events. The increase in water levels at the shoreline is caused by the combination of low atmospheric pressure, which tends to raise the water surface, and strong winds which cause a build-up of water on the coast. The magnitude of the storm surge and extent of the coastal flooding is related to the:

- Storm intensity, track position, and forward speed;
- Pressure setup;
- Wave processes and wave setup;
- Tidal elevation; and,
- Wave runup and overtopping at the shoreline.

The purpose of the hurricane surge assessment is to develop the associated wave, surge and flood levels for each of the synthetic hurricane events. An example of the maximum wave runup elevation for the 25-year hurricane event is shown in Figure A.29, for Profile 28. For this storm, the maximum significant wave height at the toe of the beach slope is 1.3 m, and the wave runup elevation (for an infinite slope) is 4.0 m above datum. The flow depth on the beach crest is 0.27 m (at an elevation of 3.27 m). From the beach crest to some distance inland, overtopping water will partially drain back towards the sea. This distance was estimated to be 30 m based on the profile. The overtopping rate 30 m from beach crest is estimated to be 10 L/s/m, and 16% of the waves are estimated to overtop the beach crest. The elevations shown on the hazard maps are the flow depth on the crest when overtopping occurs, and the wave runup level when no overtopping occurs.

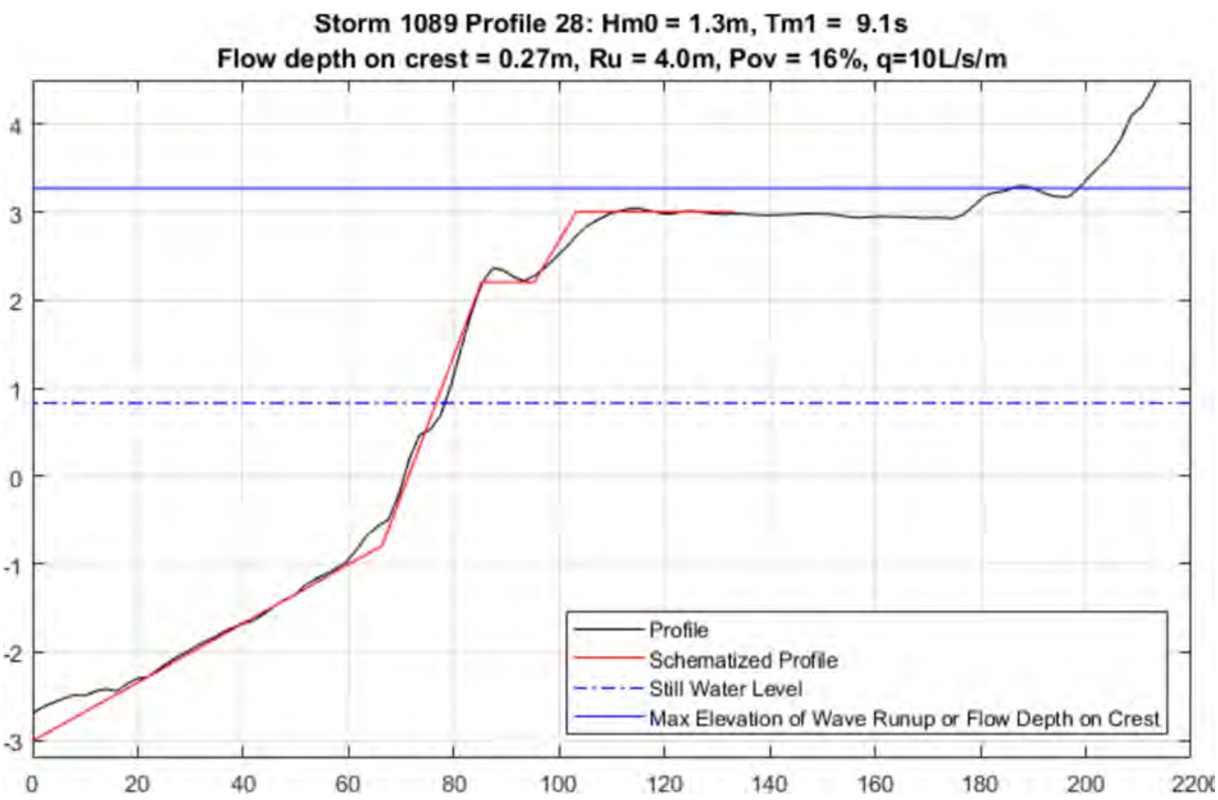

Figure A.29. Example of Maximum Wave Runup Elevation and Overtopping Rate. (Source: Baird, 2017).

Two sea level rise scenarios were assessed using the wave runup and overtopping methods. In the first scenario, a sea level rise of 0.3 m was considered. For depth-limited wave conditions, this scenario resulted in wave heights approximately 20% larger at the toe of the beach slope or structure and overtopping rates considerably larger. The overtopping rates were calculated for the 198 profiles at MHHW as the base condition (+0.6 m datum), and for a sea level rise scenario of +0.3 m (+0.9 datum).

The information on the hazard maps (see Annex 4) shows the flooded region (coastal surge flooding or backshore flooding for specific areas) for different return period events, and also provides an indication of the wave height on top of the crest, as well as the inland propagation distance. NCRIPP flooding maps are prepared for a sea level rise scenario where the mean sea level has reached 0.6 m, or a 0.25 m increase relative to the present.

There are two important factors that will impact the flooding extent due to storm surge that are not considered in this simulation approach: walls and buildings. Walls and buildings will impact where water can flow as water propagates inland, or as water returns to the sea. In some instances, the buildings and walls may be very effective at blocking flow, and in other instances, they may have minimal impacts. The influence of these structures and whether they improve or exacerbate the flood situation would need to be defined on a case by case basis when a detailed local flood assessment was being completed.

Wave hazards at the crests of coastal cliffs

Wave impacts against coastal cliffs may send significant volumes of water upward as spray. This water may be carried by its own momentum or the wind tens of metres inland. In some cases, the force of the up-rushing water may entrain rock from the seabed or cliff face, creating a more serious hazard. Spray may cause additional hazards such as reduced driving visibility and deterioration of building materials. A building setback is recommended around all coastal cliffs but given the very site-specific nature of the hazard the setback needs to be evaluated on a case by case basis.

In Barbados, the northeast coast fits this description and there is evidence of large boulders being deposited at the top of cliffs during severe storms. While the southeast coast does have vertical cliffs the spray, overtopping tends to be lower as the water depths are shallower at the base of the cliff and the barrier reef limits wave heights at the shoreline.

Figure A.30. Overtopping and spray near Animal Flow Cave. Source: (Source: Baird, 2017).

Shoreline erosion – Beaches

Erosion hazards around Barbados can be classified according to two primary types of shorelines: beaches experience variable erosion trends in response to storms and long-term trends in the sediment patterns, while cliffs experience much slower erosion in addition to sudden collapses.

Shoreline fluctuations are naturally occurring processes that, in and of themselves, are not hazards, and only become hazards when human activities and development encroach within the shoreline. In some instances, these human activities may accelerate the severity of the resulting hazards. Over the short-term, beach environments, impacted by flood and erosion processes, may undergo alternating periods of erosion and accretion as they attempt to achieve a dynamic equilibrium with the forces acting upon them. Over the long term, beaches experiencing a positive sediment budget (i.e., more sand and gravel incoming than outgoing) are generally accreting shore forms while those experiencing a negative sediment budget are eroding. Considering the future, sea level rise is generally expected to cause shoreline recession as resulting greater depths would allow more wave energy to reach the shoreline. As such, the depiction and evaluation of the hazard susceptibility of beaches in Barbados should be dependent on information and understanding of short-term fluctuations as well as long-term beach sediment budget including potential sea level rise impacts.

Baird (2016) predicted that under IPCC (2013) least optimistic RPC8.5 scenario, and with the current alongshore and onshore sand supply rates, most beaches in Barbados would lose 20% to 50% of their existing sand volumes by 2100 if no mitigation measures are implemented.

The impact was predicted to reduce under more moderate IPCC (2013) scenarios approximately proportional to the SLR value. Model predictions indicated that beaches on the southwest and west coasts of Barbados are the most susceptible to SLR due to the manmade structures along the densely populated shoreline.

Erosion Hazard Zone at each survey station was then defined as the zone between the most seaward position of the 0.6 m LD shoreline (i.e. the Blue Point) and the most landward position of the 0.6 m LD shoreline plus the average of the top 5 greatest setbacks (i.e., the Orange Point). This was considered to reasonably cover short-term shoreline fluctuations and the impact of future sea level rise for the 50-year plan.

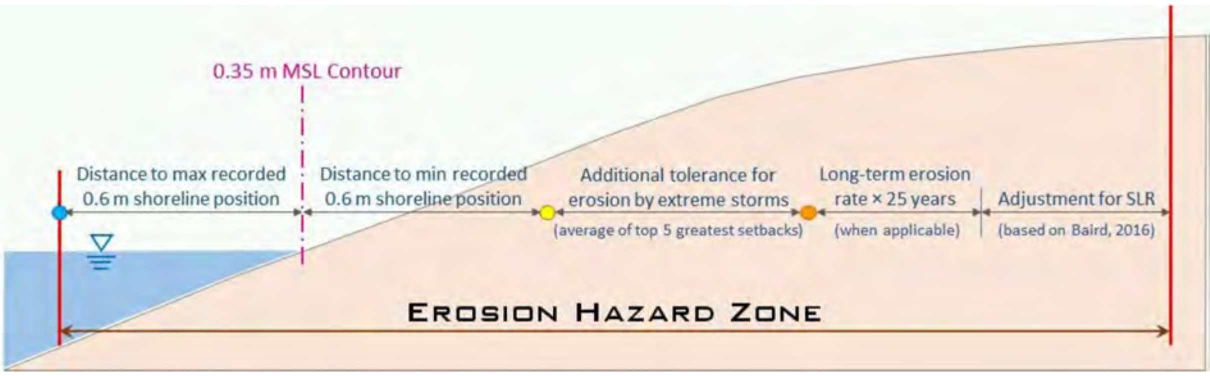

Figure A.31. Summary of Various Elements Defining the Erosion Hazard Zone. (Source: Baird, 2017).

The beach erosion hazard assessment relies heavily on historical data to understand how beaches respond to storms within the context of the natural conditions of each beach. There are many beaches that do not have recorded profile data, which necessitates professional judgment to define the erosion hazard. The numerical modelling completed by Baird for the CRMP work (Baird, 2016) provided insight into beach response in Barbados and sea level rise impacts. Local knowledge of beaches in Barbados and the common underlying cobble layer was important to finalizing an approach for undertaking this study.

The erosion hazard zone was defined based on interpolation of recent historical erosion/accretion trends obtained from profile survey data. While this is believed to be a reasonable approach, the results are expected to be more reliable for beaches located in the proximity of profile survey stations (that are less impacted by the interpolation process). Furthermore, our analysis did not explicitly consider the impact of very strong storms that could damage the structures that presently limit beach erosion potential. As mentioned before, without accurate subsurface information it is impossible to know the exact response of a beach to a very severe storm and how the underlying cobble beach could also be changed.

The analysis did not include an assessment of the condition of coastal wall and other defences that would limit the beach erosion in most developed areas of the coast. The assumption is that these walls, revetments or other structures would be maintained (or rebuilt) to “hold the line” against long term erosion trends. The trimmed hazard zones reflect our knowledge of local structures and how erosion may be limited but were not based on structural assessments.

Shoreline erosion - cliffs

Three components of marine energy affect the recession of the various cliffs around the island. In order of perceived recession-related damage impact, these are: (1) wave climate associated with regular close-by or directly shoreline-impacting CAT1-3 and further away CAT 4 and CAT 5 Hurricanes and surges, (2) wave conditions associated with the regular Northeast Trade Winds, and (3) extreme wave conditions associated with periodic, but rare earthquake-induced seismicity-related tsunami events combined with direct shoreline impacting CAT4-5 Hurricane events.

Cliff Erosion Rates

Stability-driven recession rates differ for each of the cliff types due to significant differences in their morphology and failure behaviour. The total setbacks computed for the various cliff types around Barbados completed under the CRMP include a component addressing rate of recession. This rate was based on historical erosion rates derived from aerial photograph comparisons.

Five cases have been evaluated – 10-year, 25-year, 50-year (which corresponds precisely with and has been benchmarked against the two actual 50-year increment measurement studies), 100-years and ultimately 500 years. These estimates have been made for each of the Type A, B, C, D and Type E cliffs.

Estimating erosion rates based on incremental air photo information provides a disjointed snapshot view of an overall slow geological process. For all cliff types, actual change in cliff morphology and shoreline geometry generally occurs as a series of step changes. It is likely these changes are only associated with significant "impact" events such as major storms, which can trigger changes in cliff stability such as increasing the undercut depth to where it might reach a critical joint, or where serious inundation occurs into a low stability cliff situation due to overtopping of "protection" provided by sand beaches or fallen blocks.

Once wave information was defined, statistical means and interpolation of historical erosion rates were then extrapolated for periods of 10 years, 25 years, 50 years, 100-years and 500 years, as listed in Table A.6.

Cliff type			Erosion Rate		
	Case 1 m/10 years	Case 2 m/25 years	Case 3 m/50 years	Case 4 m/100 years	Case 4 m/500 years
Type A	0.1	0.25	0.50	0.70	1.40
Type B	1.00	2.20	4.00	6.00	12.50
Type D	2.50	5.30	10.00	15.00	30.00
Type E1	3.20	6.80	13.00	19.00	38.00
Type C	3.80	8.10	15.00	23.00	45.00
Type E2/E3	5.80	12.50	23.50	35.00	70.00

Table A.6. Summary of Cliff Erosion Rates for each case. (Source: Baird, 2017).

Case 1: Very limited erosion occurs over a 10-year time span for the stronger Type B and Type A cliffs. The Type D, Type C and Type E cliffs also have limited erosion but as storms affect these weaker cliffs more, their erosion rates are still perceptible.

It is critical to reiterate that for slopes that fail instantaneously with large volume rather than in small increments, any given 10-year period could include large shoreline change due to a block failure of the Type A or Type B cliffs, or a landslide within a Type D2 or Type E2 cliff zone, due to basal failure.

The erosion rates provided are average rates that cannot represent these one-off events. Rate relationships over a longer duration will tend to greater accuracy, but again are subject to uncertainty of individual one-off events.

Case 2: In a 25-year period, greater erosion is predicted, in some instances increasing the setback stability point significantly from the 10-year point. Care should be utilized in selection of what might be an appropriate period for design.

Case 3: The 50-year record defines precisely the base time interval data used for calibration of all of the regression relationship equations.

Case 4: Although the 50-year erosion rate measurement data were previously linearly extrapolated out to represent a 100-year frequency period, the increasing frequency of larger hurricane events occurring in a 100-year period based on recurrence of more recent high energy events than in the past, potentially greater recession rates might occur in the future.

Case 5: The 500-year period, which mirrors the 1% exceedance 475-year period used in earthquake seismicity likely reflects a reasonable snapshot geologically of the time over which real cliff erosion at a map scale might be determinable.

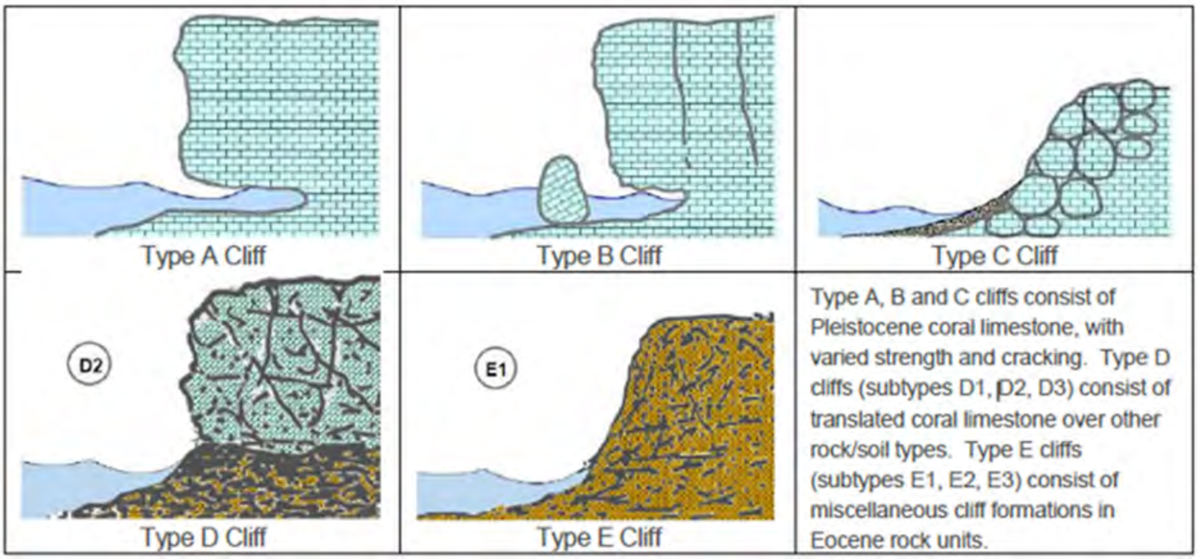

Figure A.32. Cliff types. (Source: Baird, 2017).

Rainfall induced flooding

Predicting rainfall induced flooding in Barbados is a significant task as it requires both broad scale long term rainfall data, and detailed information that covers the entire country. The NCRIPP hazard assessment defines the island wide flooding hazard through available data sources, two numerical models, and no scope or schedule to measure rainfall/runoff and supplement significantly limited calibration data.

The impact of climate change on precipitation intensity and depth on a small scale is still uncertain. A previous climate change analysis described in a previous study by Baird (Baird, 2017) indicated that maximum precipitation intensity in Barbados could decrease by 70 percent or increase by 45 percent. The large error bars and uncertainty are due to limitations in the current state of climate modelling capabilities. Since Barbados is a relatively small and isolated island, the climate models are unable to capture changes in sub-daily precipitation patterns with an appropriate resolution. Although there is uncertainty in whether the rainfall intensity will significantly decrease or increase, simulations were completed to better define what the worst-case scenario (in terms of climate changed induced variation in rainfall intensity) may be. It was not necessary to repeat the lower return period events as the current 50-year return period event would become a 10-year return period event if rainfall intensity increases by 45 percent.

The rainfall induced hazard has some overlap with the storm surge flood hazard. During a tropical system that may cause rainfall induced flooding, there may also be storm surge, including wave overtopping for beach berms. Many strong rainfall events in Barbados are associated with tropical events that have minimal storm surge. However, it is likely that the more severe storm surge from strong hurricanes that would include significant rainfall. When considering combined flooding from rainfall and storm surge, it is only very specific coastal regions that could possibly be impacted (e.g.: the Constitution River)[9].

The model results from the 100-year return period precipitation induced flooding event on the Western Plateau were compared to previous flooding studies in Holetown Lagoon (Baird, 2017). As an example, Figure A.33 illustrates the flood extent after a 100-year return period event.

Figure A.33. 100-year return period precipitation event in Holetown.

Earthquake

The Caribbean region is a tectonically diverse region of the Earth marked by the intersection of four major lithospheric tectonic plates (North America, South America, Cocos, and Nazca) with the Caribbean plate, deep oceanic trenches and associated Benioff zones of shallow and deep earthquakes, active volcanoes, fault-bounded submarine marine extensional basins, and seismically-active transform faults in northern South America, Hispaniola and Cuba (Benz et al. 2011). This tectonic diversity has resulted in a history of frequent moderate to large earthquakes, tsunami and volcanic eruptions. The location of Barbados east of the region of deeper subduction results in an absence of volcanic activity, and a lower rate of historic earthquake occurrence when compared to the volcanic islands farther west.

[9] Considering the joint probability of rainfall and storm surge flood events was only considered by Baird through basic assumptions only.

In the absence of the time and resources to undertake a major revision of the Salazar et al. (2013) analysis for the NCRIPP hazard, Golder considers that the Salazar et al. (2013) seismic source model, which is at present the best-available for Barbados. Accordingly, Golder has directly used the results of this model to develop earthquake ground motions for NCRIPP.

Results of Golder analysis show that the higher levels of earthquake shaking occur along the eastern coast of Barbados, particularly on the younger sediments and reclaimed land in and surrounding Bridgetown, and in parts of the Scotland District. The distribution and variation of near-surface site soil conditions in Barbados are key factors that influence ground surface earthquake ground shaking.

Landslide

The landslide hazard assessment has been carried out for an area of the island bordering the central east coast called the Scotland District. The majority of the Barbados land area is capped by coralline limestone (of Quaternary age), however in the Scotland District, the older (Tertiary age) ancient sea-bed sediments outcrop and are exposed at surface in many places. These sea-bed sediments are prone to landslides and the geology in this area, while variable, is dominated by poorly consolidated clayey sediments and weak clayey rocks (mudstones, shales) interspersed with more competent, more consolidated sandy sediments, sandstones and siltstones. The susceptibility to landslides for each of the eleven geologic units present in the Scotland District has been considered as part of this assessment.

Maps showing the distribution of risk classification in the Scotland District for each of the hazards considered as part of the stability analyses have been developed to support the landslide hazard assessment of Component 2 of the NCRIPP. The calculated Factors of Safety (and the associated Probability of Failure) are based on consideration of the properties (lithology) of the different geologic units as well as the groundwater conditions (from investigation and analysis carried out as part of the GSI-CRMP study (Golder, 2016 and 2017), the detailed topography (from the DEM produced from the 2015 LiDAR survey (Baird, 2015c), and the seismic loading (from the Seismic Hazard Assessment). The results indicate a relatively high a degree of correlation between the documented areas of distress and the estimated High-Risk zones, in particular for the fully saturated hazard condition.

The resulting estimated slope risk classification zones for each of the four (4) hazards considered (i.e., 50 Year Erosion condition, Fully Saturated condition, Seismic (1 in 475 year) condition, and Seismic (1 in 2,475 year) condition) are presented on a series of four maps.

The results indicate that the Seismic (1 in 2,475 year) condition represents the highest risk to the slopes in the Scotland District, while the 50 Year Erosion condition represents the lowest risk to the slopes in the Scotland District.

Tsunami

Barbados is susceptible to tsunami waves originating from far-field, near-field and local (< 300 km distant) sources. Near-field sources originate from within the Caribbean Sea region, and far-field sources from areas outside the Caribbean Sea and the western Caribbean Sea. Major far-field sources of tsunamis include tectonic faulting events along the eastern margin of the Atlantic Ocean, volcanic flank collapses from volcanic islands in the Atlantic Ocean, and continental shelf landslides off the western coasts of Europe and Africa.

Numerical modelling was carried out to estimate the extent of inundation and run-up around the island of Barbados for tsunami events with a return period of approximately 100-years. Larger events were also considered to provide context with respect to potential inundation for these more extreme events; however, hazard maps were only produced for the 100-year tsunami events. Data generated from the seismic hazard assessment were used to define the 100-year return period. The 1839 and 1843 earthquakes were used to support the hazard mapping given the proximity of these historical events to Barbados and recognizing that the frequency of occurrence is the same order of magnitude.

Tsunami hazard maps were generated around the island of Barbados using the 1839 and 1843 earthquake events as these are considered a conservative representation of the 100-year return period event. The maximum inundation generated by the fourteen simulations was used to define the inland extent of the hazard maps. A map showing a typical plot of maximum elevations and inundation around the island is shown in Figure A.34. The image also shows the detailed mesh resolution defined along shore and inland in order to predict inundation. Higher waves were observed around the north end of the island and north of the port in Bridgetown where values of 0.9 m were predicted by the model. The rest of the island was impacted by levels less than 0.9 m.

Climate change impacts are depicted in the hazard maps through simulations at a higher water level, representing a high tide (0.6 m) plus 25 cm of sea level rise. We have not considered possible changes to the shore protection or natural beach berm heights that may accompany such a change in sea level.

In general, very little inundation occurred for the 100-year tsunami, although it is important to note that this does not imply that Barbados is not at risk of larger tsunami events. To illustrate this, an extreme seismic event was simulated to provide some context on the potentially destructive nature of tsunamis. Using a coarse mesh, a tsunami generated by a (hypothetical) 8.53 magnitude earthquake approximately 200 km immediately east of Barbados was simulated using the MIKE21 model. The results showed predicted wave heights of approximately 9 m along the east coast of Barbados and 7 m around Bridgetown.

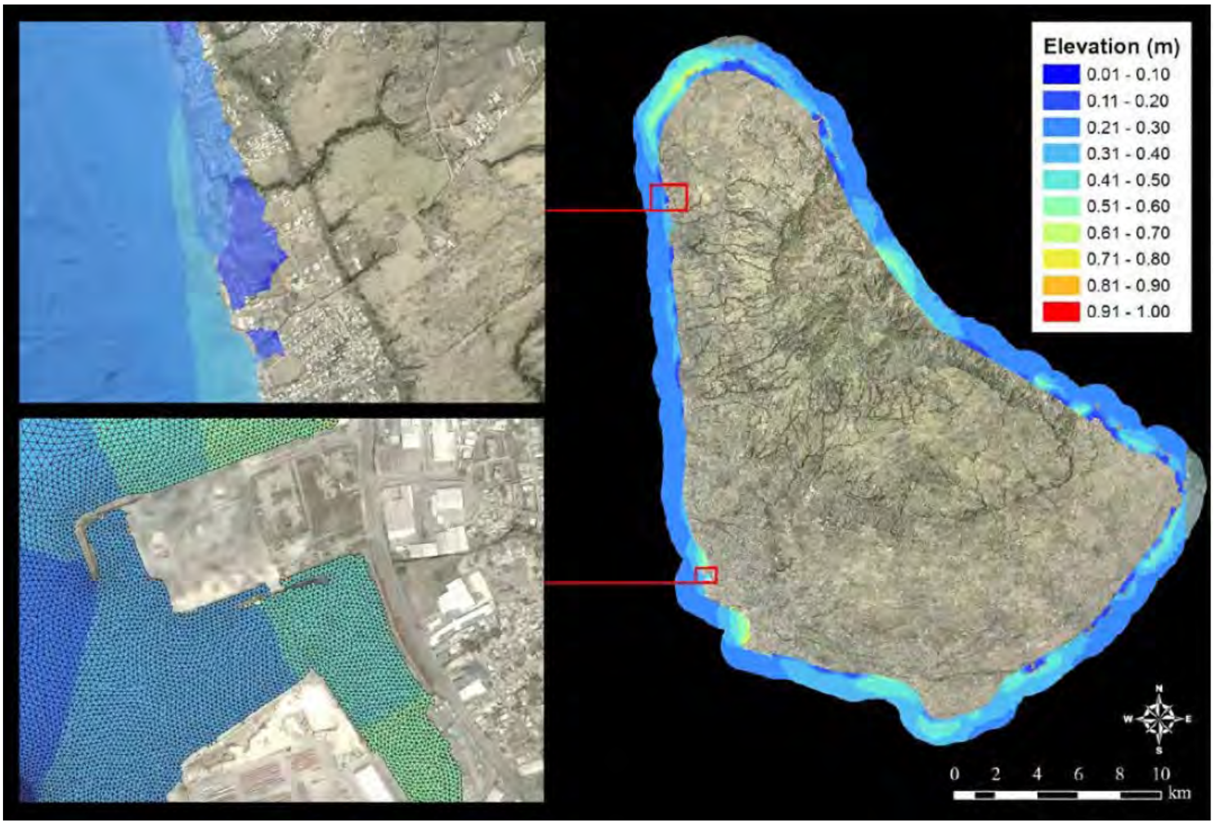

Figure A.34. Example of maximum elevations and inundation around Barbados (1839 Event). (Source: Baird, 2017).

A2.3.2. NCRIPP vulnerability assessment

The hazard assessment defined the spatial extent and severity of hazards (exposure), while the vulnerability assessment documents the assets and looks at two factors: exposure and susceptibility. Exposure implies that an asset is located where a hazard exists, and susceptibility implies that the hazard can have an adverse impact of the asset. Both exposure and susceptibility are required for an asset to be vulnerable.

A wide range of assets were catalogued from data obtained from the CZMU, previous phases of CRMP, other government agencies, and field data collection. These assets included the housing stock, tourism plant, critical facilities, physical infrastructure, community resources, and environmental resources. The primary economic sectors in Barbados were identified through a range of sources, and these were mapped spatially through land use listed for each property parcel from the BRA. A social vulnerability assessment was also performed, which used different techniques to quantify and map socially vulnerable populations in Barbados at the enumeration district level.

Vulnerability mapping was undertaken by grouping similar hazards (water, earth, wind and oil) and similar assets. Water included rainfall flooding, storm surge, tsunami and coastal erosion. Earth included landslides and seismic hazards.

Susceptibility of assets was derived based on a scoring system that was generally qualitative in nature but translated relative susceptibility into a numeric score. Susceptibility was also specific to hazard groups due to the varied nature of the hazards being considered. For example, a concrete house might be better in a wind event; however, a wood frame house may sustain less damage in a seismic event. Combinations of hazards and assets each had a susceptibility defined.

A final analysis was undertaken to examine regions that had higher hazard vulnerability and increased levels of social vulnerability. These areas were described as having compounded vulnerability and would be some of the most at-risk areas in the event of a hazard event.

In summary, the main outputs from the NCRIPP vulnerability study are as follows:

- A spatial database of assets in Barbados.
- Valuation of many of these assets.
- An evaluation of susceptibility of these assets.
- An evaluation of vulnerability of all the catalogued assets in Barbados.
- Vulnerability maps organized by classes of similar assets and groups of hazards. These maps may include up to 65 tiles to cover all of Barbados at 1:5000, although only regions with active hazards and assets were included in the map sets (see sample maps in Annex 5).

Identification, location and financial valuation of assets in Barbados

Six groups of assets have been identified, located and assessed to conduct the vulnerability analysis and the further risk analysis: housing, tourism plants, critical infrastructure, physical infrastructure, community resources and environmental resources. Each group is presented below. The complete description, data sources and valuation can be consulted in the Final Vulnerability report (Baird, 2017b).

Housing stock: the housing stock assessment aims to better understand factors related to the quality of the home.

Figure A.35. Roof Types from Field Survey. Clockwise from top left: Hip, Flat, Lean-to, and Gable. (Source: Baird, 2017b).

Tourism plant: consists only of primary tourism operations such as restaurants, hotels and resorts but does not include the support industries. There is some complication due to the fact that many rental properties may be classified as residential, instead of being classified as part of the tourism plant. These rentals may be widely spread in Barbados and are generally absorbed into the housing stock statistics.

Critical facilities: consist of facilities that will be instrumental during and after a natural disaster. These assets are:

- Emergency shelters: often located in schools or churches and are inspected every two years under the direction of the Ministry of Education, Science, Technology and Innovation. These inspections outline the integrity of the structures and whether the shelters are intended for use during (category 1) or also after an event (category 2).
- Emergency services: include hospitals, fire stations and police stations.
- Barbados Defence Force (used for exposure assessment, not for vulnerability).
- Ports and landing facilities are especially important on a small island such as Barbados that relies heavily on imported food and goods. These facilities take on an even greater importance in the aftermath of a natural disaster as they provide gateways for aid and supplies to enter the country for relief and rebuilding efforts. Grantley Adams International Airport (GAIA), the Barbados Port Inc. (BPI), and Port St Charles are the three primary ports and landing facilities. These three locations maintain a staff of customs and immigration officers where personnel and goods may legally enter Barbados. In addition, during emergency situations, there are several other locations which may be used as temporary ports of entry including the Careenage, the Barbados Coast Guard Base, the Shallow Draught, Port Ferdinand, Oistins and Conset Bay.

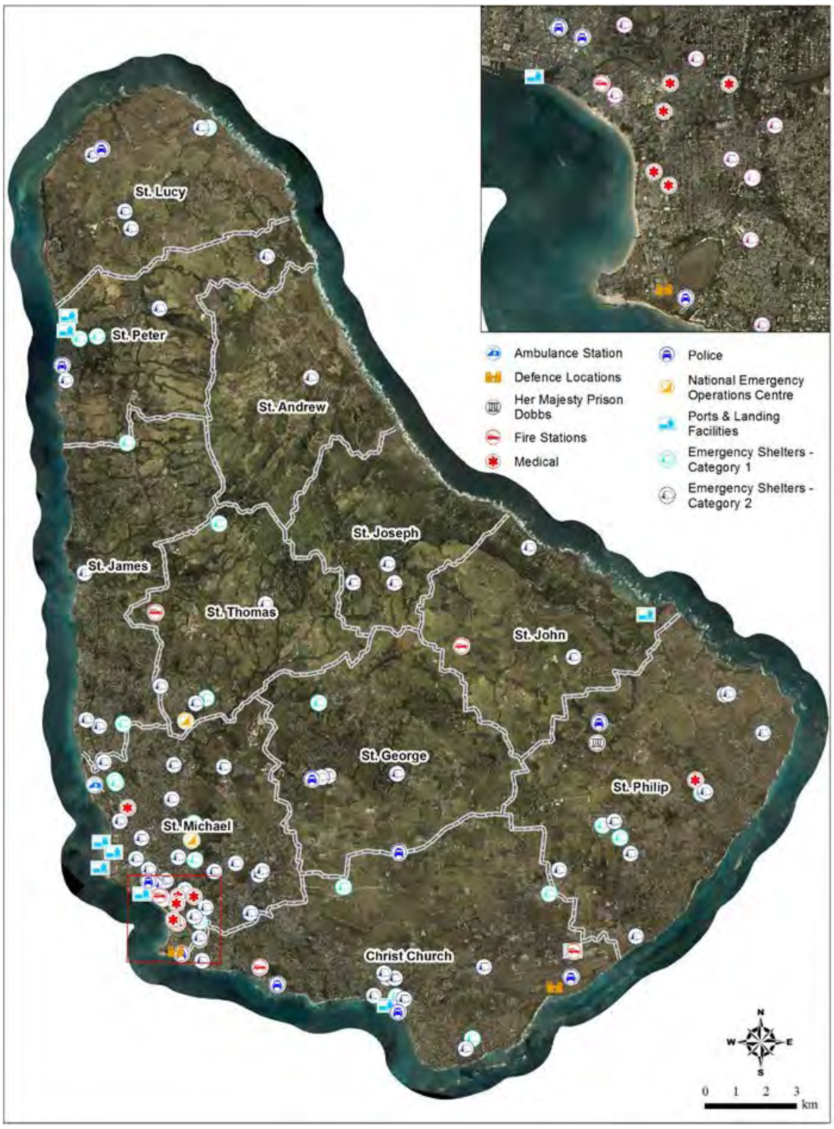

Figure A.36. Critical facilities. (Source: Baird, 2017b).

Physical infrastructure: damage to physical infrastructure is more readily defined in terms of what impacts it may have on emergency services or recovery operations after a disaster. Physical infrastructure catalogued included:

- Roads and bridges.
- Telecommunications.
- Power Generation and Distribution.
- Water and Sewer.
- Surface Drainage.
- Landfill and Recycling.
- National Monuments.

Community resources:

- Schools, Churches, Post Offices, Libraries, Community Centres and Banks
- Homes for the Aged & Children's Homes
- Public Buildings (located on property owned by the government)

Environmental resources: described in section A.2.3.

Once the assets are identified and located, asset classes have been developed for two purposes: to assist in determining values and (later) risks; and to allow more efficient plotting of vulnerability.

Asset classification is more aligned with similar asset properties and susceptibility, rather than exposure. The comments and results of valuation of each asset category can be found in the report Final Vulnerability Report (Baird, 2017b).

Social vulnerability

Societal conditions and exposure to natural hazards influence the vulnerability of communities and places. The most vulnerable people are likely to be those whose needs are not sufficiently considered in the planning of local response and relief organizations (Flanaganet al, 2011).

Therefore, identifying and overlaying the several social characteristics that influence social vulnerability in the Barbadian context, offers an indication within the context of the NCRIPP, of where the highest levels of social vulnerability might occur on the island.

The methodology used to develop the Social Vulnerability Index (SVI) for the NCRIPP is based on five demographic categories; Socioeconomic, Gender, Age, Special Needs and Property Type, comprising eight key census variables:

The Socioeconomic category was calculated using two variables:

1. Unemployment rate - The unemployment rate is the number of unemployed persons divided by the total labour force in an Enumeration District (ED)
2. Persons per household - Average number of persons who live within a household in an ED

Gender was determined by the following variable:

3. The percentage of women - The ratio of women to men in an ED

The Age category was calculated by two variables:

4. The percentage of children - The ratio of children to adults in an ED
5. The ratio of retired persons - the number of persons retired in relation to the total population in an ED

The Special Needs category was determined by the following variables:

6. The mobile impairment rate - the ratio of persons who are immobile divided by the total number of persons within an ED
7. The rate of disability - the number of persons with a disability divided by the total number of persons within an ED

The Property category was based on:

8. The ratio of wooden properties - the number of 100 percent wooden structures divided by the total number of structures within an ED

. These variables were ranked from highest to lowest across all (ED) in Barbados. In a second approach to identifying social vulnerability, a count or flag was provided of the number of individual variables with percentile ranks of 0.75 or higher for each of the five themes and for the ED overall, as number of mobility impaired people in a district, among many others. As a third method to view social vulnerability, a bidirectional matrix was used to simultaneously assess the results of the SVI and Vulnerability Flags approaches. Ranking was classified into three subgroups: low, medium, and high.

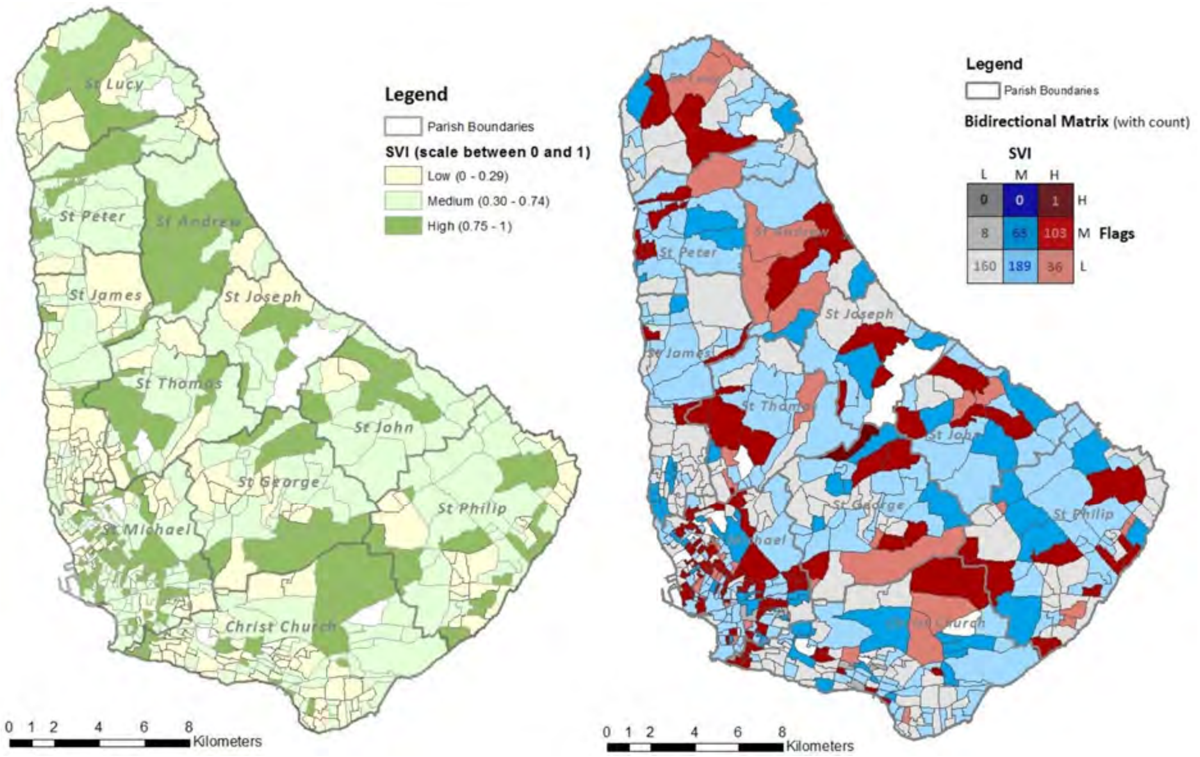

Figure A.37. Left: Social Vulnerability Index by Enumeration District. Right: Bidirectional Vulnerability by Enumeration District. (Source: Baird, 2017b).

The SVI provides an opportunity to build resilience by implementing targeted vulnerability reduction and risk mitigation programs directed at the most vulnerable geographic areas. At the same time, it demonstrates the need for island wide efforts focused on, *inter alia*:

- increasing wide-based public awareness on disaster planning and preparedness;
- increasing support for community-based disaster management groups;
- establishing early warning systems, with an emphasis on the needs of especially vulnerable groups – children, the elderly and the physically or intellectually challenged;
- enforcing standards for housing stock on the island; and
- engagement with the insurance sector to encourage the development of affordable plans for low to medium income households to aid in the recovery and rebuilding phase.

It is important to note that this analysis only considers statistics aggregated over the enumeration district and does not consider smaller regions within an enumeration district that may be more vulnerable.

Social vulnerability is most pronounced in the face of a disaster, when socially vulnerable populations are faced with hazard exposure and hazard vulnerability. The social and hazard vulnerability compound to create some of the most difficult and dangerous circumstances. For example, there may be compounding vulnerabilities if a socially vulnerable population is vulnerable to storm surge in a coastal region. Compounding vulnerability (social and hazard) is discussed further in Section Areas of Special Consideration.

Economic Sectors

Mapping of employment type to land parcel definition is the ability to spatially assess what types of employment are occurring in different areas of Barbados. This allows spatial assessment of exposure and vulnerability for different employment sectors in response to a hazard event.

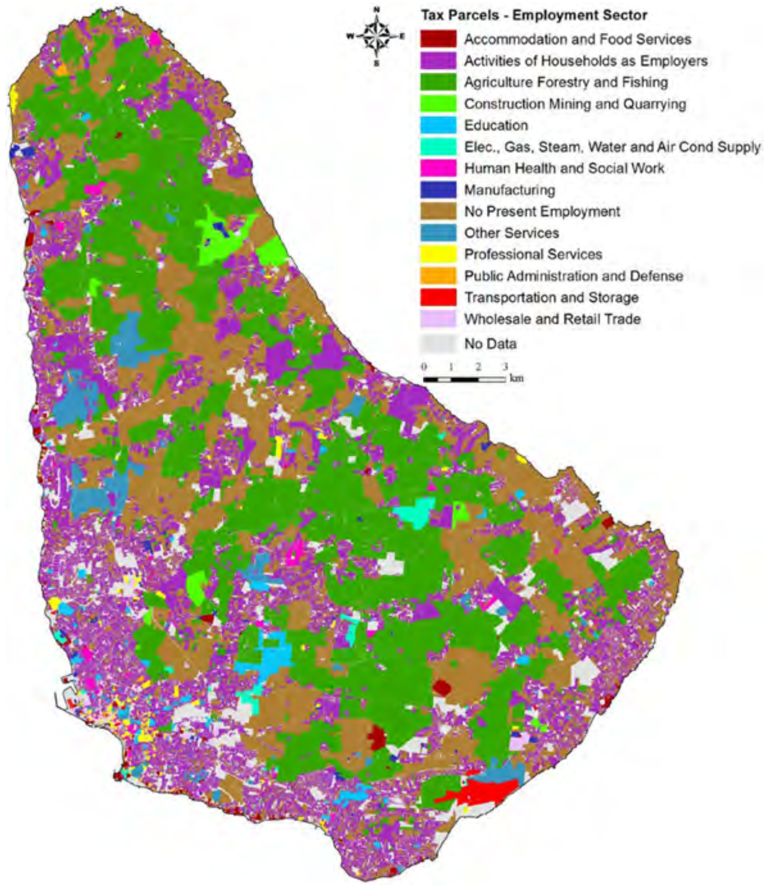

Figure A.38. Mapping of employment sectors in Barbados. (Source: Baird, 2017b).

It is important to consider that all employment sectors have vulnerability related to their reliance on employees. If employees do not have a home, or are not able to travel to work, then economic productivity will be severely impacted. This means that housing stock and many other assets can all impact a wide range of economic sectors.

Vulnerability mapping and scoring system for vulnerability assessment

Vulnerability is a combination of exposure to one or more hazards, as well as being susceptible to being damaged by that hazard. For example, a road may be exposed to water and wind hazards; however, the road would have little susceptibility to damage from winds. Conversely, water may erode and damage the road. It is therefore important to undertake vulnerability mapping based on either an individual hazard, or on the basis of a group of similar hazards. For the NCRIPP study, we have grouped hazards into four categories:

- Wind: This only includes the wind hazard.
- Water: This includes tsunami inundation, rainfall induced flooding, storm surge and coastal erosion.
- Earth: This includes seismic events (ground accelerations but not tsunamis) and landslides.
- Oil Spill: This only includes the oil spill hazard (limited to nearshore waters and shoreline only).

Determining the vulnerability of assets was undertaken using a scoring system, some of which was data-driven and some of which was more subjective. The scoring system was developed so that each asset is scored separately for different groups of hazards (wind, oil, earth and water). Exposure and susceptibility for each hazard/group are combined to obtain the vulnerability scoring. Vulnerability maps present the results of the vulnerability analyses (see sample maps in Annex 5).

Areas of Special Consideration

Areas of special consideration consist of regions that have increased social vulnerability and increased hazard vulnerability.

It is important to consider that there is significant variability within an enumeration district, both in terms of hazard vulnerability and social vulnerability. Therefore, the areas of special consideration demonstrate regions that are likely to require special consideration, but the results are not definitive. It would have been misleading to only identify very specific locations because there is not the data to support very specific conclusions. The maps presented in this section highlight: the top 5% range (blue); the 5% to 10% range (purple); and the 10% to 20% range (red). Areas of special consideration are most likely in the blue zone but may also occur in other regions.

The compounded vulnerability of SVI and water hazards is presented in Figure A.39. Areas of special consideration in these plots consist of areas with increased vulnerability and those areas that are more prone to flooding, such as some regions near Holetown, regions along the south coast, and some isolated inland areas.

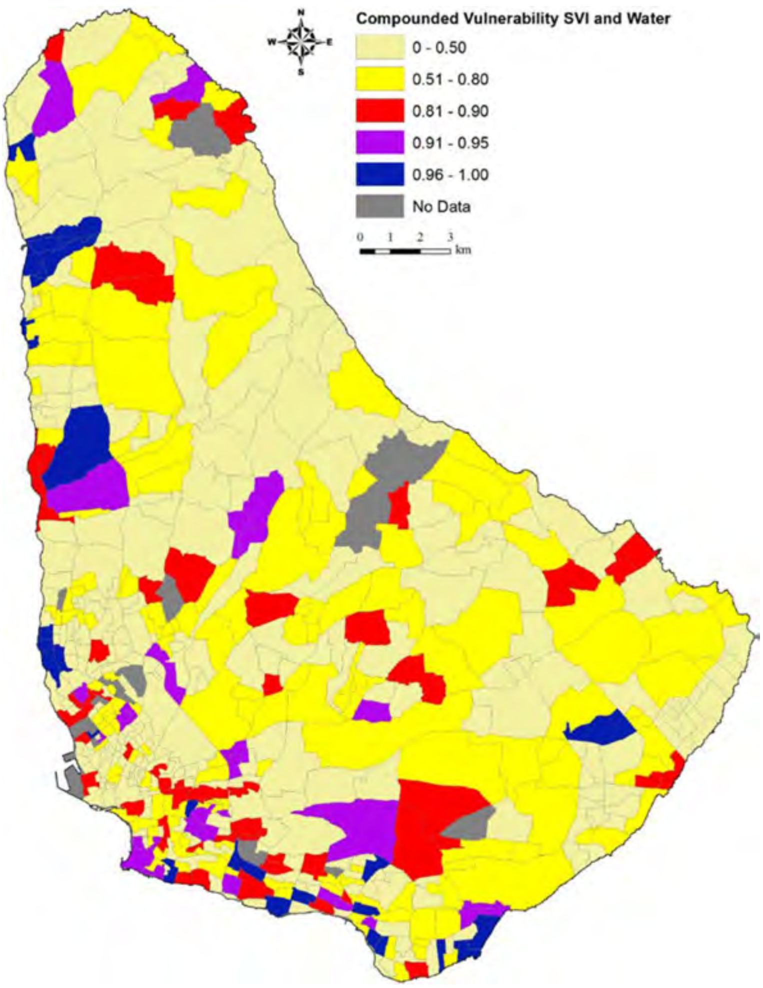

Figure A.39. Compounded Vulnerability: Social Vulnerability and Water Vulnerability. (Source: Baird, 2017b)

The earth hazards (landslide and seismic) are combined with the SVI and are presented in Figure A.40, using the same colour scheme as the water hazards. The regions of greatest compounded vulnerability create a more distinct pattern, with higher vulnerability levels in the Scotland District due to landslide threat. Some other localized regions are also present along the coast where weaker soils result in height ground accelerations during an earthquake.

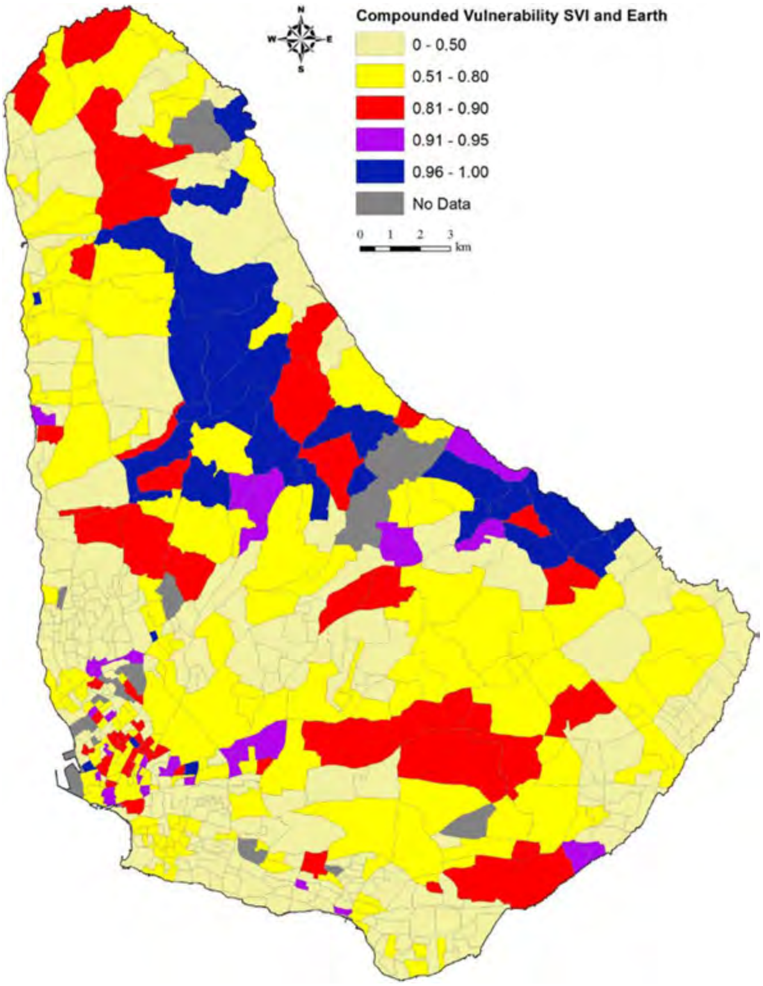

Figure A.40. Compounded Vulnerability: Social Vulnerability and Earth Vulnerability. (Source: Baird, 2017b)

The compounded vulnerability of SVI and Wind are shown in Figure A.41. Because the wind hazard is consistent throughout Barbados, the resulting map is really a combination of SVI and the housing stock's wind susceptibility (primarily about structure type and condition). The results are not as well clustered as some of the other results; a fairly random pattern appears to exist. With the variability in housing stock within an enumeration district, the compounded SVI and wind vulnerability may be less reliable compared to some of the other indicators.

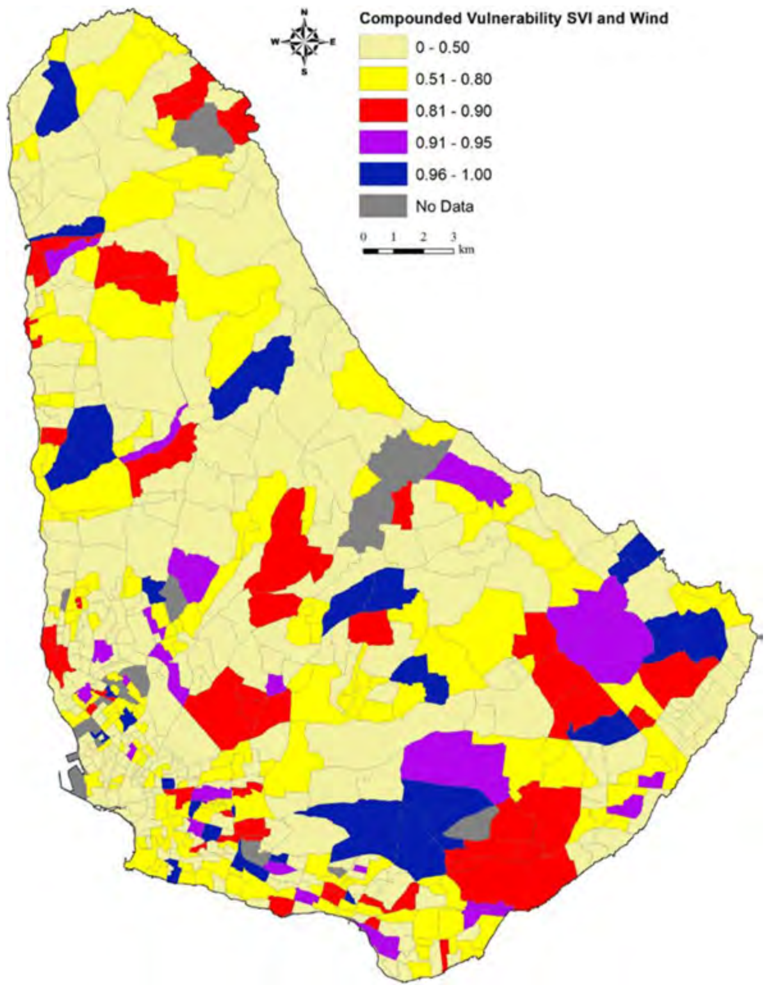

Figure A.41. Compounded Vulnerability: Social Vulnerability and Wind Vulnerability. (Source: Baird, 2017b)

A2.3.3. NCRIPP risk assessment

Based on the hazard and vulnerability assessments, the final phase of the NCRIPP study involved calculating financial damage (referred to as risk in this study) resulting from the assessed hazards. Risk is computed for multiple hazards at various return periods for a range of assets. Most of the damage values were based on buildings, which were classified based on the 2015 LiDAR Study and supporting data from the Barbados Revenue Authority and the 2010 Barbados Census.

Some of the hazards were found, as expected, to be very severe, while others are of much less concern. The hazards with the largest risk were found to be flooding due to storm surge and flooding due to rainfall. An overview of the risks is outlined in order from largest to smallest as follows:

- Seismic risk was ranked as the highest financial value of any of the hazards; however, this was assessed for a much higher return period than other hazards. Seismic was assessed as per the values prescribed in the building code of 475 years (10% chance of occurring in 50 years) and 2,475 years (2% in 50 years). The total risk values of BBD 18 billion and BBD 30 billion were determined for these two events.
- Flooding due to storm surge has a large influence on residential, commercial and tourism assets, with totals damages in the range of BBD 3 billion for the 100-year condition. Some of the largest damages are in the Bridgetown area, although with limited information on the urban drainage in this region, we believe the risk in this area is likely overestimated.

- The risk of flooding due to rainfall for the 100-year event is estimated to be approximately BBD 900 million. This includes slightly more damage in the commercial sector rather than residential buildings, with the greatest damages in Bridgetown.
- Winds during a hurricane at the 100-year level are estimated to cause BBD 1.7 billion in damage, with about 60% of that damage being to residential buildings.
- Risk due to the 100-year tsunami is estimated at BBD 31 million, which is located primarily in the vicinity of the Careenage. With a future sea level rise of 25 cm, the damage increases and is approximately BBD 80 million. These are very likely conservative estimates based on some of the assumptions in the hazard analyses.
- Risk due to landslides in the Scotland District is estimated at BBD 21 million for the 100-year event. Such an event could happen at many different locations in the Scotland District and the specific location could significantly vary this number. Damage to infrastructure such as roads is not considered in these values.
- Risk due to coastal cliff collapse is cumulative with collapses occurring in numerous locations rather than as a single large event. The cumulative damage over a 50-year period is estimated to be in the range of BBD 7 million, which increases to BBD 18 million over the next 100 years (expressed as 2017 values).
- The oil spill hazard was demonstrated through oil spill modelling and industry statistics to have minimal risk, with annual risk values in the order of a few thousand dollars. This does not imply that no spill will ever happen, but suggests that with industry standard practices and preparedness in place, no further mitigation and preparedness efforts are required for oil spills.

The Hazard Report (Baird, 2017) showed that a Sea Level Rise (SLR) of 25 cm had only limited impact on storm surge, but more impact on tsunami inundation. The date by which 25 cm of SLR has occurred varies greatly with different studies, but a typical range is approximately 30 to 60 years from today.

The most common return periods for the hazards analyzed were in the range of 50 to 100 years; these data have been compiled for the relevant hazards and are plotted below. This plot (Figure A.42) shows the large disparity in the risk for some of the hazards, as well as the difference between the 100-year and the 50-year events. The large difference for the two return periods for wind is evident, while the more similar return period results for storm surge is also shown.

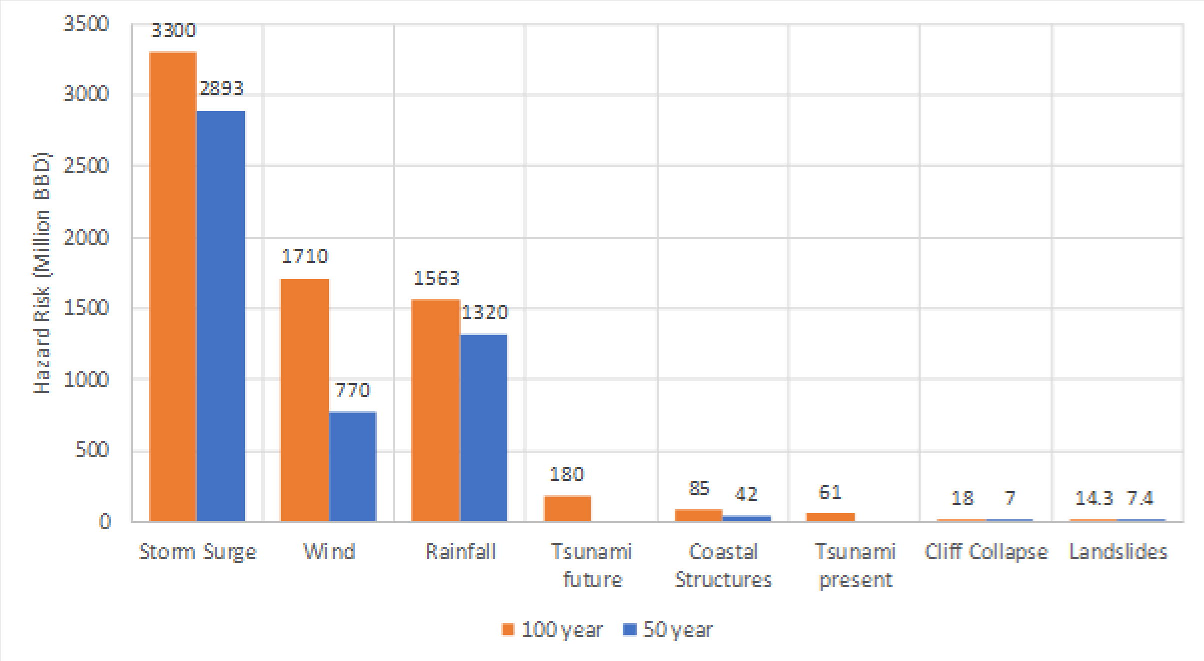

Figure A.42. Hazard Risk (Million BBD). (Source: Baird, 2018).

The annual expected damage is derived from the damage associated with various return period events and the annual probability of occurrence. This process has been completed for the time span of the 10-year event to the 100-year event, with the results plotted below. These expected damage values are intended for comparisons between hazards, rather than for any sort of budgeting purposes as there is considerable estimation in defining the shape of some of these curves.

Seismic damages are not depicted in this figure due to the different return periods that were assessed.

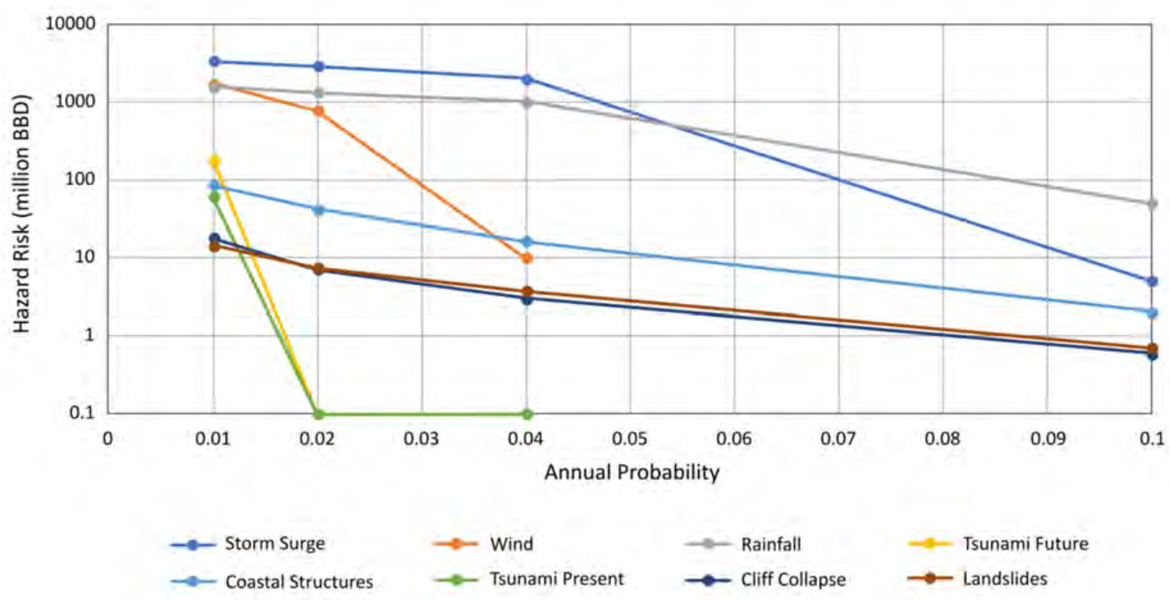

Figure A.43. National maximum probable loss by hazard. (Source: Baird, 2018)

Wind risk

The potential for severe wind damage in Barbados is high; this was strongly demonstrated through the extreme hurricane damage in the northern Caribbean during the 2017 hurricane season.

Risk from the wind hazard was assessed for Barbados based on the exposure to the hazard, and the susceptibility of various assets to wind damage. The wind hazard was derived based on statistical analysis of hurricanes and tropical storms and a Monte Carlo analysis of thousands of hypothetical storm tracks. The wind exposure in the vicinity of Barbados is essentially equal throughout the area; all regions of Barbados are thus assumed to have the same design wind speeds (see Table A.7), regardless of proximity to the coast or local land profile. Localized adjustments to winds are applied based on surface roughness such as trees, and buildings, which is obtained from the LiDAR survey (Baird, 2015c). The vulnerability to wind damage was based on statistical information describing the building parameters, which introduced spatially varying vulnerability to the wind hazard.

Return period	3 sec Gust Speed (m/s)
20	34
50	42
100	47

Table A.7. Design wind speeds. (Source: Baird, 2018)

Asset values were obtained from the Barbados Revenue Authority tax parcel database. These improved values (structure values) were available for most properties and were the primary source of information for asset valuation.

Structural properties considered in the wind damage assessment included roof shape, roof covering, structure size/height, building material (e.g. wood/masonry) and various other parameters. The FEMA HAZUS software was used to describe the expected losses due to wind.

Damage was assessed for all structures in Barbados, and catalogued as damage to either a residential or commercial structure.

Content losses are not considered for wind damages, since for the typical damage levels that are expected (up to the 100-year event), content damage is limited.

Mapping of wind losses is presented based as the sum of the loss for each hectare (100 m by 100 m) throughout Barbados.

Figure A.44 presents the residential and commercial wind damage. The Hazard Risk Atlas (Baird 2018) includes values of wind damage on tiles of 65 maps for residential and commercial buildings (note that commercial includes all non-residential buildings), as well as for the tourism plant (selected tiles only).

Residential Wind Damage: In a 100-year event, damage is widespread throughout Barbados, and closely follows the distribution of the housing stock. Residential housing stock totals approximately BBD 29 billion, and damage estimates are approximately BBD 1.0 billion, or about 3.6% of the total residential value. Losses at the 50-year level were significantly less, which shows the sensitivity of the damage to wind speeds. Note that content losses were not included in these estimates and that rebuilding value is typically in the order of 50% higher than the damage estimate.

Commercial Wind Damage: In a 100-year event, commercial damage is estimated to be approximately BBD 660 million, which represents just over 5% of the commercial structure value in Barbados. Content losses are not included in this estimate. Damage is clustered in St. Michael, as well as along the south and west coast, largely due to tourism assets. Damage throughout the remainder of Barbados is scattered, although increased damage occurs in isolated locations. Some localized higher damage occurs in Newton Industrial Park, Warrens, Wildey, Belleville, Bridgetown and the Port.

Tourism Wind Damage: Wind damage to the tourism sector is a subset of the commercial sector and was computed at BBD 270 million for the 100-year wind event. This represents about 8% of the total tourism asset value (BBD 3.3 billion). Damage is much more localized in specific areas along the coast, including the southwest coast, Carlisle Bay and St. James (Paynes Bay through Heron Bay). Additional losses are noted on the east coast close to Crane. Damage that can be linked to specific structures must consider that structure-specific susceptibility information was not available for these analyses.

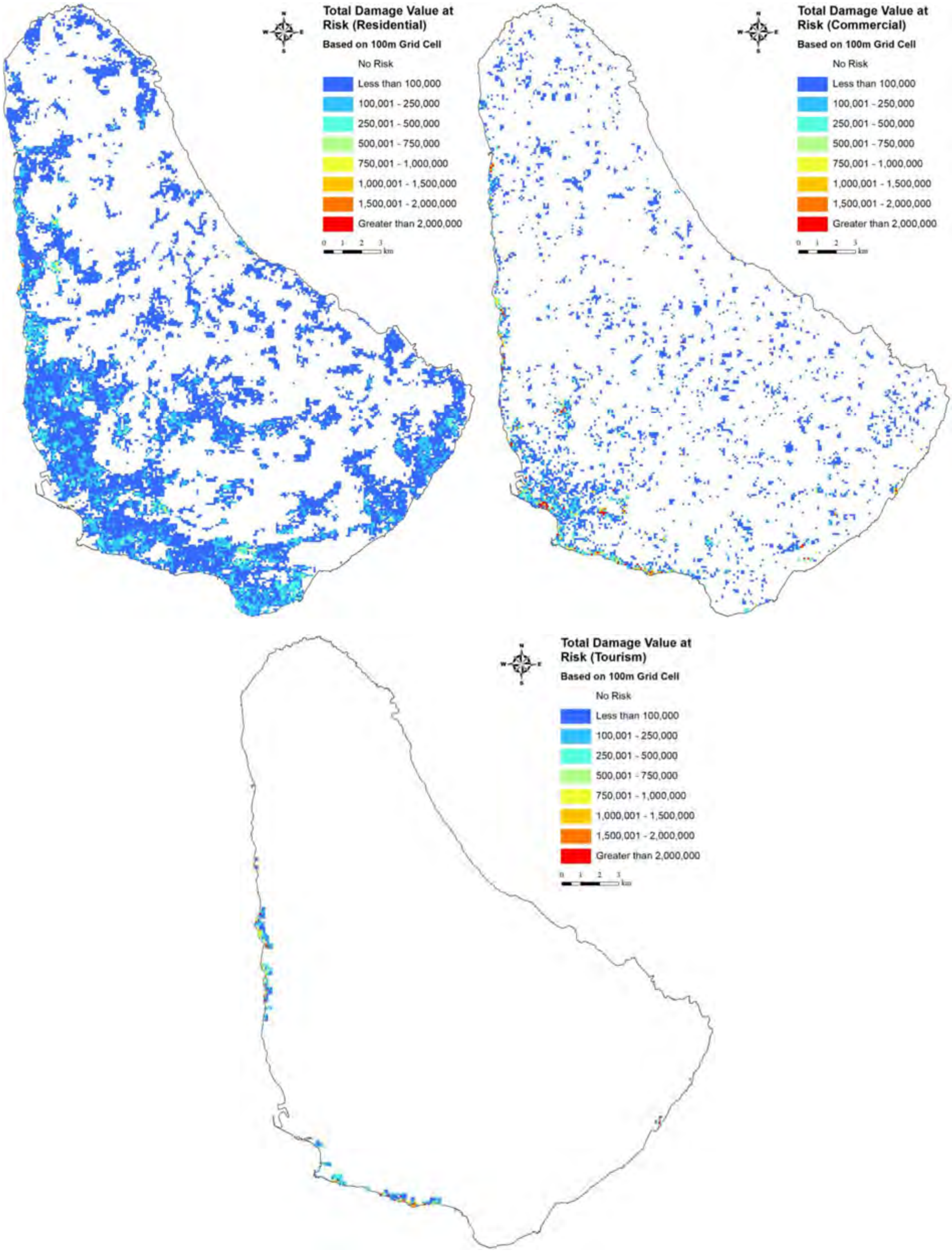

Figure A.44. Map of Wind Risk from 100-year Event (Residential on upper left, Commercial on upper right, Tourism on bottom). (Source: Baird, 2018b).

Storm surge risk

Storm surge typically occurs in Barbados during a tropical storm or hurricane, and includes the processes of pressure setup (due to low pressure in a storm), wind setup (from onshore winds), wave setup (associated with large onshore waves) and wave runup as the waves impact the shore or structures. Storm surge was assessed through the simulation of hundreds of hypothetical storm events using a Monte Carlo approach. Coupled numerical models of waves and storm surge defined the conditions close to the shore, while profile models were used to assess runup and overtopping along the shore. Storm surge can be very localized and a strong event on one coast may occur while other coasts see little impact. As a result, the runup and overtopping estimates vary significantly from site to site, and the impacts are highly variable depending on shoreline topography.

Approximately 250 profiles were defined around Barbados to define the storm surge exposure. Where runup did not exceed the beach or cliff face, the exposure region is very close to the shore and typically has little to no impact since structures are generally further landward. In instances where the runup exceeds the beach elevation, inland inundation will occur and in extreme cases waves may impact buildings.

Damage to buildings was assessed based building footprints that were defined from the recent LiDAR study (Baird, 2015c). The Improved values for the properties were obtained from the Barbados Revenue Authority, while information on the building susceptibility was defined from information obtained from the 2010 Barbados Census. Census data were available at the enumeration district level and provided statistical guidance on building construction and other parameters. Buildings were defined as having a first-floor elevation of above or below 0.6 m, which impacted their flood susceptibility.

Building-specific flood damage was estimated as the percentage of structure loss versus water depth. These data were derived from U.S. estimates and applied for different types of structures. Loss data are summed by one hectare parcels and are limited to coastal areas where this type of flooding is expected. Assets are group into residential and non-residential categories, and are also presented separately for the building stock. Losses for building contents and vehicles are also considered, in addition to loss of life.

Residential Surge Damage: Damages due to storm surge are greatest along the developed SW through west coasts and sum to about BBD 650 million for the 100-year event, or close to BBD one billion if a 50% content loss assumption is applied. The majority of these losses are within the parishes of St. James and Christ Church, accounting for about two-thirds of this value. Losses on the other coasts are minimal in comparison. Bridgetown also has significant damage, although these are generally more commercial than residential properties.

Commercial Surge Damage: Commercial damage from storm surge at the 100-year level totals about BBD 1.1 billion in structure damage, with content damage doubling this value to a total of BBD 2.3 billion. Close to half of this damage occurs in the central Bridgetown area, in the vicinity of the Careenage through Fontabelle to the shallow draught harbour. The storm surge flooding hazard, particularly close to the port, was identified as likely being conservative in terms of its extent and depth due to the lack of details regarding urban drainage in the area.

Tourism Surge Damage: The risk to tourism structures in Barbados due to storm surge primarily occurs along the SW and west coasts in the parishes of St. Peter, St. James and Christ Church. The majority of commercial flood damage in the Bridgetown area is not associated with tourism, but general commercial assets instead. The total structure damage to the tourism sector is estimated at BBD 870 million, plus content losses that are estimated at an additional 100% for commercial assets (tourism is a subset of commercial).

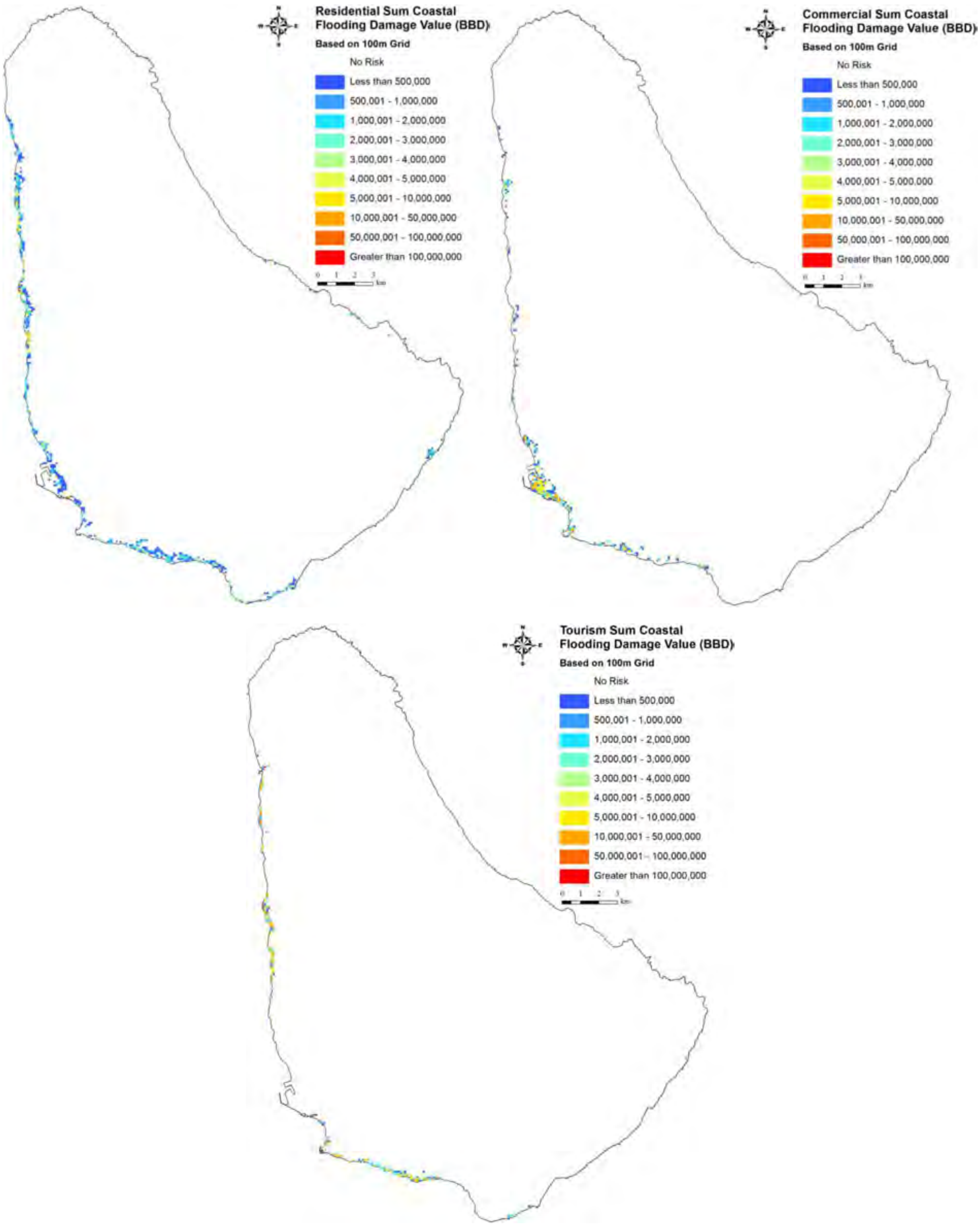

Figure A.45. Map of Storm Surge Risk from 100-year Event (Residential on upper left, Commercial on upper right, Tourism on bottom). (Source: Baird, 2018b).

Coastal erosion - beaches risk

Coastal erosion risk can be manifested through damage to beaches, damage to coastal structures, or erosion of coastal cliffs. These processes are all related in that they are caused by a combination of short- and long-term degradation due to wave attack; they also have significant differences.

Beach erosion and cliff collapse are cumulative process that happen over a period of many years, although for both processes event-based losses will occur.

Beach erosion is different than other hazards as the beach will accrete and erode in response to varying wave conditions, including major storms. Assigning beach damage immediately after an event may not be appropriate since some natural recovery of the beaches occurs. Therefore, only long-term erosion of beaches can be assigned a numerical damage value; however, this is a continuing loss value each year based on long term trends, rather than being associated with a specific event.

Estimates of long-term beach erosion were undertaken through statistical analyses completed on the surveyed beach profiles from CZMU's long term monitoring program. Estimates of long-term trends were developed for each station, and broader estimates by coastline were developed. These results are shown in Table A.8. Table A.8 also provides the change in value under different beach width scenarios. The annual value change represents the losses/gains per year as a result of long-term trends in the beach width. These long-term trends are based on the last 10 to 30 years (depending on the site) of beach survey data.

Coast	Long term beach change (m/yr)	Beach length (Km)	Annual Area Change	Without SLR	With SLR (3mm/yr)
West	-0.08	16	-1298	-3.2	-4.1
Southeast	-0.05	6	-317	-0.2	-0.3
Northeast	-0.18	9	-1586	-1.3	-1.4
Southwest	0.16	8.5	1366	3.8	3.3
Carlisle Bay & Brandons	1.23	2	2468	10.1	9.9

Table A.8. Estimation oflong-term terns of beach erosion. (Source: Baird, 2018).

Beach values were derived by examining the total contribution of beaches to tourism in Barbados, in addition to other uses that provide value. This value was distributed to the beaches based on the approximate beach width and relative use level on the beach. Beach values and associated losses are not based on specific site issues such as the adjacent property values, but are based on general trends.

The annual erosion damage to the beaches (considering beach loss only, not structures) is in the order of BBD 3.2 million along the west coast, and 1.3 million along the northeast coast. The southwest coast and the region of Carlisle Bay and Brandons are accreting and therefore (technically) increasing in value.

A SLR of about 3 mm/yr will cause a recession of about 24 mm per year on an 8:1 sloped beach, resulting in additional total losses of about BBD 2 million per year. It is important to consider that these losses are not evenly distributed in Barbados; west coast damages increase by an addition BBD 1 million per year. Gains on the southwest coast are slightly reduced if SLR is considered. The southwest coast erosion/accretion is often linked to shoreline restoration works and is not spatially consistent. There may be some sections of beaches on the SW coast that are eroding and do not follow the general trend; localized erosion maybe an ongoing trend. Also gains in one location (e.g. Carlisle Bay) are not directly transferrable to losses in other locations, such as the west coast where erosional losses are higher.

Figure A.46 presents the change in beach value with 2m loss (BBD). Sub-Area maps also present this information at local scale.

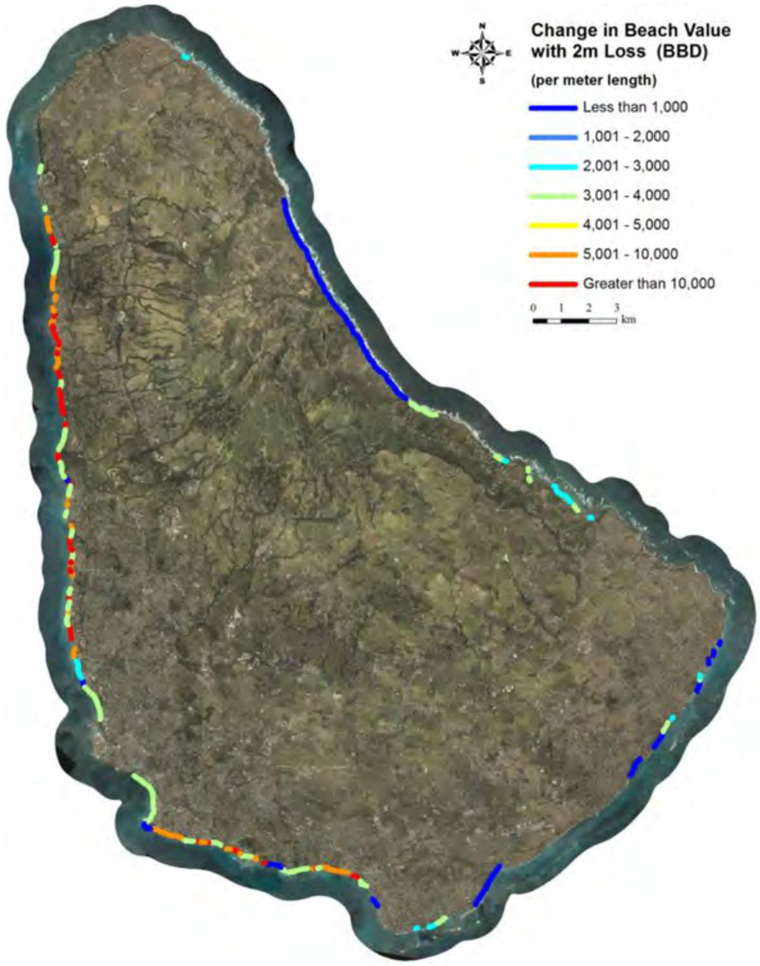

Figure A.46. Change in Annual Beach Value for 2 m Reduction in Beach Width. (Source: Baird, 2018b).

Damage to coastal structures was also assessed based on very limited information (no field studies or inspections were completed). The lengths of different types of structures was determined based on aerial imagery and structure values were estimated based on Baird's local knowledge of structures and construction costs. An estimate of the structure conditions was also applied in a statistical manner (percentage of robust, acceptable and poor condition) in addition to an estimate of the damage level from different storm events. From this an estimate of the financial risk to various structures was developed; however, it needs to be emphasized that all these data are based on statistical estimates and local knowledge. No site inspections were completed and consequently specific structures at risk were not identified.

Coastal cliff collapse may be associated with a specific wave event, or a cliff may be seriously weakened in an event and fail in the weeks, months or years that follow. However, cliff damage is generally more cumulative than occurring during a specific event. The frequency of coastal cliff collapse is estimated by assessing the historical failures of different classes of cliffs, and then determining what percent of the cliff length may be expected to fail over different time periods. The different cliff classifications were established to reflect the integrity of the rock, the shape of the cliff and the likely failure mechanisms.

Cliff Type	Length of Coast (m)	50-year Setback		50 year Losses					
		Number of Buildings	Value of Buildings (M BBD)	Expected Loss of Cliff (m)	Cliff Loss	Developed Frontage	Loss of Structure Probability	Number of Buildings	Value of Buildings (M BBD)
A	10900	47	190.9	50	0.46%	26%	0.12%	0.06	0.2
B	18800	119	263.5	400	2.13%	38%	0.81%	0.96	2.1
C	19700	160	346.8	150	0.76%	49%	0.37%	0.59	1.3
D	5300	43	7.74	50	0.94%	49%	0.46%	0.20	0.0
E	600	13	5.4	60	10.00%	130%	13.00%	1.7	0.7
Total	**55300**	**382**	**814.34**	**710**	**1.28%**	**41%**	**0.92%**	**3.5**	**BBD 4.38**

Table A.9. Cliff losses by cliff type. (Source: Baird, 2018).

Cliff failures are difficult to predict for any specific location; the probability of a cliff failure is assessed in a uniform manner along the length of the cliff. There are two aspects to understanding structure risk at a cliff. First there is the probability of having cliff failure occur somewhere along the coast. There is also then a probability that the failure will be fronting a structure that is close enough to a cliff to cause damage.

Cliff failures that intersect with or are close to a structure are assumed to result in complete loss of the building. There are 382 structures that lie within the 50-year setback that was established during this study, and our estimate of the expected building losses over the next 50 years is 3.5 structures. These are most likely to occur along type E and type B cliffs. The value of the building loss over the next 50 years (in today's dollars) is BBD 4.4 million. Loss of life and content loss is a possibility, but depends on whether there are any warning signs that permit evacuation to occur.

Structures that are threatened by cliff collapse are almost exclusively residential structures. There are very few other types of structures such as the Crane Hotel (which has a specially engineered foundation) and Some structures at the Arawak Cement Plant.

Rainfall flooding risk

Flooding due to rainfall is common in Barbados and can occur throughout many parts of the island. Flooding from rainfall could be due to a widespread tropical depression/storm, a hurricane, or even very localized downpours. Rainfall estimates for Barbados relied on data from 1971 with recent updates by the Caribbean Institute for Meteorology and Hydrology (Baird, 2017). The CIMH data provided revised intensity-duration-frequency (IDF) curves for Barbados, which were modified to represent different rainfall intensities over Barbados.

Hydrological modelling used a combination of the SWAT model (which considered soil type, and infiltration and built upon previous modelling efforts in Barbados) and the MIKE21FM model for simulating the spatial extent of the flooding in some of the broad flat areas. Numerical modelling of flooding did not include urban drainage features such as ditches and culverts; it represents overland flow that would be indicative of flooding when the local drainage was overwhelmed. The numerical model did not include the effects of building and walls on how flood water will travel. Therefore, the results of these simulations should be considered with the knowledge that this study does not represent the definitive flooding study for all of Barbados.

Census data were available at the enumeration district level and provided statistical guidance on building construction and other parameters. The census data were applied to the LiDAR-derived building definitions and an estimate of the first-floor elevation (above or below 0.6 m) impacted their flood susceptibility.

Building-specific flood damage was estimated as the percentage of structure loss versus water depth. These data were derived from U.S. estimates and applied for different types of structures. Assets are grouped into residential and non-residential categories and are also presented separately for the building stock. Losses for building contents and vehicles are also considered, in addition to loss of life.

Residential Rainfall Flooding Damage: Residential risk is generally more present along the coasts where flatter land is present and where there is typically a higher housing density. Some pockets of higher risk occur in regions such as Speightstown, Holetown, Six Roads and scattered pockets throughout St. Michael and Christ Church. When assessing losses at the sub-parish level (20 regions described in the Risk Report (Baird, 2018), two thirds of the damage occurred in Central Bridgetown, Christ Church West, and St. James (urban). Residential damage is estimated at BBD 370 million, plus 50% to include damage to contents (total is BBD 550 million).

Commercial Rainfall Flooding Damage: Commercial damage associated with the 100-year event is most prevalent in the Bridgetown area, where flooding issues and commercial properties intersect. Regions of Fontabelle, Cheapside and along the Careenage/Constitution River are some of the more damaged regions. In other parts of Barbados, there are only small isolated regions where commercial damage is expected to occur at higher levels, including Speightstown, Holetown, Spring Garden, Worthing and a few other regions. The total commercial damage is estimated to be about BBD 500 million for the 100-year event. If content losses are included, this estimate doubles to about BBD 1 billion.

Tourism Rainfall Flooding Damage: Damages to the tourism sector arising from the 100-year rainfall event are similar in character to the commercial damages, except there is much less damage in the central Bridgetown area. Other regions, such as Speightstown and Holetown, show significant damage, along with the south end of Carlisle Bay, and Worthing to St. Lawrence Gap. The losses are typically very close to the shore since these are the regions that are most commonly defined as tourism. Tourism damage, which is a subset of commercial damage, is estimated to total BBD 145 million in a 100-year event. One half of this occurs in St. James while Bridgetown, Christ Church and St. Philip complete all but 1% of the damage that is outside these four regions. The total damage, if content losses are included, would double the damage estimate to almost BBD 300 million.

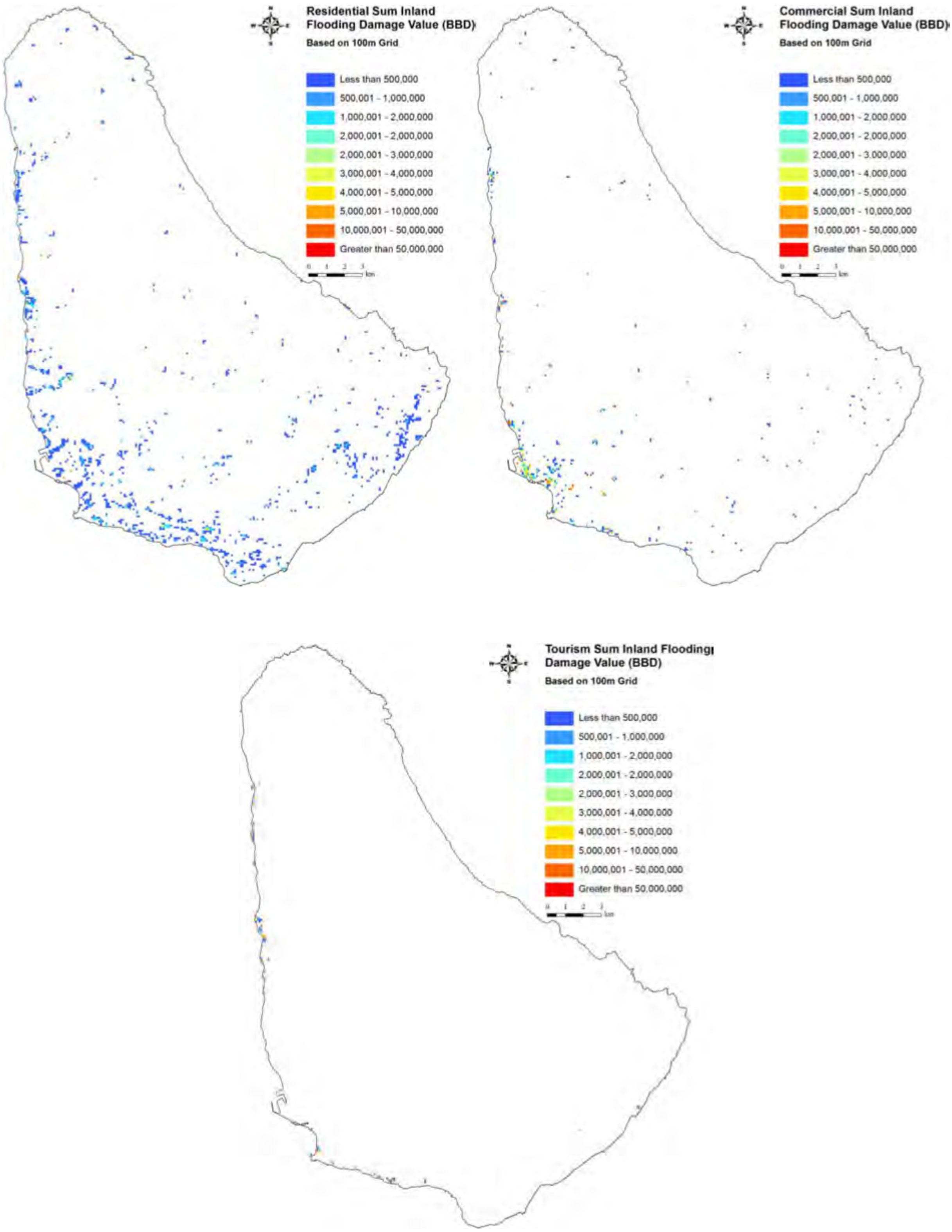

Figure A.47. Map of Rainfall Flooding Risk from 100-year Event (Residential on upper left, Commercial on upper right, Tourism on bottom). (Source: Baird, 2018b).

Seismic risk

Seismic hazards for this study were developed by Golder Associates based on the results of existing studies such as Bozzani et al. (2011) (a regional study for the Eastern Caribbean) and ground motions estimates for Barbados by Salazar et al. (2013). Ground accelerations are then modified according to the geological site class and soil amplification factors specified in the 2015 International Building Code for the 475 and 2475 year return period events. Note that the return periods assessed for the seismic hazard are in alignment with building code approaches to new construction, and are much greater than the return periods examined for other hazards in the NCRIPP.

Seismic conditions and damage are evaluated based on the Peak Ground Acceleration (PGA) modified by site class; each structure in Barbados is as signed a PGA value that is associated with the 475 and 2475 return period events. Note that the return periods assessed for the seismic hazard are in alignment with building code approaches to new construction, and are much greater than the return periods examined for other hazards in the NCRIPP.

Barbados and its immediate vicinity have a limited history of seismic activity. This results in uncertainty in the overall ground acceleration values, as well as uncertainty in the ability of typical Barbadian structures to withstand seismic motion. As a result, the overall damage levels have significant uncertainty.

Damage levels due to seismic hazard were determined based on the probability of five damage states, ranging from “none” (no damage to structure) to “complete” (100% damaged), for a given building type and peak ground acceleration (PGA) value from the HAZUS technical manual. Six different types of structures were considered: Wood 1 to 2 story, Concrete 1 to 3 story, Concrete 4 to 7 story, Masonry 1 to 2 story, Masonry 3+ stories, and Chattel. Expected damages are assigned to each structure based on an estimate of the number of stories in the building, and a probabilistic approach based on the types of buildings in the enumeration district.

The damage levels in Barbados are extreme from these higher return period events. Losses are significantly influenced by the assumed level of code adherence in Barbados. Mapping is undertaken based on a low code adherence, although this may be somewhat conservative. Losses are still extreme for high code adherence. Including content loss increases the damages by 60% to 70%. The total structure value in Barbados (based on BRA “improved value” estimates) is BBD 42 billion. This suggests that a 475 year seismic event would involve structure losses at BBD 21 billion, or BBD 34 billion if contents a reconsidered. Reconstruction costs are estimated to be 50% higher than the improved value in the BRA database (plus content replacement).

Residential Seismic Damage: The total residential structure value in Barbados (based on BRA “improved value” estimates) is BBD 29 billion. A total residential structure damage value of just over BBD 10 billion is expected in a 475 year seismic event, which is approximately one third of the structure value. Reconstruction costs are estimated to be 50% higher than the improved value in the BRA database (plus content replacement).

The damages are generally distributed in a manner that is consistent with the residential development density, although regions with higher structure values (e.g. coastal St. James) have higher monetary damage than some regions of central St. Michael.

Differences in building type (wood versus concrete) may also contribute to the patterns in the seismic risk m aps. For example, southern St. James has a much higher proportion of concrete structures than northern St. Michael, which is consistent with damage calculations.

Commercial Seismic Damage: Mapping of commercial seismic losses is highly linked to the location of the more valuable commercial assets. For example, there are regions in central Bridgetown and in the Warrens area where higher losses are observed. The more developed west and southwest coasts also show higher losses. Grantley Adams Airport shows as a region of higher loss, but this is based on averaged building properties and no seismic specific building inspections. Expected damages are in the range of BBD 7.2 billion, which is approximately 57% of the commercial building stock. Tourism would be expected to have similar overall losses to other commercial assets.

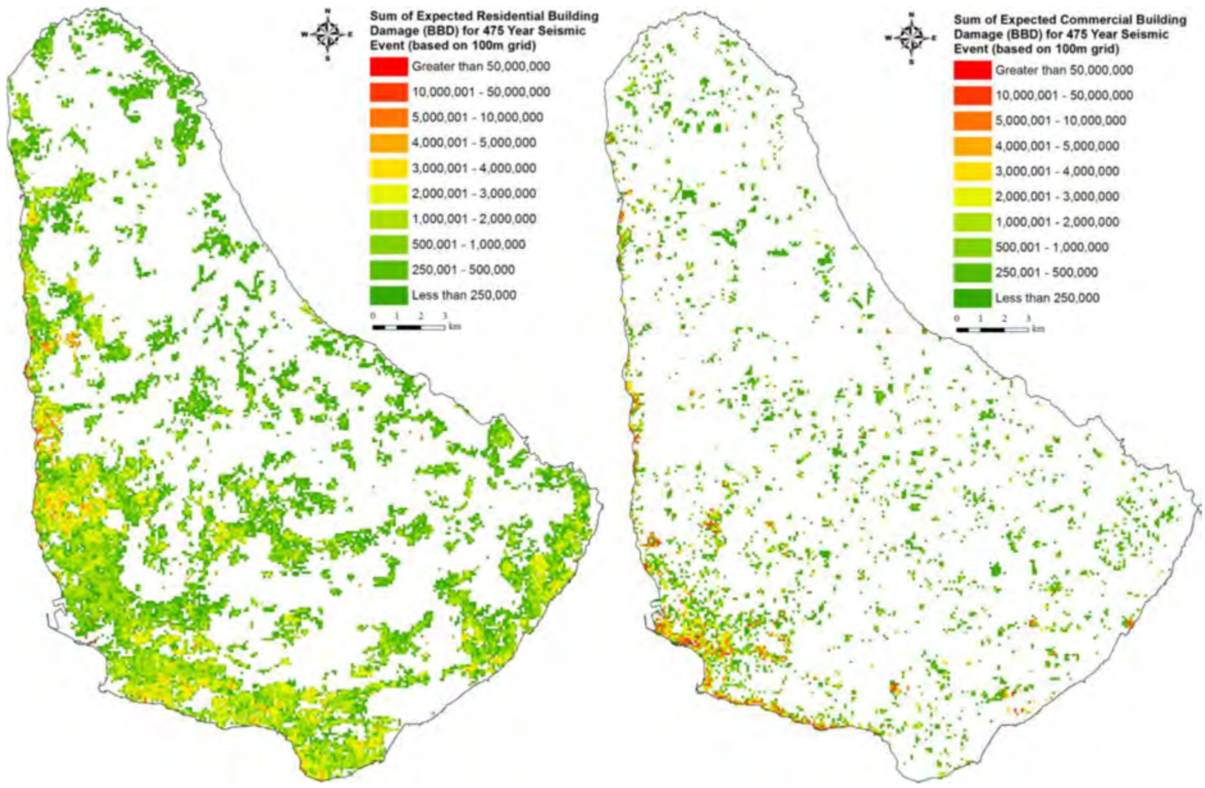

Figure A.48. Map of Damages due to 475 year Seismic Event (residential on left; commercial on right). (Source: Baird, 2018b).

Landslide risk

Landslide risk in Barbados is generally limited to the Scotland District, which contains very different soil types to the remainder of Barbados. As Barbados was gradually pushed up from the ocean floor, a coral cap developed, that was subsequently pushed above sea level. In the highest parts of Barbados, this coral cap has crumbed away, leaving behind the clays of the Scotland District which underlay the coral cap. These clays, with varied characteristics, form the hills and valleys which can be prone to landslides.

Landslide hazards were evaluated based on soil properties and slope angles, using topographic information from the 2015 LiDAR study (Baird, 2015c). Defining slope risk is not a precise science since it depends on accurate depiction of soil characteristics and definition of these characteristics through depth. Slope stability is classified as low, medium and high based on local slope angle, and the soil properties associated with different regions.

Historical landslide information was assessed, and an estimate of the area associated with different return period events was developed. The largest of known historical events was used as guidance in estimating the 100-year event, in which an estimated 2% of the Scotland District may fail. There are significant uncertainties in these estimates; however, they provide general guidance for assessing overall risk and are presented in Table A.10.

Return Period	Approx. Failure Area	Annual Exceedance Probability	Chance of Failure at Any Location for Medium & High Risk Regions	
			Areal Probability	**Annual Probability**
100 year	1.2 km^2 (2% of 60)	0.01	0.027	0.00027
25 year	0.3 km^2 (0.5% of 60)	0.04	0.007	0.00028
5 year	0.03 km^2 (0.05% of 60)	0.2	0.0007	0.00014

Table A.10. Chance of failure at any location for medium and high risk regions. (Source: Baird, 2018).

The risk to structures in the Scotland District is based on having building assets in medium or high risk areas; buildings in areas listed as "low" were not considered in the risk assessment. Each building that is medium or high risk is then assigned a spatial probability of being part of a particular X-year landslide event.

The total value of structures in the Scotland District is approximately BBD 1.0 billion based on the BRA database that documents the improved value. Just over half of these structures by value (BBD 528 million) were found to be located in medium to high risk areas. The results of the risk (see Table A.11) analyses show that in a 100-year event, approximately 1.4% of the buildings could be lost, for a value of BBD 14 million. Residential buildings and possible landslide damage amount to about 90% of the risk in the Scotland District. If a 100-year slide impacted a more or less developed area, the damages could be minimal, or could be many times higher than the predicted value.

	Value in Million BBD		
	All Structures	**Residential**	**Commercial**
Total Structure Value	1,024	901	123
At Risk Value	528	465	63
5 Year Event Loss	0.37	.33	.04
25 Year Event Loss	3.7	3.3	0.4
100 Year Event Loss	14.3	12.6	1.7
Average Annual Risk	0.68	0.60	0.08
Cumulative Risk 50 Years	34	29.9	4.1

Table A.11. Landslide risks (in Million BBD). (Source: Baird, 2018).

In addition to the landslide risk listed in this table, there are also losses that occur on a regular basis as a result of gradual ground creep, which can result in cracking of foundations and damage to building stability. These ongoing damages are not included in the above statistics, which are more focused on larger events.

Residential building damage: Residential structures make up the vast majority of structures in the Scotland District and account for about 95% of the expected losses over the next 50 years. Some of the more populated areas are located in flatter regions that are less prone to landslides, and therefore do not contribute to the damage totals. The regions of Belleplaine and Lakes are examples of regions where some houses are in more expose d locations, while other houses are much less exposed. Overall, the expected damages are distributed in small pockets throughout the Scotland District and largely follow the roads and settlements. Few areas are considered low hazard exposure and thus low risk.

Commercial building damage: Landslide related damage to commercial (anything that is non-residential) is limited in the Scotland District due to the fact that only 6% of structures reclassified as non-residential. The expected losses over the next 50 years are estimated at about BBD 1.8 million, which is only about 5% of the total losses when considering all structures. Some of the more valuable non-residential assets are located in flatter re ions of the Scotland District (close to the coast). The following maps show only scattered pockets where damages are expected.

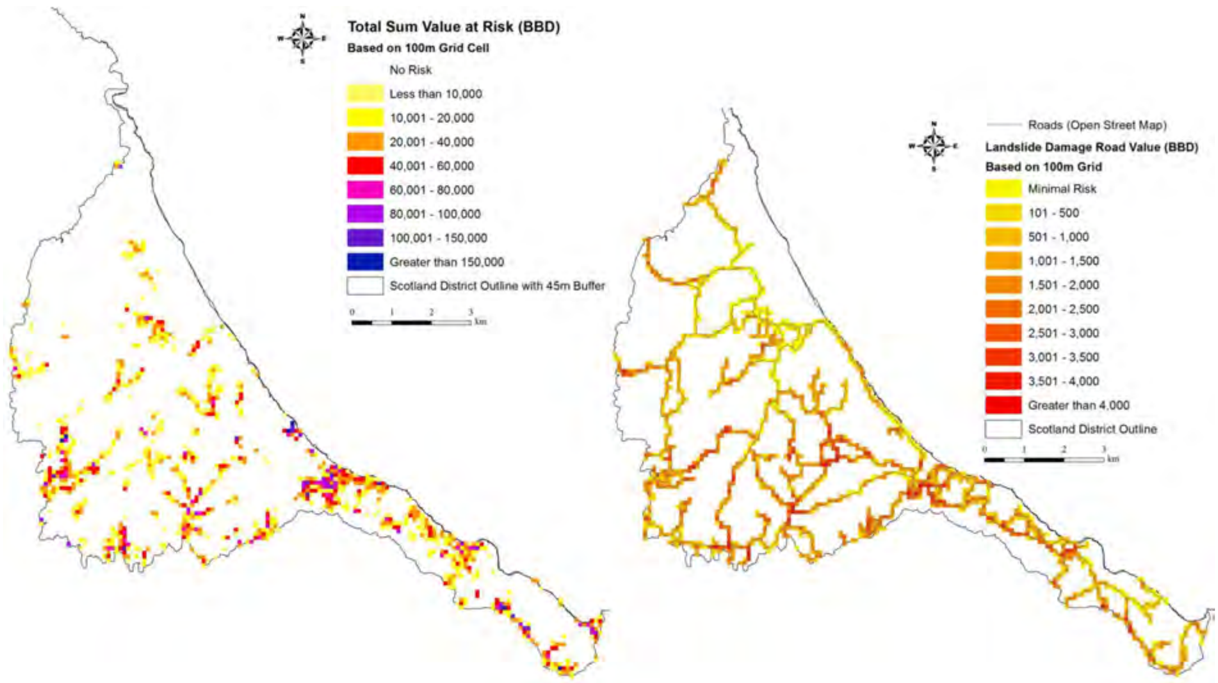

Figure A.49. Maps of Landslide Risk in Scotland District: right: structures; left: roads. (Source: Baird, 2018b).

Tsunami risk

There are a number of challenges in defining the tsunami risk, primarily related to uncertainties in the location, type and overall geometry of the generating mechanism. The Caribbean is a tectonically diverse environment, with many plate boundaries, some of which are transverse and others close to Barbados are subduction faults. There are also volcanic cones that could collapse and/or explode and the potential for submarine landslides. All of these are possible events and some of these would constitute events that may occur on the scale of 10,000 years or longer, while others are much more frequent. Many of the processes that are associated with volcanic activity along the lesser Antilles are far enough away and directed towards the west, such that their direct impact on Barbados would be limited. As a result of these factors, tsunami hazards in Barbados are minimal at the 100-year level, which is supported by the limited historical data for tsunami damage.

The most probable tsunami threats in the vicinity of Barbados at the 100-year level involve a subduction earthquake, similar to those that occurred in 1839 and 1843 to the east of Martinique. These events caused some damage in the northern Lesser Antilles and only limited impacts in Barbados. There is the potential for a large subduction event directly east of Barbados, although there is no historic evidence of such events, suggesting that these events would be well beyond the 100-year event.

The 100-year event in Barbados was simulated with various tsunamis similar to the 1839 and 1843 events. The overall dimensions of the seafloor movement were varied in numerous simulations, along with the orientation and position. There are so few strong historical seismic events recorded in the region that defining specific parameters for an expected 100-year event is close to impossible.

Seafloor displacements were supplied to the MIKE21 Flexible Mesh hydrodynamic model and the propagation and runup of the tsunami around Barbados was simulated. The tsunami waves were typically less than 0.5 to 1 m in height, and only in selected areas did the tsunami waves overtop the beach crest to cause flooding. The model results were also found to be quite varied around Barbados, with higher runup in some areas and much less in other areas. Sensitivity analyses were completed for a range of similar events (in magnitude, not in position and orientation) and one of the more damaging events was selected to represent the 100-year tsunami event. With this selected approach, the damages listed below are believed to be conservative.

Residential Tsunami Damage: Residential damages from a 100-year tsunami event in Barbados are limited to only a few selected areas. These areas are best characterized as regions that are generally much more protected, and therefore have lower beach berms protecting the land. The regions of Brighton (Spring Garden) and Oistins are two such areas. Damages were calculated using the same approach as storm surge, and are estimated at BBD 6 million, plus content damage for a total of BBD 9 million.

Commercial Tsunami Damage: Commercial damages from a 100-year tsunami are mostly in the region of Bridgetown, where tsunami waves enter the Careenage and spill into the downtown area. The total structure damages are estimated at BBD 83 million, although 70% of these damages are associated with three of the one-hectare grid cells. This suggests that much of the losses are in a very specific area, and therefore the reliability of these numbers is dependent on whether the damaged buildings are properly represented. The highly localized damage suggests that further investigation may be required to gain confidence in these values.

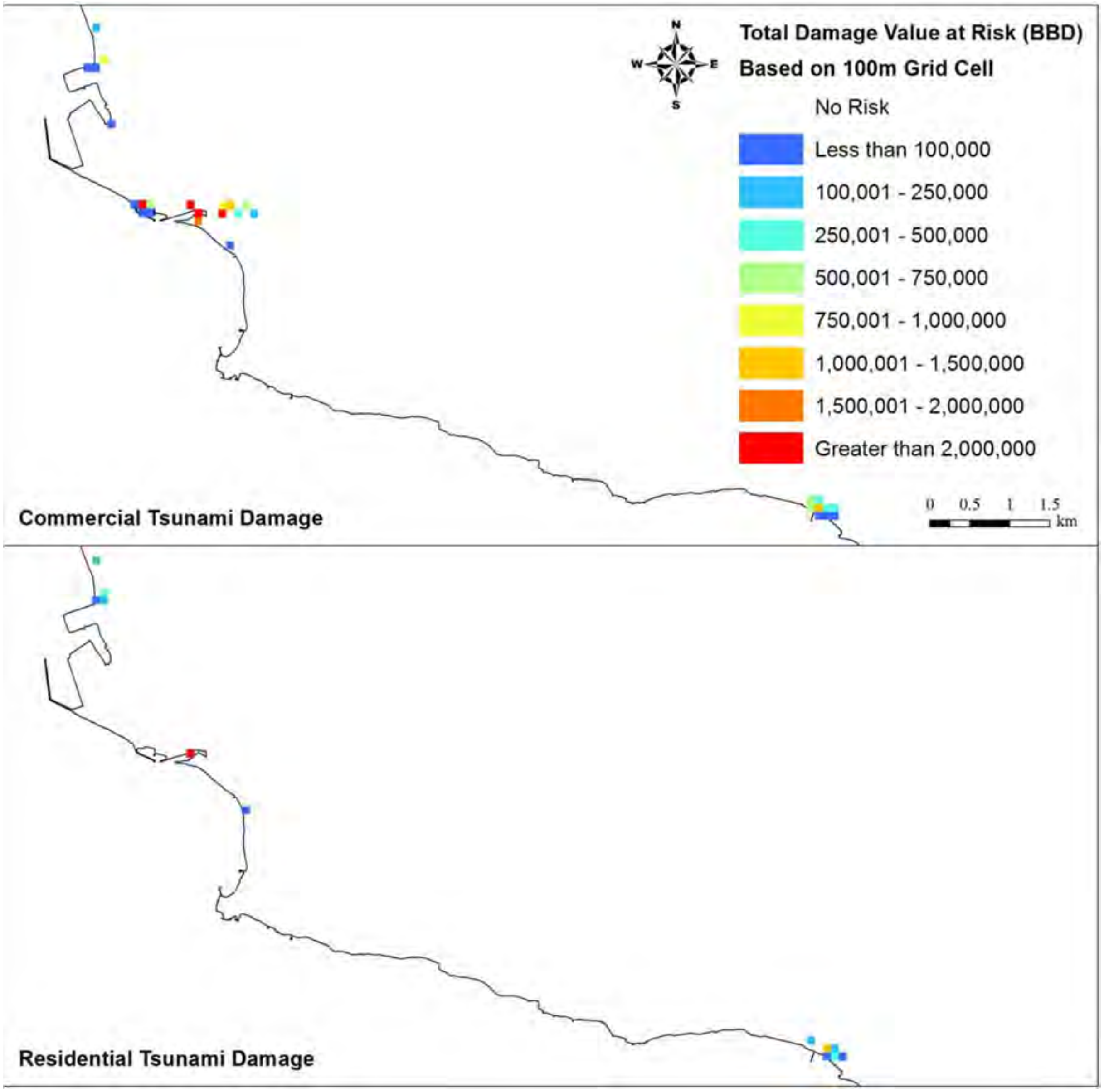

Figure A.50. Map of Damages from 100-year Tsunami Hazard (Source: Baird, 2018b).

Marine Oil Spill Risk

Oil spill risk was found to be minor in Barbados. Offshore spills that could impact the fishery or tourism at an island-wide scale are extremely rare (annual risk estimated at 1 in 100,000) and as a result the financial risk is negligible. There is the potential for spills in the region of Oistins, where transfer of light processed products takes place. Spills from this type of operation could impact on the south coast, but typically disperse and evaporate quickly; a shoreline clean-up is rarely required for these types of spills.

There is potential for spills to occur in the vicinity of the port; however, these are typically isolated near their source and escaping oil is blown towards the west due to the prevailing winds. Risks are small and can be mitigated through industry standard response and containment procedures. There is the potential to have port delays in the event of a spill; however, there are many port delays that occur on a regular basis and attempting to define a specific event and the associated damage is not useful when considered in the broader context of everyday operations.

Marine oil spills were found to be small enough in frequency, size and risk that mapping of oil spill risk was not undertaken for this project.

Application of the NCRIPP Risk Results

The results from the NCRIPP risk study provide valuable insight into the relative magnitudes of the risks, as well as the shape of the curves and the potential differences between less common (e.g. 100-year) and more common (e.g. 10 year) events. It also provides insight into the spatial distribution of the hazards, vulnerability and risk. These types of information will be beneficial to Barbados in establishing overall priorities in terms of which hazards warrant more planning attention, and in what regions. With some hazards having annual average damage values one or two orders of magnitude higher than other hazards, decisions on where to direct effort should be apparent.

The NCRIPP platform also provides the ability to carry out a series of analyses that could be applied to risk mitigation, emergency preparedness, or other applications. The NCRIPP platform will provide the user the ability to examine scenarios that may involve a single building, a selected region, or could be applied country-wide. Typical applications would involve making changes to the hazard exposure, or making changes to the susceptibility of assets. There are also possible uses for emergency preparedness. These types of applications could rely on the existing mapping, or could make use of the user-driven functions of the NCRIPP. Examples of these applications are provided below.

Hazard Mitigation

The NCRIPP system and maps, along with historical knowledge of hazard exposure, may lead to interests in reducing risk in some areas. Hazard reduction is one manner in which the risk can be reduced, and the NCRIPP system could be used to examine the impacts of various alternatives. Hazard exposure mitigation potential is outlined below for the different groups of hazards.

- Water Hazards: Risk values due to storm surge, rainfall flooding, and tsunamis are all computed in a similar manner, with damage largely dependent on depth of flooding. Changing the exposure could involve rerouting of flood water (regionally or locally), installing barriers of some type, reducing wave heights (and therefore overtopping), improving storm drainage, or various other alterations.

- Earth Hazards: These consist of landslide and seismic hazards, and there are limited manners in which these hazard exposures could be reduced. For seismic hazards, there is nothing that can be done to reduce exposure, other than to be selective in where development occurs (although this makes minimal difference). Similarly, for landslides, the best way to impact exposure is through site selection. Some schemes to stabilize soils may be proposed, and the effectiveness would need to be translated into a change in the slope risk rating (low, medium or high).
- Wind Hazards: These hazards are unlikely to be mitigated through changing exposure; the manner in which wind hazard are mitigated is through susceptibility (likely some structural alteration).
- To assess mitigation options, the NCRIPP system would be used to complete a "before and after" assessment of the mitigation. The system would first be queried using the region of interest for the existing hazard conditions and a summary of the risk results would be produced by the system. The alteration to the hazard level would then be applied, perhaps through a revised flood depth or a change in the wave impact zone. The NCRIPP system would then produce a revised risk summary. Comparisons of these scenarios would be undertaken outside of the system, perhaps in excel or some other system that would allow the user to present the results in the most effective manner.

Exposure Mitigation

Exposure mitigation might be better considered as part of site selection, perhaps for a new development in a region where hazards are present. In this case, we are assuming that the hazard is not being varied, but the position of the asset could be adjusted in some meaningful manner. This would be more likely to be applicable on a larger property, as spatial differences on a small property may not be possible to assess within the resolution of the analysis.

The NCRIPP system would be assessed with an existing, or perhaps multiple proposed scenarios and the risk would be computed for one or a suite of hazards. Structures would be assigned using a shapefile for each of the scenarios being tested, and the appropriate information would need to be supplied with each building (first floor elevation, wall type, roof type, etc.). The require parameters will be provided in the NCRIPP documentation.

The results from this type of assessment would be (among other data) the annual average damage, which is a good overall risk indicator that might be used in site assessment. Other factors would also need to be considered in a broader cost/benefit analysis to understand if one scenario was preferred over another.

Emergency Preparation

The NCRIPP system is not intended as a system that would be used for decision making during an emergency. However, the information provided by the system could be used for emergency preparedness including:

- In preparing for emergencies, there are items such as shelters and/or other supplies that should be allocated according to the expected need. Emergency response regions could be developed, perhaps centred close to public facilities or expected distribution centres. If polygons were developed to surround the relief centres, the risk could be summed in these regions and boundaries could be adjusted or stocked appropriately for the anticipated need.

- Planning routes for evacuation or emergency response: The NCRIPP will provide information on what regions may require evacuation (or may be impacted). It will also provide general guidance on what roads may be exposed so that plans can be made to follow less impacted routes. The NCRIPP does not do this automatically, but provides the information for use by emergency response staff. However, the NCRIPP is not a real time system and other information would also be expected to be used, especially during an emergency as the hazard data is statistical in nature and only provides an estimate for specific events that were simulated, not a forecast of a potential future event.
- Identifying regions of compounded risk: During the vulnerability phase, a social vulnerability index was developed. This index provides an indication of what regions may require proportionally more assistance before and/or after a disaster. Regions with higher risk (financial) and higher vulnerability could be identified through the existing maps, or a platform user with GIS skills could examine the combined occurrence of higher risk and higher social vulnerability.

Use of the NCRIPP Risk Results for the ICZM Plan

The results of the NCRIPP constitute the basis for a longer strategy for DRM and CCA in Barbados aimed at reducing disaster risks, that is, the likelihood of loss of life, injury, or destruction and damage from a disaster in a period of time (UNISDR, 2015).

The objective of an ICZM Plan is complementary and embraced to the objective of a DRM plan, as the hazards, vulnerability and risks in the coastal area are closely related to the management of coastal resources. In this sense, this ICZM Plan mainstreams the results of the NCRIPP into the main guidance provided:

- Delimitation of the CZMA has been designed including hazards related to coastal processes:
    - Storm surge inundation area for a 100-years return period.
    - Tsunami inundation area for a 100-years return period.
- Definition of setbacks based on hazardous areas, including:
    - Delimitation of inundation setback based on inundation areas due to storm surge and tsunami with 100-years return period.
- Identification of priority Actions (Part C and D) to be performed by the CZMU and key actors as DEM and CDEMA for DRM and CCA.