Ministry of Environment, Energy and Climate Change

Seychelles Coastal Management Plan

2019–2024

GFDRR
Global Facility for Disaster Reduction and Recovery

Building Disaster Resilience in Sub-Saharan Africa

THE WORLD BANK
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Table of Contents

Boxes

Figures

Map

Photos

Tables

List of acronyms

BEWARE	Bayesian Estimator for Wave Attack in Reef Environments
CAMS	Climate Adaptation and Management Section
CBD	Convention on Biological Diversity
CCD	Climate Change Division
CMP	Coastal Management Plan
CCS	Seychelles National Climate Change Strategy
CZMU	Coastal Zone Management Units
DECC	Department of Energy and Climate Change
EBA	Ecosystem-based Adaptation
EIA	Environmental Impact Assessment
EMPS	Environmental Management Plan of Seychelles
GCCA	Global Climate Change Alliance
GDP	Gross Domestic Product
GIS	Geographic Information System
ICZM	Integrated Coastal Zone Management
IPCC	Intergovernmental Panel on Climate Change
JICA	Japanese International Cooperation Agency
LWMA	Landscape and Waste Management Authority
MEECC	Ministry of Environment, Energy and Climate Change
MHILT	Ministry of Habitat, Infrastructure and Land Transport
MM	mapping and monitoring program
NBSAP	National Biodiversity Strategy and Action Plan
NCIP	National Coastal Infrastructure Plan
NGO	nongovernmental organization
NOAA	U.S National Oceanic and Atmospheric Administration
RCP	Representative Concentration Pathways
SDS	Sustainable Development Strategy
SSLUDP	Seychelles Strategic Land Use and Development Plan
SIDS	Small Island Developing State
SSDS	Seychelles Sustainable Development Strategy
TNA	Technology Needs Assessment
UNDP	United Nations Development Programme

All dollar amounts are U.S. dollars unless otherwise indicated.

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Mahé coastline. Photo:miniloc.

Foreword

Over the past three centuries, there has been a significant change in the global climate. According to historical records, global average surface temperature has increased by 1 degree Celsius since the 1850s. More recently, we have experienced 16 of the 17 warmest years on record since 2001. Climate change is real as indicated by the Intergovernmental Panel on Climate Change (IPCC). Small Island Developing States (SIDS) such as Seychelles are likely to be impacted by factors such as coastal erosion, flooding, tidal variations and tropical cyclones that are exacerbated by climate change.

The impacts will be more pronounced along the coastal plateaus of Mahé, Praslin and La Digue, where 90 percent of the total population and critical infrastructure are located. Moreover, the growing population and economic development will simply add more pressure on land use and the natural resources along the coastal zones. We need to protect the natural assets for our coastal communities and for future economic prosperity.

The Government of Seychelles is therefore adopting an integrated approach to sustainable development by placing more emphasis on and investing in the various adaptation strategies to be able to cope with factors that are exacerbated by climate change. A group of experts from the Department of Energy and Climate Change (DECC), with the assistance of consultants from the World Bank felt the need to address the hazards affecting Seychelles' coastal zones by developing the country's first Coastal Management Plan (CMP).

The CMP was developed in consultation with all stakeholders to enhance understanding about the risks associated with climate change and development pressures around the coastal zones in Seychelles. The Plan takes into consideration existing studies that focus on coastal hazards relating to overtopping, sea level rise, and flooding along the shoreline in Seychelles. Presently, the Ministry of Environment, Energy and Climate Change (MEECC) intervenes with other partners during extreme events and executes various coastal management efforts to combat such hazards. However, the interventions are normally short-term strategies of the hard-engineering character. The Plan will provide the missing guidance on the right long-term nature-based interventions that can be combined with the existing strategies to effectively deal with the hazards.

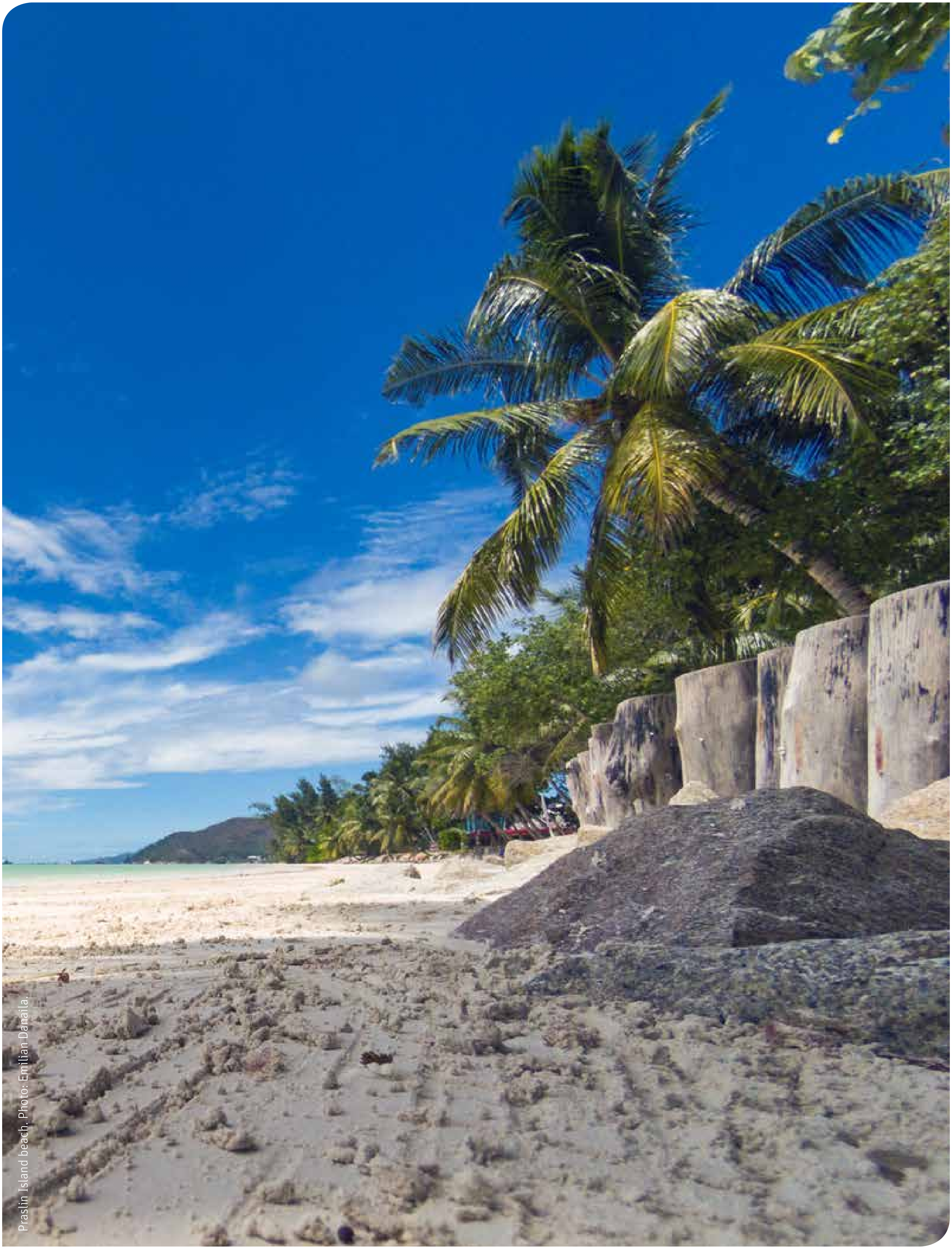
Such measures will help to build coastal resilience and proper management of the coastal zones. They will also help to reduce future coastal risks for coastal communities, support healthy coastal ecosystems, and encourage sustainable coastal economic development by strengthening the capacities to deal with these challenges.

The CMP is therefore an important milestone for Seychelles. It will provide not only a framework for all of the coastal management initiatives but also an opportunity for the people to become more aware of the seriousness of Climate change and the developments affecting our islands.

I am thankful to the staff of the MEECC who dedicated their efforts to facilitating the whole development process of the CMP. I am also thankful to the World Bank consultants who devoted their time and effort to making the CMP a reality for the people of Seychelles. The CMP highlights the importance of collaboration and partnerships, which are essential for Seychelles to move in the right direction toward becoming climate resilient. The clock is ticking and the race has begun. As one of the world's smallest nations, we are walking the talk and tackling climate change and all of its issues head on.

It is therefore my honor to commend the first CMP (2019-2024) to all stakeholders for its implementation.

Mr. Wallace Cosgrow
Minister of Environment, Energy and Climate Change



Praslin Island beach. Photo: Emilian Danaila.

1. Introduction

1.1 Why a coastal management plan?

As a small island developing state (SIDS), Seychelles relies heavily on its coastal zone for economic development, critical infrastructure, and housing. Given Seychelles' mountainous topography, about 90 percent of the population and most critical infrastructure is concentrated in the narrow coastal plateau surrounding the main populated islands of Mahé, Praslin, and La Digue. The mean elevation of the coastal plateau around the granitic islands is 2–10 metres above sea level (Alvarez Cruz et al. 2011). This coastal stretch includes main roads, electricity and water supply infrastructure, ports, fisheries infrastructure, and buildings, including hotels. Most of the critical infrastructure, such as roads, power stations, and food storage facilities are situated in the range of 2–4 metres above sea level and thus most vulnerable to coastal flooding, coastal erosion, and the effects of sea level rise (Government of Seychelles 2017). The country depends on its coastal zones for most of its economic activity such as tourism and fishing. Tourism is growing rapidly; the number of tourist arrivals per year increased from 170,000 in 2007 to an expected 350,000 in 2017 (Strategic Land Use and Development Plan 2015). The number of tourists is projected to grow to 400,000 in 2040.

The coastal zones have been affected by several disasters in recent years, including coastal erosion of Anse Kerlan on Praslin since the 1980s, flooding disasters caused by the Indian Ocean tsunami in 2004, flood inundation in Victoria in 2004, and coastal flooding in the north of Mahé in 2007 (JICA 2014). The government of Seychelles has prioritized the management of the effects of coastal erosion and flooding, for example, through the 10-year Environmental Management Plan of Seychelles (EMPS) in promulgated in 2000.

The coastal zones also hold the vast majority of Seychelles' natural capital, including coral reefs and sandy beaches with occasional wetlands preceding these ecosystems. Its iconic beaches are of pivotal importance for tourism, which accounts for 58 percent of Seychelles' gross domestic product (GDP) (World Travel and Tourism Council 2017). However, these ecosystems also provide significant coastal protection for Seychelles' coastlines; mangroves, coral reefs, and wetlands play a crucial role in stabilising the coast—limiting its exposure to erosion, storm surges, and tsunamis.

At the same time, land suitable for development is a scarce resource in Seychelles. Since the 1980s, large areas of land have been reclaimed along the east coast of Mahé to facilitate urban and industrial expansion and the development of the international airport. The reclaimed land is protected by revetments with a height of 2–4 metres above mean sea level.

Continuous development in the coastal zone as well as the effects of climate change will further increase coastal flood and erosion risks in the decades ahead. The two major effects of climate change on coastal hazards and vulnerability in Seychelles are long-term sea level rise and tropical and extratropical storm changes.

Furthermore, the population of Seychelles is projected to grow to over 130,000 by 2040 (Strategic Land Use and Development Plan 2015) and lead to larger concentrations of people and assets in the coastal zone. Climate change adds additional threats through rising sea levels, changing precipitation patterns, and warming sea surface temperatures. In particular, water warming has had a devastating impact on the state of coral reefs in Seychelles, causing mass coral bleaching events in 1998 and 2016 that eradicated about 90 percent of the live coral cover around the three main islands. In addition, projected rises in sea levels will increase coastal flooding and erosion in the future (Alvarez Cruz et al. 2011).

A resilient Seychelles needs a comprehensive Coastal Management Plan (CMP) that reflects the risks associated with coastal flooding and erosion today and anticipates future effects. Several studies conducted in recent years have described these risks and coastal impacts. However, this information is scattered and has not yet been addressed by a single policy document. **The CMP consolidates this information and provides a framework for its use for coastal management, adaptation, and risk management.** Understanding coastal risks will support the design of effective coastal management policies and optimize the allocation of available resources in an implementation agenda.

1.2 Objectives and scope of the plan

1.2.1 Objectives

This CMP aims to help maintain and protect the coastal zone to reduce coastal risk, support healthy ecosystems, and enable sustainable coastal economic development. It provides direction and guidance for use of Seychelles' coastal resources to achieve better, sustainable, and proactive coastal management. The Climate Adaptation and Management Section (CAMS), which is responsible for implementing coastal management policies, is the main implementing section for this CMP. However, government bodies and agencies, such as the Town and Country Planning Authority, the Land Transport Agency, Seychelles National Parks Authority, and several other organizations have a stake in coastal management. This plan can help to inform their respective policies and help to identify synergies with coastal management actions implemented by the CAMS and other government bodies.

More specifically, **the objectives of the CMP are to:**

- Reduce the effects of coastal hazards on humans and coastal properties
- Harness the function of coastal ecosystems, such as beaches and dunes, wetlands, coral reefs, and mangroves, to reduce coastal risks
- Improve the general understanding of key physical, ecological, economic, and climate change–induced processes that affect coastal risk and resilience in Seychelles
- Prevent the increase of coastal risk by facilitating coastal development planning and climate change adaptation
- Strengthen the capacity within the government to effectively develop and implement coastal management policies
- Promote awareness and understanding of the value of coastal ecosystems for coastal resilience
- The CMP consolidates available studies, information, and guidance to manage Seychelles´ coastal zones to achieve these six core objectives.

1.2.2 Content and Scope

Chapter 2 describes current coastal management practices, institutional context, and related policies. It also describes the development of this CMP. Chapter 3 consolidates the available information on coastal flooding, coastal erosion, and, in relation to those processes, the effects of climate change in Seychelles. Chapter 4 presents actions for coastal management, organized into the following themes:

- Monitoring and research
- Coastal infrastructure
- Risk-based land planning
- Capacity building
- Awareness raising

For each theme, a set of regulatory and programmatic actions is defined, ranging from incremental, low-tech, and economic to more systemic, high-tech, and resource intensive. The implementation agenda, chapter 5, presents a detailed plan that includes consideration of the timeline, financial implications, staffing requirements, and institutional capacity.

This plan focuses on management of the coastal zone, defined as the land area below the 10-metre flood line and the outer edge of near-shore reef systems, and approximately 1 kilometre from the shore. There are no comprehensive datasets for either bathymetry or benthic habitat; therefore, the reef edge is approximated by a 1-kilometre buffer around the coastline.

This CMP formulates priorities and actions to reduce coastal flood risk and coastal erosion. Coastal zone management priorities and actions are provided at two levels:

- On a general level, chapter 5 provides guidance for designing and implementing coastal infrastructure projects.
- The implementation plan for prioritized actions identifies investments only in coastal priority areas. These priority areas are referred to as Coastal Zone Management Units (CZMUs).

All CZMUs are located in the three main islands of Seychelles: Mahé, Praslin, and La Digue. These units should be managed integrally, and each would require specific coastal management to address coastal impacts. This CMP does not address coastal management in the Victoria urban areas because the Victoria Masterplan 2040 constitutes an integrated development plan for Victoria.

This plan acknowledges the importance of natural systems, such as coastal vegetation and dunes, coral reefs, mangroves, and wetlands for the reduction of coastal risks. Hence, effective coastal management extends beyond the management of the shoreline and coastal infrastructure such as groynes. Therefore, the CMP also addresses the management of these coastal ecosystems. The CMP intersects with aspects of watershed management, conservation, land use planning, and marine spatial planning.

The plan has been developed by the Division of Energy and Climate Change (DECC) of the Ministry of Environment, Energy and Climate Change (MEECC). The policy actions proposed in the CMP for coastal management primarily consist of policies in the domain of DECC, but also relate to other policies implemented by MEECC, such as Seychelles Sustainable Development Strategy (SSDS), the National Biodiversity Strategy and Action Plan (NBSAP), Protected Area management, and the Marine Spatial Planning Initiative. Also, through this plan, DECC will engage with the Ministry of Habitat, Infrastructure and Land Transport (MHILT) to integrate coastal management policy objectives in land use planning and infrastructure development.


La Digue. Photo: LRPhotographies

2. Why a coastal management plan?

2.1 Outline of the Coastal Management Plan

This Coastal Management Plan (CMP) is structured as follows: following the introduction, chapter 2 provides an overview of current coastal management policies and practices in Seychelles and describes the genesis of this document; chapter 3 describes coastal risk in Seychelles and provides an overview of available knowledge on coastal flooding and erosion and its (potential) consequences; chapter 4 presents the priorities for coastal management and identifies concrete actions proposed to address them; and chapter 5 concludes with an implementation agenda for the prioritized coastal management actions for the period 2019–24.

2.2 Current legislation, policies and strategic documents that affect coastal management

Seychelles has worked on Integrated Zone Management (ICZM) planning since the early 1990s (Government of Seychelles 2000), but this has proved difficult to put into practice due to the diversity of stakeholders in the coastal zone and to sectoral fragmentation. In addition, a regional process for ICZM development under the Nairobi Convention is ongoing, for which the Environment Protection Act was revised in 2016. Table 2.1 summarizes a number of policies, laws, regulations, and planning guidelines already in place that affect coastal development, coastal management activities, support the protection of coastal ecosystems, and the adoption of measures to protect the coast from the impact of coastal hazards and climate change.

Table 2.1: Overview of Legislation, Policies, and Strategic Documents that Affect Coastal Management Practices in Seychelles.

Name	Year adopted	Main contents	Lead agency	Status
Environment Protection Act	1992, rev. 2016	The main instrument for environmental protection in Seychelles; it addresses protection of the coastal zone, with only passing reference to its vulnerability to the impact of climate change	MEECC	Recently updated and in force; does not specifically address climate change
Town and Country Planning Act	1972, updated June 2012	Under revision the 25-m setback from the high tide water mark currently being applied by the MEECC will be incorporated into the new version	Seychelles Planning Authority; MHILT	Does not specifically address the coast, wetlands, or climate change
State Land and River Reserves Act	1903	Provides for a setback of 10 m on either side of a river but does not specifically mention the coastal zone or wetlands	MEECC	Does not specifically address the coast, wetlands, or climate change
Beach Control Act	1971	Helps preserve the natural amenities of the seashore and prevent any danger, obstruction, or annoyance to the users of the seashore or the sea		
Removal of Sand and Gravel Act	1991	Provides abstraction licenses for permission to abstract sand and gravel		
Land Reclamation Act		Gives permission and provides the schedule for appropriate land reclamation		
Blue Economy Roadmap	2017	An integrated approach to ocean-based sustainable development that brings together economy, environment, and society, consistent with the Sustainable Development Agenda 2030, Aichi Target 11 of the CBD, and the Paris Agreement on Climate Change	Blue Economy Department, Office of the Vice President	
Seychelles Climate Change Strategy	2009	Provides a coherent and consolidated approach to climate change–related policies, programs, and projects		
Sustainable Development Strategy 2012–20	2011	An approved national instrument that incorporates national priorities for sustainable development and lays out a roadmap for the implementation of those priorities		
Strategic Land Use and Development Plan	2015	Provides a framework for guiding future development through 2040	MHILT	
Wetland Policy	2005, rev. 2017	Protect and conserve wetlands in order to benefit from their functions and values it is under review and has yet to be specifically integrated into any laws or regulations	MEECC	Under review

Note : CBD = Convention on Biological Diversity; MEECC = Ministry of Environment, Energy and Climate Change; MHILT = Ministry of Habitat, Infrastructure and Land Transport.

2.3 Current coastal management practices

2.3.1 Institutional context and capacity

In Seychelles, coastal management actions are designed and executed by the Coastal Unit within the Ministry of Environment, Energy and Climate Change (MEECC). The Climate Adaptation and Management Section (CAMS), which hosts the Coastal Unit, is the entity responsible for coastal management and falls within the Climate Change Division (CCD) of the Department of Energy and Climate Change (DECC).

The budget available to execute coastal management actions has fluctuated over the past years but is equivalent to SR 2 million in 2018.

Most of the coastal problems identified by the government—such as erosion, overtopping, and flooding—that lead to a project intervention by the Coastal Unit are identified by the district administration offices and observations by district staff. The assessment and evaluation, design, and quantification of the intervention are executed by technicians of the CAMS. Projects and interventions are prioritized based on urgency, risk level, and availability of funds. Project implementation is mostly executed by external contractors under the close supervision of CAMS staff. Table 2.2 provides an overview of coastal management projects that have been implemented from 2015 through 2018.

Table 2.2 Coastal Management Projects Implemented 2015–18.

Year	Project
2015	
La Passe (La Digue) rock armouring and beach nourishment	Coastal protection and erosion prevention of the coast of La Digue by rock armouring the area and beach nourishment by adding sand in front of the rock armouring to help speed up the process of re-creating a small beach.
Anse à la Mouche—phase 3: coastal rehabilitation works	Topographical Survey undertaken to determine accurate levels to determine the height of the structure to be built.
2016	
Anse à la Mouche—phase 1: coastal rehabilitation and remedial works	Phase 1 consisted of timber piling along the coast of Anse à la Mouche in 2011. The timber was not treated and began to rot. CAMS implemented rock packing to help strengthen the damaged timber, as well as rock binding and repair of the pathway in the park.
La Passe—rock armouring and beach nourishment	In the second round of beach nourishment, sand was added at the footing of the rock armouring to create a small beach, boosting the quantity of sand currently in the area.
Anse Gaulette—erosion and damage to the road infrastructure	Emergency rock dumping was done along the side of the road to protect the coast and road infrastructure from further erosion.
2017	
Anse à la Mouche—phase 3: coastal rehabilitation works	100 m of rock armouring along the coast to protect against further erosion
Anse à la Mouche—phase 3: coastal rehabilitation works	Installation of benches donated by LWMA to beautify the small area that was backfilled behind the rock armouring
Anse à la Mouche—phase 4: coastal rehabilitation works	Continuation of phase 3 of rock armouring, construction of a groyne, and restoration of outlet
Anse Gaulette—topographical survey: coastal protection and rehabilitation works	Obtain a detailed topographical map of the area to determine what kind of structures to implement and the height of the proposed structures to mitigate erosion
North East Point—High tidal wave surges and wave overtopping	Rock dumping along the coast of North East Point to prevent wave overtopping from damaging the road infrastructure

Table 2.2 Coastal Management Projects Implemented 2015–18 (cont.).

2018	
North East Point dune land protection	Placement of rock boulders to restrict vehicular access to the dune land to prevent future erosion
Au Cap dune land protection	Placement of concrete bollards to restrict vehicular access to the dune land to prevent future erosion
Anse Boileau—coastal rehabilitation works	Restoration of existing damaged sea wall, construction of new section of sea wall and reparation of damaged outlet
Beau-Vallon—coastal rehabilitation works	Continuation of existing sea wall at Beau-Vallon to help protect the dune land from erosion and to prevent the trees from being uprooted

Note: LWMA = Landscape and Waste Management Authority.

2.3.3 Available studies and information to develop the Coastal Management Plan

A number of studies and reports have focused on coastal risk and management in Seychelles. These studies vary in regional scope, timelines, and methodological approach. To inform the development of this CMP, an overview and summary of the main studies, information included, and their highlights are outlined in this section. This information has been used to provide an overview on coastal hazards in the following section and has been used to draft policy actions adopted in this plan.

A preliminary hazards analysis of sea level rise and coastal flooding in Seychelles islands was carried out in 2011 (Alvarez Cruz et al. 2011) This study is known as the Cuban study. The study included information on general characteristics of the islands; coastal hazard information, including extreme coastal flooding estimates and flooding mapping with sea level rise; and a preliminary identification of priority areas for coastal management. The study also identified some causes of the impacts and provided overall recommendations.

Another study for coastal erosion and flood control management in Seychelles (JICA 2014) conducted four main activities: a basic study of data on coastal flooding and erosion, through local surveys and analyses of water levels, rainfall, waves, and historical erosion, to identify priority areas and propose recommendations; the formulation of a coastal conservation plan and a flood management plan for four priority areas; three pilot construction projects in 2013, including monitoring; and technical transfer of the coastal conservation and flood management plans.

For the North East Point in Mahé, the Coastal Processes Study (Borrero et al. 2016) analysed historical coastal erosion and the coastal processes associated with these shoreline changes. Through numerical simulation of waves and currents, the study described and explained the seasonal fluctuations of beach width. The study also provided historical data and field measurements on wind and wave climate and sea levels. Overall, the North East Point study represents a comprehensive local study that can be used to inform local coastal management actions, but can also be taken as a good example for other areas.

2.4 From current practices to a coastal management plan

This document has been prepared by CAMS with support from other sections in the MEECC and a technical team from the World Bank. For this plan, existing studies on coastal adaptation and hazards such as erosion and flooding have been reviewed for the purpose of summarising the available knowledge in an accessible way for policy officers. The coastal management priorities and actions as formulated in this plan are the result of a stakeholder engagement process involving government sections other than DECC and CAMS, district administrators, civil society, and the private sector. The process consisted of the following steps:

- Definition of the scope of the CMP (March–April 2018)
- Description and classification of the coastline; review and consolidate findings of existing studies and policy documents (March –September 2018)
- Bilateral stakeholder engagement (July 2018)
- Draft policy actions (July–December 2018)
- Draft coastal management plan document (July 2018 – January 2019)
- Stakeholder workshops (November 2018)
- Develop final report and validation workshop (February 2019)

3. Coastal risk in Seychelles

This chapter describes the available knowledge of coastal flooding and erosion in Seychelles—underlying processes, coastal risks, and the role of nature and natural capital in coastal areas.

This chapter consolidates findings from several studies on coastal risk, management, and coastal adaptation strategies (see outline in appendix C). The study conducted by the Japanese International Cooperation Agency (JICA) (2014) on erosion and flood management is one of the most important sources of information, in combination with the study conducted by the government of Seychelles into the coastal flooding and sea level rise (Alvarez Cruz et al. 2011). With regard to natural capital, a number of studies are being conducted for the marine spatial planning initiative and there are a number of older economic valuation studies of Seychelles ecosystem services (Cesar et al. 2004; Mathieu et al. 2003). In addition, a detailed local study has been conducted by the United Nations Development Programme (UNDP) to model coastal processes and explore the potential of nature-based solutions (Borrero et al. 2016).

3.1 Seychelles coastal landscape

The land areas of the three main islands that are the focus of this CMP are Mahé (155 km^2), Praslin (38 km^2), and La Digue (10 km^2). The islands consist of steep granite mountains surrounded by narrow plains and coral reefs. The coasts are classified into three types: rocky granite cliffs, flat sandy beaches, and reclaimed artificial coasts. The plains are characterized by coral reefs, sandy beaches with occasional wetlands behind, and stretches of mangroves. These plains are relatively small, covering 5 percent of the total area of Mahé and Praslin and 16 percent of La Digue. The reclaimed land is protected by revetments with a height of 2 to 4 metres above mean sea level.

The majority of the islands are surrounded by coral reefs, covering an area of approximately of 1.690 km^2. Many of these corals were affected by the mass coral bleaching events of 1998 and 2016 caused by abnormally warm waters—live coral cover was reduced by about 90 percent.

More than 90 percent of the population and all economic activities are located on the narrow coastal plateau of Mahé Island. Seychelles is economically, culturally, and environmentally vulnerable to the potential effects of climate change and associated extreme events. Vulnerability characteristics, such as concentration of development on narrow coastal zones, and nonresilient populations and ecosystems, make Seychelles extremely sensitive to climate change and its associated effects. The economic importance of the tourism sector also makes the islands dependent on their coastal landscape and natural capital. The impact of climate change on coastal livelihoods from sea level rise, wave action, storm and tidal surges, extreme sea-surface temperatures, and coastal flooding are a direct threat to livelihoods, infrastructure, and the economy in Seychelles.

In Seychelles, the sand on the beaches comes from the breakdown of corals and other carbonate-depositing marine organisms; there are very few beaches where terrigenous inputs are dominant. The best-developed beaches are found where the reefs are narrow, while behind broader reef flats the beaches are narrower and the sand is coarse-grained. Offshore waves are dominated by the northwestern monsoon and southeastern trade winds.

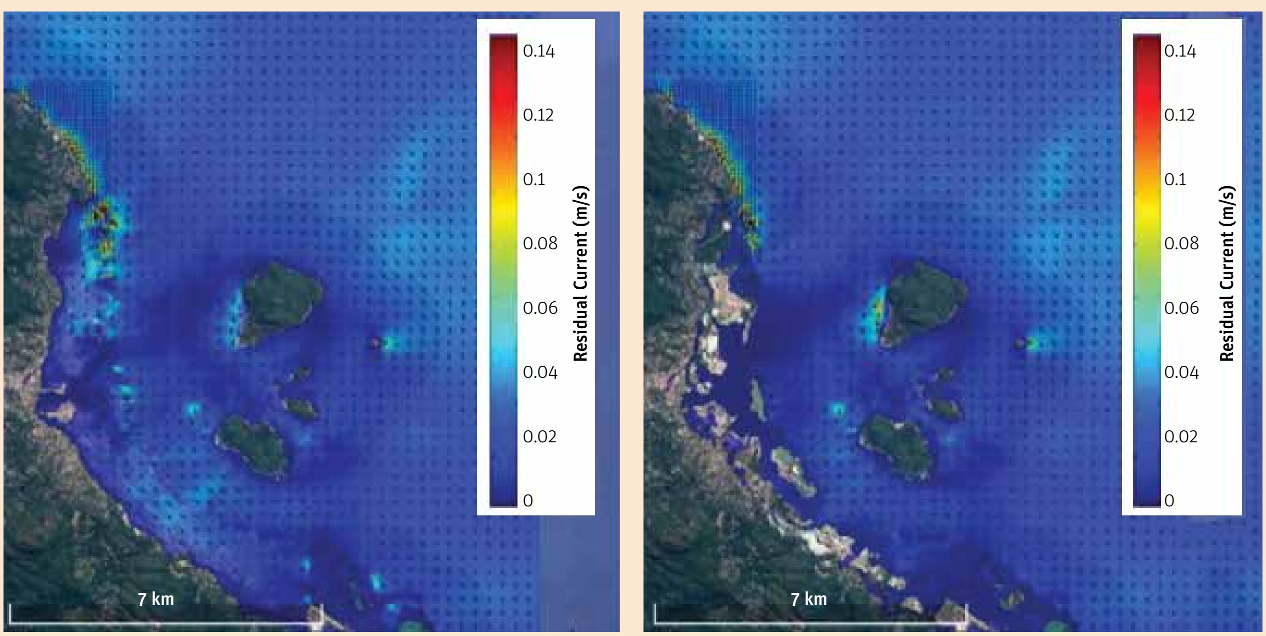
The country has also seen substantial land reclamation. Land reclamation, or land fill, is the process of creating new land from the ocean bed. In Mahé, in particular, land fill has taken place on the east coast between Northern Victoria and Pointe La Rue. The Land Reclamation Act provides a legislative framework for reclamation projects. In addition, a land reclamation project requires an environmental impact assessment, for which guidelines are determined under the Environment Protection Act.

Besides the creation of new land for development, land reclamation destroys the original seabed and can create effects in adjacent areas, as reported in Mahé. Land reclaimed in Victoria on coral reef beds led to a loss of sediment at North East Point on the northern coast and modified the original circulation of water and sediment along the coast (box 3.1).

Box 3.1: Coral Reefs, Land Reclamation, and Coastal Processes in North East Point, Mahé.

The hydrodynamic regime was significantly altered at North East Point and the Eastern Mahé down to the airport at Pointe La Rue. Prior to the land reclamation, wave-driven currents during the southeastern trade wind season pushed sediment northward along the coast. However, after the reclamation, the current patterns changed and this link was interrupted. Additionally, where parts of the reef flats have been removed, waves tend to penetrate further toward the coastline resulting in an overall increase in wave energy between the airport and the study area.

Photo B1.1: Comparison of Currents Fields Before (left) and After (right) Land Reclamation in Victoria.



3.2 Coastal hazards in Seychelles

3.2.1 Overview of coastal processes

Coastal flooding and erosion result from complex processes and interactions between waves, tides, and surges with the local bathymetry and the coastal landforms and ecosystems. Coastal flooding is caused by the combined actions of waves, astronomical tides, storm surges generated by cyclones, and other factors such as sea level rise. Shoreline changes occur from both natural and human-induced causes and over a wide range of temporal and spatial scales. Coastal erosion can have diverse causes, such as episodic short-term erosion from extreme storms; long-term erosion associated with changes in wave intensity or direction; or coastal structures in the coastal zone that influence and affect the transport of sediments.

Many coastlines change between seasons and years depending on the different coastal characteristics and types of beaches. Sediment transport also occurs along shore and cross-shore, and the relative importance of each depends on the local climate characteristics and the coastal configuration. For example, open coast sections, like the North East Point, are dominated by longshore sediment transport and respond to seasonal changes in the wind and wave climate. In contrast, other regions of Seychelles present pocket beaches, like Baie Lazare, where sediment transport is constrained by natural headlands, and the resulting coastal landforms are different.

This section provides an overview of available information on coastal hazards for Seychelles. The subsections on coastal flooding and erosion rely on global, regional, and local data from available studies for the three main islands and other specific coastal studies (see chapter 2). In addition, climate change will have an effect on coastal hazards through increased sea levels, changing sea-surface temperatures, and potential changes in storm patterns. The effects of climate change on coastal flooding and erosion are addressed in section 3.3.

Structural man-made interventions along Seychelles coastlines, such as land reclamations, groynes, and revetments, change wave patterns, near-shore currents, and bathymetry and, thus, can also potentially affect the longshore sediment transport (evidence of this process having been reported in North East Point (Borrero et al. 2016) and on the priority sites studied by JICA (2014); see photo 3.1, and coastal flooding. Similarly changes in ecosystems, such as bathymetric changes associated with coral degradation, can also affect coastal processes and result in flooding and erosion. A loss of the buffer function of mangroves and coastal vegetation can also increase flooding risk. The role of this natural protection is briefly discussed in subsection 3.4.

Photo 3.1: Examples of Extreme Erosion in Praslin.

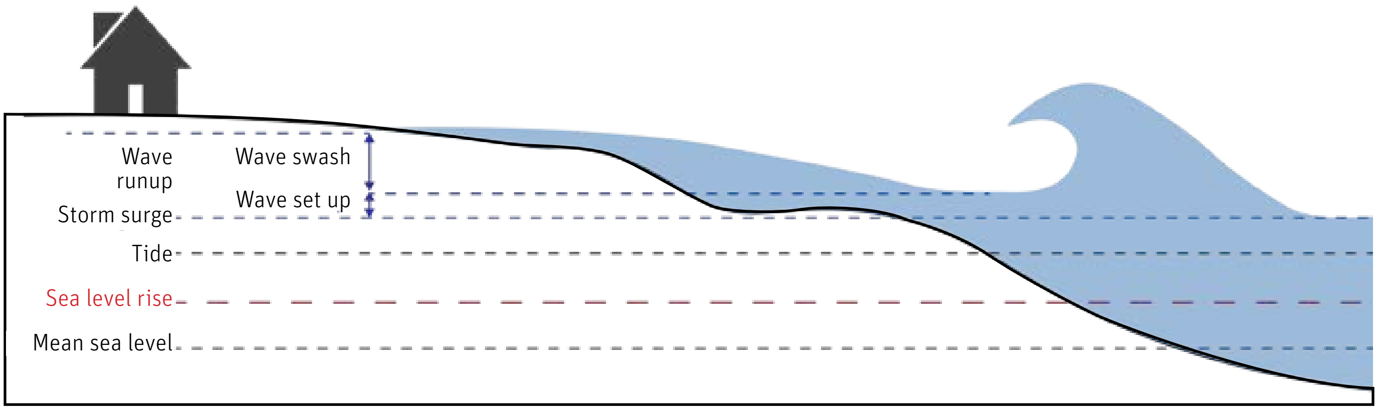
Source: JICA 2014.

3.2.2 Coastal flooding

Coastal flooding often occurs during extreme water-level events that result from the simultaneous and combined contributions of different factors, such as high astronomical tides, storm surge, large waves, and mean sea level anomalies (Losada et al. 2013).[1] Astronomical tides are sea level variations produced by the gravitational interactions of the

[1] Other factors that affect flooding are associated with nonmeteorological events such as tsunamis. For example, the tsunami generated by the Indian Ocean Earthquake in 2004 reached Mahé Island at 4.4 metres above mean sea level at its peak.

Figure 3.1: The Water Level Components that Contribute to Coastal Flooding.



earth, moon, and sun. Storm surges result from the effect of atmospheric low pressure and wind stress over the sea surface, which are typically associated with tropical cyclones. Wave-driven flooding results from the propagation effects of offshore waves and depends on the offshore conditions, but also on local coastal features, such as local bathymetry. Wave runup is the maximum vertical height above the still water elevation (tides and surges) to which the water rises on the beach or structure (see figure 3.1) and depends on the local water level, the incident wave conditions, and the nature of the beach or structures (such as reefs, beach, and coastal profile). The contribution of these factors, usually described as total water level, can be used to infer flooding inland. The following sections describe the different contributors to coastal flooding in Seychelles.

3.2.3 Tropical cyclones

Tropical cyclones, generated from October to May and occurring about 500 to 600 kilometres from Seychelles, are a rare phenomenon in Seychelles. Records from 1972 to 2001 show that the islands are outside the major storm routes (JICA 2014). However, the 1953 and 2006 cyclones caused great damage. In 2016, tropical cyclone Fantala damaged infrastructure in the Farquhar Atoll, the archipelago's outer island, with winds of 330 to 345 kilometres per hour. It was reported that all the infrastructure on the islands suffered substantial damage except for cyclone-proof facilities (Government of Seychelles 2017).

Although the probability of potentially damaging wind speeds in Mahe, Praslin, and La Digue is lower than in northern areas closer to the tropical cyclone belt (about a 20 percent chance of landfall in the next 10 years, according to estimates from Thinkhazard[2]), the impact of cyclones should be considered in all phases of coastal projects, in particular during design and construction. Cyclone damage occurs not only through wind but also through cyclone-induced heavy rainfall and subsequent flooding, as well as through coastal flooding. Therefore, project planning decisions, project design, and construction methods should consider the impact of tropical cyclones.

In the absence of more concrete analyses, a worst-case scenario can be assumed when a tropical cyclone or depression passes close to Seychelles and causes extremely high tides and flooding simultaneously. Several tropical cyclones whose eyes had passed close to Victoria have had significant effects. For example, the devastation of tropical cyclonic Bondo (2004) produced coastal flooding and heavy rains in Mahé. Modeling for the region of tropical cyclone Bondo showed a maximum storm surge of 0.84 metres (Alvarez Cruz et al. 2011), which adds to the regular variations in sea level from tides and can occur atop wave-driven flooding. In the worst-case scenario, buildings or roads below 2.5 metres above the present mean sea level could be inundated.

3.2.4 Tidal variations

The tidal range in Mahé has a mean high-water spring of 1.63 metres and mean low-water spring of 1.11 metres and 0.45 metres at Pointe La Rue (JICA 2014). The astronomical

[2] Global Facility for Disaster Reduction and Recovery. http://thinkhazard.org/en/report/220-seychelles/CY.

tidal fluctuations at the Pointe La Rue tide gauge (located near Victoria) present a maximum range of 2.06 metres over an approximately 10-year record of measured data (with a maximum of +1.19 metres and minimum of -0.875 relative to the mean over the full data range). The asymmetry seen in the maximum and minimum recorded tidal levels is due to the trend of rising sea levels that is seen on the tide gauge (approximately 0.65 centimetres per year since 2005) (Borrero et al. 2016). Based on the observed tidal range, the tidal conditions for 10-, 25-, and 100-year return times were estimated by JICA as a design condition for drainage measures (JICA 2014 and table 3.1).

Table 3.1: Return Period of High Tide Levels in Meters above Mean Sea Level.

Return period (years)	High tide (metres above mean sea level)
1	1.19
10	1.33
25	1.44
100	1.61

Source: Based on data from JICA 2014.

3.2.5 Offshore wave conditions and extreme sea levels

In Seychelles, the offshore wind and wave climate is dominated by the northwest monsoon season (from November to April) and the southeast monsoon or trade winds season (from May to October). The largest and most energetic waves come from the southeast during the southeast monsoon season, characterized by stronger winds and higher waves (table 3.2). The rest of the year is dominated by the northwest monsoon season, when the southeast trade winds are generally lighter, and the energetic southern swells are replaced by periods of wind and swell from the northwest.

There are stark differences in intensity and direction of waves between the seasons. Spatial and temporal variability of waves is a critical factor for coastal management in Seychelles because it drives the coastal processes that produce flooding and erosion. However, the local wave conditions on the shore depend on the coastal orientation and bathymetric features. The coastal study carried out for the Northeast Point (Borrero et al. 2016) sourced hindcasted wind and wave data from global datasets of the European Centre for Medium-Range Weather Forecasts and the U.S. National Oceanic and Atmospheric Administration (NOAA). Based on this information, offshore significant wave heights were estimated for 1- to 200-year return periods[3] (table 3.2). However, wave propagation models for the North East Point show higher waves and marked differences in flooding areas between the northwest and southeast monsoon seasons, indicating that local coastal flooding should account for the local propagation effects. This is particularly relevant in Seychelles, which has strong spatial and temporal variability in offshore conditions; different coastal alignments and orientations; complex bathymetries with shallow coral reefs; and different coastal forms that vary bays with open coasts, and beach, dunes, and coastal vegetation.

Table 3.2: Return Period for Offshore Significant Wave Height for the North East Point.

Return period (years)	Offshore wave heights, southeast direction (metres)	Offshore wave heights, northwest direction (metres)
1	2.81	1.60
5	3.18	1.75
10	3.30	1.97
30	3.45	2.34
50	3.50	2.64
100	3.57	3.02
200	3.62	3.49

Note: Results are shown for southeast directional waves defined by incoming directions between 120 and 180 nautical degrees and northwest directional waves defined between by incoming directions between 280 and 340 nautical degrees. Offshore wave heights are derived from the analysis presented in Borrero et al. 2016.

An analysis of extreme coastal flooding levels conducted by JICA (2014) provided an estimate of total water levels (or flood heights) for the main three islands. They are outlined in table 3.3 for three different return periods. The same study identifies high-risk areas in the three main islands by combining flood heights with information on local topography. These areas are summarized in box 3.2.

[3] A return period, also known as a recurrence interval, is an estimate of the likelihood of an event. It represents the inverse of the probability that the event will be exceeded in any one year. For example, a 10-year flood has a 1/10 = 0.1, or 10 percent, chance of occcuring in any given year. Return periods are usually used for risk analysis and coastal infrastructure to design structures to withstand an event with a certain return period.

Table 3.3: Summary of Coastal Flooding Flood Heights by Return Period for the Three Main Islands.

Return Period	Mahé	Praslin	La Digue
25	3.47-4.83	2.82-4.99	2.80-4.57
50	3.57-4.96	2.89-5.13	2.87-4.68
100	3.66-5.07	2.96-5.27	2.93-4.79

Source: JICA 2014.
Note: Range of values gives mean to maximum values of flood height.

Box 3.2: Summary of Coastal Locations at Risk from Flooding.

Mahé:

- The majority of the coastal sectors in Mahé are susceptible to extreme coastal flooding
- The most highly exposed coastal areas are English River, St Louis, Bel Air, Cascade, and Pointe La Rue
- Regions between Providence and the airport are also affected: Boileau and the inland coast beaches Beau Vallon, Port Launay Beach, and Grand Anse
- Au Cap, Anse Royale, Takamaka, and Anse can also experience moderate flooding
- The North East Point experiences more frequent floods

Praslin:

- Praslin is very sensitive to coastal flooding throughout all its extension
- The south coast, mainly Grand Anse and Anse Kerlan, is more susceptible to greater flooding
- On the north coast, Cote d'Or is one of the sections most exposed to flooding
- Anse Possession, Anse Boudin, and Anse Lazio present lesser risks of flooding

La Digue:

- The west coast is very low lying and prone to flooding.

Source: Alvarez Cruz et al. 2011.

3.2.6 Coastal flooding: historical records

There is currently no comprehensive database of historic flooding incidents. As noted in section 2.3, coastal flooding events are often identified by district authorities and CAMS staff. In addition, the preliminary assessment of the study of the impact of sea level rise (Alvarez Cruz et al. 2011) provides an expert-based description of flooding events occurring in the years leading up to 2011, when the study was conducted. The study states that:

- Coastal flooding is more frequent between Anse Grave and Anse Source d'Argent on the island of La Digue
- On Praslin, coastal flooding occurs almost along the entire south coast of Praslin at Anse Kerlan and Anse Consolation
- In 2004, the tsunami caused intense coastal flooding along the north coast of Praslin, at Cote d'Or, Anse Volbert, Anse Petit Coeur, and Anse Possession
- In Mahé, coastal flooding occurs most frequently in the sector between Anse Aux-Pins and Anse Marie-Louise on the east coast and at North East Point
- At Pointe La Rue, coastal flooding coincides with high tides two or three times per year. On the west coast, the heaviest floods occur in Anse à la Mouche and Anse Boileau
- Floods occur less frequently on the west coast than on the east coast. Coastal flooding has reached a maximum of 50 metres inland, with considerable damage to roads and buildings, and erosion on the beaches

3.2.7 Coastal erosion

Beaches and dunes change their shape in response to winds, wave and current forces, and sand availability. To improve understanding of beach dynamics, scientists and engineers track these changes by measuring the profile, or cross-section, of the beach. Coastal erosion causes vary from man-made interventions; natural climate variations (wave energy that increases and changes direction); bathymetry variations; and coral complexity loss (Sheppard et al. 2005; Reguero et al. 2018).

Observations show that coastal erosion in naturally stable areas has been linked to increases in sea level combined with coral bleaching and storm surges (Sheppard et al. 2005). Coastal erosion in Seychelles has also been caused by human activities together with natural drivers. Human causes include the construction of coastal roads and coastal armouring (coastline hardening), modification of natural processes, and degradation of coastal vegetation and interruption of beach processes for various reasons, including unplanned coastal access.

In the future, the impact of climate change will be felt most on the coastal zone, which will exacerbate these effects. The mitigation solutions for coastal erosion would therefore require a holistic diagnosis of these causes and their spatial and temporal scales to inform effective solutions.

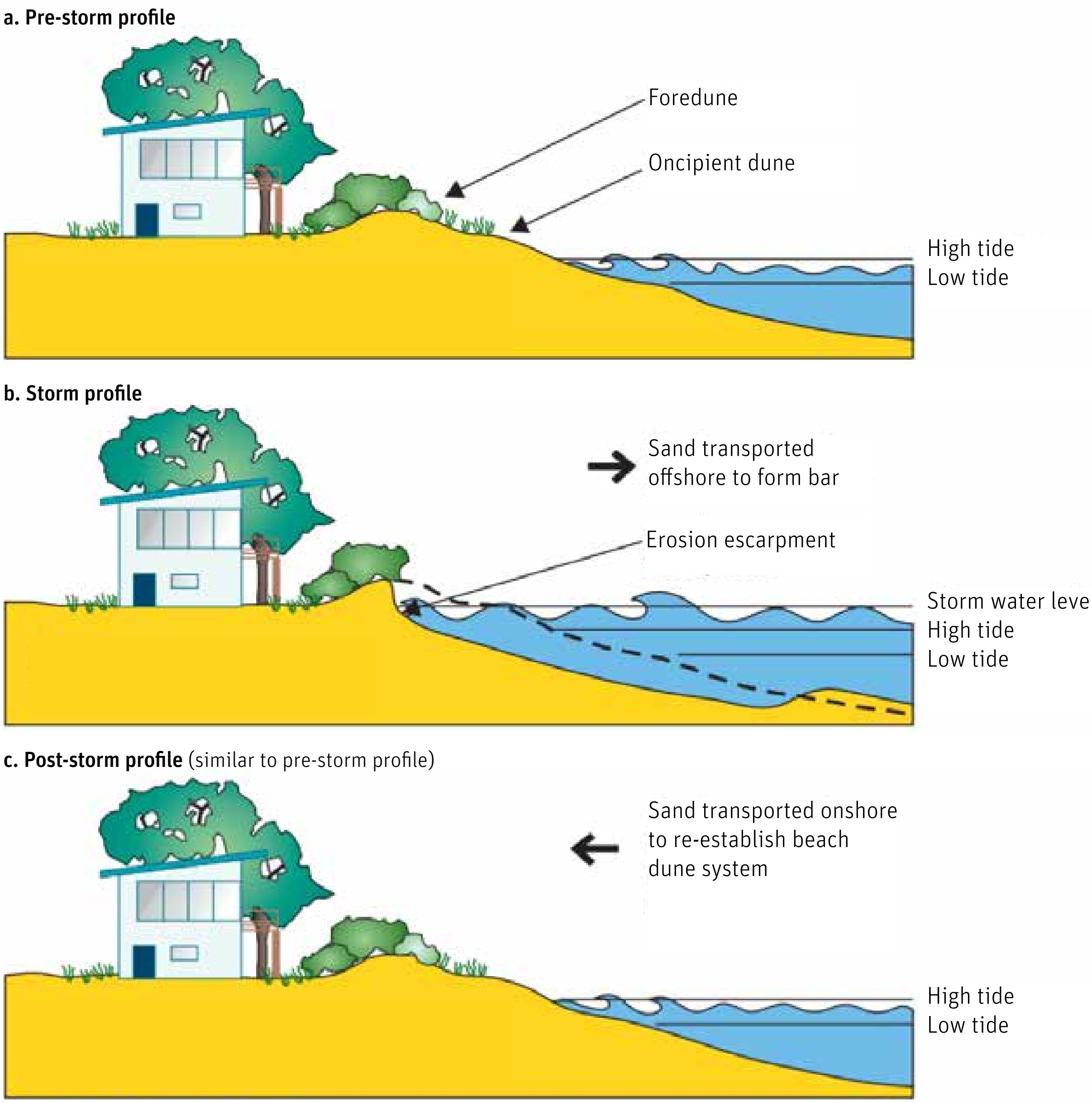
To better understand these processes and inform potential effective solutions and management, coastal erosion can be classified as different types:

Seasonal Profile Changes

Beaches get sand from both the ocean and the land. Ocean currents can move sand along the coast to build beaches. Dunes and other landward sand deposits deposit sand on a beach in response to the forces of wind and waves. High waves can cause a beach to change its shape, or profile, by redistributing sand across the shoreline (see figure 3.2).

To absorb high wave energy, beaches and dunes give up sand to the waves, which carry the sediment seaward. This raises the seafloor and flattens the overall profile of the beach. Waves then shoal and break further offshore, minimising their erosive impact. This typically happens in response to seasonal shifts in wave energy. Beaches recover from these natural changes when smaller waves slowly move the sand back onto the beach during calm periods and winds blow sediment into the dunes to be captured by coastal vegetation.

Figure 3.2: Seasonal Beach Profile Adjustment.



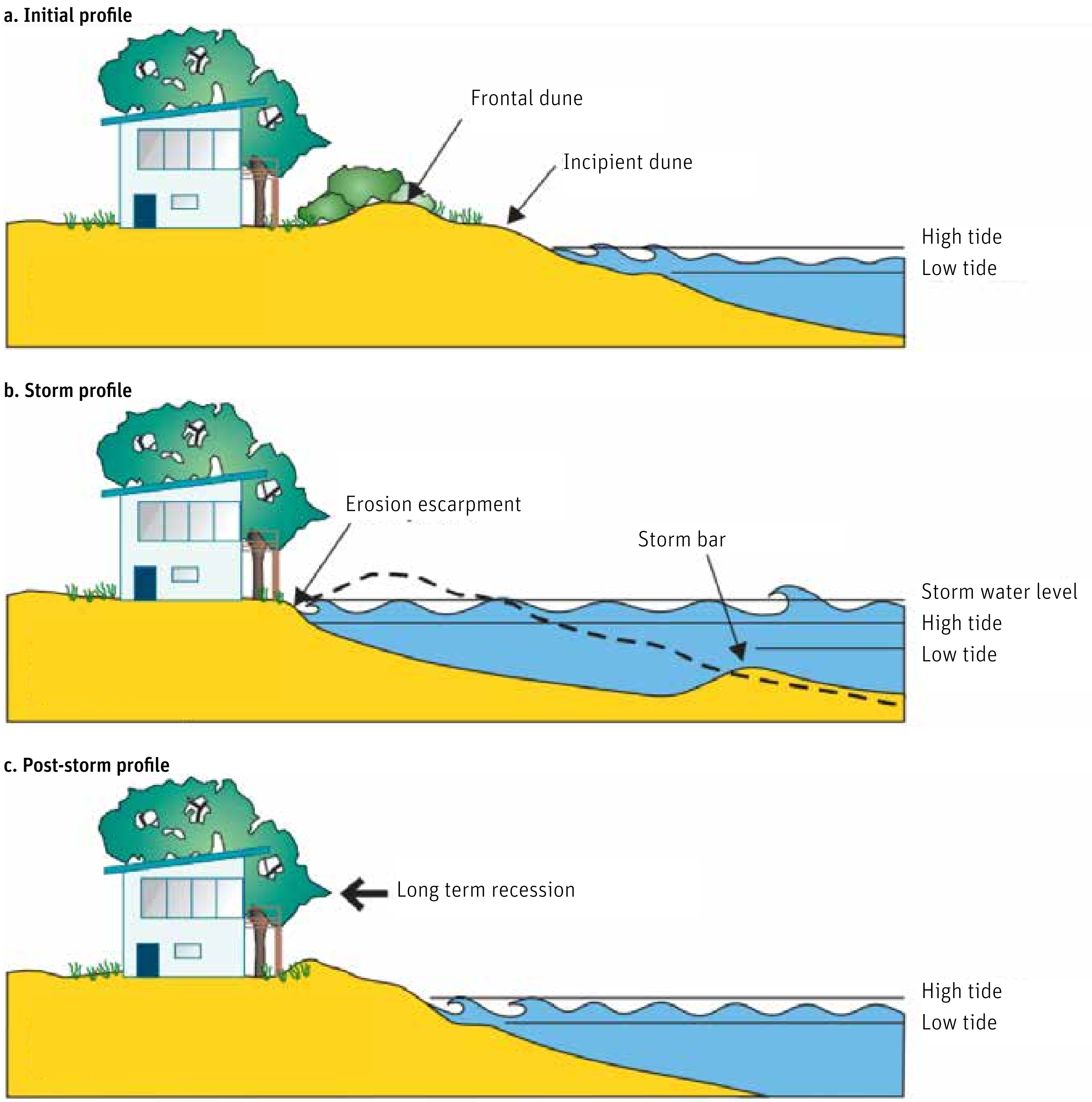
Source: NSW Department of Land and Water Conservation 2001.
Note: The beach erosion-accretion cycle does not cause a permanent loss of sand or shoreline retreat.

Chronic Erosion

However, beach erosion or recession (figure 3.2) can occur in the long term through loss of sand from the system, which results in a progressive retreat of the shoreline landward. Recession occurs when some of the sand is permanently lost from the system, for example, when a groyne interrupts the flow of sand to adjacent beaches. This results in less sand available for the beach's natural processes, which impedes the re-establishment of the original beach profile and leads to long-term shoreline erosion.

Erosion caused by repeated episodes of high wave attack typically affects the upland immediately behind the beach, constantly drawing upon sand stores there to feed the profile changes (figure 3.3). Sands stored in dunes and fossil shorelines are moved onto the beach by this process. Beaches benefit from this source of sand, and they

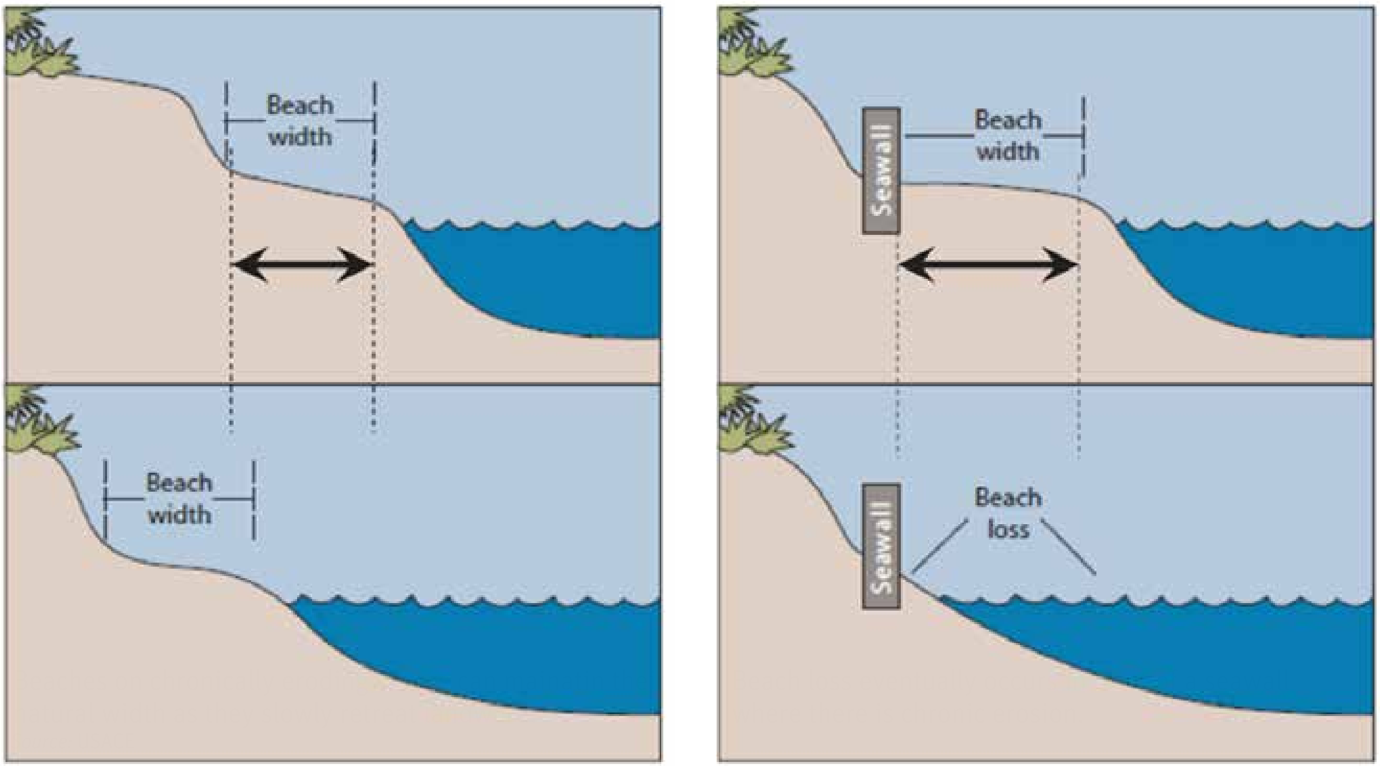
Figure 3.3: Long-Term Beach Erosion and Recession of the Shoreline due to Permanent Sand Loss.



Source: NSW Department of Land and Water Conservation 2001.

Figure 3.4: Processes of Shore Hardening and Beach Loss.

a. Normal beach retreat **b. Blocked beach retreat**



Source: California Coastal Commission 2014.

remain wide and healthy even as the land behind them erodes. Chronic erosion can cause land loss but not beach loss. Erosion appears when there is a deficit of sediment and insufficient input (either from longshore currents that run along the beach, or from land inputs or coral reefs). In some instances, land loss by erosion can be an important source of sand to many beaches.

Therefore, an understanding of the variations in local patterns of wind and wave dynamics can provide crucial information for deciphering beach processes and identifying effective management tools for coastal land conservation and beach preservation.

Coastal structures, such as seawalls, can also produce similar effects by interrupting these natural movements of sand across the beach profile. This process is represented in Figure 3.4.

Longshore erosion

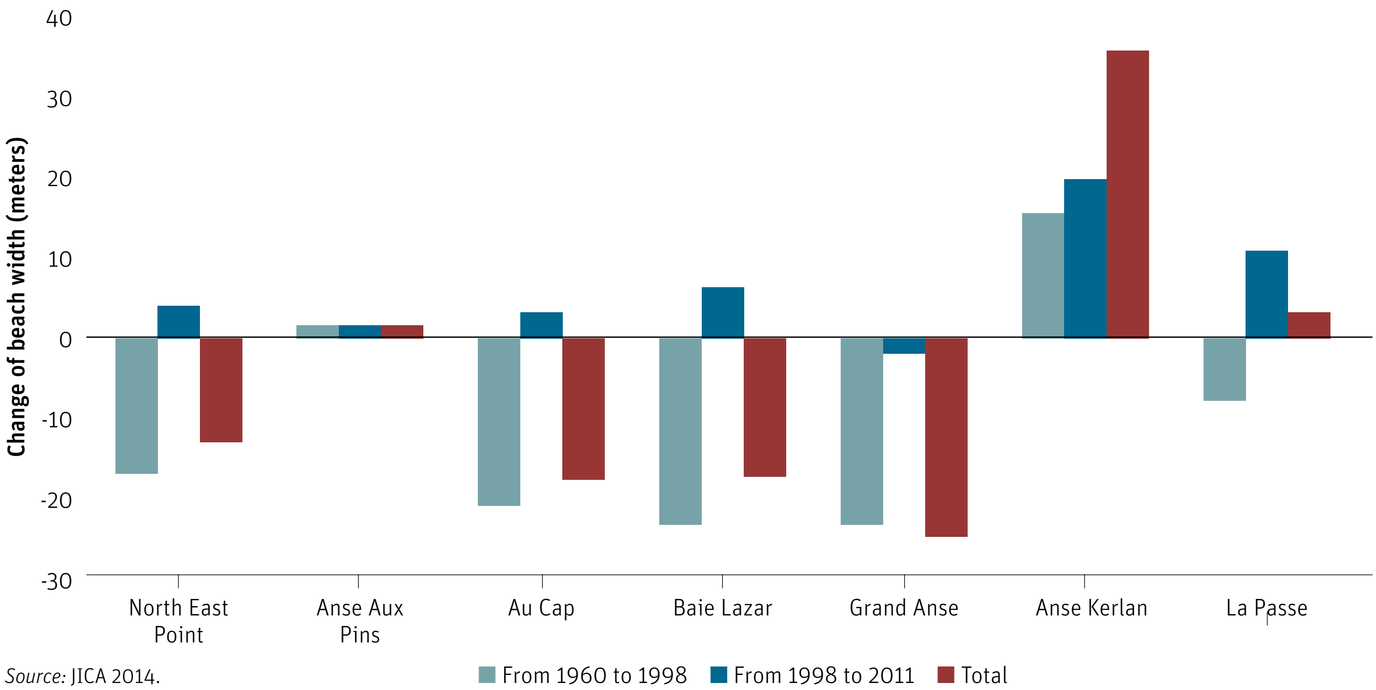
The variation in waves is a key component of the process of coastal erosion because waves are able to reach high onto the beach and into the dunes during storm seasons. Many local features combine to determine the pattern and process of wave action on the shores: the presence of reefs and offshore channels, the orientation of the coast to the prevailing winds and the approach of distant waves, the offshore depth variability, and short-term weather systems that drive wave-generating winds in unusual ways.

Waves that approach the shore from an angle are also capable of causing currents that flow along the coast, known as longshore currents. These can move sand from one end of a beach to another.

Monitoring erosion

Several different observation techniques can be used to monitor beach erosion. Erosion rates can be derived from time series of historical charts, field observations, and remote sensing and numerical models. In Seychelles, there is no comprehensive beach erosion monitoring program. However, the erosion and flood management study conducted by JICA (2014) analysed beach erosion in some priority areas: North East Point, Anse Aux Pins, Au Cap, and Baie Lazare in Mahé, Anse Kerlan in Praslin, and La Passe in La Digue. The analysis for the JICA report was based on 1960 maps, 1998 Geographic Information System (GIS)

Figure 3.5 Changes in Beach Width at Priority Sites.



Source: JICA 2014.

data and recent Google Earth and aerial photos. The average long-term changes in the coastline from 1960 to 1998 and from 1998 to 2011 are shown in figure 3.5.

The JICA analysis found that about 20 metres of the coast had been eroded in the 38 years from 1960 to 1998 at North East Point, Au Cap, Baie Lazare, and Anse Kerlan. From 1998 to 2011 the erosion was not severe, and some coasts accreted. The accuracy of determining the coastline is about plus or minus 5 metres on the maps or aerial photos. The coast at Grand Anse next to the coast at Anse Kerlan has been accreting continuously. At La Passe, the coast was eroding until 1998, but has accreted recently. No changes were detected at Anse Aux Pins. A description of coastal erosion at priority sites is found in JICA (2014). These results demonstrate a strong temporal variability in the erosion patterns. This indicates that sediment transport assessments are needed for identifying the causes and processes that drive erosion at each site. Examples of erosion in different locations can be seen from photos 3.2, 3.3, and 3.4.

A detailed description of sand movement at North East Point can be found in Borrero et al. (2016). Georeferenced Google Earth aerial images were used to analyse the sand movement. Using a set of images covering the period January 2009 through November 2014, researchers compared the interseasonal variability in beach widths, finding seasonal variations of 15 to 30 metres. Ground control points, consisting of fixed locations such as corners of buildings, roadways, and rocks that were distributed across the image area, were used to verify the positional accuracy of the imagery. This information was combined with numerical modeling of waves and currents. The study determined that the beach at North East Point undergoes seasonal fluctuations of beach width, driven by monsoonal wind and wave conditions. The study also determined that the primary driver of sediments is wave action as opposed to tidal, wind, or pressure-related effects. However, the study indicated that coastal erosion changes and evolution should be explained at the local scale, as the seasonal changes are comparable to the changes observed since the 1960.

3.3 Coastal risks and climate change effects

Sea level rise and future changes in storms are the two major elements of climate change that create coastal hazards and vulnerability on the coastal zone in Seychelles.

The sea level has been monitored since 1993 at Pointe La Rue, Mahé. The analysis of 18 years of data showed a sea level rise rate of 5.6–6.6 millimetres per year between 1993 and 2010. If this rate remains constant over the course

Photo 3.2: Example of Beach Erosion and Rock Armouring Collapsing in the South of Anse Royale.

Source: Alvarez Cruz et al. 2011.

Photo 3.3: Examples of Erosion in La Digue.

a. Beach erosion and vegetation collapsing

b. Detail of beach erosion and toe of vegetation and mainland

Source: Alvarez Cruz et al. 2011.

Photo 3.4: Sand Movement at North East Point.

a. Beach profile and vegetation cover

b. Erosion of the upper beach profile

Source: World Bank (photo taken July 2018).

of the century, the sea level will rise 0.3 metres by 2050 and 0.6 metres by 2100 over the levels of 2010. However, the regional sea level in the southwest Indian Ocean is expected to rise between 0.4 and 0.6 metres from 2070 to 2100 as compared with the period from 1960 to 1990.

The end-of-the-century dynamic projections from the Intergovernmental Panel on Climate Change (IPCC) for the Representative Concentration Pathways (RCP) 4.5 and 8.5 for Mahé, Praslin, and La Digue are estimated between 0.55 and 0.75 metres above present mean sea level (see figure 3.6).

In Seychelles, offshore waves are dominated by the northwestern monsoon and southeastern trade winds. The wave climate is not expected to change significantly unless the patterns of the monsoons change. However, future changes in the storm patterns in the tropical cyclone belt, as well as the Southern Hemisphere swells, will determine the extent of extreme coastal flooding and erosional events in the islands. Even if offshore wave conditions do not change, greater wave energy will reach the coastal zones of Seychelles due to the combined effects of sea level rise and coral reef degradation and the erosion of reef flats (Sheppard et al. 2005). Both factors will contribute to more severe coastal erosion and more frequent coastal flooding than at present (Alvarez Cruz et al. 2011).

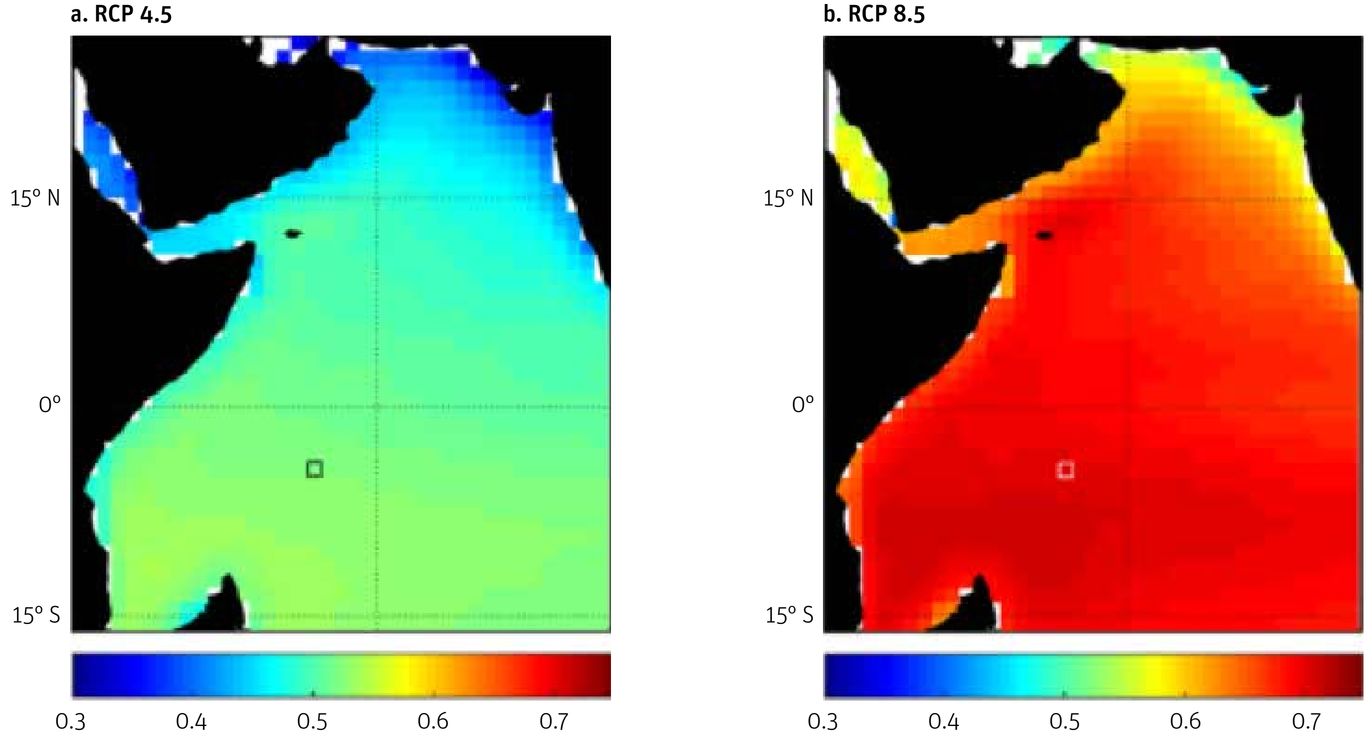
Sea-level rise threatens significant land, as outlined in table 3.4. This amount of sea level rise is alarming and likely plays a key part in the observed instances of erosion that are occurring throughout Seychelles (Borrero et al. 2016). For example, assuming a simple equilibrium model of beach profile, 0.5 metre of increase in sea level rise represents between 25 and 50 metres of beach recession, in the absence of other factors or sediment inputs.

In the case of Mahé, with the caveats of such simple model, between 2.5 and 5 metres of beach width loss per decade could be explained by the historical sea level rise according to the measured records (Borrero et al. 2016). In places such as North East Point, where the extent of the beach recession is limited by the presence of hard structures (such as the road) or rocks, the increase in sea level will manifest as more frequent occurrences of wave overtopping and increased sand removal during storms, when waves are bigger and sea levels are higher (Borrero et al. 2016).

Climate change will also affect the coral reefs that protect the coastline of Seychelles against flooding and erosion

Figure 3.6: Projection of Rise Above Mean Sea Level by 2100.

a. RCP 4.5 **b. RCP 8.5**



Source: Church et al (2013).
Note: Seychelles is shown by the square in the lower left of each panel.

Table 3.4: Land Area Exposed to Flooding for Different Return Periods Under Current and Future Sea Levels.

	Current Sea Levels					
Island	1-in-25-year	Percentage	1-in-50-year	Percentage	1-in-100-year	Percentage
Mahé	12.51	6.09%	12.59	8.14%	12.79	8.27%
Praslin	6.9	18.28%	6.92	18.33%	6.94	16.38%
La Digue	1.43	14.50%	1.44	14.60%	1.46	14.81%
	Future Sea Level Rise of 40 cm					
Island	1-in-25-year	Percentage	1-in-50-year	Percentage	1-in-100-year	Percentage
Mahé	13.31	8.60%	13.37	8.64%	13.52	8.74%
Praslin	7.02	18.60%	7.04	18.65%	7.07	18.73%
La Digue	1.52	15.42%	1.54	15.62%	1.55	15.72%

Source: Based on data from Alvarez Cruz et al. 2011.
Note: Values of land area are expressed in square kilometres. The percentages are calculated over the total surface area of the island.

(Sheppard et al. 2005). Degradation of the coral reefs, which function as natural breakwaters, can modify coastal processes and result in adverse consequences on coastal areas (Reguero et al. 2018; Beck et al. 2018) as described in the following section. The reduction of live coral cover and erosion of dead coral structures on reefs can result in more severe coastal erosion and higher wave runup than at present. Even if offshore wave conditions do not change, the loss of coral cover will result in deeper water depths on reef flats; the significantly higher water level on the reef will cause waves to lose less energy and greater wave energy will reach the coastal zones of Seychelles. This effect has been referred as "pseudo–sea level rise" (Sheppard et al. 2005).

Climate change could damage the natural protection reefs offer today. The thermal stress created by the 1998 and 2016 El Niño events resulted in coral bleaching of coral reefs in Seychelles. The recovery of coral reef ecosystems after the 1998 events that was observed on most monitoring sites (Graham et al. 2015) was wiped out by the 2016 bleaching events. The mass bleaching events reduced live coral cover to less than 5 percent of pre-1998 levels according to recent estimates.

3.4 The importance of coastal ecosystems for a resilient coast

Ecosystems such as coral reefs, beaches and dunes, and coastal vegetation protect coastlines against erosion and flooding. This section explains the basic principles of why these types of ecosystems provide coastal protection.

3.4.1 Coral reefs

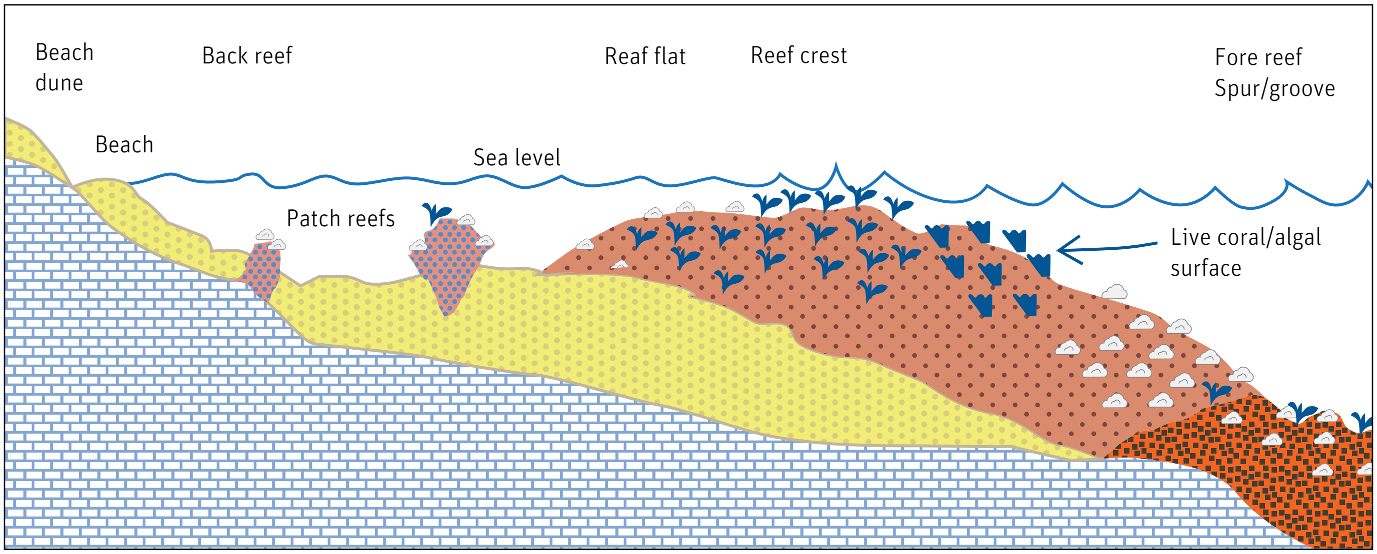
Coral reefs naturally protect coasts from erosion and flooding by attenuating wave energy and supplying and trapping sediment. Coral reefs attenuate a great fraction of wave energy as waves propagate through them (Ferrario et al. 2014; Sheppard et al. 2005). However, the transformation of waves through reefs varies greatly depending on reef geometries and configurations. Wave transformation in reef environments is more complex than the simple breaking of waves (Rosman and Hench 2011; Baldock et al. 2014).

Reefs function much like low-crested breakwaters: they protect shorelines primarily by dissipating wave energy. (Coral reefs reduce wave energy by up to 97 percent (Ferrario et al. 2014).) But their effects on coastal processes are more complex, and it has been demonstrated that they control erosion and flooding through a broader influence on wave and current patterns (Reguero et al. 2018). Several factors affect how effective reefs are in reducing wave energy and thus protecting the coastline: reef type, height of reef crest and water depth, reef morphology, and reef surface roughness. These parameters are related to the health of the coral reef, and their degradation can affect the coastal protection they provide.

Coral reefs form part of a broader system that includes the forereef, the reef crest, the lagoon, beach, dunes, and vegetation. The processes and interactions are numerous and complex but, in general, they can be summarized as follows (see also figure 3.7):

- Coral reefs protect shorelines primarily by absorbing and dispersing wave energy, mainly by breaking waves at the

Figure 3.7: Schematic Representation of a Fringing Reef Ecosystem: Visualization of the Effects of Friction and Bathymetry on Wave Attenuation.



Source: World Bank 2016.

seaward edge and through bottom friction as the waves cross the reefs (Monismith 2007; Hardy and Young 1996; Gourlay 1994).

- Coral reefs, through their uneven surface roughness, also create frictional drag for waves, which further dissipates energy. This dissipation depends on the substrate type: sand and pavement offer little friction, large coral formations (more than 30 centimetres) on the reef surface create the greatest friction. Frictional drag over a reef flat may be over several times other substrates (Monismith et al. 2015) and increases as water levels over the reef crest decrease (Huang and Hwang 2012). When reef structural complexity is reduced (for example by storms or erosion), this frictional benefit also decreases.
- After waves break and attenuate, the mean water level rises onshore (an effect known as wave set-up) and currents and reef circulation are set in motion, which in turn drive the transport of sediments and nutrients (Longuet-Higgins and Stewart 1961; Lowe 2005). Waves also propagate in groups generating an oscillation of the mean sea level; when waves break over the reefs, this component is liberated (creating infragravity waves) and generates "surf beat" onshore, which is an oscillation of the mean sea level in periods typically between 80 and 300 seconds (Dean and Dalrymple 1991).
- Coral reefs also influence the direction of waves and influence the surf zone currents. The configuration of the reef crest and lagoon has a direct effect on refraction and diffraction, which changes the wave direction and height. These processes have a direct effect on the shoreline and its stability.
- Individual reefs cast a shadow effect on waves much larger than the reef itself. A continuous reef structure is critical for wave energy attenuation and influences the position of the shoreline. Discontinuous and semicontinuous reef crests in the Caribbean were found to reduce approximately 27 percent less wave energy than continuous reef crests (Roberts 2011), and yet a matrix of isolated reefs can be remarkably effective in attenuating waves (Gallop et al. 2014).

However, coral reefs and the coastal protection they offer are under threat from different stressors and disturbances that include both natural as well as anthropogenic factors:

- **Natural factors** include thermal stress and bleaching, biological diseases, and impact from storms. Coral bleaching occurs when water is too warm as corals expel algae that live in their tissue and turn white. Although bleached corals are not dead and they can survive bleaching events, they are more vulnerable to other stressors and more subject to mortality. Coral reefs are also affected by damage from typhoons and tsunamis, such as the Indian Ocean tsunami in 2004, whose large waves can damage the reef structure (map 3.1).

Map 3.1: Tsunami Impact on Coral Reefs and Sea Grass Beds.

Source: UNEP 2005.

- **Anthropogenic factors** are caused by human action in the marine environment that is physically destructive to coral, including: dredging channels and vessel groundings; mooring that fractures coral skeletons; coral mining; sediment and water pollution; and overfishing (Jaap 2000)fisheries and tourism, coastal protection, geological processes, and aesthetic wonder. A principal cause of reef damage in Florida is ships running into reefs. The other major human impact on Florida's reefs is dredging for beach renourishment and channel maintenance. In response to chronic reef damage, federal and state agencies and consultants have developed techniques to restore, as best possible, reefs impacted by human disturbance. These efforts include salvaging sponges and corals, removing loose debris from the reef, rebuilding three-dimensional (3-D. For example, a boat anchor dropped onto a reef produces significant damage to the reef structure. Also, a reef lives in a symbiotic relationship with herbivorous fish that feed on the algae on the surface of these corals. Overfishing can lead to seaweed growth and a decline in coral.

3.4.2 Beaches and dunes

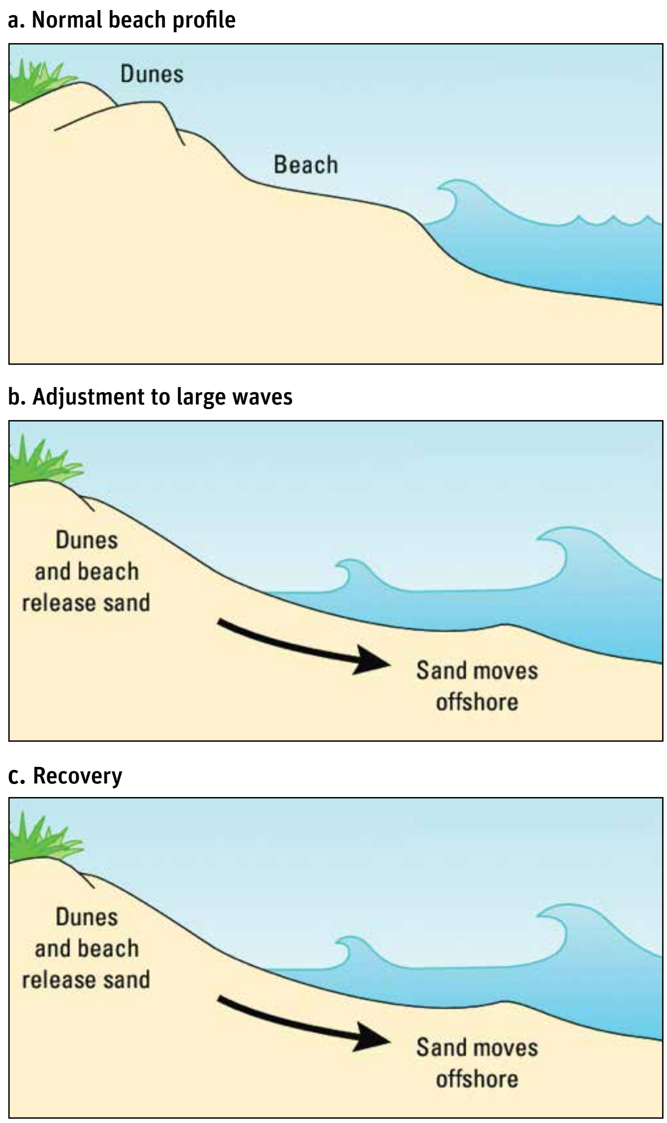
Beaches are generally defined as stretches of sand or smaller loose particles (such as pebbles, shells, or gravel) that exist between the water and the land. Dunes are landforms that occur when there is a sufficient supply of sand or sediment and strong enough wind to promote sediment transport and some type of obstacle, often vegetation, that allows the sand to accumulate. In many instances, healthy dune systems rely on the presence of a healthy and extensive root system from dune grasses and other vegetation to maintain their shape.

Beaches and dunes are naturally dynamic environments that fluctuate in size and shape year to year based on the effects of wind, waves, tides, and storm events, and sand availability. They reduce the impact of coastal storms by acting like a buffer along the coastal edge and absorbing and dissipating the energy of breaking waves, either seaward or on the beach itself. These processes are essential to the maintenance of the natural system and, if interrupted or suspended, can have important negative effects on the width and shape of the coastline and its ability to provide flood and erosion protection.

Dunes serve as a barrier between the water's edge and inland areas, taking the brunt of larger storm surges. Dune structure and vegetation dissipate the energy of the waves and act as a natural containment to prevent the passage of storm surges to coastal inland areas. Even when the height of the storm surge and waves surpass the dune crest, the level of inland flooding will be lower because of the reduced energy of the waves and reduced volume of water capable of going over the dune crest.

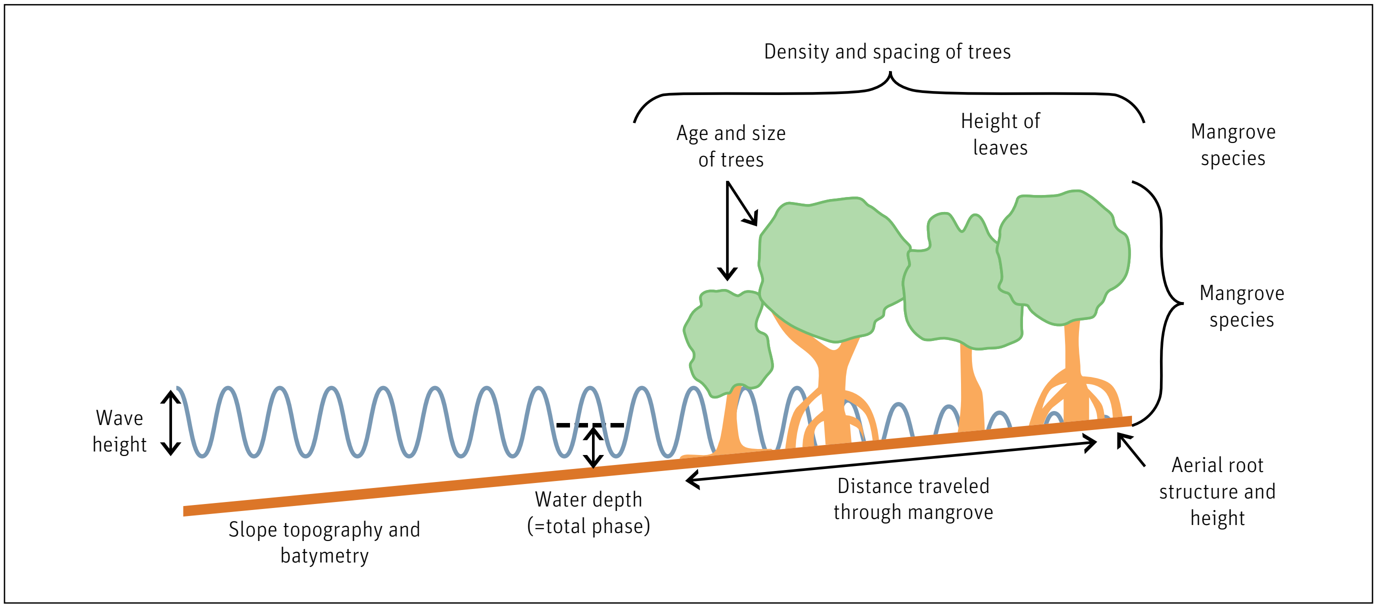
Dunes also function as a sand reservoir to offset beach erosion during storm events. During storm events, sand is moved to the lower part of the beach profile and wave action on the dunes provides sand to restore the beach profile, which recovers over time and progressively rebuilds the dunes through the combined action of wave and wind (see figure 3.8). When a beach is stable, erosion will not result in a long-term landward movement of the beach (all

Figure 3.8: Beach Erosion-Accretion Cycle.



Source: Fletcher et al. 2012.

Figure 3.9: Schematic Representation of Wave Attenuation by Mangroves.



Source: World Bank 2016.

the sand moved offshore during a storm eventually moves back onto the beach as shown in figure 3.8). Recession occurs when some of the sand is lost from the system.

Vegetation is critical for dune stability and effective coastal protection. The stems, leaves, and roots of the dune vegetation dissipate wave energy by creating friction, mitigating the waves, and reducing flood levels. Roots also fix and stabilize the sediment, increasing its resistance capacity, and dissipating the energy of the waves by increasing the effort needed to move the sediment. Vegetation is necessary, therefore, both for dune formation and consolidation.

The wider a beach or dune system, and the more space between the sea and any developed or populated areas, the more effective and efficient the system will be at reducing the impact of coastal hazards. However, the natural protection provided by beaches and dunes requires more space than traditional built infrastructure such as seawalls.

3.4.3 Coastal vegetation

Coastal vegetation, such as mangroves and estuarine wetlands, provide coastal defense services by reducing flood risk for coastal communities, mainly through wave height attenuation. Studies suggest wave height can be reduced by 13 to 66 percent over a 100-metre-wide mangrove belt, and by 50 to 100 percent over a 500-metre-wide mangrove belt.

A number of factors affect the rate of wave height reduction through the mangrove forest: the density of vegetation, the presence of aerial roots (present only in some mangrove species), the underlying topography, the height and period of the incoming waves, and the water depth (which influences the type of vegetation the waves pass through—aerial roots, trunks, or branches). See figure 3.9.

3.4.4 Environmental degradation can create or aggravate coastal impact

Given Seychelles' coastal landscape (as elaborated in previous sections), degradation of the coral reefs and beach and dune systems can particularly exacerbate coastal impact. Examples in several countries show that degradation of reef flat corals reduces the protection they offer and leads to increased erosion and flooding. For example, a study in Grenville Bay in Grenada, in the Caribbean, showed that coral degradation led to intense erosion in specific sections of the bay, while healthy reefs in other sections still maintain a stable and safe shoreline today. Information from a global assessment of flood protection provided by coral reefs estimates that, for a 1-in-25-year flood, reefs provide about an 80 percent flood reduction (Beck et al. 2018; Mapping Ocean Wealth[4]).

A study on coastal protection by coral reefs in Seychelles in 2005 (Sheppard et al. 2005) reported that the reef flats and fringing reefs around the three main islands, Mahé, Praslin, and La Digue, are known to dissipate much of the offshore

[4] The Nature Conservancy, Mapping Ocean Wealth, https://oceanwealth.org.

wave energy. Before 1998, many of the reef flats examined (ten sites across the three main islands) were covered with 0.5-metre-high thickets of branching corals and by massive or boulder forms of nearly equal height from the coral genus Porites in particular. With these corals eradicated, several characteristics of the reefs visibly changed:

- The removal of the coral skeletons increased the depth of water over the reef flat. The crumbling of these expanses is increasing the gap between their tops and sea level, creating a localized "pseudo–sea level rise" on the reef flats.
- When the reef flat corals eroded away or became rubble, the three dimensional structure of the reef flat surface was reduced from a state of rough, mixed, irregular coral thickets and boulders to a much smoother surface of rubble or even to flat limestone, both of which present much less friction to waves and hence have a reduced ability to attenuate wave energy and flooding (Harris et al. 2018). The same research also shows that coral reef structural complexity provides important coastal protection from waves under rising sea levels (Harris et al. 2018).
- The effects of coral erosion apply even to reefs that never had much coral on the reef flat—the reef crest corals also die, which slightly changes the shape of the wave-breaking zone seaward of the reef crest (Sheppard et al. 2005).

3.5 Coral reefs as natural infrastructure: Identifying where corals have a higher potential for coastal protection

In 2018, a study estimated the contribution of coral cover (that is, the rugosity of the reef) for coastal protection in Seychelles (World Bank 2018). For all reef-lined coasts of three main islands, the study identified the sites with the highest potential for the reduction of wave runup through coral reef restoration. Wave runup was used as a proxy for coastal flooding levels. The analysis was carried out first using remote sensing and existing datasets to estimate key site parameters such as reef width, depth, roughness, and beach slope. Site specific offshore wave conditions for the study were obtained from JICA (2014). The reef morphology and hydrodynamic forcing was used in the Bayesian Estimator for Wave Attack in Reef Environments (BEWARE) system to estimate runup under a range of different scenarios, including reef roughness as a proxy for live coral cover.

The absolute runup reduction for Mahé is given in figure 3.10. Results for Praslin and La Digue are included in appendix E. The highest potential runup reduction for the east coast of Mahé is at Anse Royale and Anse aux Pins, which are both concave bays with wider reefs. On the western side, Baie Beau Vallon and Anse à la Mouche show higher potential, although Baie Beau Vallon was flagged for having very mild forereef slopes. The potential runup reduction shows strong variability at priority sites Baie Lazare and Anse Nord d'Est, likely due to their complex coastlines and reefs. These locations should be modelled in greater detail if they become a priority for restoration.

3.6 Exposure of coastal communities and assets

3.6.1 Exposed assets to coastal flooding

Coastal risk is a function of the likelihood of the coastal hazards (such as erosion and flooding) and their potential consequences. Estimating the potential consequences requires quantifying the people, communities, and capital exposed to coastal risk. In this section, different types of exposed assets are considered: people, roads, critical infrastructure (utilities, hospitals, emergency services, and other public buildings) and other buildings. Past studies on coastal flooding and erosion have provided coastal exposure estimates, which are slightly outdated due to continuous coastal development. Table 3.5 outlines exposure in the coastal zone (that is, in areas that would be inundated during a 3-metre coastal flood) for Mahé, Praslin, and La Digue according to 2014 and updated estimates.

An assessment was made of the number and share of buildings and roads that will be inundated during a flood of 2.5 metres above the present mean sea level (Alvarez Cruz et al. 2011; JICA 2014) (table 3.5). Using existing Geographic Information System (GIS) analysis, they found that 2017 buildings (14 percent) in Mahé, 1601 buildings (63 percent) in Praslin, and 321 buildings (48 percent) in La Digue could be expected to be inundated under a worst-case scenario, including 11 hospitals, 15 schools, 21 restaurants, and 69 hotels and guesthouses on the three islands. The results also showed that 67 kilometres of roads in Mahé, 43 kilometres in Praslin, and 7 kilometres in La Digue could be inundated. In other words, 42 percent of the coastal main roads in Mahé, 72 percent in Praslin, and 27 percent in La Digue are expected to be inundated (JICA 2014).

Figure 3.10: Runup Reduction along Reef-Lined Coast of Mahé.

Note: The change in runup by varying the roughness has been visualized in a so-called "bacon strip plot." In this way, we can visualize the effect that friction has on the runup reduction. For every transect we visualize the absolute reduction in wave runup between the case of no friction minus high friction (outer strip), no friction minus medium friction (middle strip) and no friction minus low friction (inner strip), where darker colours give a large reduction and light colours suggest that there is little difference.

Table 3.5: Assets Exposed to Coastal Flooding.

	Mahé		Praslin		La Digue	
	Count	% of total	Count	% of total	Count	% of total
Buildings (count)	2017	14	1601	63	321	48
Roads (km)	67km	42	43km	72	7km	27

Source: JICA 2014.

3.6.2 The natural capital of the coastal zone

Tourism is a pivotal economic sector in Seychelles. According to the World Travel and Tourism Council (2017), the direct contribution of tourism to the country's gross domestic product (GDP) is 22.2 percent, which places Seychelles 6th in the global rankings. The total contribution of tourism to GDP—including indirect effects—is estimated at 58.1 percent (World Travel and Tourism Council 2017, 24)Travel & Tourism creates jobs, drives exports, and generates prosperity across the world. The International Year provides an enormous opportunity to further showcase the tremendous economic, social, cultural, environmental, and heritage value that the sector can bring. The right policy and investment decisions are only made with empirical evidence. For over 25 years, the World Travel & Tourism Council (WTTC. Its natural capital, the beauty of its natural environment and resources, draw travelers to Seychelles to enjoy its beaches, ocean, and tropical flora and fauna (World Bank 2017).

Ecosystems and the coastal habitats such as beaches and coral reefs are important tourist attractions in Seychelles.

For example, the tourism value of the coral reefs has been estimated at between $0.3–0.9 million per square kilometre (Spalding et al. 2017; Mapping Ocean Wealth[5]).

However, the degradation of coastal ecosystems, beach erosion, and increasing coastal flood risk pose a threat to the sustainability of tourism in Seychelles. Although hard evidence is lacking, there seems to be little doubt that the beaches of the three main islands represent extremely valuable natural capital and, thus, are essential for the economy. But these beaches are exposed to coastal risks. Beach loss is observed and expected to increase in the decades to come as a result of sea level rise and further degradation of the coral reef ecosystems.

An accurate economic valuation study of ecosystem services associated with tourism is currently lacking. An ecosystem services assessment is planned for the spring of 2019 under the Marine Spatial Planning Initiative Seychelles.

3.7 Main knowledge gaps to better understanding and managing coastal risk

From the review of existing practices and available information, some gaps in knowledge were identified:

- **Lack of data on the historical evolution and condition of coral reefs.** The crucial role of coral reefs in coastal protection and production of sand has been acknowledged in these coastal studies (JICA 2014; Alvarez Cruz et al. 2011) but, currently, there exist no data on their status, health, and evolution, which hampers their study and management with respect to erosion and flooding. Many of the priority areas identified by the different studies are protected by wide, shallow reefs, which determine the wave propagation and current circulation and in turn influence flooding and erosion. Future interventions should focus on how coral reefs have been changing and establish a direct link with coastal erosion and flooding, for adequate management of coastal impact.
- **The different studies and reports vary in scope, level of detail, information, and timelines.** An integrated compilation of the available information in a single document is needed to increase accessibility to the information and better enable its application.
- **Better information on local wave climate conditions, wave propagation patterns, and dominant sediment transport processes will be needed to inform targeted solutions and interventions.** These should include quantitative information on seasonal changes, wave propagation and circulation patterns in nearshore waters (particularly in reef environments), sediment transport studies to asses chronic and extreme erosion events, and the extent of flooding and overtopping to aid in the design of coastal infrastructure.
- **The local study of the North East Point provides an example of study of flooding and erosion trends.** Such detailed data and analysis are needed to inform coastal management and interventions. Detailed information is also needed for other priority sites. Specific information from wave climate variation and sediment transport is crucial to assessing the causes and potential solutions for erosion and flooding in Seychelles. Although the available studies have focused on historical time spans to identify the patterns of risk, there is limited information on the processes driving flooding and erosion in the priority sites of Mahé, Praslin, and La Digue. This gap in knowledge is particularly critical to enabling effective and long-term sustainable solutions for the exacerbated impacts of climate change in the coastal zone. This information should be combined with a prognosis of the effects of future waves and potential changes in the nearshore bathymetry (for example, from reef changes) to assess what changes in flood risk and erosion rates could be expected in the future.
- **Near-shore bathymetry data** are currently unavailable for most of the coastal zones of Seychelles, but crucial to the study and planning of effective projects.
- **Better assessment of coastal flood risk** and the causes of erosion are also needed.

[5] The Nature Conservancy, Mapping Ocean Wealth, https://oceanwealth.org.

4. Priorities for coastal management

4.1 Introduction to the priorities for coastal management

This Coastal Management Plan (CMP) identifies five priorities for coastal management. Coastal resilience can be achieved only by addressing all priorities for coastal management in an integrated approach, as they all contribute to building resilience. Figure 4.1 shows how these priorities can be combined to build coastal resilience.

The priorities are defined as follows:

- **Monitoring and research** of processes that affect the coastal zone to inform sustainable coastal management
- **Coastal infrastructure,** including engineered structures and natural systems that protect the coastline against flooding and erosion, such as groynes, sea walls, coral reefs, and coastal vegetation
- **Risk-based land planning,** including policies and planning practices that aim to reduce coastal flood and erosion risks for new and existing developments
- **Capacity building** to improve the level of experience and expertise in the government for implementation and enforcement of good coastal management
- **Awareness raising** to inform and engage the public, mobilize support, and spark collective action for better coastal management

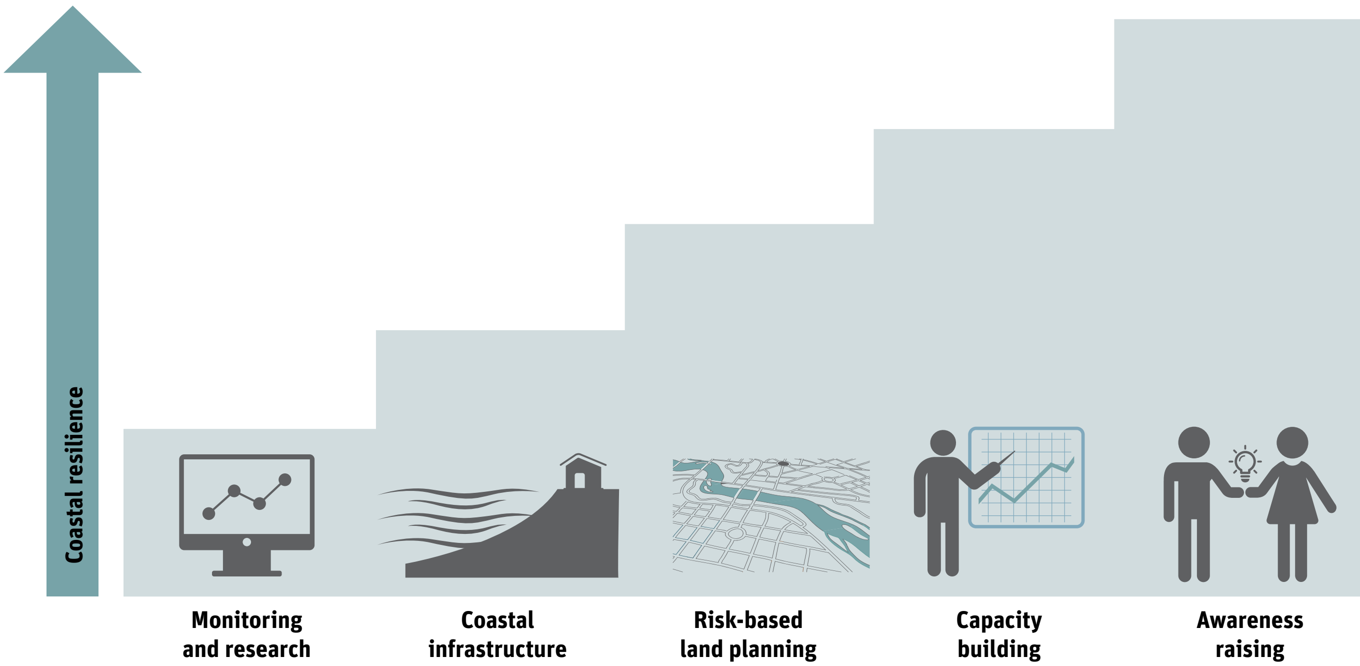
For each priority, this CMP defines a number of actions, which are classified as programmatic or regulatory:

- **Programmatic actions** are investment projects in, for example, coastal infrastructure, wetland rehabilitation, and awareness raising campaigns.
- **Regulatory actions** include policies and legislation that affect management of the coastal zone, such as coastal setback regulations and building codes for developments in flood prone areas.

Under monitoring and research, a number of actions are defined, such as monitoring flooding and erosion events, mapping benthic habitats and monitoring water quality. These monitoring actions will enable better understanding of coastal risks, allow a proactive approach toward coastal effects (instead of reacting after the consequences of flooding and erosion are apparent), and better planning and management of the coastal zones.

Under coastal infrastructure, actions are listed for coastal sections in need of protection from coastal erosion and flooding and requiring investments in coastal infrastructure. This includes a range of

Figure 4.1: A Suite of Measures to Build Coastal Resilience and Implement Better Coastal Management.



potential options, including restoring the natural coastal ecosystems, engineering coastal structures, or both.

Risk-based planning aims to limit the number of people exposed and vulnerable to coastal flooding and erosion by minimising the economic effects of coastal hazards on infrastructure and properties. These actions focus on integrating flood and erosion risk into planning instruments, for example through restrictions on development in areas frequently affected by coastal hazards or by regulating and enforcing building codes in such areas.

Capacity building actions are designed to enhance the institutional and technical capacity in government sectors to enable effective coastal management. Such actions might include technical training, promoting cross-sectoral collaboration, or international collaboration to promote best practices.

Awareness-raising actions focus on informing and mobilising the public, civil society, and the private sector. A better understanding of the risks, impact, the potential solutions, and the need to manage these high-risk zones will enhance the support for coastal management policies. Actions might include education at schools or campaigns organized at the district level to inform the general public about the potential effects of climate change.

The actions proposed in this CMP are either applicable at the national level or target specific locations of the coastal zone. The areas most affected by coastal erosion and flooding require priority action. Section 4.2 describes the definition and identification of priority coastal zone management units (CMZUs). Section 4.3 describes the actions by priority, both at a national level as well as by coastal zone management unit.

4.2 Coastal classification and management units

Sustainable coastal management practices build on a baseline understanding of coastal processes. Each coastal zone has unique and specific features that coastal managers, planning authorities, and engineers need to consider when managing resources and planning coastal development and interventions. Therefore, management of the coastal zone needs to be approached from a system perspective. The effectiveness of the potential solutions will be determined by an adequate understanding of the dominant processes (such as wave propagation, sediment transport, and flooding) at the scale of the coastal system.

For these reasons, this CMP has determined priorities areas for specific CZMUs (see figure 4.2) that: (1) represent areas in need of coastal protection and specific management; and

Figure 4.2: Spatial Locations of the Coastal Zone Management Units.

(2) are defined through a spatial delimitation that considers the reach of coastal processes and a landward and seaward limit following the definition of the coastal zone described in section 1.2.2.

The areas not considered a specific CZMU are: (1) general purpose coastal zones, where the general guidance provided in this chapter applies; or (2) those that have their own more detailed planning instruments and require more specific guidance than the designated CZMUs (such as Victoria).

A CZMU can be considered to be a coastal subsystem, determined by the wave action, bathymetric features, ecosystems, coastal landforms, topographic features, and the general coastal configuration. The CZMUs define areas where changes in coastal processes (such as nearshore wave processes, currents, and sediment transport) are broadly self-contained and should, therefore, be managed integrally to ensure effective coastal protection. Any intervention, such as a coastal structure, in these units should acknowledge and consider its effects on wave propagation and sediment transport to avoid unplanned effects, such as erosion downstream, to identify effective and long-term solutions and avoid future effects that would require additional investment in coastal protection.

The spatial definition of the CZMUs (figure 4.2) is based on four main criteria:

- Regions in need of coastal protection measures, identified as priority zones in JICA (2014) or those identified by the Climate Adaptation and Management Section (CAMS) (see appendix D) where past erosion protection projects have been or are planned to be implemented in the future
- The spatial definition defined by a 1-kilometre buffer seaward to contain the forereefs and the nearshore bathymetric features
- The landward limit defined by the 10-metre ground height, an elevation taken as the limit of the low-lying area that could be affected by coastal impacts or present development close to the coastline

- The lateral boundaries corresponding to sections of the coastline that maintain the coastal processes inside the unit to enable management of the coastal processes from a system-based perspective

Table 4.1: List of Coastal Zone Management Units.

Island	CZMU	Location
Mahé	CZMU-01	North East Point
	CZMU-02	Anse Aux Pin
	CZMU-03	Au Cap
	CZMU-04	Anse Royale
	CZMU-05	Baie Lazare
	CZMU-06	Anse a La Mouche
	CZMU-07	Beau Vallon
	CZMU-08	Anse Boileau
	CZMU-09	President’s Village
La Digue	CZMU-10	La Passe
	CZMU-11	La Passe - south
	CZMU-12	Anse Severe
	CZMU-13	Anse Gaulette
Praslin	CZMU-14	Anse Consolation
	CZMU-15	Grand Anse
	CZMU-16	Anse Kerlan
	CZMU-17	Anse Boudin
	CZMU-18	Cote D-Or

For each CZMU, appendix H includes a summary card (see figure 4.3) with critical information to advise coastal management and priority interventions in each unit. The summary cards complement and summarize the contents of this chapter and represent a management tool for informing decisions and management actions in each CZMU. They include:

- A synthesis of the main information and analyses from the available reports, studies, and datasets on coastal hazards and coastal processes
- Current and historical coastal management practices and projects implemented
- An outline of priorities, recommendations, and considerations for coastal management and future interventions
- Useful resources and data
- Satellite image and mapping information on topographic levels (3-, 5- and 10-metre ground heights above mean sea level), roads, buildings and hotels, and other relevant information (such as photos) and notes

The summary cards are intended to constitute a planning and management tool that can be regularly updated; digital versions of the maps have been prepared in Quantum Geographic Information System (GIS), an open source software, so they can be updated and adapted in the future.

4.3 Actions

4.3.1 Monitoring and research

The root causes of current and future coastal problems and risks include: development in hazard-prone areas, limited coastal protection investment, degradation of coastal ecosystems, and the effects of climate change (such as sea level rise and thermal stress that can damage coral reefs). Many of these processes are insufficiently monitored. More comprehensive mapping and monitoring of coastal areas is necessary to facilitate coastal management.

Sustainable coastal management practices require a good understanding of coastal processes. For this, accurate information is needed on coastal processes and dynamics, especially in the face of climate change. This baseline information—which is currently lacking in many places (Government of Seychelles 2015; Government of Seychelles 2017)—is essential for designing effective investments in coastal infrastructure. An ambitious coastal mapping and monitoring program (MM) for the islands of Mahé, Praslin, and La Digue, with a focus on the CZMUs is identified in the next section of this plan. This program is designed to allow more proactive planning of needs and actions. The mapping and monitoring program focusses on developing:

- **MM1.** A comprehensive baseline **nearshore bathymetry map**, with special attention to shallow bathymetric features, which are key to the beach condition, and the complex reef environments.
- **MM2.** Comprehensive **monitoring of beach erosion-accretion patterns** by profiling vulnerable sites but also using remote sensing technologies that can allow more affordable, swifter, and regular surveillance of the coastal zones and their condition. This may include an assessment of

Figure 4.3: Example of a Graphic in One of the Summary Cards.

Note: The contour lines represent ground heights. Hotels, buildings and roads are also represented.

sediment balances (sources and deficits), the relationship of such sediment balances with historical (and potential future) shoreline evolution, and an assessment of possible sources of sand for beach nourishment and restoration.

- **MM3.** A comprehensive map of **coastal and benthic habitats** as a baseline and to allow subsequent monitoring.
- **MM4. Coastal hydrodynamic data.** Better information on coastal hazards is crucial not only for designing setbacks for flood and erosion risk, but also for the optimization of designs of coastal armouring, detached breakwaters, and submerged structures. This information should include: wave propagation information, surf zone currents, and sediment transport rates. Large proposed interventions and CZMUs where longshore transport is the dominant driver should be given priority.
- **MM5. Coastal exposure and vulnerability mapping.** Identify sites potentially most affected by flooding and erosion and link to coastal setbacks and land use policies.
- **MM6. Enhanced monitoring of flooding and overtopping events,** to identify and anticipate the need for protection ahead of further damage (such as road damage that increases the need for spending and reparations) Develop a national (spatial) data-sharing policy to enhance cross-sectoral collaboration for coastal mapping and monitoring.

Shoreline evolution and beach monitoring should be prioritized in all the CZMUs, but particularly in those where beach and dune restoration and vegetation restoration are the best alternatives for coastal protection. Shoreline evolution can be periodically monitored from satellite and aerial imagery.

Table 4.2 outlines the priority actions for the CZMUs. (Specific information on actions and recommendations for each CZMU can be found in the summary cards.)

4.3.2 Coastal infrastructure

This CMP presents a mid- to long-term strategy for investments, regulations, and policy for coastal infrastructure.

Table 4.2: Actions for Coastal Zone Management Units.

Action	Mahé	La Digue	Praslin
MM1: nearshore bathymetry	CZMU-01 North East Point CZMU-02 Aux Pins CZMU-03 Au Cap CZMU-04 Anse Royale CZMU-09 President's Village	CZMU-10 La Passe CZMU-11 La Passe South CZMU-12 Anse Severe CZMU-13 Anse Gaulette	
MM2: monitoring of beach erosion/accretion pattern	CZMU-01 North East Point CZMU-05 Baie Lazare CZMU-06 Anse a La Mounche CZMU-07 Baie Beau Vallon CZMU-08 Baie Boileau		CZMU-14 Anse Consolation CZMU-15 Grand Anse CZMU-16 Anse Boudin
MM3: coastal and benthic habitats	CZMU-01 North East Point CZMU-02 Aux Pins CZMU-03 Au Cap CZMU-04 Anse Royale	CZMU-10 La Passe CZMU-11 La Passe South CZMU-12 Anse Severe CZMU-13 Anse Gaulette	
MM4: coastal hydrodynamic data	All	All	All
MM5: Coastal exposure and vulnerability	All	All	All
MM6: Monitoring of flooding and overtopping events	CZMU-01 North East Point CZMU-05 Baie Lazare CZMU-06 Anse a La Mounche CZMU-07 Baie Beau Vallon CZMU-08 Baie Boileau		CZMU-14 Anse Consolation CZMU-15 Grand Anse CZMU-16 Anse Kerlan

Current practice in coastal infrastructure deployment, maintenance, and permits takes a short-term perspective. As a consequence, urgent problems are generally addressed through reactive and hard engineering approaches such as the (re)construction of river outlets through concrete revetments, seawalls, and rock armouring to protect land or road sections threatened by erosion and flooding. Furthermore, some of the designs implemented thus far have failed or have had to be repaired shortly after their construction (see photo 4.1). This plan presents a shift toward proactive planning of effective infrastructure that is sustainable and can be maintained in the longer term.

Most of the coastal infrastructure in Seychelles is constructed and maintained by the government. In some areas, coastal infrastructure is financed by private parties, for example to protect a beach near a property. Specific guidelines and considerations for these situations are also provided because these interventions can affect other public lands in adjacent ecosystems or result in unintended effects elsewhere. This further demonstrates the need for integrated planning and design within the CZMU.

Photo 4.1: Examples of Existing Coastal Infrastructure Affected by Coastal Erosion or Flooding.

a. Road reparation in Praslin

b. Failed riprap revetment in front of vegetation belt and road section in Praslin

c. Large shoreline recession at historical seawall in La Digue

Source: World Bank 2018.

At the national level, there is a need for better guidance in engineering design and project implementation to develop more effective and sustainable infrastructure for coastal protection. Chapter 5 presents an implementation plan and provides some recommendations for how to design coastal projects. Chapter 5 includes:

- Adaptive coastal management—periodic updates of the CMP
- Implementation guidance and protocols for coastal infrastructure projects for contractors and government staff
- A proposal to integrate coastal infrastructure (including beach and dunes, coastal vegetation, coral reefs, and mangroves) in marine spatial plans and land use planning.

Different coastal infrastructure interventions are considered for each CZMU depending on the dominant processes, types of coastline, and other factors. The recommended interventions for each CZMU are included in each summary card. An extended description of coastal infrastructure options is given in appendix F.

The different coastal infrastructure measures are organized depending on the location along the coastal zone (see figure 4.4):

- **Nearshore interventions** involve projects designed to modify the wave and current patterns and act on erosion and flooding control. If well designed, these approaches can be very effective and provide protection to large sections of the shoreline. However, these interventions are more challenging to study, design, and implement. They include detached breakwaters, low-crested breakwaters, reef breakwaters, and nonstructural coral restoration.
- **Shoreline interventions** are meant to hold the shoreline in place, avoiding further erosion, but can have local erosional effects. These measures include hard options, such as retaining seawalls, rock armouring, and groynes, but also other soft or green infrastructure options such as restoration of the beach profile and beach-dune systems. However, it is important to study these interventions for their cross- and longshore effects. For example, groynes have upstream and downstream effects that need to be accounted for to determine the adequate length and spacing between structures but also to foresee effects in the rest of the CZMU.
- Backshore measures take place further away from the shoreline but are critical to coastal protection and the response of the coastal system to storms (see, for example, the discussion of natural cycles of beach systems in chapter 3). Maintaining the natural processes of the shorelines is a form of sustainable coastal adaptation that also reduces the need for future interventions, for instance, flexible control of the evolution of coastal dunes through a reduction of wind action with several techniques (plantings, wind-shields,

and cover), or preservation of backshore vegetation as a flood and erosion buffer as short- and medium-term protection against sea level rise, particularly during storms. The measures in this typology include backshore restoration, vegetation restoration, and coastal setbacks that respect the dynamic processes of beach and dune systems. These interventions may also involve delineating coastal setbacks for the protection of the vegetation (to avoid degradation of vegetation and the effects of loss of coastal protection on those using the beaches for recreation) and therefore the beach profile, or limitation, concentration, or elimination of road access to beaches.

The different projects are described below, but more insight is provided in chapter 5.2.2 in the National Coastal Infrastructure Plan (NCIP). This classification is also in line with the climate change adaptation strategies of "protect, accommodate, and retreat" as outlined in JICA (2014 and table 4.3).

The proposed interventions are described below:

Nearshore interventions:

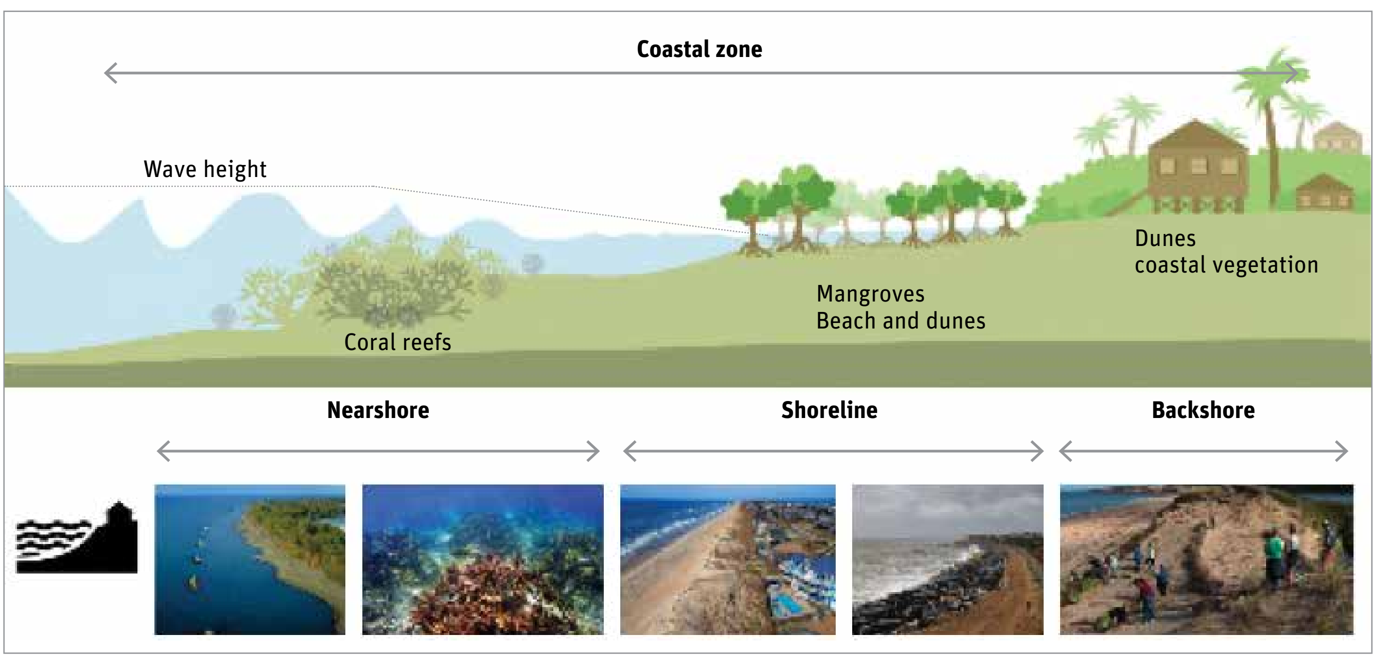
- **Detached breakwaters** are hard engineering measures built in the sea, parallel to the coast, to influence wave propagation and currents and hence reduce wave energy eroding the coastline. Their goal is to prevent beach erosion through the reduction of wave heights in the lee of the structure and reduction of longshore sediment transport (see appendix F). The higher the breakwater, the lower wave energy transmission, but at the cost of greater aesthetic impact. Detached breakwaters can be designed as single, segmented, emerged, or submerged, depending on the shoreline. However, submerged structures for coastal erosion have not been used in Seychelles. Some submerged or low-crested structures can be used for erosion control and influence the hydrodynamic system. For example, landfilling and artificial islands create similar shadowing effects, which are beneficial for coastal sections in the protected zone. Furthermore, there are technical guidelines for the environmental design of these structures that can

Table 4.3: Coastal Infrastructure Options to Target Erosion.

Climate change adaptation strategy	Technology components for coastal erosion
Protect	Nourishment and beach restoration; groyne; detached breakwater; coastal revetments
Accommodate	Regulation; environmental impact assessment; risk mapping; reinforcements and improvement to houses; awareness raising; emergency protocols and response; early warning systems
Retreat	Setback and zoning rules; relocation

Source: Based on data from JICA 2014.

Figure 4.4: Coastal Zone Representation Including Infrastructure in each Section.



Source: Figure adapted from The Nature Conservancy, https://coastalresilience.org.

be used for design and implementation. Although groynes have been the prioritized structures for longshore transport management, detached breakwaters can create less downstream disconnection and erosion areas and should be studied for coastal sections where longshore sediment transport requires intervention to slow down the transport of sediment and accrete the shoreline. In these cases, appropriate sections need to be designed for each CZMU and studied in detail to identify where they could be applicable, the most appropriate design, and whether they should be combined with nourishment of sand to advance the shoreline.

- **Breakwaters** are hard measures that aim to shelter harbour basins and entrances. Breakwaters are made of rocks or concrete blocks that dissipate wave energy and modify wave propagation, in addition to reflecting wave energy back into the sea.
- **Low-crested submerged and reef breakwaters** are submerged, or slightly emerged structures designed to be significantly overtopped by waves. Their design is similar to that of detached breakwaters, but a moderate transmission of wave energy is allowed while maintaining significant wave dissipation. Their behaviour is based on the same mechanisms that make coral reefs a natural infrastructure. They can used in ports for protection of outer basins where wave transmission by overtopping is acceptable, but most typically, are used in shallow water for coastal protection. Low-crested breakwaters can be combined with environmental restoration or coral gardening.
- **Coral reef restoration** involves technologies to restore or strengthen the natural status of coral reefs and maintain and improve their ability to reduce wave energy reaching the shore, thus protecting a beach from erosion and maintaining the coastal processes (propagation of waves and current circulation) that ensure shoreline stability. These techniques may involve coral gardening and natural and artificial measures (Jaap 2000)fisheries and tourism, coastal protection, geological processes, and aesthetic wonder. A principal cause of reef damage in Florida is ships running into reefs. The other major human impact on Florida's reefs is dredging for beach renourishment and channel maintenance. In response to chronic reef damage, federal and state agencies and consultants have developed techniques to restore, as best possible, reefs impacted by human disturbance. These efforts include salvaging sponges and corals, removing loose debris from the reef, rebuilding three-dimensional (3-D. Structural reef restoration and augmentation are examples of coral restoration that involve physical structures or substrates (such as large boulders or underwater structures) on existing degraded coral reefs to raise their height and enhance coral recruitment to reduce wave energy dissipation. Corals can be planted on the structural substrate, but in the case of coral disappearance (for example through bleaching), the physical structure remains and maintains a level of wave dissipation.

Shoreline interventions:

- **Seawalls and armouring:** Coastal armouring includes the use of seawalls, revetments, bulkheads, levees, and dikes to maintain the shoreline and prevent erosion and flooding. Solid structures along the shoreline (such as rock armouring and retaining walls or longitudinal beach-top walls) permit the maintenance of dwellings, but they harden and artificialize the shoreline and require regular maintenance and potential sand recharging or other protection to prevent failure and scouring. This is usually the approach of last resort and is most appropriate where the primary problem is one of storm-induced damage rather than chronic erosion. However, it has been the typical response to intermittent as well as chronic erosion hazards.
- **Groynes:** Coastal erosion control techniques use structures that are designed to reduce sediment losses and thus slow the rate of erosion. The intent is to protect the backshore by trapping and holding sand to stabilize the beach. The trapping characteristic of this approach may cause adverse impacts to adjacent beaches if sand that would normally migrate through or accrete on neighbouring beaches is held in the project area.
- **Beach and dune restoration:** Beach restoration involves the placement of sand on an eroding shoreline to resupply deficiencies in natural sand volume caused by waves and currents or human activity, or to counteract shoreline retreat caused by sea level rise. The restoration of a dune system with endemic coastal vegetation may constitute a major component of the effort because the dune system further enhances the sand storage capacity of the shoreline and provides additional mitigation against the effects of storm or seasonal wave erosion. Dune and beach restoration recognizes that the beaches and dunes form an interconnected system, including the upper beach profile vegetation. These interventions aim to fight coastal erosion and future flooding to manage the shoreline allowing the

natural processes to advance to and retreat from the shoreline as needed. These interventions should be complemented with appropriate vegetation reinforcement and setback and land use policies. Beach restoration projects, including beach nourishment through sand recharge, will require (1) identifying sand borrow areas, and (2) coordinating lower beach profile restoration with upper beach restoration through vegetation and maintenance of setback and backshore elevation for flood protection.

- **Backshore restoration and coastal setback** measures involve management of the back shore for maintaining the beach-dune processes, restoration of dunes (elevation and vegetation cover) to prevent beach erosion and provide flood protection, the use of vegetation as reinforcement of the beach profile, and a green belt to provide damage to the active beach profile. This approach is a form of " **accommodation and retreat**," that is, the beach is allowed to behave as it will regardless of the causes of erosion or the impact that shoreline retreat may have upon the upland region. This is an appropriate response in areas where erosion or flooding problems are so severe that hazard mitigation is not economically viable or in areas where the natural appearance of the shoreline, and the natural patterns of shoreline change, are important to the character and attractiveness of the system. Accommodation and retreat can be implemented through a coastal setback instrument. These measures also involve wetland and watershed management to prevent flooding or deterioration of the natural coastal infrastructure through pollution of the coral reefs.

Given the different physical conditions and processes in the different CZMUs, the following actions are prioritized in table 4.4 for each CZMU. Descriptive information on the actions is found on the CZMU summary cards.

Table 4.4: Coastal Infrastructure Actions by Coastal Zone Management Unit.

Action	Mahé	La Digue	Praslin
Nearshore coastal infrastructure			
Detached breakwaters	CZMU-03 Au Cap CZMU-04 Anse Royale	CZMU-11 La Passe South	CZMU-16 Anse Kerlan (south)
Low-crested or submerged structures	CZMU-09 President's Village CZMU-03 Au Cap		CZMU-14 Anse Consolation CZMU-15 Grand Anse
Coral reef management and/or restoration	CZMU-01 North East Point CZMU-02 Anse Aux Pins CZMU-03 Au Cap CZMU 04 Mahé (Anse Royal - north) CZMU-05 Baie Lazare	CZMU-10 La Passe CZMU-11 La Passe South CZMU-12 Anse Severe	
Shoreline coastal infrastructure			
Groynes		CZMU-10 La Passe	CZMU-16 Anse Kerlan (north)
Seawalls and armouring	CZMU-02 Anse Aux Pin CZMU-07 Beau Vallon CZMU-08 Anse Boileau	CZMU-10 La Passe CZMU-13 Anse Gaulette (road section)	
Beach and dune management or restoration (sand recharge)	CZMU-01 North East Point CZMU-03 Au Cap CZMU-06 Anse La Mouche CZMU-07 Beau Vallon CZMU-08 Baie Boileau CZMU-05 Baie Lazare	CZMU-12 Anse Severe CZMU-13 Anse Gaulette	CZMU-15 Grand Anse CZMU-16 Anse Kerlan (south) CZMU-18-Cote D'Or
Backshore dune vegetation management or restoration	CZMU-01 North East Point CZMU-03 Au Cap CZMU 04 Mahé (Anse Royal - north) CZMU-05 Baie Lazare CZMU-07 Baie Beau Vallon	CZMU-12 Anse Severe CZMU-13 Anse Gaulette	CZMU-15 Grand Anse CZMU-16 Anse Kerlan CZMU-17 Anse Boudin CZMU-18 Cote D'Or

Table 4.4: Coastal Infrastructure Actions by Coastal Zone Management Unit. (cont.)

Backshore coastal infrastructure

Wetland management or restoration	CZMU-01 North East Point CZMU-07 Beau Vallon	CZMU 10 La Digue-01 (La Passe) CZMU 11 La Digue -02 (La Reunion)	
Watershed management	CZMU-02 – Anse Aux Pins CZMU 04 Mahé (Anse Royal) CZMU 05 Mahé (Baie Lazare) CZMU 06 Mahé (Anse a La Mouche)	CZMU 10 La Digue-01 (La Passe) CZMU 11 La Digue -02 (La Reunion) CZMU 12 La Digue - 03 (Anse Severe) CZMU 13 La Digue - 04 (Anse Gaulette)	CZMU 14 Praslin-01 (Anse Consolation) CZMU 15 Praslin-02 (Grand Anse) CZMU 16 Praslin-03 (Anse Kerlan)

4.3.3 Risk-based land planning

The coastline of Seychelles' main islands is increasingly developed as the population grows and the tourism industry expands. The scarcity of land on the coastal plain is particularly visible in Mahé, where large-scale land reclamation has taken place. However, similar processes are present in Praslin and La Digue. Land planning to manage coastal risk needs to be developed on the three main islands.

Risk-based land planning can consist of measures that address the exposure or the vulnerability to hazards. Measures that address exposure aim to limit the amount of development in areas that are likely to be affected by flooding or coastal erosion, whereas the measures that address vulnerability make properties, people and infrastructure already in these areas less susceptible to flooding or coastal erosion.

In planning instruments, such measures are implemented through restrictions or conditionalities. First, a land use plan could restrict new development (or existing development through resettlement) in flood hazard zones. For example, in many countries it is common practice not to develop zones affected by floods of 1-in-25 or 1-in-100-year return periods.

Second, planning instruments can enforce certain conditionalities for new or existing properties and infrastructure, such as building codes to ensure that buildings and infrastructure can withstand a design flood. Such conditionalities can be integrated in land use plans for specific zones, but can also enforced through permitting or an environmental impact assessment.

In a Practice Note on Flood Management in Small Island Developing States in the Pacific, the World Bank provides a scheme to evaluate current practices of risk-based land use planning in relation to international best practices (World Bank 2017).

The **current process of risk-based land planning** in Seychelles for new developments consists of the following steps:

- Developers may request preplanning advice from the Planning Authority on their applications.
- Developers file applications for new developments with the Planning Authority, which determines whether the application aligns with the Seychelles Strategic Land Use and Development Plan (SSLUDP). Subsequently, the application is sent to CAMS and other sections in the Ministry of Environment, Energy and Climate Change (MEECC) for evaluation.
- Coastal flood risk for new developments is evaluated in the permitting phase by policy officers of CAMS in the MEECC.
- The evaluation of the application for flood risk by CAMS policy officers is guided by two informal policies: (1) a coastal setback of 15 to 25 metres from the high-water mark to protect against coastal flooding and to protect coastal vegetation, and (2) a qualitative evaluation of historic flooding events based on local knowledge.

In figure 4.5, this current planning practice is described as "proxy control" of flood and erosion risk (riparian reserve), where the informal setback is applied as a proxy for coastal flood risk and erosion prevention through the protection of coastal vegetation. In addition, although perceived historic flood levels are considered, this process is informal and subjective and does not use information on the historical or future flood risk.

Given the increasing concentration of people, infrastructure, properties, and economic activity in low-lying coastal areas and the foreseen climate change impacts, Seychelles´ coastal risk will increase. The need to improve risk-based land planning practices in Seychelles is urgent. Several strategic policy documents have highlighted the need for implementing risk-based planning:

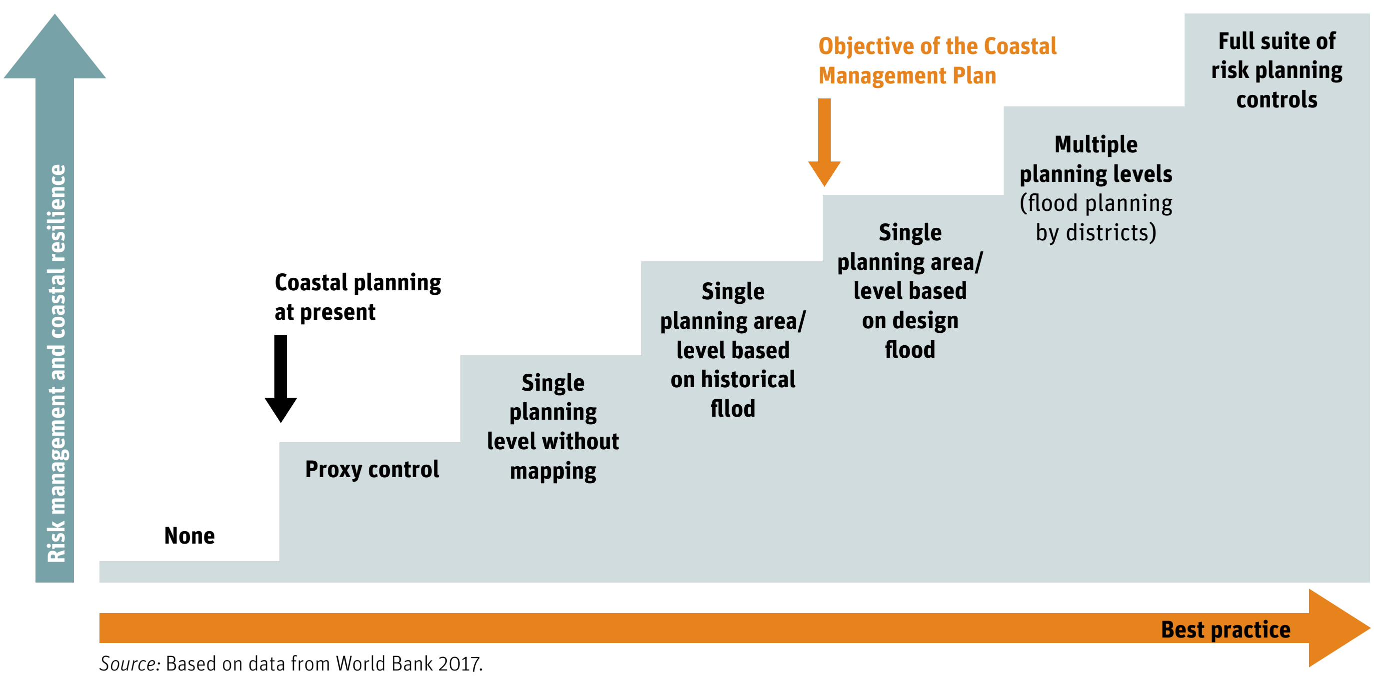
- The **Blue Economy Roadmap** (2018): One of the principles laid out in this strategic document is "reducing vulnerability to economic and environmental shocks and resilience planning."
- The **SSLUDP** (2015) specifically highlights the need for risk-based land planning in Seychelles:
  - One of the outcomes of the spatial strategy is: "address issues of climate change and resilience in locating new development"
  - The SSLUDP also stresses that "biodiversity resilience to climate change will be further promoted through the protection of areas to the landward side of naturally resilient habitats such as mangroves. As the sea level rises, these habitats will 'migrate' inwards, thereby protecting the terrestrial area to the landward side of these habitats"
- The **Sustainable Development Strategy** (SDS) (2012) identifies "Land Use, Coastal Zones and Urbanization" as one of the key programs for improving land use planning and making the coast more resilient against climate change.
- The **Seychelles National Climate Change Strategy** (CCS) (2009) states that "drainage plans and guidelines for development on both coastal and hilly slopes are lacking and where present poorly enforced." In addition, the adaptation action plan in the CCS outlines several coastal management actions, including investment in green infrastructure for coastal adaptation and coastal restoration projects.

This CMP proposes a number of actions to improve risk-based planning practices. The ambition is to advance from the current level—proxy-based planning—to a single planning level based on design flood practice (figure 4.5).

The following actions are proposed in line with international best practices:

- **Define and implement a coastal setback policy** (box 4.1). In the proposed policy, the coastal setback is (1) a proxy for a coastal flood hazard area; and (2) a planning tool to

Figure 4.5: Best Practice Levels of Risk-Based Land Planning.



Source: Based on data from World Bank 2017.

Note: The lower level indicates the present situation, and the upper arrow indicates the foreseen level of risk-based land planning after implementation of the CMP.

protect the beach and dune systems as well as coastal vegetation to safeguard coastal integrity. Although hazard maps for planning remain unavailable, a static coastal setback can ensure the protection of coastal systems and against the immediate impact of overtopping and coastal flooding.

- **Develop flood hazard maps for coastal and pluvial-fluvial flooding.** It is an international best practice to integrate flood hazard zones into the SSLUDP (World Bank 2017). Such integration requires commonly accepted hazard maps validated at the local level. To develop these products, specific expertise on flood hazard mapping needs to be strengthened or outsourced.
- **Integration of flood hazard maps in the SSLUDP:** Successful integration of flood hazard maps in land use planning requires changes in policies and legislation. The SSLUDP needs to be updated to include appropriate measures. Moreover, institutional learning and cross-sectoral collaboration are required to ensure that policies are successfully implemented and enforced.
- **Training for risk-based land planning at the Planning Authority:** Technical risk assessment and risk-based planning training for policy officers at the planning authority and CAMS.
- **Cross-sectoral collaboration and training** to ensure implementation of risk-based planning practices with related sectors such as land transport, the tourism industry, and several other sectors that are developing the coastal zone. If risk-based land planning is to be implemented, training is required to inform and engage these stakeholders.

4.3.4 Capacity building

Implementing the priorities for coastal management requires strong technical capacity in various areas including: geospatial analysis and remote sensing; design and implementation of coastal infrastructure projects; and understanding of modeling the impact of coastal climate change. Studies conducted by the Global Climate Change Alliance (GCCA) project in Seychelles identified the necessity for a capacity needs assessment and a technology needs assessment for climate change adaptation (Government of Seychelles 2017). This study noted that capacity building was required in implementing agencies, including the Department of Energy and Climate Change (DECC) of the MEECC.

These capacity needs are acknowledged in this CMP and prioritized, specifically through the following actions:

Box 4.1: Proposed Coastal Setback Policy.

To regulate development along the coastline, it is common practice in most places in Seychelles to maintain a coastal setback for new developments of 25 metres from the high-water mark. However, such a buffer is not always maintained, leading to properties being located in the flood hazard zone or damaging protective ecosystems. Parallel to and in collaboration with the development of this CMP, the MEECC is developing the National Coastal Setback Policy. This new national policy aims to formalize coastal setback practices along beach-lined coastal areas across Seychelles and thereby mitigate the impact of coastal hazards, mitigate erosion, and protect the scenic quality of the coast.

The key components of the National Coastal Setback Policy (currently in preparation) as they relate to the CMP are:

- Developments shall be set back at a distance of 25 metres from the innermost point of the seaward side of the coastal vegetation line. In the absence of a clear coastal vegetation line, a proxy coastal vegetation line shall be determined based on the overall vegetation line of the coastal area where the property is located.
- Developments behind the setback, but below 3 metres above mean sea level are considered developments in the flood hazard area. For such developments specific construction guidance will be proposed, such as construction on pillars.
- Owners of existing properties located in flood hazard areas should invest in coastal infrastructure (either engineered or nature-based) to reduce their vulnerability to flooding.

- **Geospatial mapping:** training of MEECC staff in open source geospatial information systems and Openstreetmap software for (1) the development of risk maps and identification of areas of highest potential for impact and damage; and (2) maintaining coastal management summary cards and updating information
- **Flood mapping:** how to understand and use flood hazard maps for coastal management
- **Project design and implementation** of coastal infrastructure projects, including coastal modeling
- **Adaptive coastal management:** training to build capacity in CAMS to continuously update the coastal management summary cards and periodically revise the CMP
- **Nature-based and hybrid solutions:** how to integrate and implement nature-based solutions in coastal planning
- **Coastal modeling and coastal design:** developing baseline data and tools to assess coastal projects, potentially with a National Coastal Modelling Suite that can be applied by the government and contractors to assess the effects of coastal projects on flooding and shoreline evolution
- **Network:** host international conference or similar events on green infrastructure and nature-based solutions in Small-Island Developing States (SIDS)
- **Coastal Zone Management Units:**
  - Specific training and capacity building in each district level, or at least in each CZMU before interventions are implemented, and at the planning phase.
  - Follow-up district-level training on coastal adaptation and use of CZMU summary cards as a planning tool.

In addition to the identified training needs, the government of Seychelles acknowledges that more capacity for staffing, facilities, and budget is needed structurally to safeguard coastal resilience for the future, especially considering the expected impact of climate change in Seychelles.

4.3.5 Awareness raising

There is a need for awareness raising among the general public and among sectors in government, civil society (such as school and university students and researchers), and the private sector. Cross-sectoral awareness raising among government sections should address coastal risks, coastal management priorities, and the effects of coastal climate change and adaptation needs. This is especially important in the CZMUs where risks and potential solutions are most pressing. Communication tools such as videos, factsheets, and posters could facilitate this process. For communication with the general public, videos and infographics could serve as communication tools. An outline of potential actions includes:

- Develop communication materials to inform other sectors such as tourism, investment companies, infrastructure, and transport agencies
- Raise awareness among the population and district administrators of the importance of maintaining the coastal ecosystems for resilience and flood prevention using visuals, videos, and infographics describing the functions of this natural infrastructure
- Education programs in schools focusing on the impact of climate change and the importance of coastal ecosystems for Seychelles
- Strengthen collaboration with NGOs and other partners on the communication of adaptation projects

5. Implementation agenda

This chapter presents an implementation agenda for the coastal management actions and priorities outlined in chapter 4. These actions based on a review of current local and international knowledge, practices and projects, projects that are planned already, protection needs, and stakeholder and government consultation.

Section 5.1 provides recommendations on how to design and implement projects and update the Coastal Management Plan (CMP), and section 5.2 provides an implementation plan that prioritizes the actions presented in chapter 4.

5.1. Coastal management for coastal resilience

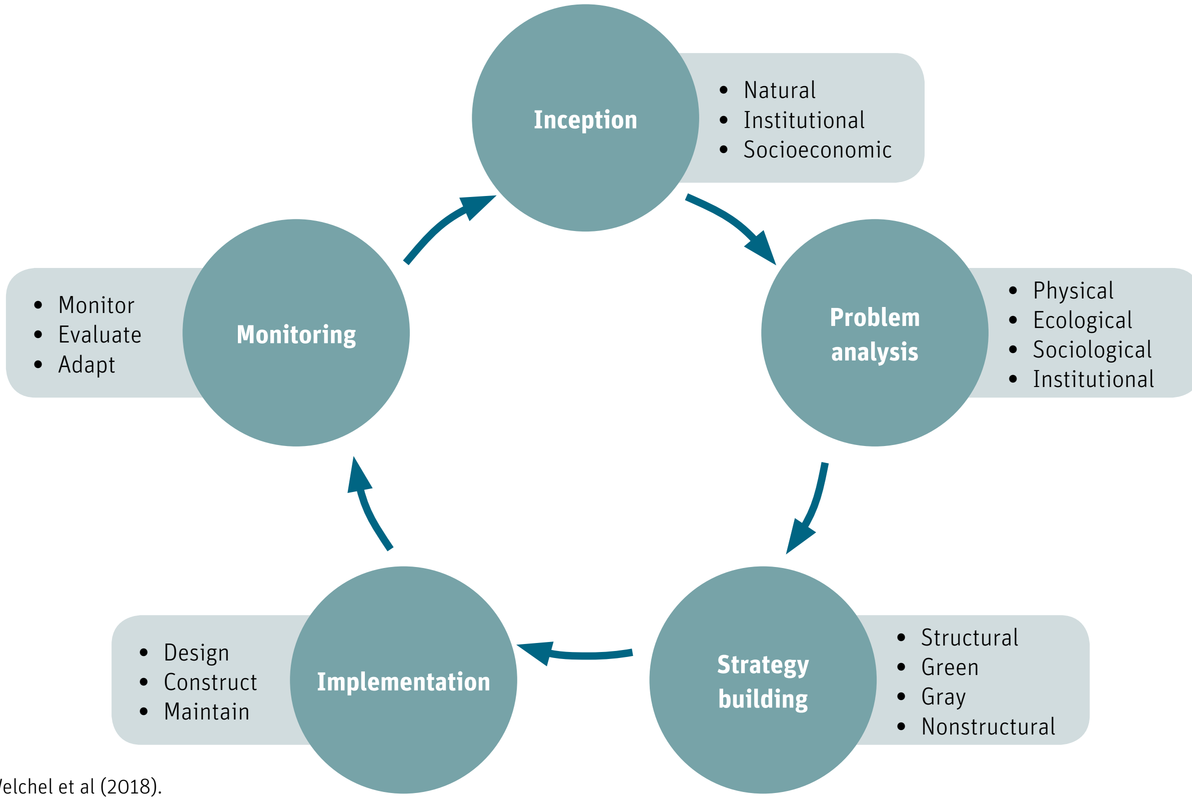
5.1.1. Adaptive coastal management

Current risks and added climate change challenges in coastal areas need to be addressed through integrated approaches that address threats, conflicts of interest, and the littoral or coastal process and dynamics (both the concentration of human population, activities, and settlements in coastal areas and sediment transport patterns). Adaptive coastal management involves a structured, iterative process of optimal decision making in the face of uncertainty, with an aim of reducing uncertainty over time through systematic monitoring (figure 5.1). In this way, decision making simultaneously maximizes one or more resource objectives and, either passively or actively, gathers information needed to improve future management.

Adaptive management should be considered in the design and adjustment of each project whenever possible. As shown in figure 5.1, this process starts with the recognition of adaptation and risk management needs from both natural (new storm impacts or reef degradation) and socioeconomic changes (new areas developed or new infrastructure) in the coastal zone. The analysis of problems and protection needs could therefore change in the future, which would require adapting the strategies and the prioritization of measures, including coastal structures and green infrastructure options. The implementation of these measures should also be monitored so the information on their performance (such as the structural stability of riprap sections and other downstream effects) can inform the new designs or enable corrections in the implementation plan and agenda.

This adaptive management cycle applies not only to overall coastal management, but also to individual projects and actions. A process is proposed in the following section that can be applied to the design and adaptive management of single interventions, at the project and at the scale of a Coastal Zone Management Unit (CZMU).

Figure 5.1: Adaptive Coastal Management Process Using General Policy and Planning Cycles as Integration Points.



Source: Welchel et al (2018).

The CMP will be updated, revised, and appropriately adapted every five years to reflect the changing conditions in the coastal zone (areas at risk, development, policy and regulation). Specifically, the following steps should be taken:

- Revise coastal risk assessment (see chapter 3) to better understand the coastal impacts and causes. This information is critical to inform effective solutions and appropriate management actions.
- Assess changes in ecosystems, bathymetry, and impacts of storms. This information helps understand, refine, and inform actions and the need for coastal protection or amend inadequate or incorrect management actions (such as addressing the causes of reef degradation or vegetation deterioration in the backshore of beaches).
- Revise, add, and adapt the CZMUs and the monitoring priorities as needed to account for new realities and new data availability in the coastal zone.
- Revise priorities for coastal management (see chapter 4).
- Record coastal infrastructure implemented, including, costs, sections, and the monitoring of performance and effects within the CZMUs where the project was implemented.
- Revise and adjust the Implementation Agenda and CMP (section 5.3).

5.1.2. Guidance for designing and implementing green and grey coastal infrastructure projects

It is key to follow a consistent procedure for the design and planning of coastal infrastructure projects. Some guiding principles for the engineering of these projects are provided below, while more elaborated technical insight is provided in appendix G.

The solution to coastal engineering problems begins with an understanding of the root causes of coastal impacts and the need for a coastal solution. The planning and design of coastal infrastructure is the umbrella under which the project evolves from conception to functional, detailed technical design. **The design team should understand the causes and evolution of the system** to provide an effective solution before any intervention is undertaken.

The phases and steps listed below ensure the problem is addressed in an effective way. These steps are proposed based on international best practices.

- **A coastal modelling study** of the CZMU should address:
  - Hydrodynamic conditions: offshore wave climate and wave propagation and currents patterns
  - Sediment transport patterns and coastal shoreline change
  - Runup and flooding, including areas affected
- **Assess the expected situation without the project**: Assess coastal impacts and the potential benefits of reducing these risks. Alternative schemes are measured against the without-project conditions, that is, what would prevail in the future if no project is constructed. This is the foundation for evaluating the potential for alleviating the problems and maximising the opportunities. The without-project condition should specify potential increases in flooding and erosion.
- **Prefeasibility analysis of possible alternatives:** Formulate alternative plans in a systematic manner (at a reconnaissance level) to ensure that all reasonable alternative solutions are identified early in the planning process. The promising alternatives will be refined in subsequent iterations. Each alternative should be assessed by how well it resolves the problem while meeting other constraints (such as budget or technical resources) and whether it does so in a cost-effective way. The benefits and cobenefits (such as to landscape value, tourism, and fisheries) of each alternative will be compared against the without-project plan. Analysis of each alternative will also need to consider constructability and long-term operability within the constraints imposed by the local conditions, for example, whether sand is available for regular renourishment of a beach, or whether concrete or machinery can be deployed in an inaccessible area.
- **Selection of alternative:** Compare the benefits and effects of the alternative solutions and find the most feasible and reasonable option. The alternatives should be compared against the without-project conditions to assess how the proposed solution addresses the original coastal problems. These comparisons can be made on the basis of physical effectiveness, economic costs and benefits, environmental quality, and other social benefits.
- **Detailed construction design:** Test the alternatives to make sure that the project will survive the impact of expected events (stability) and still be able to perform its intended function (functionality).
- **Monitoring and adaptive management:** Postconstruction inspection and monitoring ensure that the construction conforms to the design and evaluate the project's performance.

Considerations for the assessment of coastal impacts of large-scale land reclamation projects

In view of the major economic benefits from investments on reclaimed land, such as on Eden Island in Mahé, the reclamation of more land in the future should be assessed from a coastal resilience and management perspective. However, these projects should consider that reclaimed areas of the ocean occupy the original seabed, causing a loss of existing ecosystems and the services they provide. Also, land reclamation modifies the circulation and processes in adjacent coastal areas, which can have adverse effects in other communities and coastal areas.

According to the Environment Protection Act (see table 2.1), a class-1 environmental impact assessment (EIA) is required for land reclamation projects. The current guidelines for a class-1 EIA[6] acknowledge the need for a systems perspective when analyzing environmental impacts, but lack specificity on the effects on coastal processes. Historic EIAs for reclamation projects, such as the EIAs conducted for phase III (1998) of the reclamation and the reclamation of Ile Aurore (2010) address the effects of changing currents to some extent, but did not foresee the reported beach loss at North East Point. For example, a recent study has concluded that this beach loss was partly caused by current modifications caused by reclamation activities (Borrero et al. 2016). Besides the lack of mitigation measures focusing on coastal processes, there is a lack of enforcement of the mitigation measures that were proposed in the EIAs. Several of the mitigation measures proposed in historic EIAs on land reclamation have not been implemented.

Either a number of revisions to the EIA guidelines or a different interpretation of the EIA process are required to ensure a more inclusive and specific EIA framework with regard to potential impacts and mitigative measures in the coastal zone. These revisions need to be studied in more detail, but could address the following issues:

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6 Republic of Seychelles, Ministry of Environment, Energy and Climate Change. http://www.meecc.gov.sc/index.php/what-we-do/environment-impact-assessment/.

- Detailed guidance on coastal modeling of the effects on processes and circulation in neighbouring areas, particularly focusing on permanent changes in the currents and sediment transport and balances after project implementation.
- Off-site compensation schemes for lost habitat and ecosystems from land reclamation projects. Compensation schemes could include restoration or enhanced protection of similar habitats elsewhere, also referred to as "habitat banking." (Hill and Gillespie 2009; Pontee et al. 2016; City of Lincoln, Nebraska 2004). Alternatively, a compensation scheme could take an innovative approach and compensate for the loss of ecosystem services.
- Specific assessment of coastal defenses to protect the land reclaimed (such as riprap protection, or hybrid schemes that use nature-based approaches to partially compensate for habitat destruction) and risk mapping of flood zones in new areas and the effects on flood and erosion risk in neighbouring areas.
- Assessment of the circulation of water in channels and lagoons, with special attention to runoff drainage to avoid flood impacts landward from the occupied zone.

For example, a comparative analysis of ecological compensation programs in Australia, Germany, South Africa, the United States, and the United Kingdom, found three design aspects that may improve compensation program outcomes: (1) integration of compensation measures with conservation landscape planning; (2) adequate commensurability of ecosystem functions and services (that is, compensation for services loss, rather than for mere surface occupied); and (3) an open-access centralized reporting system (Koh, Hahn, and Ituarte-Lima 2014). The review also identified four safeguards that contribute to the protection of ecological and social benefits: (1) allocating equal responsibility for weighting and monitoring to an organization independent of the project developer; (2) considering local livelihoods at both the impact and proposed compensation site or project; (3) ensuring access to recreation and coastal areas; and (4) stakeholder participation and consultation with the directly affected community.

In Seychelles, special attention should be paid to the effects of runoff flooding and coastal flooding and erosion from a risk-planning perspective. Some reclamation projects have coastal protection benefits behind, but other adverse effects along shore. They may also create stagnant water and other flooding-related problems in other communities.

The four recommendations and safeguards outlined above should be applied to enable responsible coastal management in land reclamation projects.

5.2. Implementation plan for prioritized actions

5.2.1. Overview

The implementation plan proposes a number of actions and an investment agenda that can provide protection in the coastal zones that were identified as priority areas. The implementation plan focuses on investments in both traditional and nature-based solutions. Hereafter, we will refer to them as "grey" and "green" coastal infrastructure. The implementation plan also includes the needed investments in monitoring and research and capacity building that are required for the planned investments in coastal infrastructure.

However, it needs to be stressed that this **implementation plan does not secure coastal resilience for the decades ahead**. It signifies an investment portfolio of the most pressing coastal needs for the period until 2024, as identified through a review of coastal studies and the stakeholder engagement process. In addition, the priority areas—the CZMUs—as formulated in this CMP focus on the three main islands and exclude Victoria.

The total cost of the implementation plan is estimated at \$13.2 million, with an additional total expected capacity for effective implementation of 20 percent (\$2.6 million). The costs of no action for the coastal zone have not been quantified for this CMP as a whole, but include the impacts of storms and sea level rise and the consequences of the loss of beaches for tourism and the Seychellois population.

To meet the objectives defined in the introduction of this document, the **actions and investments include both grey and green coastal infrastructure.** The priority actions in this implementation plan are based on a portfolio of already planned coastal infrastructure projects, and green and grey coastal infrastructure actions in high coastal risk zones that were identified in the stakeholder engagement process. The locations are organized by the protection needs and risk levels, according to existing impacts on infrastructure and communities (see chapters 3 and 4). The costs of the planned investments are obtained from historically implemented projects or obtained from other regions for reef restoration.

5.2.2. Implementation plan for coastal infrastructure

The types of measures to control coastal erosion and flooding are allocated by CMZU according to geophysical processes, bathymetric features, and land occupation and uses. The proposed array of measures in this implementation agenda combines construction of hard or heavy-weight maritime structures (groynes or detached breakwaters) or longitudinal beach-top structures (seawalls, rock armouring, or riprap), with green infrastructure solutions (restoration of the natural beach profile and processes, restoration of dunes and vegetation, submerged low-crested reef breakwaters).

In this CMP, the actions are organized by where they are deployed (with potential implications for implementation and modeling) as explained section 4.3.2: (1) measures in the nearshore; (2) measures along the shoreline; and (3) backshore measures. Table 4.4 in chapter 4 prioritizes these measures by CZMU. In order to enable cost estimation for coastal infrastructure action, unitary costs by type of measure were estimated based on past projects implemented by the Ministry of Environment, Energy and Climate Change (MEECC). Unitary costs for the three types of measures are shown in table 5.1. In absence of better local information, the unitary costs coral reef restoration were taken from a global review of restoration costs (Ferrario et al. 2014).

Table 5.1: Unitary Costs for Implementation Plan.

Action	Unit definition and approximate cost estimate (U.S. dollars)	Considerations and uncertainties
Nearshore interventions		
Detached breakwaters for erosion control	1,600 per m[a]	Based on MEECC cost of groynes; construction needs to be assessed given the lack of examples in Seychelles
Low-crested submerged and reef breakwaters	1,600 per m[a]	Based on MEECC cost of groynes; the costs are assumed to be the same as for detached breakwaters but could be less due to savings in materials
Coral restoration	1,300 per m[b]	
Shoreline interventions		
Rock armouring and retaining walls or longitudinal beach-top walls	Seawall: 3,300–4,000 per m Rock armouring: 600–1,900 per mc	Based on MEEC projects
Retaining wall (including backfilling)	3,700 per m	Estimated from costs in Beau Vallon and Anse Boileau
Rock armouring (including backfilling with sand)	1,800 per m	Estimated from costs in Anse Aux Pin and La Passe
Groynes	1,600 per m	Based on Anse à la Mouche project
Beach and dune management and restoration	Sand recharge: 1,900 per m Restoration of dune and landscaping: 600 per m	Nourishment based on average estimatesd for North East Point, Baie Lazare, Anse Kerlan, and La Passe Dune restoration based on landscaping and beach nourishment costs
Backshore interventions		
Backshore restoration and coastal setbacks	Timber piling and landscaping: 600 per m Dune restoration and vegetation: 600 per m Maintaining setbacks for vegetation and road access control: 600 per m	Based on landscaping costs

Note: MEECC = Ministry of Environment, Energy and Climate Change. Cost estimates were converted from Seychelles rupees at a rate of SR 13.5351 = US$1.

a. Project costs from the United Kingdom indicate that the costs could be lower than the costs of groynes.
b. Based on the median value in Ferrario et al. 2014.
c. Revise and redesign sections for rock armouring, accounting for adequate rock weight.
d. JICA 2014.

Maintaining and restoration of coral reefs as a natural infrastructure

Coral reef restoration and management were identified as key measures for maintaining, conserving, and recovering the natural protection reefs provide. The stakeholder input also confirmed the need to conserve, maintain, and enhance this natural infrastructure for its coastal protection benefits.

Coral reef restoration and conservation may involve a roster of techniques, including artificial reefs; coral gardening and transplantation; physical substrate modification or indirect restoration through water quality management; or establishing marine protected areas. Although maintaining the "living layer" of reefs through coral planting will not provide sufficient friction for flood attenuation, it helps to maintain the reef and avoid further collapse, therefore preserving its current coastal protection. For this reason, coral reef management and restoration should always be considered alongside other measures for coastal protection. Without active management, reefs can degrade further, significantly increasing coastal risk. (Research shows that risk could double in reef environments for each loss of 1 metre in depth of reefs and their frictional dissipation of waves.) Investment in risk prevention is critical.

Proactive reef restoration can be effective for risk reduction. For significant flood attenuation and coastal protection, reef restoration requires a structural substrate, in the form of a submerged or reef breakwater (reef blocks, submerged structures, or artificial reef breakwaters, see Reguero et al. 2018), that can have an effect on coastal processes (wave propagation, currents, and sediment transport) and provide coastal protection.

"Structural" reef restoration could be a promising option but should be carried out through a sequential approach, such as scaling up coastal resilience investment, advances in reef restoration at large scale (including its connection to public-private partnerships), and in combination with hybrid schemes.

Table 5.2 provides an outline of the priority projects and their costs. Costs have been estimated by multiplying the unitary costs estimated in table 5.1 with the estimated size of the project. This list has been developed based on the priority projects from list of actions in chapter 4.

The total costs for the implementation of the plan are estimated at $13,182,000, with an additional total expected capacity for effective implementation of 20 percent ($2.6 million). The investments in monitoring, research, and capacity are described in section 5.2.3.

The implementation plan for green and grey coastal infrastructure is shown in figure 5.2 by priority. The priorities correspond to the priority level column in table 5.2.

- **Current average annual spending:** Average of spending over years 2016 and 2017 in coastal infrastructure projects
- **Planned projects:** Projects that were planned and budgeted before the development of the CMP.
- **High priority projects:** Green and grey coastal infrastructure identified as high priority through stakeholder engagement and informed by coastal risk studies.
- **Remaining National Coastal Infrastructure Plan:** Remaining projects that are included in the Coastal Infrastructure Plan in CZMUs that require coastal protection.

Table 5.2: Projects Recommended by Unit and Implementation Plan.

CZMU	Name	Proposed actions	Priority level	Estimated cost ($, thousands)
01	North East Point	Low-crested breakwater or detached breakwaters	CMP	640
		Coral reef management and restoration	CMP	260
02	Anse Aux Pin	Low-crested breakwater or detached breakwaters	High priority	320
		Rock armouring (including backfilling with sand)	Planned	517
03	Au Cap	Low-crested breakwater or detached breakwaters	CMP	320
		Coral reef management and restoration	CMP	260
04	Anse Royale	Rock armouring (including backfilling with sand)	CMP	54
05	Baie Lazare	Beach and dune management and restoration	High priority	1,425
		Coral reef management and restoration	CMP	260
06	Anse à la Mouche	Backshore dune vegetation management and restoration	CMP	600
07	Beau Vallon	Retaining wall (including backfilling)	Planned	665
		Backshore dune vegetation management and restoration	High priority	600
08	Anse Boileau	Retaining wall (including backfilling)	High priority	421
		Beach and dune management and restoration	CMP	2,850
09	President's Village	Low-crested breakwater or detached breakwaters	CMP	160
10	La Passe	Groynes	CMP	160
		Coral reef management and restoration	CMP	130
11	La Passe - South	Rock armouring with sand nourishment	Planned	185
		Backshore dune vegetation management and restoration	CMP	600
		Coral reef management &and restoration	CMP	130
12	Anse Sévère	Backshore dune vegetation management and restoration	CMP	225
13	Anse Gaulette	Retaining wall (including backfilling)	CMP	111
14	Anse Consolation	Rock armouring (including backfilling with sand)	CMP	54
15	Grand Anse	Backshore dune vegetation management and restoration	High priority	600
16	Anse Kerlan	Groynes	High priority	160
		Backshore dune vegetation management and restoration	CMP	225
17	Anse Boudin	Backshore dune vegetation management and restoration	CMP	300
18	Cote d'Or	Beach and dune management and restoration	High priority	950

Note: CZMU = Coastal Zone Management Unit; CMP = Coastal Management Plan. The estimated costs for projects that were already planned have been left as originally budgeted.

Figure 5.2: National Coastal Infrastructure Plan.

Note: The costs are aggregated from table 5.2, based on the priority level column. The current average annual spending represents sum of estimated annual spending over the implementation period of this CMP (2019–2024).

5.2.3. Monitoring and research and capacity building

This CMP aims to build coastal resilience by addressing risks associated with coastal hazards erosion and flooding by prioritising projects and an infrastructure plan. However, a thorough understanding of these hazards and their potential effects is required to design and implement effective actions. The implementation of these projects requires data, technical capacity, and monitoring.

For example, erosion mitigation and management require an understanding of the causes of erosion. This can be achieved through examination of past land use patterns, including sand mining, circumstances of reef degradation, analysis of historical aerial photos and beach profiles, the history of storms and wave events, and the recollections of long-time shorefront users. Flood mitigation and management require an understanding of areas prone to flooding and the potential impact of public infrastructure (such as roads and transport), private property, population, and the role of coastal infrastructure in protecting the coastline. This can be achieved by identifying flood prone areas (such as coastal zones in the CZMUs below the 3-metre ground height) or by local surveys after storm damage.

In addition, it has also been observed that some of the coastal projects that have been implemented over the years require significant maintenance or have failed due to inadequate design. This highlights the need for improving data collection and modeling capacities to assess other coastal interventions and large-scale projects in the CZMUs.

In section 4.3.1 (monitoring and research actions) and section 4.3.4 (capacity building actions), comprehensive priority actions for these topics have been listed. For cost estimates of a comprehensive monitoring and capacity building program, we refer to recent studies on technology and capacity needs for coastal adaptation (Government of Seychelles 2017).

For this CMP, a number of actions from sections 4.3.1 and 4.3.4 have been prioritized based on the monitoring and research and capacity needs of the proposed implementation agenda for coastal infrastructure (see table 5.2). These actions are often a combination of monitoring and research and capacity building:

- Develop **nearshore bathymetry and benthic mapping** in the CZMUs before implementing projects. Baseline information on bathymetry is essential for the design of coastal projects. Without bathymetry, hydrodynamics cannot be studied, and project implementation and the proposal of solutions are limited. Bathymetry should be developed for all CZMUs, but in particular for those most subject to erosion and flooding and with very complex features, such as coral reefs. Changes in reef health and hence in bathymetry can also modify wave patterns, the current, and sediment transport, and in turn drastically affect flooding and erosion.
- Continuous **monitoring of beach and shoreline evolution, as well as dune and vegetation lines**. Prioritize CZMUs where beaches and coastlines are eroding and where causes cannot be easily identified, in particular in CZMUs dominated by longshore transport.
- **Coastal hydrodynamic data.** Better information on coastal hazards is crucial not only for designing setbacks for flood and erosion risk, but also for the optimization of designs of coastal armouring, detached breakwaters, and submerged structures. This information should include wave propagation information, surf-zone currents, and sediment transport rates. If not possible for all CZMUs, for large interventions, the CZMUs where longshore transport is the dominant driver should be prioritized.
- **Coastal modeling system.** Develop modeling capacity in coastal hydrodynamics and coastal projects. This modeling system should include coastal models, data, and tools to design repeat projects (proposed in section 5.3.2). The modeling system could include, for example, baseline bathymetry and topography data; wave, currents, and sediment transport models; and tools to calculate structures such as groynes, seawalls, and ripraps. In addition to software, adequate training should be provided to the MEECC policy officers and technical staff to mainstream the approach presented in the foregoing section to the design of coastal interventions, which will represent a reduction in costs, regular maintenance, side effects, and increase the functionality and longevity of coastal infrastructure projects.
- **Coastal armouring redesign.** Several rock armouring projects have failed due to insufficient rock size for the slope stability and inadequate design. This represents a misuse of resources and investment because the damaged sections require repair and are ineffective for erosion control. This intervention would create section designs for each CZMU where rock armouring is suggested to protect specific sections of road. The stability of these sections would also benefit from augmenting the beach width in front of the armouring to provide further erosion and flood protection. The rock armouring should also be complemented with vegetation, dunes, and beach restoration in neighbouring areas to counteract the enhanced local erosion. The designs require appropriate consideration of rock size, layers and diametre, and stability design (through the use of a coastal engineering or rock-armouring manual). Wave conditions are required for accurate design, but in absence of better data, extreme values can be used, although they represent an overestimation in design and hence in costs.
- **Monitoring changes in coastal development** to identify and prevent future coastal risks and the need for intervention.

Table 5.3 provides the estimated budget for the capacity data and technical needs. Figure 5.3 shows the corresponding budget needs for technical implementation of the National Coastal Infrastructure Plan.

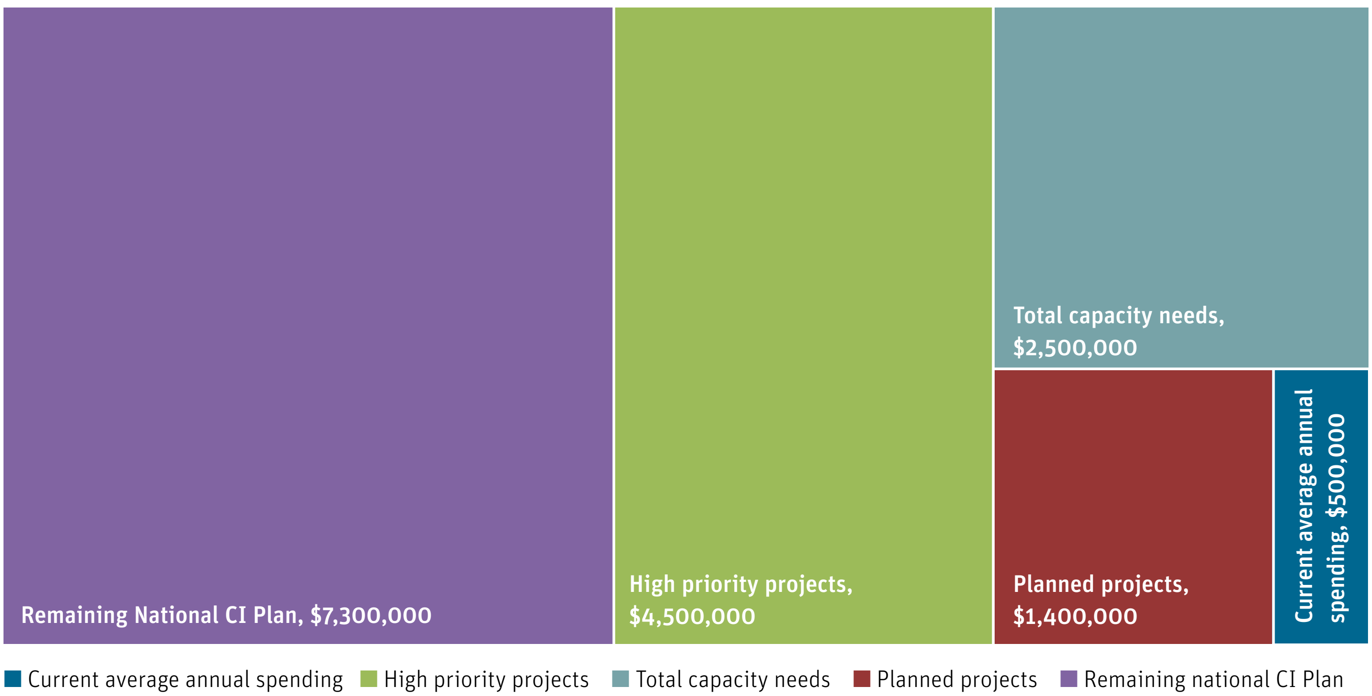
The estimated budget for capacity data and technical needs totals $2.6 million. However, this represents only the capacity and data needs for the successful design, implementation, and adaptive management of coastal projects in the current implementation agenda. Overall, it represents 19.7 percent of the costs of the implementation plan for coastal protection projects.

Currently, the Climate Adaptation and Management Section (CAMS) does not have a budget for investments in capacity building, monitoring and research (see figure 5.3, no “Current average”).

Table 5.3: Estimated Needs for Capacity, Monitoring, and Research for Effective Implementation of Infrastructure Projects.

Monitoring and research (M) or capacity building actions (C)	Estimated budget (U.S. dollars)	Percent over Infrastructure Plan
Coastal hydrodynamic data collection (M)	200,000	1.53
Bathymetric survey and technology (M, C)	1,000,000	7.65
Habitat mapping and technology (M, C)	300,000	2.30
Shoreline, beach, and coastal vegetation evolution monitoring (M, C)	500,000	3.83
Redesign and prepare coastal infrastructure (C)	250,000	1.91
Coastal modelling system and training (C)	350,000	2.68
TOTAL	**2,600,000**	**19.90**

Figure 5.3: Total Breakdown of the Implementation Plan Including Monitoring and Research and Capacity.



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Appendix A
Measures at Priority Sites according to the JICA Coastal Conservation Plan

Table A.1 Coastal Risk Levels Across Sites.

Level of rsk	Coast at present	Coast in future
High		Anse Kerlam
Moderate	North East Pont, Baie Lazare, Anse Kerlan, La Passe	North East Point, Baie Lazare, La Passe
Low	Au Cap, Anse Royal, Anse a la Mouche	Au Cap, Anse Royale, Anse a La Mouche

No.	Name of coast	Extent of erosion problem	Priority coast
1	North East Point	Long-term erosion and wave over-topping on coastal road Selected as representative coast of this type	◉
2	Anse Aux Pins	Small beach scarp and protected by reclaimed land	
3	Au Cap	Long-term erosion and wave over-topping on coastal road with revetment	
4	Anse Royale	Long-term erosion and wave over-topping on coastal road with revetment	
5	Anse Takamaka	Little erosion and protected by coral reef	
6	Baie Lazare	Long-term erosion and wave over-topping on coastal road with no structures	◉
7	Anse a La Mouche	Accreted coast with pile revetment under RECOMAP project	
8	Anse Boileau	Little erosion with pile revetment under RECOMAP project	
9	Beau Vallon	Stable beach but large variation requires future improvement	
10	Anse Kerlan	Severe erosion caused by longshore transport with groynes	◉
11	Anse Lazio	Beach scarp without reef requires future improvement	
12	La Passe	Erosion and accretion by breakwaters	◉

The ◉ symbol shows the priority coasts. RECOMAP: Regional Programme for the Sustainable Management of the Coastal Zones of the Indian Ocean Countries.

Classification of Coastal Erosion and Mitigation Measures.

Classification	Problems	Mitigation measures
Coast with long-term changes	Erosion caused by offshore sediment transport	Nourishment of sediment loss, setback/zoning, relocation.
Coast with erosion by changes in waves	The changes in wave height and direction bring coastal changes by on-offshore and longshore transport.	Setback/zoning of changing area, groynes or sand bypass for longshore transport, nourishment for offshore transport, regulations.
Coast with erosion influenced by structures	Coastal structures bring coastal erosion and accretion. Breakwaters, groynes and revetments cause coastal erosion a,of adjacent beaches.	EIA, regulations, structural measures according to type of impact
Pocket beach	A pocket beach is protected by the headlands, hence it is stable. In future, erosion by economic development and climate change.	Do-nothing, land use regulations, EIA

Source: JICA 2014.

Table A.2. Coastal Management Plan Priority Sites.

North East Point

Item	Explanation
Coastal conditions	The 2km-long coast is located in the northeast part of Mahé and is protected by a narrow reef and beach rock. Waves come from the northwest from December to March and from the southwest from May to October. A coastal road and houses are located along the coast and the beach is used by local residents for recreation.
Problems	Erosion and wave run-up at high tide on the coastal road affect traffic. The beach was eroded for 20 m in width from 1960 to 2011 and the seasonal variation was about 20 m. Possible causes of the long-term erosion are offshore transport.
Evaluation of alternatives	Sand and gravel nourishment was selected to compensate for the loss of sand and to make beach use even the needs of maintenance because revetment causes loss of sand in front of the revetment.
Content of the plan	Sand nourishment for 20 m in width for a 2-km stretch of the beach is proposed with maintenance nourishment.

Baie Lazare

Item	Explanation
Coastal conditions	The coast is located on the southwest coast of Mahé and is partly protected by a coral reef. Wetland has formed behind the sand bar where the coastal road and houses are located. The Baie Lazare River flows into the wetland and flushes out the sand bar in time of flooding. This possibly causes loss of sand from the beach.
Problems	Coastal erosion and wave run-up affect the coastal road, shops, and houses along the beach. Coastal erosion started two or three years before 2008. Stone and wooden pile revetments were constructed in the past and today broken revetments remain
Evaluation of alternatives	Maintenance of the beach by sand nourishment is better than direct protection by revetment because revetment causes loss of sand from the beach. The prevention of sand loss in times of flooding by a submerged reef in front of the channel is not feasible because of the cost. Traffic control at high tide is not reliable and other measures are necessary against the future sea level rise.
Contents of the plan	Sand nourishment for 20 m in width for a 400 m-stretch of beach is propose with maintenance nourishment. It is necessary to monitor the beach profile for estimation of the cause of erosion and the necessary sand volume for maintenance.

Anse Kerlan

Item	Explanation
Coastal conditions	The coast is located in the west part of Praslin and is protected by a coral reef. It receives waves from the northwest in winter and from the south in summer, resulting in seasonal changes in longshore sediment transport. Along the coat, hotels and restaurants are developing for tourism activities. The coast has one of the best beaches in Praslin.
Problems	The erosion causes the loss of property and use of the sandy beach for bathing. This results in deterioration of tourism activities. Originally, at Anse Kerlan the beach sand was transported from the north to the south and deposited at Grand Anse. After the erosion became severe, five groynes were constructed in 1960 and they prevent the return of sediment from the south. The coastal road was shifted inland because of the erosion.
Evaluation of alternatives	In view of the fact that the beach is important for tourism, sand nourishment and grove construction are appropriate for recovering the beach and reducing longshore transport. A revetment may cause loss of beach sand.
Contents of the plan	Three groynes and sand nourishment for 20 m in width for a 1,000 m stretch of the beach are proposed with maintenance nourishment to stabilize the beach.

La Passe

Item	Explanation
Coastal conditions	The coast is located in the west part of La Digue and is protected by a wide coral reef and Praslin Island to the west. Therefore, waves come from the north and south, and not from the west. A jetty is provided for the ferry to Praslin. The anchorage is protected by three breakwaters
Problems	The breakwaters at the jetty cause accretion at the anchorage and erosion of the south beach. Erosion causes loss of sand anf wave over-topping in the hospital grounds. The anchorage is difficult to use and needs dredging.
Ealuation of alternatives	To reduce accumulation of sediment in the sheltered area, a groyne with sand bypass from the anchorage to the eroded beach was proposed. Rearrangemnent of the breakwaters and groynes is one alternative. However, it would be necessary to conduct a detailed study and that is not within the action plan. The arrangement of the groynes was considered for future development based on the existing proposed plan.
Contents of the plan	One groyne and sand bypass of 1,000 m3 of sand from the anchorage to the south beach are proposed.

Source: JICA 2014.

Appendix B

Multiple Criteria Analysis Table of Coastal Adaptation Technologies

Table B.1: Results of Multiple Criteria Analysis for Prioritising Coastal Adaptation Technologies.

	Criteria and indicators								
	Financing	**Implementation barriers**	**Climate-related**	**Economic**	**Social**	**Environment**	**Institutional**		
Coastal adaptation technology	Direct cost	Ease of implementation	Reduced vulnerability	Avoided damage	Level of community engagement	Co-benefits	Enhance governance	**TOTAL**	**RANK**
Mapping	18.7	11.3	20.0	8.5	2.5	10.0	9.5	**80.47**	**1**
Dune rehabilitation	20.0	9.0	10.0	0.0	3.8	6.7	9.5	**58.92**	**5**
Wetland restoration	19.6	9.0	15.0	3.9	3.8	10.0	8.0	**62.96**	**2**
Seawalls/revetment	14.5	13.5	18.0	4.5	2.0	0.0	8.0	**60.44**	**4**
Detached breakwater	17.5	7.5	15.0	2.8	2.3	0.0	7.0	**52.00**	**7**
Coral reef repair	17.9	7.5	15.0	3.0	2.5	3.3	9.5	**58.71**	**6**
River outlet improvement	16.5	13.5	15.0	8.5	2.0	0.0	8.0	**63.46**	**3**
Coastal setbacks	0.0	3.8	1.0	20.0	2.5	10.0	8.0	**45.25**	**8**

Source: Government of Seychelles 2017.

Appendix C
Synthesis of Available Information for Coastal Management

A number of studies and reports have focused on coastal flooding and erosion. However, these studies vary in regional scope, timelines, and methodological approaches. To inform the development of a unified Coastal Management Plan (CMP), an overview and summary of the main studies, the information included, and their highlights are outlined in table C.1.

Table C.1: Summary of Coastal Management Studies Available for the Main Islands.

Title; author; date	Summary points
Preliminary Hazards Analysis of Sea Level Rise and Coastal Flooding in Seychelles Islands Ministry for Science, Technology and Environment, Environmental Agency, Hazard, Vulnerability and Risk Group (Alvarez Cruz et al. 2011)	The study includes information on: ■ General characteristics of Seychelles, including geological characteristics, climate, bathymetry, and topographical relief. ■ Coastal hazards, including: historical local sea level rise and estimates of future global sea level rise; description of wave climate tidal variations and surge modeling for tropical cyclone; analysis of coastal flooding by calculation of total water levels, represented by the combination of surges, tides, and wave runup, for historical and future conditions with sea level rise. ■ Wave propagation patterns through a shallow water model to show the effect of wave action in different sections of the islands. ■ Description of coastal erosion and flooding through site visits. ■ Identification of some priority areas: coastal flooding in and erosion in beach north of Mahé (Russian Castle); coastal flooding along the coastal section of the international airport; Anse Kerlan, Praslin, for coastal erosion, coastal erosion south of the pier access to La Digue. ■ Some causes of the impacts and provides overall recommendations.
The Study for Coastal Erosion and Flood Control Management in the Republic of Seychelles Japan International Cooperation Agency (JICA) (2014)	The study included four main activities: ■ Basic study: Collection of existing data related to disasters in the coastal zones and the study of the causes of coastal erosion and flooding in priority areas. The study included surveys, monitoring and observation of rainfall and water levels, analysis of waves, coastal erosion, and probability of rainfall and flooding. The coastal erosion analysis compared shorelines between 1960–98 and 1998–2011. ■ Formulation of plans for coastal conservation and flood management: To account for coastal characteristics and the damage caused by coastal erosion, four coastal locations were selected as priority areas and coastal conservation plans were formulated in a detailed study. The plan for flood management was divided into the plan for Victoria Town and the plan for other flood risk areas. ■ Pilot projects: Pilot projects were selected from the coastal conservation and flood plans based on urgency, and all or part of the plan was executed. For coastal protection, sand nourishment and groyne construction were proposed to maintain the sandy beaches (an important resource for tourism) in the coastal conservation plan. Pilot coastal projects were implemented in April 2013 to study the applicability of the plan and show its effectiveness though long-term monitoring. For flood mitigation, drainage and river improvement were proposed to mitigate inundation problems in the flood management plan. The river improvement includes increased flow capacity from the wetlands to the sea. An outlet was constructed as a pilot project, which showed its effectiveness together with suggestions for improvement. The technology for coastal conservation and flood management was transferred to the members of all the related government organizations.

Table C.1: Summary of Coastal Management Studies Available for the Main Islands. (cont.)

Title; author; date	Summary points
Coastal Processes Study: North East Point, Mahé Island, Seychelles Borrero et al. (2016)	This study provides a comprehensive assessment of coastal process in the North East Point, Mahé Island: ■ The study focuses on the analysis of coastal process and seasonal erosion-accretion cycles associated with natural wave climate changes in the North East Point. The study finds that the beach at North East Point undergoes seasonal fluctuations of beach width. These variations are driven by monsoonal wind and wave conditions. ■ The study provides historical data and field measurements on wind and wave climate and sea levels. ■ The authors conducted an analysis of shoreline change from historical aerial imagery between 2002 and 2015 and field surveys to measure shoreline fluctuations between 15 and 30 m. Analysis of aerial imagery shows the seasonal patterns of erosion and accretion, but they do not clearly show any long-term trend of erosion. ■ The study conducted wave propagation and modeling of currents and sediment transport potential to understand and explain erosion patterns and wave-driven coastal flooding along North East Point. Nearshore, the primary driver of sediment is wave action as opposed to tidal, wind, or pressure-related effects. ■ The study includes a modeling comparison of the oceanographic environment using bathymetry representative of the era before large-scale land reclamation and reef destruction. The comparison suggests that a hydrodynamic link between the offshore barrier reef (a source of beach sand) and the North East Point had been broken. This may have resulted in a reduction of the sediment delivery to the beach along North East Point. ■ Three large scale environmental effects are likely contributing to the increased bouts of episodic erosion and overtopping on to the coast road along North East Point: • The destruction of the barrier reef and land reclamation efforts have reduced the amount of sand being produced by the reef. • Coral death and degradation of the nearshore fringing reef offshore of North East Point caused by bleaching and other factors. • The average local sea level that has risen approximately 10 cm in the last 20 years.

Appendix D
Priority Sites in La Digue, Praslin, and Mahé for Coastal Erosion Protection Measures

Figure D.1: Proposed Coastal Erosion Protection Measures, La Digue.

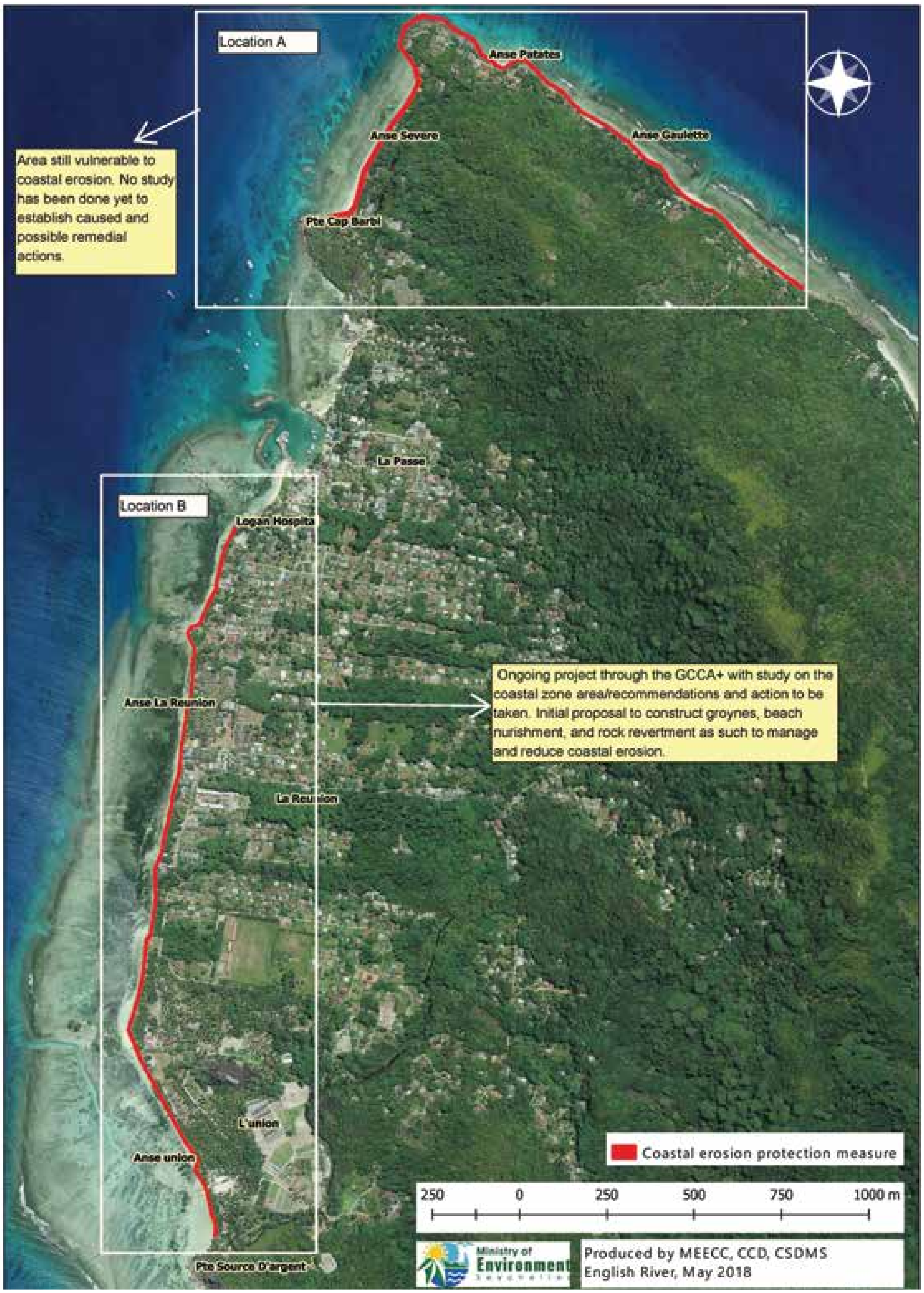


Figure D.2: Proposed Coastal Erosion Protection Measures, Praslin.

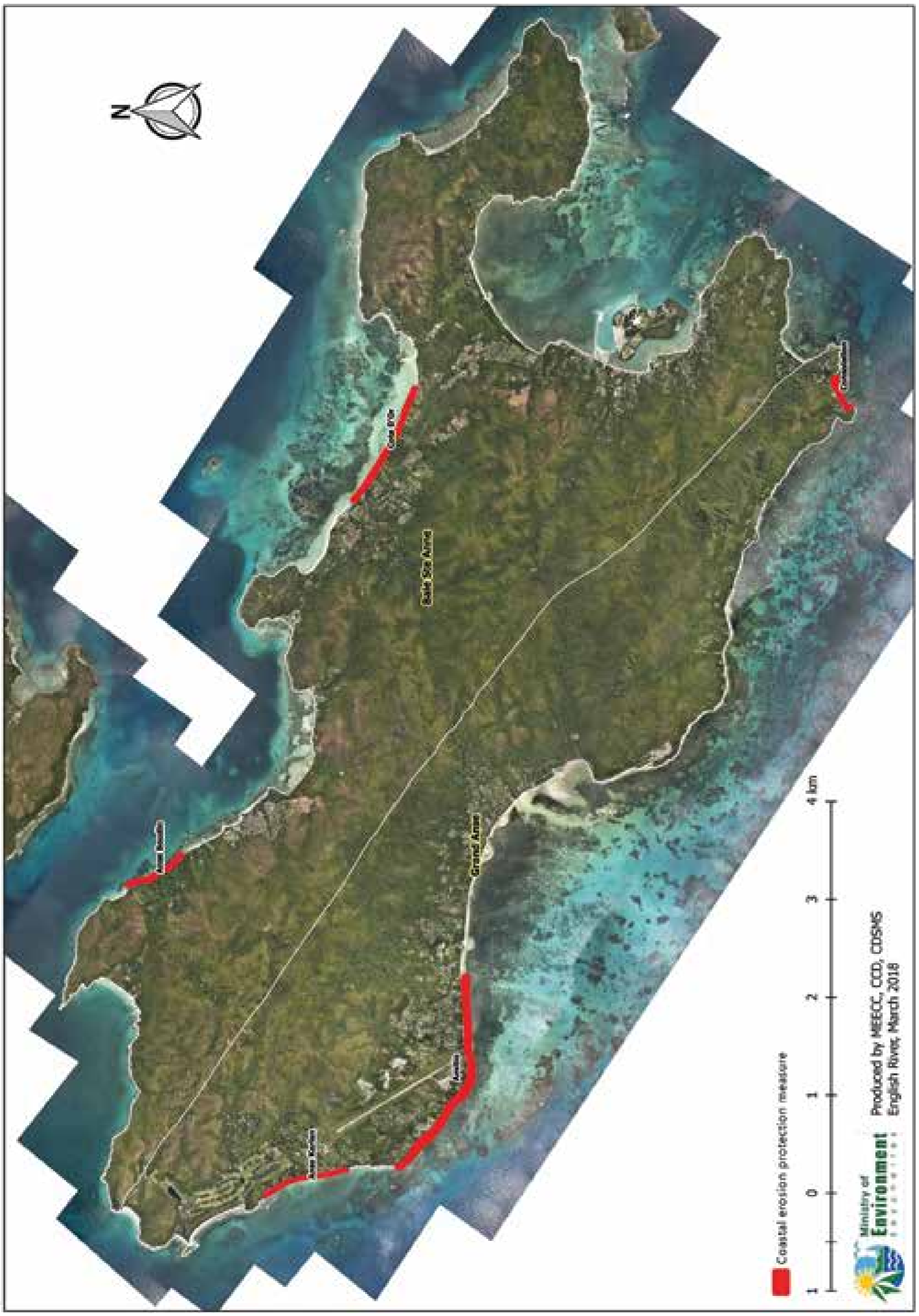


Figure D.3: Proposed Coastal Erosion Protection Measures, Mahé.

Appendix E
Results Study—Flood Protection by Coral Reefs

Figure E.1: La Digue.

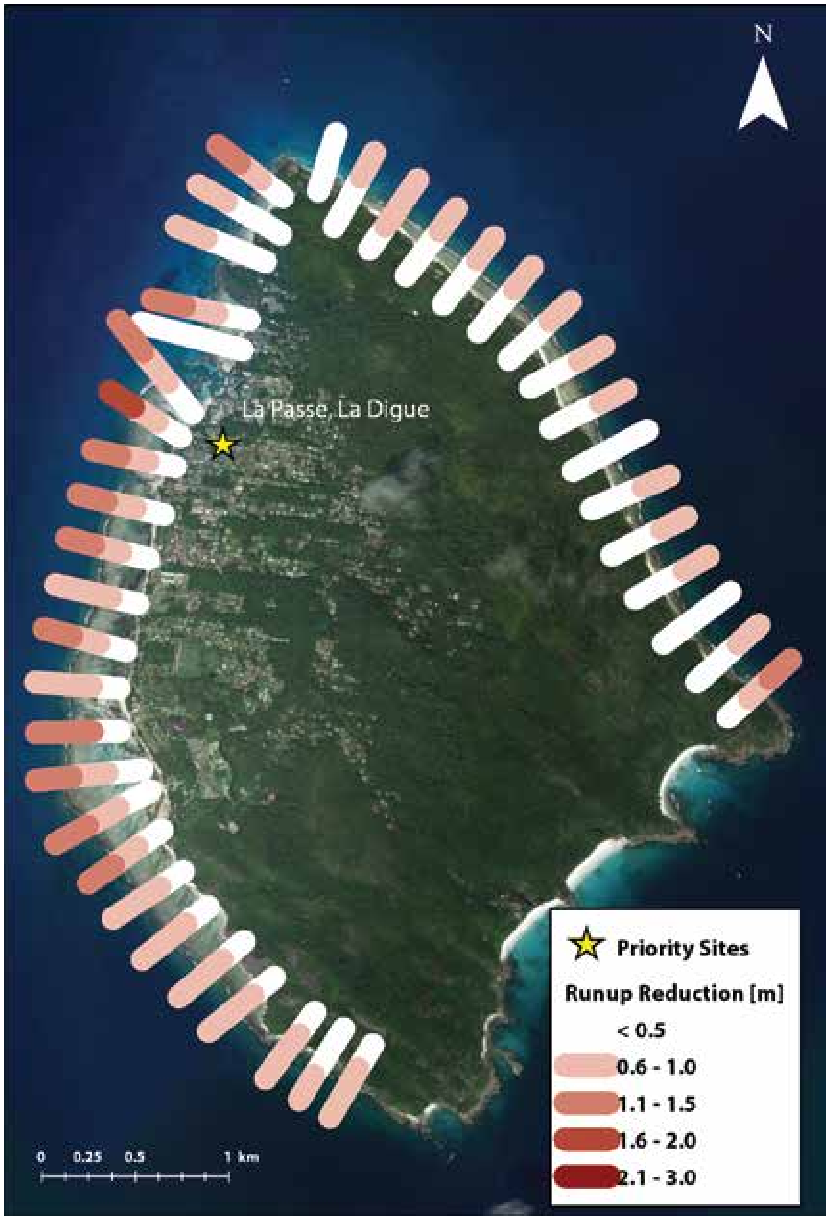
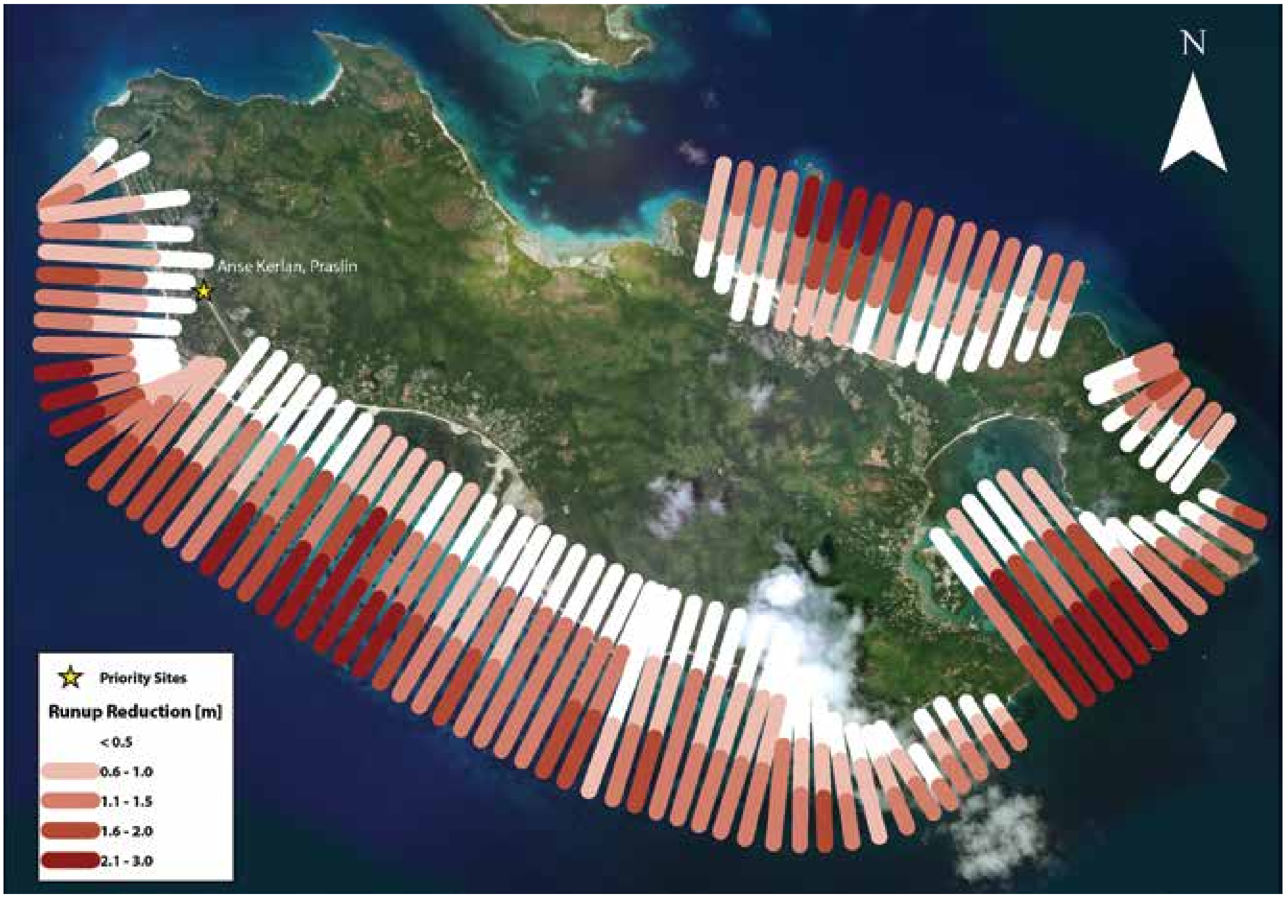


Figure E.2: Mahé.

Figure E.3: Praslin.



Appendix F
Description of Coastal Infrastructure Options

Beaches and dunes

Beaches and dunes change their shape in response to winds, wave and current forces, and sand availability. Monitoring the physical processes associated with a beach restoration project, for example, should be oriented toward establishing a sediment budget. This includes identifying and quantifying all sand sources and sinks and rates of exchange. Gains and losses in the sand budget are balanced against the changes in sand volume in the area. These can include the previous history of the coastal site, beach profiles, local anthropogenic impacts, history of storms, waves and currents, historical shoreline changes, water levels, structures, sediment characteristics, rates and volumes of transport, bathymetry, and photographic documentation.

Studies of these highly variable local patterns of wind and wave dynamics can be important keys to dispelling misunderstandings of beach processes, and unlocking effective management tools for coastal land conservation and beach preservation. In the myriad coastal settings of Seychelles, any knowledge that increases the insight into sand movement caused by wave and current action along the shoreline can also play a significant role in building consensus for community decision making. Analysis of littoral cell sediment processes and budgets is also critical to implementing a sustainable program of dune and beach restoration and nourishment.

Localized reef degradation, water quality deterioration that affects sand-generating ecosystems, sand impoundment, and dune grading are all activities that are often prevalent in the coastal zone although their true effects are often not recognized.

Sand behind walls sediment impoundment accompanies coastal armouring. Sands that would normally be released into coastal waters during high wave events and with seasonal profile fluctuations are trapped behind walls and revetments and prevented from adding to the beach sediment budget. One wall may have minimal impact, but several sections of armouring combine to reduce sand availability significantly.

Natural coastal erosion does not damage beaches that have access to a robust sediment budget. Beaches on chronically eroding coasts that are not armoured remain healthy even during shoreline retreat because sands are released from eroding coastal lands that nourish the adjoining beach. Armouring traps those sands and a sediment deficiency develops so that the beach does not withstand seasonal wave stresses and begins to narrow with time. Chronic beach erosion and beach loss eventually results. Many beaches disappear simply because they are starved of sand.

One of the most important storage sites for sand is the frontal dune system that lines many shores. As already mentioned, armouring traps these sands. Additionally, the leveling and grading with topsoil that accompanies housing construction on beachfront lots is one of the most destructive practices.

No solution for addressing coastal erosion is ever final and no coastal project is ever complete. There are no absolutes along the coast, only compromise and adaptation. It is worth remembering that no one method of erosion management is best for all locations. What works well in one place will not necessarily work well somewhere else. It is also the case that no erosion management approach will work equally well in all conditions. It is important, therefore, to monitor project performance, especially in the case of beach restoration, in order to improve technical understanding of all aspects of erosion management.

Beach restoration

Beach restoration involves the placement of sand on an eroding shoreline to resupply deficiencies in natural sand volume caused by waves and currents or human activities, or to counteract shoreline retreat caused by sea level rise. Sand placed on the beach to offset these losses may partially mitigate chronic erosion or provide a buffer to protect the back beach and upland against future storm or seasonal wave-induced erosion or flooding.

The restoration of a dune system with endemic coastal vegetation may be a major component of the effort as the dune further enhances the sand storage capacity of the shoreline and provides additional mitigation against the effects of storm or seasonal wave erosion.

Dune restoration refers to the rehabilitation of natural or artificial dunes to a better state of overall function, to gain the greatest coastal protection benefits. This is a technology aimed at reducing both coastal erosion and flooding in adjacent coastal lowlands. There are different methods depending on the site, such as building fences on the seaward side of an existing dune to trap sand and help stabilize any bare sand surfaces, or planting vegetation to stabilize natural or artificial dunes. This promotes the accumulation of sand from wind-blown sources around their stems—over time, this causes dune growth. Dune vegetation root networks also help to stabilize the dune.

Typical beach restoration involves placing sand on the upper portion of the beach profile so that it is visible and leads to an immediate improvement in beach width and scenic amenity. Sand may also be placed lower on the profile so that it is below the water level yet still acts as a feeder to the beach. Any sand that is placed within reach of the waves will immediately, and continuously thereafter, adjust to assume a dynamic equilibrium profile achieved by the natural migration of sand across the entire profile. That is, the dry beach width will decrease because sand moves offshore to feed the lower portion of the profile that is below sea level. The degree to which this sand remains in the system and continues to provide benefits to the dry beach varies from site to site and should be the focus of research designed to improve our understanding of equilibrium profile fluctuations.

Challenges to beach restoration include finding a source of sand with adequate grain characteristics that will constitute a stable beach under the expected range of wave energies. There must also be a careful determination of the necessary fill volume to not only restore the beach and dune system lost to historical erosion and development practices, but to also fulfill the uneroded potential sand volume that was denied by the presence of shoreline armouring.

Beach restoration also requires data on historical shoreline changes and projections of future patterns of change, as well as studies of waves and currents and sediment transport processes to assess the economic life and design components of the project

Potential environmental disruptions at the sand source to be mined (benthic and pelagic faunal communities and dependents) must be fully assessed and mitigated to an acceptable level among all stakeholders.

Erosion control

Coastal erosion control techniques use structures that are designed to reduce sediment losses and thus slow the rate of erosion. The intent is to protect the backshore by trapping and holding sand and thus stabilize the beach. The trapping characteristic of this approach could mean adverse impacts to adjacent beaches if sand held in the project area would normally migrate through or accrete on neighbouring beaches

Structures include groynes, T-head groynes, detached breakwaters, artificial headlands, perched beaches, reef and sill systems, dune fencing, and beach dewatering (see table F.1).

A properly designed beach erosion control project is one of the greatest challenges of coastal engineering. The complex interaction of these structures with the littoral system requires a good understanding of local beach dynamics, coastal processes, historical shoreline patterns, and acceptable performance tolerances. In evaluating the performance of a particular structure, it is important to avoid the classic mistake of misinterpreting natural profile recovery and accretion as the work of the structure.

The beach erosion control approach is more appropriate for areas where the problem is chronic erosion caused by diminished sediment supply. These structures can be very useful in areas where it is too expensive to maintain a beach by continuing to bring in large quantities of sand from an outside source. Groynes, breakwaters, and headlands work best in areas where longshore transport is much more dominant than cross-shore transport in moving sediment out of the project area. Structures alone do not protect the back beach from wave-induced flooding and erosion. They provide their benefit to the shore by trapping or holding sand in the desired location and allowing sufficient elevation of the beach profile to be maintained. It is the beach held by the structures that provides protection to the coastal upland and related human developments.

Shoreline hardening

Coastal armouring includes the use of seawalls, revetments, bulkheads, levees, and dikes in an attempt to harden the shoreline. This is usually the approach of last resort and is most appropriate where the primary problem is one of storm-induced damage rather than chronic erosion. However, it has been the typical response to intermittent as well as chronic erosion hazards.

Coastal armouring should be generally considered an “option of last resort” for managing coastal erosion. Some coastal management plans, for example that in Hawaii, have restrictions on constructing coastal armouring through its Coastal Zone Management Act (Hawaii Revised Statutes 205A) and other state and county rules and policies.

In general, an applicant wishing to install coastal armouring on a beach should show that it would not adversely affect beach processes or public access along the shoreline and that there are no reasonable alternatives. It can be very difficult for an applicant to meet these requirements, given the improving understanding of impact of coastal armouring on beach environments. As a result, landowners are increasingly seeking alternatives to traditional shoreline armouring that can preserve or restore the natural character of a beach.

Where coastal armouring causes beach loss, public access to the ocean is also reduced. Walls on narrowed beaches have the effect of privatising otherwise publicly accessible shoreline.

If armouring is placed along a chronically eroding coast, the beach in front of the structure is likely to eventually disappear. This is not due to an active aggravation of the erosion process, but rather because the back-beach reference has been stabilized while the shoreline has not. This process is called passive erosion because of the tendency for a shoreline to passively retreat up to a wall, losing the beach in the process. Many studies by coastal scientists and engineers alike support this finding.

Other challenges accompany shoreline hardening such as groyne effects, sediment impoundment and cross shore reflection. Groyne-effects occur when a portion of a wall protrudes across the shoreline and blocks longshore sand movement causing downdrift erosion. Sediment impoundment is the trapping of sand behind a wall, which leads to sand volume deficiencies. Cross-shore reflection has a localized scour effect at the ends of a wall and produces differential erosion.

Accommodation and retreat

Under accommodation and retreat, the beach is allowed to behave as it will regardless of the causes of erosion or the impact that shoreline retreat may have upon the upland region. This is the appropriate response in areas where erosion or flooding problems are so severe that hazard mitigation is not economically viable, that is, where the cost of protection would exceed the value of the investment. This may also be the preferred approach in areas where the natural appearance of the shoreline, and the natural patterns of shoreline change, are important to the character and attractiveness of the system and deemed to be of the highest priority in the socioeconomic valuation of management options.

Development patterns change in order to allow natural erosion-accretion cycles to continue without interference. This approach protects natural shoreline attributes from the impact of human alterations to coastal processes, but requires modification of human occupancy and use of the coastal zone. This is a management, rather than engineering, approach that utilizes tools such as zoning restrictions, building standards, community facilities districts, new subdivision requirements, or new rules governing permit restrictions and allowable actions in an erosion hazard area.

Examples include: changing set-back requirements for new construction, setting new limitations on development and landscaping, relocating structures threatened by erosion, flood-proofing buildings, new building standards for high winds, wave impacts, and erosion threats, land banking, and implementing a “coastal retreat” policy.

The basic assumption behind this approach is that it is easier and cheaper to retreat than to stay and wage war with coastal hazards. Developing an adaptation methodology requires an economic analysis that includes a valuation of the scenic and recreational amenity of natural shorelines.

Adaptation includes identification of “hazard zones” where human activities and future patterns of shoreline change may overlap. It is within these hazard zones that the land use tools are applied to implement adaptation. It is important, therefore, to involve the local community and the larger population of beach users in an open discussion of options and consequences, as well as uncertainties.

Priority list and description and status in Seychelles

The technology needs assessment for coastal adaptation technologies report conducted by the Global Climate Change Alliance (2019) proposed a priority of technologies including a status description of Seychelles.

Table F.1: Coastal Protection Measures and Recommendations.

Technology	Objective	Description and status in Seychelles.	Recommendation
Sea wall - stone	Protect the shoreline from erosion	Low seawalls made of stone are common in many areas around the main island of Mahé, where they were constructed during the colonial era to provide a base for roads along the coastal beaches and wetland areas. Some of these seawalls are currently being compromised by wave action. This hard engineering protective measure is no longer in favor and rarely used now.	Avoid use.
Sea wall – timber piling	Protect the shoreline from erosion	Tried out in four locations (Cote d'Or, on Praslin, and Anse Boileau, Anse Royale and Anse à la Mouche on Mahé) over the last 15 years. All sites used a double row of logs with some geotextile lining in between to retain sand. Where space permitted, this method has been coupled with attempts to replant native coastal vegetation. The success rate of timber piling in Seychelles has been inconsistent.	Used for dune restoration and revegetation but not to interrupt the cross-shore sediment transport along the beach profile, which can produce erosion of the lower beach profile.
Sea walls - concrete	Protect land and structures from flooding and overtopping	Concrete seawalls are used to protect land and structures from flooding and overtopping. They are used as reinforcement and a high impermeable structure.	Used for protection of road sections and where other options are not feasible given space requirements. Special attention should be given to the design of the toe and potential scour. It should be complemented with other measures that prevent the erosion of the shoreline.
Sea Dike	Prevent or alleviate flooding of low-lying land areas by the sea	Separation of the shoreline from hinterland by a high impermeable structure.	Use in combination with upper beach restoration and vegetation, including soil dikes.

Table F.1: Coastal Protection Measures and Recommendations. (cont.)

Technology	Objective	Description and status in Seychelles.	Recommendation
Rock armouring	Protect the shoreline from erosion	Most of the recent reclamation work around the islands of Mahé, Praslin, and La Digue has been contained with rock armouring using local granite rocks. Rock armouring has proved a successful albeit unsightly method against coastal erosion so far, although in some areas the reclaimed land itself is low lying and vulnerable to sea level rise and storm surges. Rock armouring has also been used increasingly in recent years as an urgent protective measure against instances of severe and sudden coastal erosion. The rock pilings are considered by many individuals to be an eyesore. However, in some instances the rock armours have successfully resulted in sand accretion over time and become submerged under sand. Space permitting, this technology has been coupled with replanting of dune vegetation at the top of the rock armouring. Where coastal armouring causes beach loss, reduced public access to the ocean is reduced. Walls on narrowed beaches have the effect of privatising otherwise publicly accessible shoreline.	Improve design of rock armouring by carefully selecting rock size to avoid collapse and damage. Because seawalls exacerbate erosion, complement with other beach restoration options.
Bulkhead	Retain soil and prevent sliding of the land behind	Reinforcement of the soil bank. Rarely use in Seychelles	Avoid use.
Groynes	Prevent beach erosion by reducing the longshore transport of sediment	This technique has been used extensively in the past but not always to good effect. In many cases, small, poorly designed groynes designed to protect one area of beach or encourage sand accretion have resulted in beach degradation in adjacent areas. Some groynes have been built to protect ports or mooring areas of some islands and proven effective without deleterious effect on the surrounding coast.	Experience shows that groynes can work when well designed, considering currents and allowing for sand movement. Recommended only in CZMUs when required to intervene on the longshore sediment transport, (such as Anse Kerlan, CZMU-16)

Table F.1: Coastal Protection Measures and Recommendations. (cont.)

Technology	Objective	Description and status in Seychelles.	Recommendation
Detached breakwaters	Prevent beach erosion through reduction of wave heights in the lee of a structure and reduction of longshore sediment transport	Detached breakwaters are hard engineering measures built in the sea, parallel to the coast, to reduce erosion of the coastline by wave energy. This technology has been tried only twice in Seychelles (on La Digue at La Passe and in front of the Ste. Anne harbour), in each case constructed to protect tourism infrastructure. The EBA Watershed project is considering constructing one at North East Point on Mahé to encourage sand accretion at the same site where beach nourishment was attempted a few years ago This technique could be combined with coral reef restoration to provide additional structure to raise the height of an existing reef.	Low-crested submerged breakwaters are preferred and should be implemented in shallow water areas.
Breakwater	Shelter harbor basins and harbor entrances	Dissipation of wave energy and modification of wave propagation, reflection of wave energy back into the sea.	Only for harbour operations.
Scour protection	Protect coastal structures against instability caused by seabed scour	Provide resistance to erosion caused by waves and currents	Combine with seawalls and hardening of the shoreline to prevent collapse and damage.
Coral reef restoration	Prevent beach erosion and provide flood protection	Coral reef restoration involves natural and artificial measures to improve the ability of an impaired coral reef to reduce wave energy reaching the shore, thus protecting a beach from erosion. The last 10 years have seen several coral reef restoration projects, the most significant being that initiated by the NGO Nature Seychelles in the vicinity of Cousin Island and Praslin. Most of the coral restoration work has focused on propagating coral species resistant to bleaching. This is considered by many stakeholders to be a promising technology for coastal protection.	Use coral reef restoration to maintain the natural protection of reefs, particularly in the shallow CZMUs and with complex reef bathymetries, to avoid future coastal erosion and increased flooding. Contemplate structural restoration options and coral gardening in shallow water structures.
Reef breakwater	Prevent beach erosion	Reduction of wave heights at the shore, modification of wave propagation	Consider in shallow water areas, in combination with coral restoration.

Table F.1: Coastal Protection Measures and Recommendations. (cont.)

Technology	Objective	Description and status in Seychelles.	Recommendation
Beach nourishment	Prevent beach erosion and provide flood protection	Beach nourishment has been attempted only in North East Point), using sand dredged offshore of Mahé island. The results are inconclusive, but there is consensus that this technology is too expensive and unsustainable for Seychelles.	Sand nourishment should be considered as the most effective way to manage erosion in Seychelles. However, it will be dependent on offshore sand sources and other factors such as cost. Specific coastal studies are required to assess sites, volumes, grain size, and coastal response to sand nourishment projects.
Dune restoration	Prevent beach erosion and provide flood protection	The dunes in Seychelles are generally restricted to a very narrow strip of sand between the high tide water mark and the coastal road. Over the last 20 years there have been several significant projects, mostly on Mahé, to restore the dunes with native vegetation and restrict vehicle access using bollards. At Grand Anse Mahé, a boardwalk was built to limit pedestrian access to the beach to only one route instead of many. In many cases, these restoration projects have involved the participation of communities, wildlife clubs, and schools.	Avoid construction on dunes that affect the cross-shore transport of sand into the beach during erosional events. Restore dunes and reinforce with vegetation belt.
Revegetation of the beach profile	Prevent beach erosion and provide flood protection	Some examples exist, in combination with dune restoration.	Use vegetation as reinforcement of the beach profile, and a green belt to deter impact on the active beach profile.
Wetland restoration	Provide flood protection	The rehabilitation of an impaired wetland to a better state. The most commonly restored wetland ecosystems for coastal protection in Seychelles are coastal freshwater marshes and mangroves. Seagrasses may also be employed as a coastal defense, to dampen waves, but on their own they are seldom considered adequate shore protection. Some work has been done over the past couple of decades to clean and replant some mangrove areas (particularly in Port Launay and Roche Caiman) and to clean the freshwater marsh at North East Point. When coastal wetland outlets become seasonally blocked with sand or rubbish and natural debris, the habitual response of the MEECC wetland unit is to dredge the opening to allow the river water to flow out and reduce risk of flooding.	Combine with beach restoration.

Note: EBA = Ecosystem-based Adaptation; NGO = nongovernmental organization.

Appendix G
Designing and implementing coastal projects

The solution to coastal engineering problems begins with an understanding of the root causes of coastal impacts and the need for a coastal solution. The planning and design of a coastal solution is the umbrella under which the project evolves from conception to functional, detailed technical design. Certain phases and steps ensure the problem is addressed in an effective way. The process to plan and design effective coastal solutions should be based on guiding principles that apply regardless of project type, scale, geographic siting, or sponsor.

Guiding Principles (based on USACE 2002):

- The planning process should begin with the questions "What is the problem?" and "What exactly is the project trying to accomplish?" Achieving a successful coastal project requires having a completely open mind without preconceived notions of the ultimate form of the project or a specific solution to advocate. For example, a common error in the planning process is to answer the second question with "to design a seawall" without first clearly stating the problem, that is, is the problem one of navigation difficulties in the vicinity of La Digue's marina, potential damage to buildings near the shorefront, beach erosion in a specific section of a rectilinear beach, or chronic erosion across an entire beach unit contained by natural headlands or artificial structures? These are symptoms of a problem, but they do not define the problem.
- An interdisciplinary team approach is recommended to address the planning and design of coastal projects. The nature of effects such as erosion and flooding, and their root causes (changes in wave climate, bathymetry, effects of coastal structures, or environmental degradation) require a participatory process and an interdisciplinary approach to finding effective solutions for the long term.
- Interested and affected agencies, groups, and coast-sharing partners and individuals (including the public) should be provided opportunities to participate throughout the planning, design, construction, and operation of a project. The purpose of public involvement must be to ensure the project is responsive to the needs and concerns of the public, but also to achieve effective solutions in the long term.
- The proposed project should not harm the environment or adjacent coastlines, and water quality should not be impaired. These are all requirements for a landscape or systems perspective of the coastal zone. This standpoint sets a consistent basis for formulating alternative plans and considering effective solutions.

It is also recommendable to include two levels of planning, one that looks at the problem in a reconnaissance level, and another level for a detailed study of the all the factors, conditions and alternatives. These terms are equivalent to conceptual and final design. In the first level of study, the objective is to determine if there is a technical doable solution and explore different alternatives, if they are economically and politically feasible, and environmentally sound. The detailed design differs in the degree of detail and should develop the specific solution for project implementation.

The planning process should consist of six major steps:

1. **Specify problems and opportunities.** This step requires an accurate and quantifiable definition of the problem statement using, for example, erosion rates, flood extent, temporal recurrence, and stakeholders affected.
2. **Inventory and forecast conditions if no action is taken.** These include not only the physical dimension of the site and environmental conditions, but also the alternative schemes measured against a without-project scenario (the conditions that would prevail in the future if no action is taken). This is an important step because it represents the foundation for evaluating potential solutions for addressing the problems.
3. **Formulate alternative plans.** Alternative plans and solutions are formulated in a systematic manner during both the reconnaissance and feasibility phases

to ensure that all reasonable alternative solutions are identified early in the planning process and are refined in subsequent iterations.

4. **Evaluate effects.** Evaluation of effects is a comparison of the with- and without-plan conditions for each alternative plan. Differences between each with- and without-plan condition are measured or assessed, and the differences are appraised or weighted, factoring in economic development, environmental and societal effects, and economic value of the national output of goods and services.
5. **Compare alternative plans.** Both monetary and non-monetary effects are compared for each alternative plan and solution.
6. **Select a plan.** After consideration of the various alternative plans, their effects, and public comments, the solution with the most benefits should be selected for implementation.

This process is the same for successfully engineering a solution in other engineering fields but is here limited to the discussion of coastal projects, including green infrastructure solutions.

The specific design of a coastal project should also follow ten major steps:

1. Clearly define the project problem statement, including the project objective
2. Quantify existing and most likely future conditions (with and without the project)
3. Identify and analyse alternatives
4. Select alternative
5. Develop and test functional design
6. Develop and test structural design
7. Check for constructability, operation and maintenance, and life-cycle costs
8. Select final plan and prepare plans and specifications
9. Construct project
10. Monitor and evaluate project performance

The term “functional design” refers to the effectiveness of a project at its intended function, such as the effectiveness of a breakwater at providing tranquil waters inside a harbour. “Structural design” refers to the ability of a structure to exist in the climate in which it is placed, such as the ability to withstand the effects of extreme storms without affecting its functional requirements. The term “constructability” refers to the means, methods, and materials involved in successful project construction.

More information on design and planning of coastal projects can be found in USACE (2002).

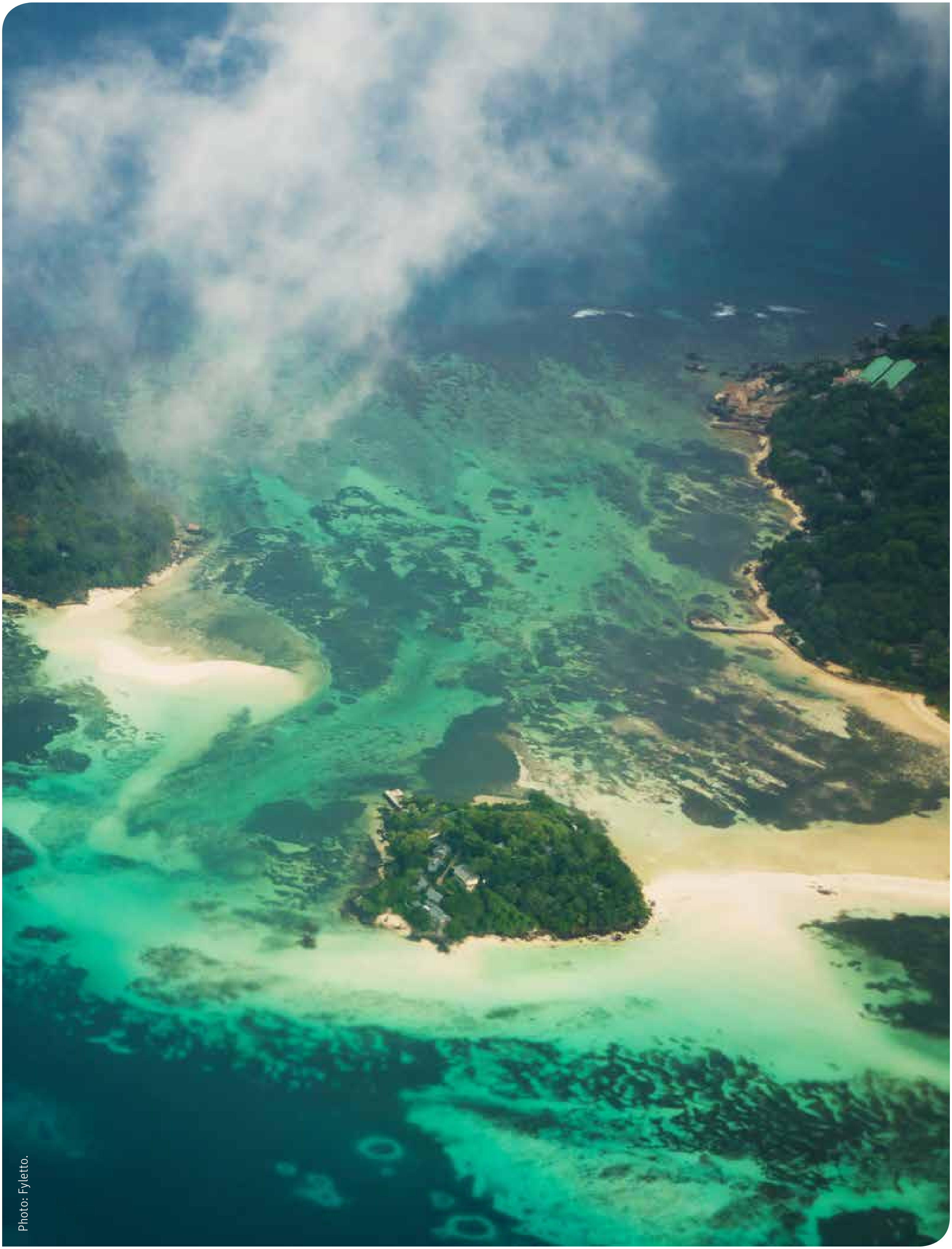


Photo: Fyletto.

Appendix H
Coastal Zone Management Units Summary Cards

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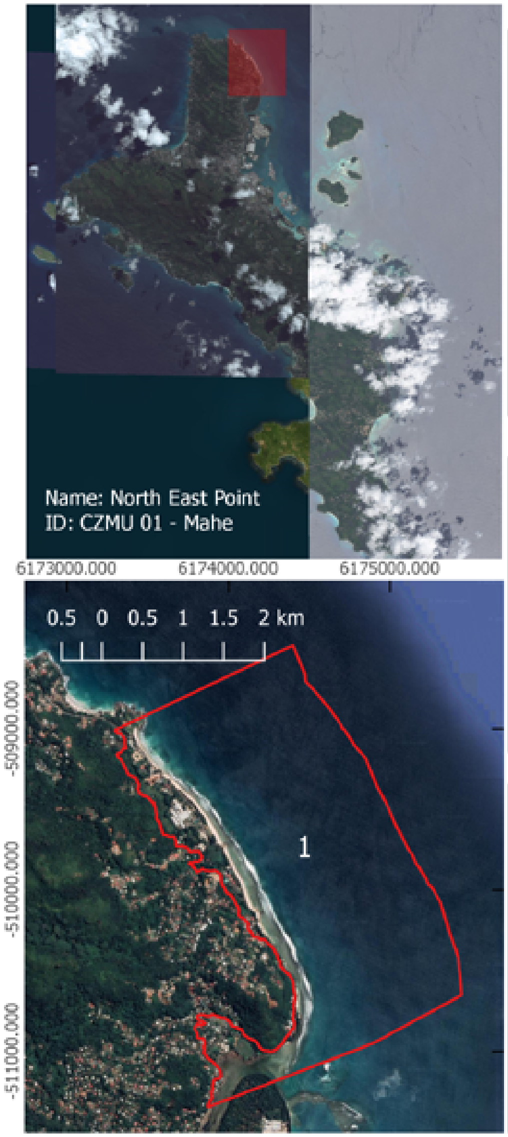
Right panel
Taken Date: 27/07/2018 14:49:23;
Coordinates: S4°34'36.58"; E55°27'46.34"

Further comments:



Coastal Hazards and Coastal Processes

Estimated wave runup (1-in-25-yr): 3.6m
Design conditions (JICA): Hs = 4m, Wave period = 8s, Direction ESE.
Level of risk (JICA): Moderate. Priority Coast

Dominant processes:
- The beach at North East Point undergoes seasonal fluctuations on beach width. These variations are driven by monsoonal wind and wave conditions.
- Prevailing offshore waves are from the South East Monsoon (SEM), but wave heights in the nearshore are larger for the North West Monsoon (NWM), which produces stronger and faster transport to the South.
- From October to March the coast is eroded in the north and accreted in the south. From April to September the change is reversed.
- Seasonal longshore transport varies between NWM and SEM conditions, producing changes in beach width by 10-40 m during periods of SEM (April-September) and NWM (October-March).
- North to South transport along the beach is faster due to the effects of the bathymetry on wave propagation.

Geomorphology:
- The northern and southern headlands and the rock outcrop in the center of the beach act as control points for the movement of sand up and down the beach.
- The overall degradation of the fringing reef has reduced the production of sand and wave dissipation, which drives northward sediment transport. Prior to 1998 (El Niño induced mass coral bleaching in Seychelles) fire coral was prevalent in the area; post 1998 coral coverage has decreased.
- Land reclamation from the South (outside CZMU), and extensive reef modification have cut off sediment supply from southern areas.

Current coastal management practices and interventions

Identified problems:
- Evidences of long-term erosion (see Resources, JICA). The reason for the long-term erosion is not clear.
- Evidences of wave run up to a height of 4.3m on the road (point a, see map), with sand deposition on the road.
- In the eroded part, waves overtop the road, especially at high tide.
- If no action is taken, the beach will be eroded opposite the road. Maintenance of the beach or the construction of a revetment is required.
- The road will require countermeasures and maintenance such as raising or regular repairing (after storms).
- In the long term, the increased erosion and wave overtopping will cause further traffic problems and damage to structures.
- Road built close to the coastal line. Road is low-lying and can easily be eroded
- The existing infrastructure does not meet the increasing development in the community (e.g. drainage/bridge)

Projects and current practices:
- Revetments and seawall in the road section (point a, see map)
- A beach nourishment project was carried out in 2013. A total of 4,000m3 or 6,600t of sand was nourished to the 400m-long coastline in the south. The nourished sand was transported to the north and formed a wide beach. The nourished south beach was eroded, and rock armored appeared.
- However, the beach nourishment has been losing sand progressively (at date of August 2018).

Priorities for Coastal Management

- Continue the beach monitoring, specifically cyclical erosion/accretion behavior to determine where and when to intervene.
- Regular beach nourishment at specific sections of the system may be necessary to maintain beach width and prevent scouring of the road and associated structures.
- It is recommended to restore the beach profile, with revegetation and continuing monitoring in the southern section of the system.
- The protection of the road with a seawall may be necessary but future scouring should be prevented with rock armoring, potentially combined with beach and vegetation restoration (increasing the green buffer seawards), through a hybrid scheme that should also attend to the longshore sediment transport and the effects between NWM and SEM conditions.
- Reef conservation and maintenance of the underwater bathymetry to avoid degradation. Loss of reef and bathymetric complexity can lead to more wave action and flooding and thus enhanced sediment transport and coastal changes.
- The directions of the measures from JICA are: continuous sand nourishment, consider setbacks in the north, and shoreline hardening as the last resort.
- Construction of rock armoring if the loss of sediment is substantial.

Malpractices to avoid & factors of special attention to consider in projects:
- The north/south transport should not be interrupted by interventions, avoid control of longshore sediment movement by groins,
- Rock armoring should be reconsidered and redesigned to prevent slope failure (as currently observed in several sections).
- To design future beach profile restoration: monitoring of the sediment transport between seasons (e.g. from satellite or drone imagery), also in relationship with the wave climate.

Resources

- JICA. 2014. The study for Coastal Erosion and Flood Control Management in The Republic of Seychelles.
- MSTEEA. 2011 Preliminary hazards analysis of sea level rise and coastal flooding in Seychelles islands. Ministry for Science, Technology and Environment, Environmental Agency
- Borrero et al 2016. Coastal Processes Study: North East Point, Mahé Island, Seychelles. GOS-UNDP-GEF
- Deltares (2018), Quick-scan runup reduction through coral reef restoration in the Seychelles. PP 54. Commissioned by the World Bank


Legend
Mahe
Elevation contours (m)
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Units_Mahe_CZ
Roads
Hotels
buildings_polygon
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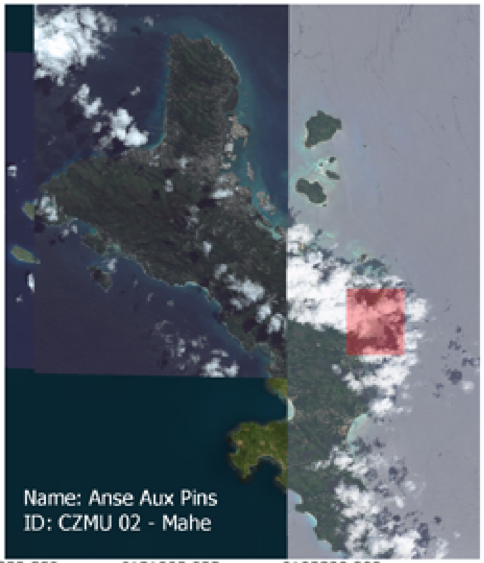

Coastal Hazards and Coastal Processes

Estimated wave runup (Mahe, 1-in-25-yr, MSTEEA): 3.5m
Design conditions (from Au Cap, JICA): Hs = 5m, Wave period = 8s, Wave Direction= SSE
Level of risk (JICA): Low.

Dominant processes:
- Well-developed offshore reef, about 650 m from the shoreline. The reef determines the hydrodynamics and circulation in the CZMU.
- A navigation channel crosses the reef in the north section, with limited effect on the CZMU hydrodynamics.
- The coastline behind the reef presents sections of narrow beaches and properties and buildings at the water's edge (with vertical seawalls). These sections are vulnerable to flooding under extreme events.
- The sediment transport is controlled by the reef channel in the south and reef channel in front of the land reclamation (north section).

Geomorphology:
- Narrow beach sections behind a shallow fringing reef.
- Land reclamation in the north section.

Current coastal management practices and interventions

Identified problems:
- The shoreline is in its majority stable, but with possible local erosion problems, as a result of different sections that alternate sedimentary (narrow beach) and hardened coastlines.
- Flooding during extreme events.
- The morphology of the coastline is determined by the reef effect on the hydrodynamics. Changes in the coral reefs will influence the whole CZMU and can result in exacerbated flooding and erosion.
- Evidences of long-term erosion.
- The coastal wetland used to store flood water; the lowland around the wetland has been developed for housing or public facilities such as schools. The developed wetland is a flood hazard area, from freshwater flooding.
- Flooding of lowland around housing development because of improper drainage.

Projects and current practices:
- Seawall construction in several sections. The revetments are vertical.

Priorities for Coastal Management

- Monitor reef health and geomorphology because they are the main driver of coastal hydrodynamics in the CZMU.
- Interventions with seawalls should study effects on adjacent coastal sections and local effects on wave reflection, since small changes in the local conditions can drive adjacent effects.
- Because the reef is providing substantial protection, hardening of the shoreline for extreme flooding should be complemented with other stabilization techniques, like small beach restoration or a vegetated living shoreline, in a way that allows sediment transport in the reef lagoon. Interventions should study these local effects on sediment transport.
- Reef conservation and maintenance of the underwater bathymetry to avoid degradation. Loss of reef and bathymetric complexity can lead to more wave action and flooding and thus enhanced sediment transport and coastal changes.
- Watershed management is critical to maintain healthy reefs (ridge to reef based management).

Malpractices to avoid & factors of special attention to consider in projects:
- Monitor local changes in beach width and map specific flooding and erosion problems. They will be likely associated with local causes and effects.
- Coastal modeling studies are needed to assess the effects of projects and interventions.

Resources

- JICA. 2014. The study for Coastal Erosion and Flood Control Management in The Republic of Seychelles. Japan International Cooperation Agency (JICA).
- MSTEEA. 2011 Preliminary hazards analysis of sea level rise and coastal flooding in Seychelles islands. Ministry for Science, Technology and Environment, Environmental Agency
- Deltares (2018), Quick-scan runup reduction through coral reef restoration in the Seychelles. PP 54. Commissioned by the World Bank.


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Mahe
Elevation contours (m)
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Units_Mahe_CZ
Roads
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buildings_polygon
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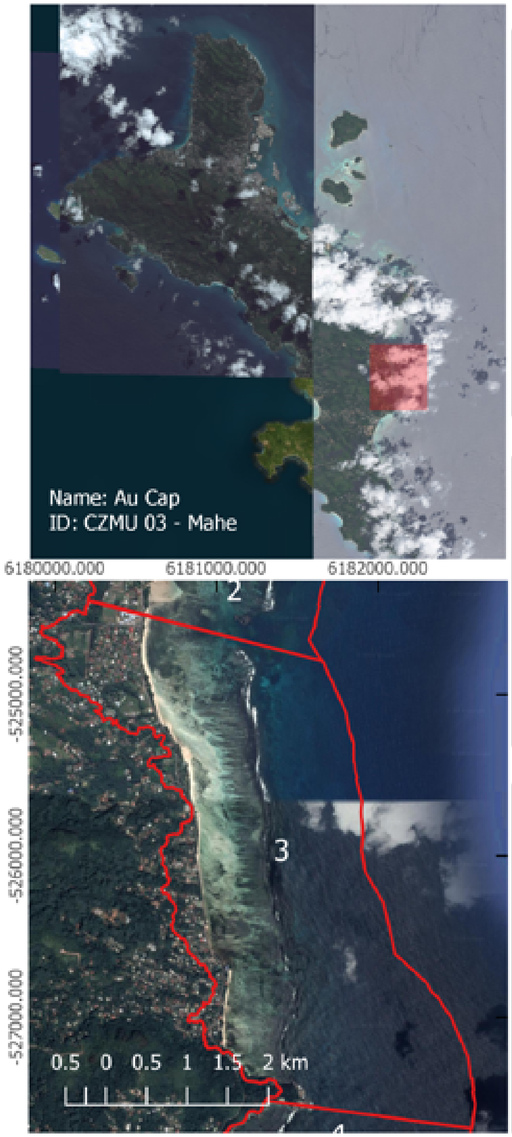


Coastal Hazards and Coastal Processes

Estimated wave runup (Mahe, 1-in-25-yr, MSTEEA): 3.5m
Design conditions (JICA): Hs = 5m, Wave period = 8s, Wave Direction= SSE
Level of risk (JICA): Medium.

Dominant processes:
- Well-developed offshore reef, with the reef crest about 650 m from the shoreline in the northern section and 360m in the southern section. The reef determines the hydrodynamics and circulation in the CZMU.
- The coastline has sections with narrow beaches and properties at the water's edge.
- The coastal properties are vulnerable to flooding under extreme events.
- The sediment transport is controlled by the reef configuration and depth.

Geomorphology:
- A channel in the reef at the northern section separates the unit and the hydrodynamics of this unit from the CZMU02.
- Narrow beach sections behind a shallow fringing reef.

Current coastal management practices and interventions

Identified problems:
- The shoreline shows historical erosion but is in its majority stable, but local erosion problems are possible.
- There are different sections that alternate sedimentary (narrow beach) and hardened coastlines.
- The morphology of the coastline is determined by the reef effect on the hydrodynamics. Changes in the coral reefs will influence the whole CZMU and can result in exacerbated flooding and erosion.
- Evidences of long-term erosion.
- Flooding of lowland around schools and housing development because of improper drainage and outlet clogging by sand bar.
- Traffic congestions during flooding of road from high tides and wave overtopping events.

Projects and current practices:
- Seawall construction in several sections. Vertical revetments.

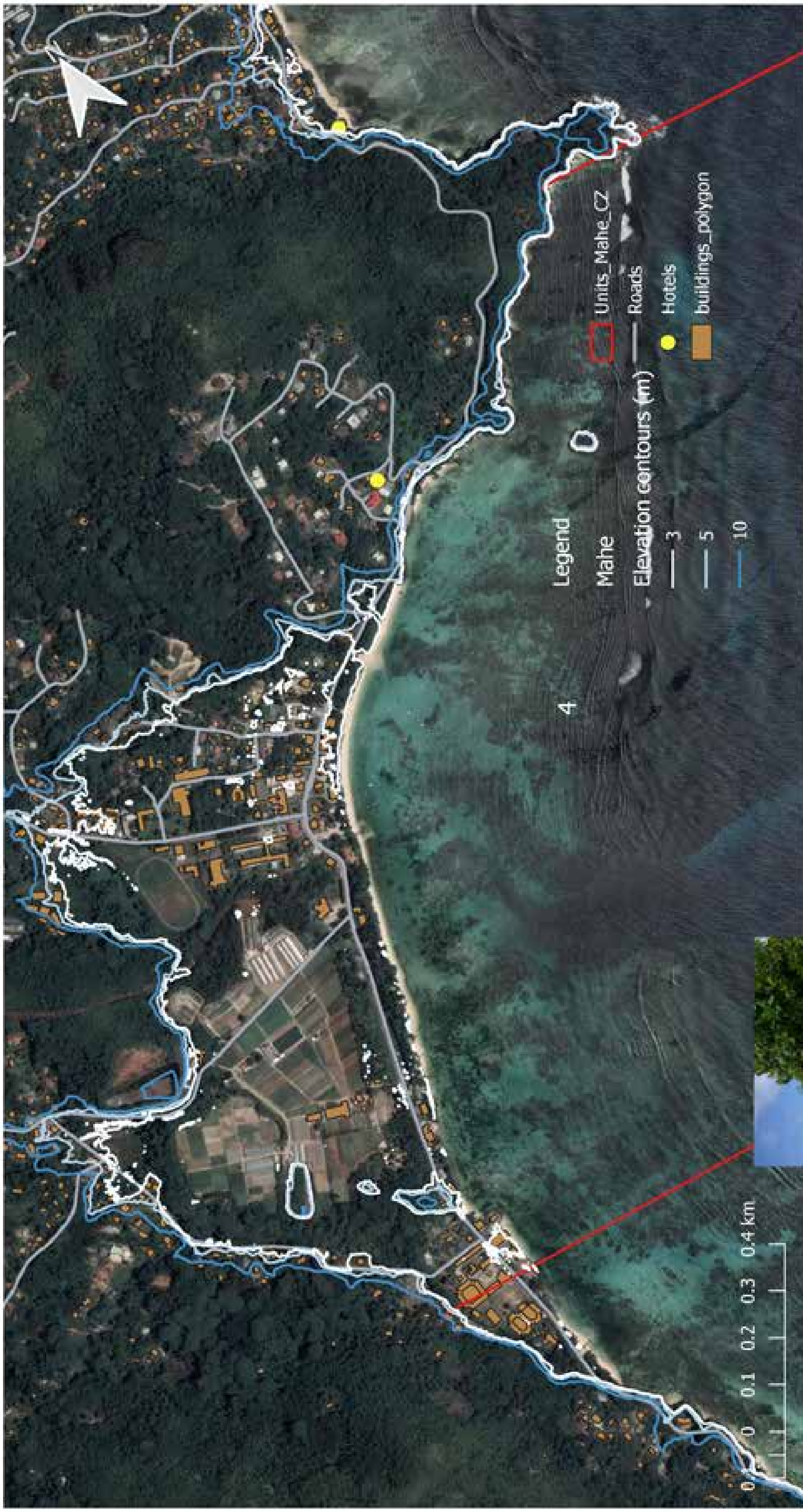
Priorities for Coastal Management

- Monitor reef health and geomorphology because they are the main driver of hydrodynamics in the CZMU.
- Monitor erosion in the southern section.
- Interventions with seawalls should study effects on adjacent coastal sections and local effects on wave reflection, since small changes in the local conditions can drive adjacent effects.
- Any interventions should study effects on sediment transport (within the lagoon). Special attention should be put on interventions that could modify the sediment transport, particularly through impermeable groins.
- Hardening of the shoreline for extreme flooding should be complemented with other stabilization techniques, like small beach stabilization or vegetated living shoreline, to permit sediment transport in the reef lagoon.
- It is recommended to stabilize the shoreline with living shorelines and vegetation, with potential small beach stabilization techniques if needed.
- Reef conservation and maintenance of the underwater bathymetry to avoid degradation. Loss of reef and bathymetric complexity can lead to more wave action and flooding and thus enhanced sediment transport and coastal changes.

Malpractices to avoid & factors of special attention to consider in projects:
- Monitor changes in beach width and map specific flooding and erosion problems within the system. They are likely associated with causes and effects within the system and south-north sediment transport effects.
- Coastal modeling studies are needed to assess the effects of projects and interventions.

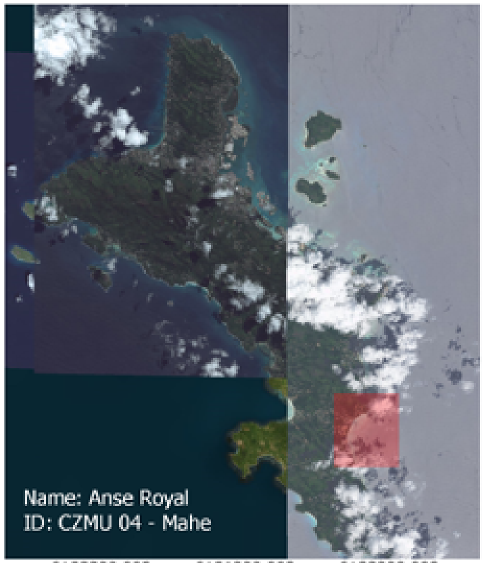
Resources

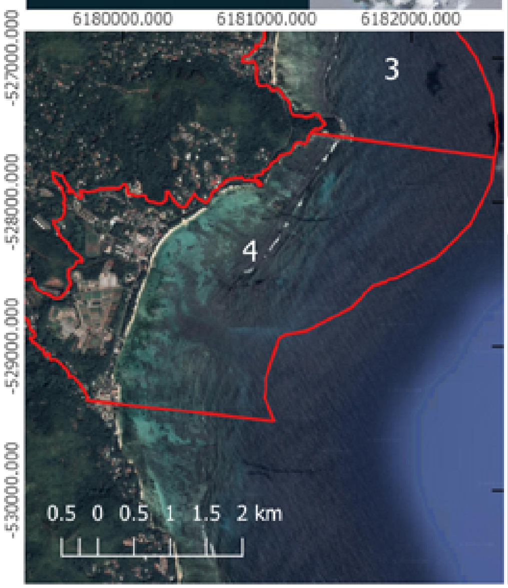
- JICA. 2014. The study for Coastal Erosion and Flood Control Management in The Republic of Seychelles. Japan International Cooperation Agency (JICA).
- MSTEEA. 2011 Preliminary hazards analysis of sea level rise and coastal flooding in Seychelles islands. Ministry for Science, Technology and Environment, Environmental Agency
- Deltares (2018), Quick-scan runup reduction through coral reef restoration in the Seychelles. PP 54. Commissioned by the World Bank.



Detail of wooden pile revetment. Front view.

Detail of revetment in the active beach profile that induces erosion.





Coastal Hazards and Coastal Processes

Estimated wave runup (Mahe, 1-in-25-yr, MSTEEA): 3.5m
Design conditions: Hs = 5m, Wave period = 8s, Wave Direction= ESE
Level of risk (JICA): Low.

Dominant processes:
- Offshore reef in the north section, with the reef crest varying from 200 m from the shoreline in the northern section and 490m in the southern section. The reef determines the hydrodynamics and circulation in the north of the CZMU.
- A channel in the middle of the CZMU separates the unit and the hydrodynamics in the north and south.
- The north section is dominated by wave refraction patterns induced by the reef system; the south receives more wave action through the channel.
- The coastline in the south presents sections of narrow beach and buildings at the water's edge.
- The southern section is more vulnerable to flooding under extreme events.

Geomorphology:
- North: beach sections behind a shallow fringing reef, dominated by the propagation effects of the channel and the reef.
- South: narrow beach section with more direct wave action.
- Wetland areas in the CZMU.

Current coastal management practices and interventions

Identified problems:
- The shoreline in the south may present local erosion problems associated with wave action during storm conditions.
- The morphology of the coastline is determined by the reef effect on the hydrodynamics. Changes in the geomorphology of the coral reef would influence the whole CZMU and result in flooding and erosion.
- Wave overtopping over revetments.
- Wooden pile revetment identified in areas with beach erosion. Wooden pile interfere in the natural beach profile processes and exacerbate erosion (see images).
- Coastal revetment damaged.
- Flooding of lowland around schools and housing development because of improper drainage and outlet clogging by sand bar.
- Coral debris come onshore with high waves during south eastern monsoon
- Salt water intrusion towards south, in the wetlands, is affecting farmlands.

Projects and current practices:
- Erosion was seen in the north and south but was not evident in the central part. Channel dredging for fishing boats may have caused the historical erosion, but is not clear.

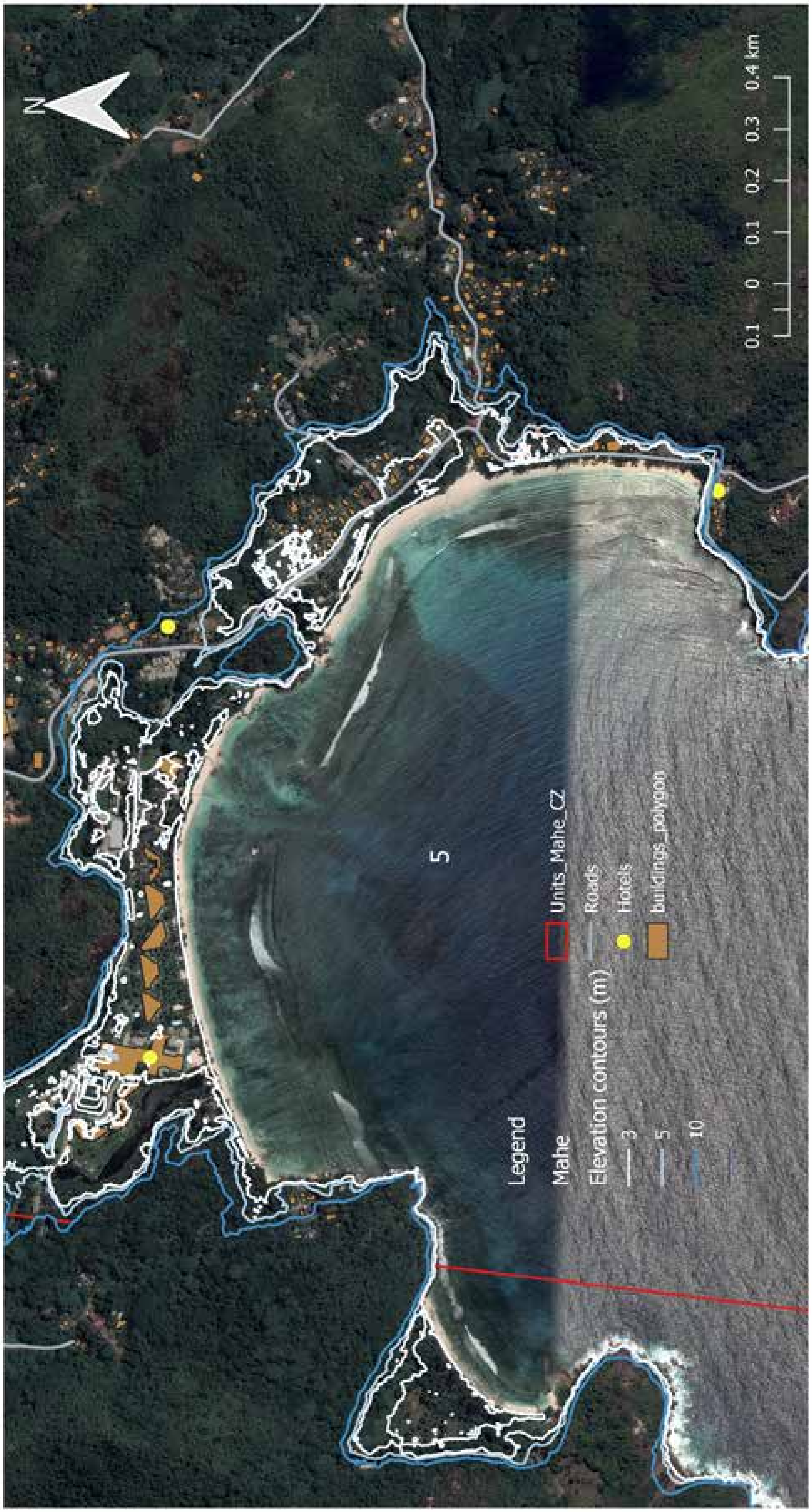
Priorities for Coastal Management

- Restore natural beach profile and vegetation. Restore the natural active beach profile by retiring wooden piling in the active profile, avoid development on the dune and upper beach profile, avoid degradation of the coastal vegetation on the dune part of the beach profile.
- Monitor reef health and geomorphology because they are the main driver of hydrodynamics in the CZMU.
- Erosion in the southern section may require intervention (south from the channel), such as rock armoring or small-scale beach stabilization techniques (e.g. small-scale groins) to accrete sediment in front of buildings. Permeable and soft solutions should be prioritized over hard measures.
- Replenish the beach and design proper infrastructure that will suit both coastal management and buildings
- Any interventions, particularly with hard measures in the south, should study the effects on adjacent coastal sections and local effects on wave reflection, since small changes in the local conditions can drive effects elsewhere.
- Reef conservation and maintenance of the underwater bathymetry to avoid degradation. Loss of reef and bathymetric complexity can lead to more wave action and flooding and thus enhanced sediment transport and coastal changes.

Malpractices to avoid & factors of special attention to consider in projects:
- Avoid hard measures (shoreline hardening or interruption of sediments) in the north section
- Monitor changes in beach width in the north.
- Monitor flooding and erosion problems in the south.
- Coastal modeling studies are needed to assess the effects of projects and interventions.

Resources

- JICA. 2014. The study for Coastal Erosion and Flood Control Management in The Republic of Seychelles. Japan International Cooperation Agency (JICA).
- MSTEEA. 2011 Preliminary hazards analysis of sea level rise and coastal flooding in Seychelles islands. Ministry for Science, Technology and Environment, Environmental Agency
- Deltares (2018), Quick-scan runup reduction through coral reef restoration in the Seychelles. PP 54. Commissioned by the World Bank.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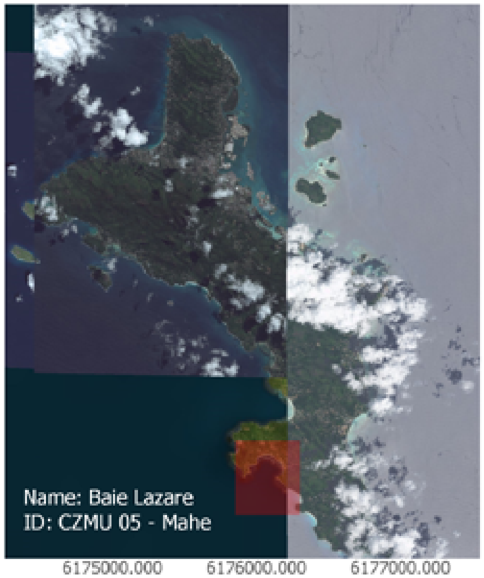
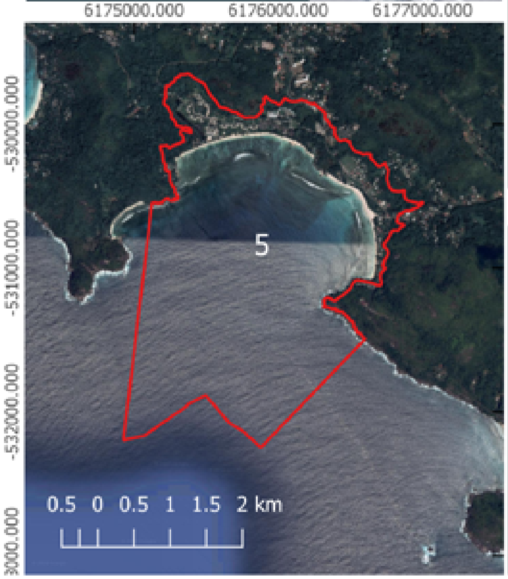
Roads
Hotels
buildings_polygon





Coastal Hazards and Coastal Processes

Estimated wave runup (Mahe, 1-in-25-yr, MSTEEA): 3.5m
Design conditions: Hs = 4m, Wave period = 7s, Wave Direction= SSW
Level of risk (JICA): Moderate. Priority Coast.

Dominant processes:
- Wave propagation effects inside the bay.

Geomorphology:
- Two system of pocket beaches, one on the west and another on the east, separated by a headland, although the beach profiles are connected between the two beaches.
- Sediment transport should be mostly contained in each beach, although it is possible to have some sediment transfer from one to the other associated with storm wave conditions.
- The coast on the east presents less width.
- The Baie Lazare River flows into the sea in the north.
- Wetlands presence in the CZMU.

Current coastal management practices and interventions

Identified problems:
- Wave overtopping on low coastal road (south) with no structures (see Resources - JICA).
- Reef excavated for a navigation channel accelerated beach erosion
- Historical long-term erosion identified. The reasons are not clear. It has been suggested that the sand bar at the river mouth was washed away during an extreme flooding event and the sediment was lost.
- Coastal erosion started two or three years before 2008.
- Wave run-up and coral debris were reported during high tides in May 2007.
- Flooding of lowland area by outlet clogging.
- The unit was affected during the 2004 tsunami.

Projects and current practices:
- Wooden pile revetments had been tried but with stability problems due to wave overtopping.

Priorities for Coastal Management

- Overtopping in the south may require intervention. Rock armoring is not recommended, and beach stabilization techniques should be preferred. These may involve revegetation of the shoreline and potential sand nourishment in the south.
- Increase height of wooden pile revetments and complement with beach and vegetation restoration.
- Interventions with hard measures in the south should study effects on adjacent coastal sections and local effects on wave reflection.
- Maintenance of the beach by sand nourishment is better than direct protection by revetment since the latter causes loss of sand from the beach.
- The prevention of sand loss by a submerged reef in front of the channel could be explored.
- For road protection, other measures will be necessary for future sea level rise, including managed retreat.

Malpractices to avoid & factors of special attention to consider in projects:
- Avoid interruption of sediments in each beach.
- Monitor changes in beach width in the south.
- Monitor flooding problems in the south.

Resources

- JICA. 2014. The study for Coastal Erosion and Flood Control Management in The Republic of Seychelles. Japan International Cooperation Agency (JICA).
- MSTEEA. 2011 Preliminary hazards analysis of sea level rise and coastal flooding in Seychelles islands. Ministry for Science, Technology and Environment, Environmental Agency
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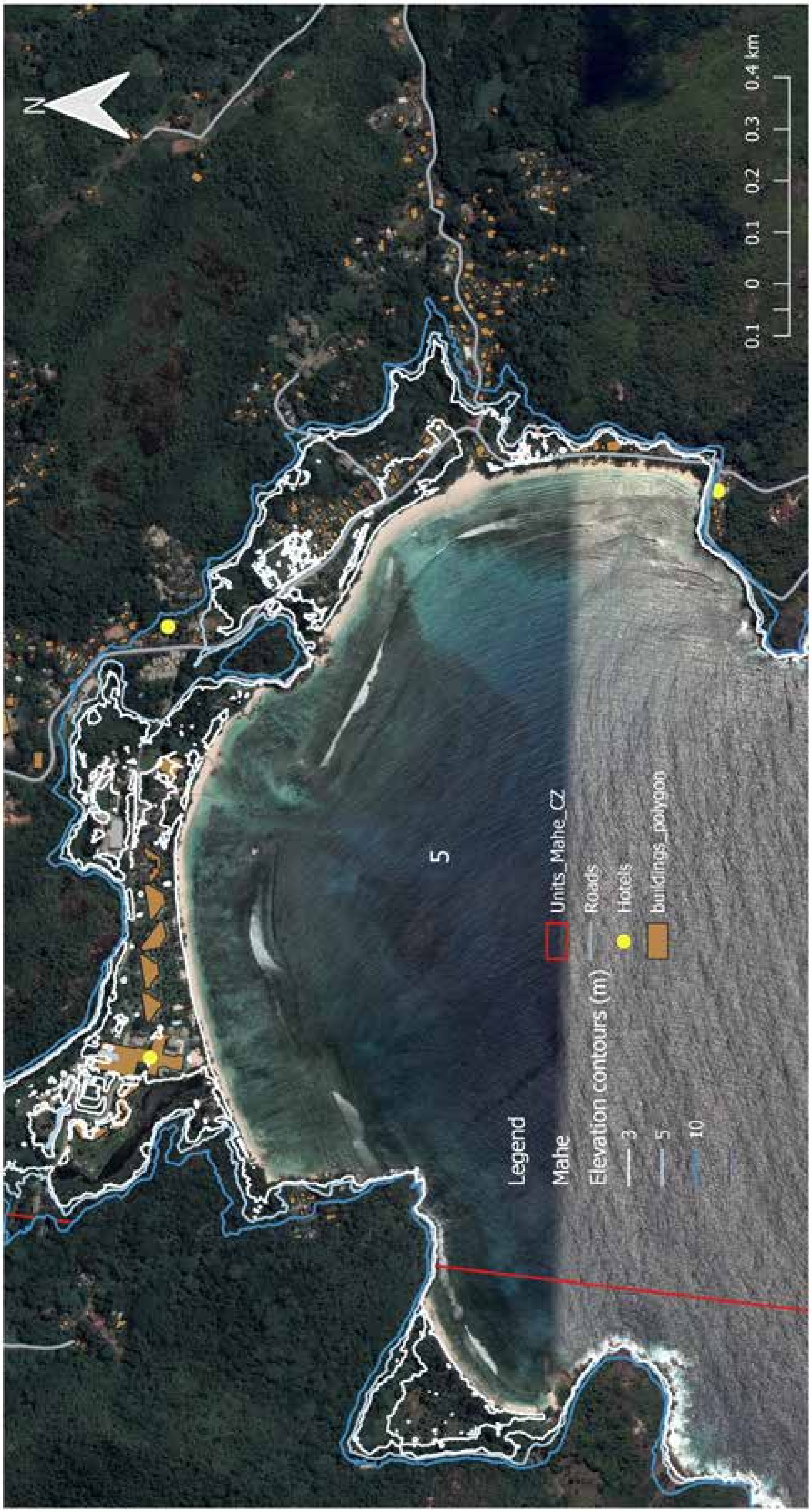
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Legend
Mahe
Units_Mahe_CZ
Roads
Hotels
buildings_polygon
Elevation contours (m)
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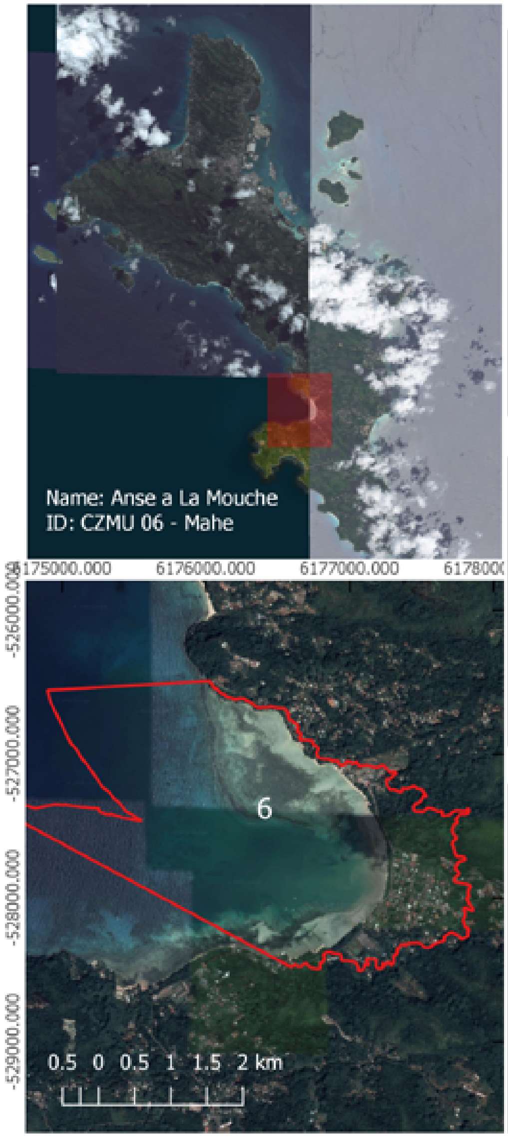

Coastal Hazards and Coastal Processes

Estimated wave runup (Mahe, 1-in-25-yr, MSTEEA): 3.5m
Design conditions: Undetermined.
Level of risk: Low.

Dominant processes:
- Wave propagation effects inside the bay.

Geomorphology:
- Narrow beaches.
- Northern section is shallower and with reefs. The northern section is more protected than the southern section.
- Southern section is exposed to wave action.
- Road section exposed in the south.
- Wetlands present in the CZMU

Current coastal management practices and interventions

Identified problems:
- Erosion and flooding during extreme events.
- Wave overtopping at high tide
- Area affected severely during 2004 tsunami, up to the 3m contour line.
- Also prone to flooding from rainfall, even with the slightest rainfall.

Projects and current practices:
- Reclamation and a jetty caused accretion in the west and the coast in the east is stable.
- On the east side of the jetty, the coast is narrow and has wave overtopping problems.
- Wooden pile revetments had been tried, but failed due to wave overtopping.

Priorities for Coastal Management

- Restore upper beach profile and vegetation. Several sections of the coastline present degraded vegetation and upper beach profile, but sufficient setback and space to the road. These section should be prioritized for beach profile restoration and revegetation.
- Overtopping in the south may require intervention. Rock armoring might be necessary, but it should be complemented with revegetation and other techniques to maintain a living shoreline. Potential sand nourishment with small stabilization interventions (e.g. permeable groins) could be possible solutions.
- Increase height of wooden pile revetments and complement with beach and vegetation restoration.

Malpractices to avoid & factors of special attention to consider in projects:
- Monitor changes in reef configuration and depth in the north, which may result in erosion in the northern section.
- Monitor erosion problems in the south.
- Avoid interruption of sediments in the system. Groins are not recommendable, and permeable ones are preferable to impermeable groins.
- Avoid hard measures, like rock armoring and substitute with beach restoration, revegetation, and reinforcement with permeable piling if needed.

Resources

- JICA. 2014. The study for Coastal Erosion and Flood Control Management in The Republic of Seychelles. Japan International Cooperation Agency (JICA).
- MSTEEA. 2011 Preliminary hazards analysis of sea level rise and coastal flooding in Seychelles islands. Ministry for Science, Technology and Environment, Environmental Agency
- Deltares (2018), Quick-scan runup reduction through coral reef restoration in the Seychelles. PP 54. Commissioned by the World Bank.


Legend
Mahe
Units_Mahe_CZ
Roads
Hotels
buildings_polygon
Elevation contours (m)
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Coastal Hazards and Coastal Processes

Estimated wave runup (Mahe, 1-in-25-yr, MSTEEA): 3.5m
Design conditions: Undetermined.
Level of risk: Low.

Dominant processes:
- Wave propagation is the main driver of coastal change and impacts.
- Changes in wave climate drive the sediment transport north/south within the CZMU.

Geomorphology:
- The beach system is contained by headlands in the south and north.
- The beach position and width are controlled by seasonal changes in the wave energy direction.
- Small reef section in the south protects beach and shoreline.

Current coastal management practices and interventions

Identified problems:
- Seasonal erosion and erosion of beach profile.
- River outlet changed due to construction of large hotel

Projects and current practices:
- Soft beach profile stabilization, using wooden vertical pilling.

Priorities for Coastal Management

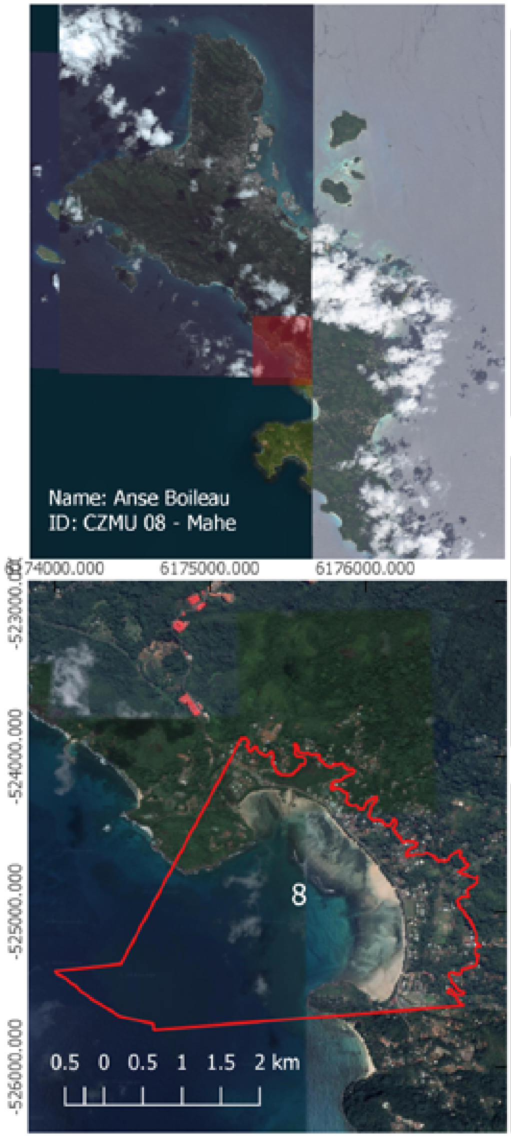
- Monitor beach width and seasonal variations
- Sand nourishment, combined with soft beach stabilization might be needed, depending on long term evolution.

Malpractices to avoid & factors of special attention to consider in projects:
- Avoid longshore sediment transport in the CZMU.
- Monitor flooding events.
- Monitor erosion.
- Do not build on dunes and coastal vegetation.

Resources

- JICA. 2014. The study for Coastal Erosion and Flood Control Management in The Republic of Seychelles. Japan International Cooperation Agency (JICA).
- MSTEEA. 2011 Preliminary hazards analysis of sea level rise and coastal flooding in Seychelles islands. Ministry for Science, Technology and Environment, Environmental Agency
- Deltares (2018), Quick-scan runup reduction through coral reef restoration in the Seychelles. PP 54. Commissioned by the World Bank.

Areas with degraded beach profile and vegetation, and degraded rock armoring.



Coastal Hazards and Coastal Processes

Estimated wave runup (Mahe, 1-in-25-yr, MSTEEA): 3.5m
Design conditions (from : Undetermined.
Level of risk: Low.

Dominant processes:
- Wave propagation is the main driver of coastal change and impacts.
- Low wave activity, significant coastal processes mainly driven during storms. South to South-West swells are the dominant driving force of changes in the sediment transport.

Geomorphology:
- Beach system contained by headlands in the west and east.
- Small reef patches help protect the shoreline, they present small channels.
- Narrow beach width across the unit.
- Sediment transport in the unit is connected but is not strong given the lack of wave activity (with the exception of storms).

Current coastal management practices and interventions

Identified problems:
- Erosion and flooding of road sections.
- Overtopping at high tide, greater than 1.8m
- Flooding occurs during rainfall and high tide.

Projects and current practices:
- Rock armoring has been damaged
- Annual opening of the estuaries is needed.

Priorities for Coastal Management

- Restore beach and dune profile and vegetation of the upper beach profile. Complement with hard flood protection (seawall) in road sections where other options are not possible.
- Monitor beach width and seasonal variations.
- Prioritize beach profile stabilization given the low wave activity, through revegetation of the dynamic beach profile.
- sand nourishment will be a potential solution because the sediment transport is contained within the CZMU.
- Interventions would require coastal modeling studies and assessments of long-term shoreline position.

Malpractices to avoid & factors of special attention to consider in projects:
- Avoid interruption of longshore sediment transport in the CZMU (e.g. avoid groins).
- Avoid development or sediment compaction in the upper part of the beach profile.
- Avoid damages to vegetation or interruptions in the vegetation belt.

Resources

- JICA. 2014. The study for Coastal Erosion and Flood Control Management in The Republic of Seychelles. Japan International Cooperation Agency (JICA).
- MSTEEA. 2011 Preliminary hazards analysis of sea level rise and coastal flooding in Seychelles islands. Ministry for Science, Technology and Environment, Environmental Agency
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Legend
Mahe
Elevation contours (m)
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Units_Mahe_CZ
Roads
Hotels
buildings_polygon
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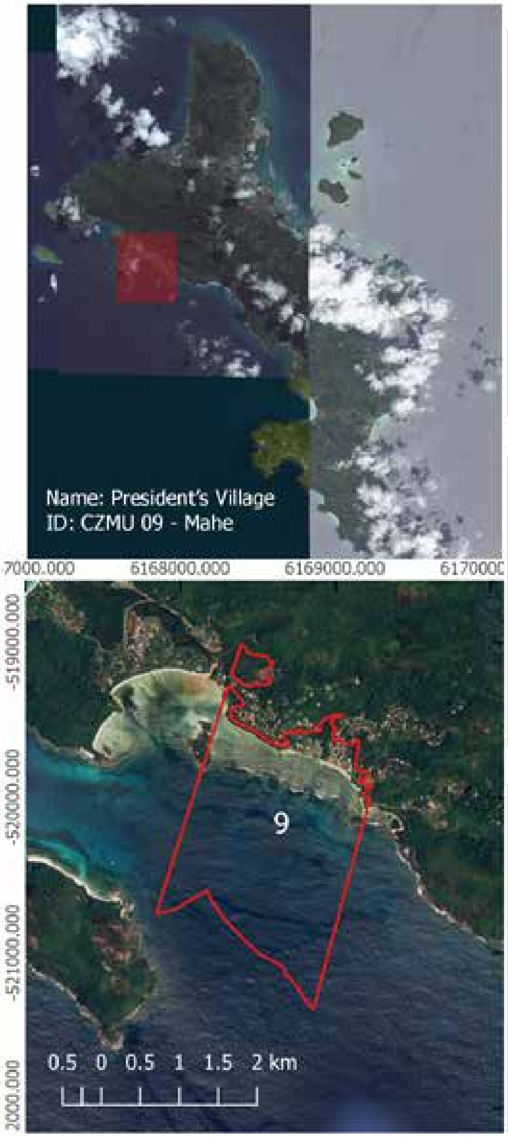

Coastal Hazards and Coastal Processes

Estimated wave runup (Mahe, 1-in-25-yr, MSTEEA): 3.5m
Design conditions: Undetermined.
Level of risk: Low.

Dominant processes:
- Wave propagation is the main driver of coastal change and impacts, they are determined by a narrow reef system.
- Changes in wave climate drive the sediment transport north/south within the CZMU.

Geomorphology:
- Fringing reef about 175m from the shoreline, protects the low-lying coastal zone.
- The reef system presents several narrow channels and is mostly parallel to the shore.
- The morphodynamics are controlled by the circulation in the reef lagoon. Beach system contained by headlands in the south and north.
- Narrow beach section.

Current coastal management practices and interventions

Identified problems:
- Erosion.

Projects and current practices:
- Rock armoring.

Priorities for Coastal Management

- Monitor beach width.
- Monitor configuration and depth of reef system.
- Avoid hardening of the shoreline.
- Beach profile stabilization techniques are preferable.
- Underwater reef structures could be an option to protect the shoreline.
- Consider other mechanisms rather than rock armoring, also for tourism interests.

Malpractices to avoid & factors of special attention to consider in projects:
- Monitor flooding events.
- Monitor beach width, associated to reef configuration and depth.

Resources

- JICA. 2014. The study for Coastal Erosion and Flood Control Management in The Republic of Seychelles. Japan International Cooperation Agency (JICA).
- MSTEEA. 2011 Preliminary hazards analysis of sea level rise and coastal flooding in Seychelles islands. Ministry for Science, Technology and Environment, Environmental Agency
- Deltares (2018), Quick-scan runup reduction through coral reef restoration in the Seychelles. PP 54. Commissioned by the World Bank.


Legend
Praslin
roads
hotel
Elevation contours (m)
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Units Praslin
Buildings
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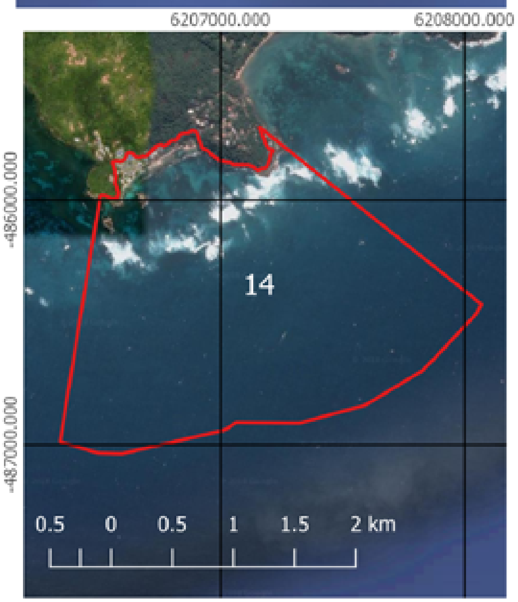

Coastal Hazards and Coastal Processes

Estimated wave runup (Praslin, 1-in-25-yr, MSTEEA): 2.8m
Design condition: undetermined.
Level of risk: Low.

Dominant processes:
- Hydrodynamics are controlled by an offshore breaking points in shallow waters, and a complex nearshore bathymetry and reef environment close to the shoreline.
- The hydrodynamics and circulation are contained by two headlands, on the west and east.
- Complex shallow water bathymetry.

Geomorphology:
- Narrow pocket beach sections behind shallow complex bathymetry.
- While surf zone area extends beyond the reach of the headlands, most of the circulation with shoreline consequences occur close to the shore within the CZMU.

Current coastal management practices and interventions

Identified problems:
- Erosion.
- Changes in the shallow bathymetry (e.g. coral reefs) can influence local flooding and erosion.

Projects and current practices:
- Undetermined.

Priorities for Coastal Management

- Monitor shallow water bathymetry and geomorphological changes.
- Along the shoreline, hard measures (seawall or adequate rock armoring) can be needed to protect the road.
- Reinforcing the hard measures with beach accretion or other type of shoreline advancement technique might be recommendable. However, the active profile will be narrow, and vegetation and profile stabilization should be preferable.
- Interventions with seawalls should study effects on adjacent coastal sections and local effects on wave reflection.
- Low crested breakwaters and coral gardening could be a solution and serve as detached breakwaters.
- Reef conservation and maintenance of the underwater bathymetry to avoid degradation. Loss of reef and bathymetric complexity can lead to more wave action and flooding and thus enhanced sediment transport and coastal changes.
- Watershed management is critical to maintain healthy reefs (ridge to reef based management).
- Enhance reef restoration
- Concave seawall to be built to help revert waves

Malpractices to avoid & factors of special attention to consider in projects:
- Avoid interventions orthogonal to the shore (e.g. groins).
- Monitor local changes in beach width and map specific flooding and erosion problems within the system since they will be associated with local causes and effects (e.g. erosion and overtopping at road sections).

Resources

- JICA. 2014. The study for Coastal Erosion and Flood Control Management in The Republic of Seychelles. Japan International Cooperation Agency (JICA).
- MSTEEA. 2011 Preliminary hazards analysis of sea level rise and coastal flooding in Seychelles islands. Ministry for Science, Technology and Environment, Environmental Agency
- Deltares (2018), Quick-scan runup reduction through coral reef restoration in the Seychelles. PP 54. Commissioned by the World Bank.


N
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Legend
Praslin
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Units Praslin
Buildings
Elevation contours (m)
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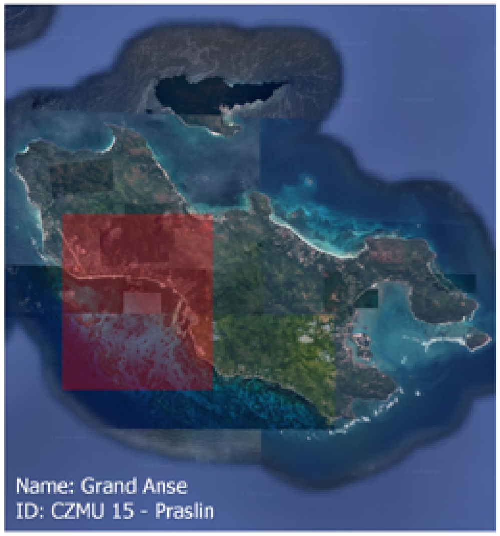

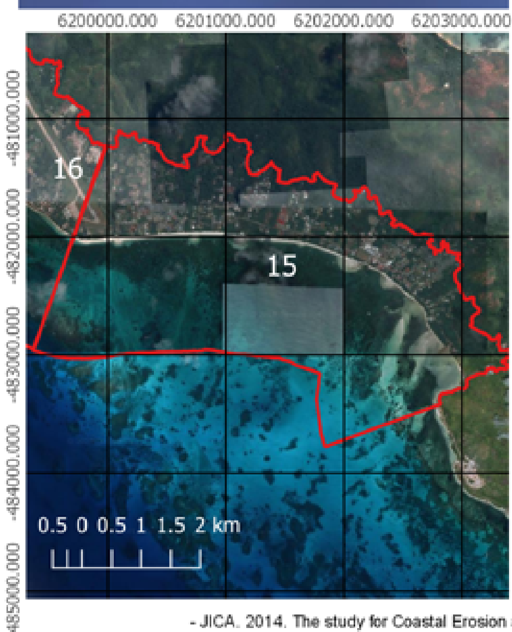

Coastal Hazards and Coastal Processes

Estimated wave runup (Praslin, 1-in-25-yr, MSTEEA): 2.8m
Design conditions (Anse Kerlan, Praslin): Hs = 4m, Wave period = 7s, Wave Direction= SSW
Level of risk (JICA): High. Priority Coast.

Dominant processes:
- Reef patches, with not clearly defined reef crests.
- Dominant longshore sediment transport processes, associated to wave propagation and current circulation.

Geomorphology:
- Semi-pocked beach system, contained on the east by a natural headland and on the west by a point with potential sediment bypass from CZMU 16.
- Narrow beach sections on the east side, close to the road.

Current coastal management practices and interventions

Identified problems:
- The shoreline is in its majority stable, but with possible local erosion problems, as a result of different sections that alternate sedimentary (narrow beach) and hardened coastlines.
- The morphology of the coastline is determined by the reef effect on the hydrodynamics. Changes in the geomorphology of the coral reef would influence the whole CZMU and result in flooding and erosion. Evidences of long-term erosion.
- Severe coastal erosion caused by longshore transport interruption by groins.

Projects and current practices:
- Seawall construction in several sections.
- Groins.

Priorities for Coastal Management

- Special attention should be put on monitoring and assessing sediment bypass (input / output) through the western limit of the CZMU.
- Erosion in the southern section, close to the road section.
- Dune restoration and revegetation should be prioritized.
- Beach profile stabilization (e.g. with vegetation and shoreline advancement), but also long-shore sediment transport interventions (e.g. permeable groins). Sand nourishment could be beneficial in the eastern side, complementing stabilization techniques.
- Interventions with seawalls and other hard measures should be avoided as they can have effects on adjacent coastal sections and local effects on wave reflection.
- For any intervention, the effects on sediment transport within the CZMU should be studied. Special attention should be put on modifying the sediment transport within the system, particularly groins.
- Reef conservation and maintenance of the underwater bathymetry to avoid degradation. Loss of reef and bathymetric complexity can lead to more wave action and flooding and thus enhanced sediment transport and coastal changes.
- Watershed management is critical to maintain healthy reefs (ridge to reef based management).

Malpractices to avoid & factors of special attention to consider in projects:
- Avoid hard measures and shoreline hardening.
- Monitor and assess sediment input-output in the western limit.
- Monitor changes in beach width on the eastern limit.

Resources

- JICA. 2014. The study for Coastal Erosion and Flood Control Management in The Republic of Seychelles. Japan International Cooperation Agency (JICA).
- MSTEEA. 2011 Preliminary hazards analysis of sea level rise and coastal flooding in Seychelles islands. Ministry for Science, Technology and Environment, Environmental Agency
- Deltares (2018). Quick-scan runup reduction through coral reef restoration in the Seychelles. PP 54. Commissioned by the World Bank.


Legend
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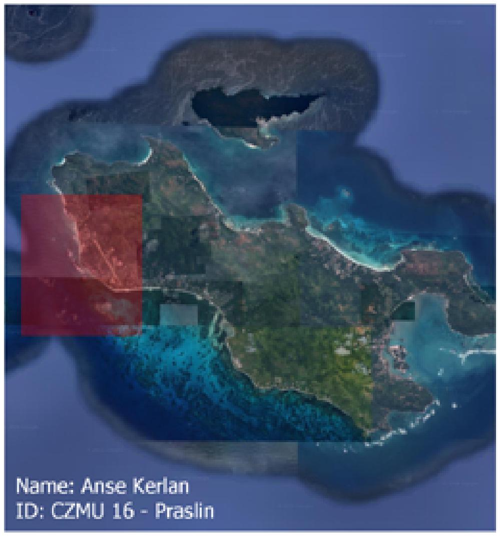
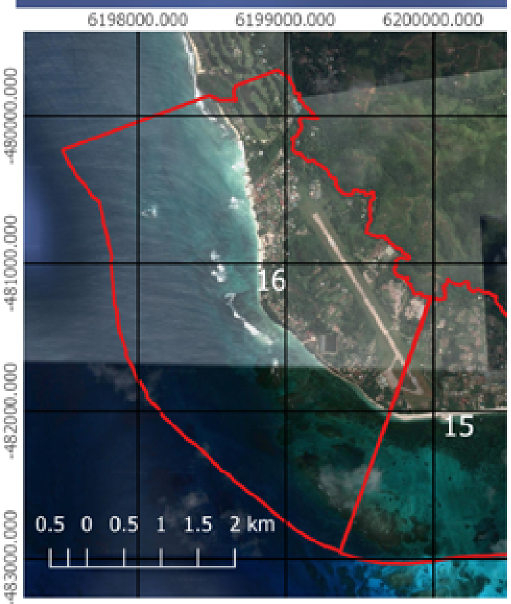




Coastal Hazards and Coastal Processes

Estimated wave runup (Praslin, 1-in-25-yr, MSTEEA): 2.8m
Design conditions (Anse Kerlan, Praslin): Hs = 4m, Wave period = 7s, Wave Direction= SSW
Level of risk (JICA): High. Priority site.

Dominant processes:
- Wave action is oblique to the shoreline and produces longshore sediment transport in the north of the CZMU, with potential seasonal changes driven by changes in wave direction.
- A natural headland and a system of closer reefs to the headland change the circulation in the south, dominated by southwards sediment transport.

Geomorphology:
- In the north, the southern section comprises a natural vegetated headland and shallow reefs, which help control the sediment in the southern beach sections.
- The northern section is more exposed to the effects of oblique wave action and subjected to stronger sediment transport. The surf zone is also closer to shore, which indicates more localized effects of any future intervention.
- In the north, the current geomorphology includes beach sections with shoreline orthogonal man-made structures.
- The most northern section is protected by a shallow reef, which stabilizes the shoreline from a natural headland to the most northern groin.
- South from the headland, the beach is narrow and exposed to longshore sediment transport.

Current coastal management practices and interventions

Identified problems:
- Longshore erosion, northwards in the north section, and southwards in the southern section (south of the headland).
- The morphology of the coastline is determined by wave action and longshore sediment transport.
- The south section presents erosion problems, narrow beach area and damages to rock armoring.
- Flooding of road sections.
- Alternative to existing measures (rock armoring) are needed.

Projects and current practices:
- Groins (linear and T-shape) interventions to control the longshore sediment transport.
- Rock armoring, south from the headland. It has been damaged.
- Seawall to protect road.

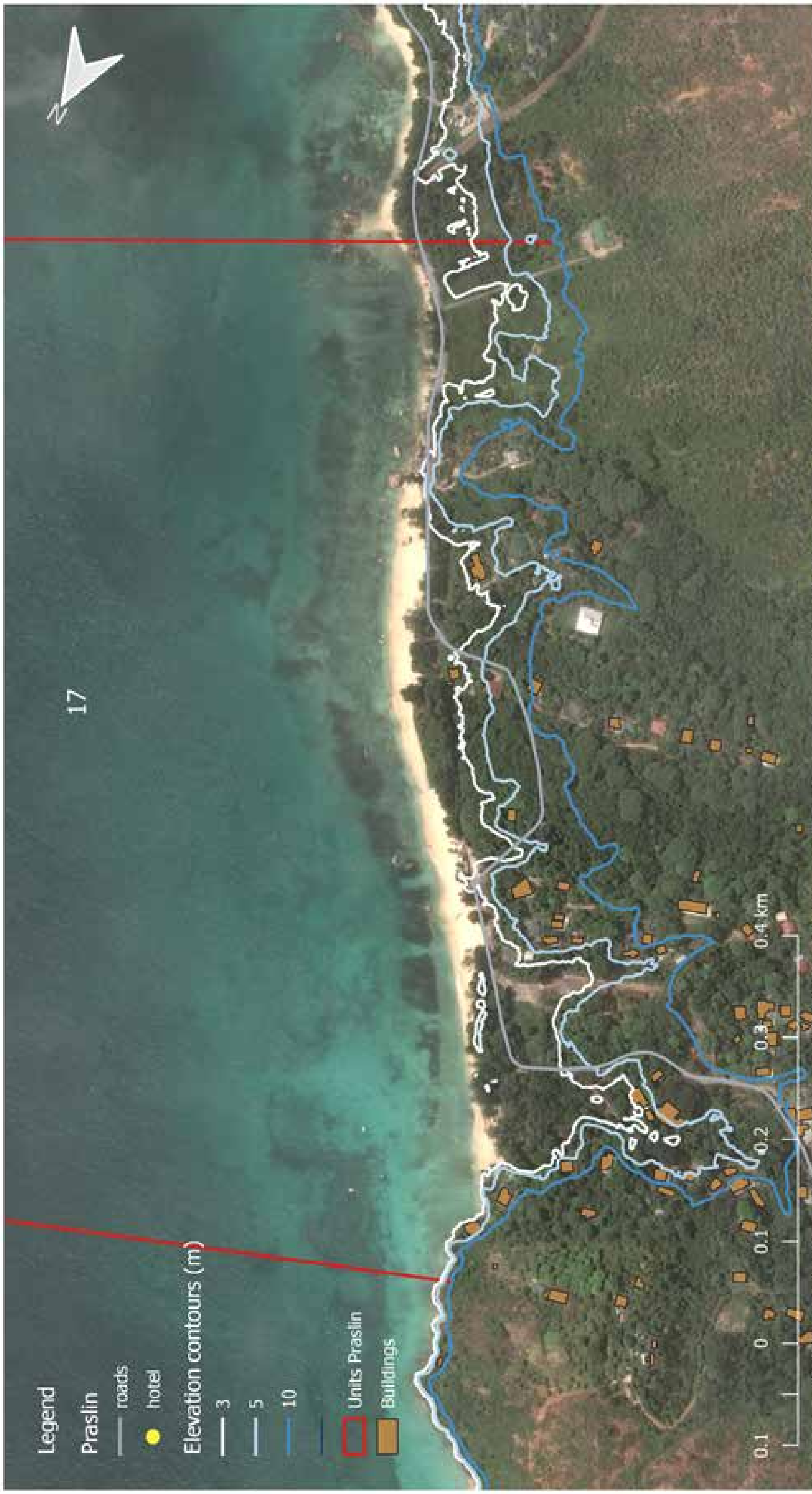
Priorities for Coastal Management

- Given the importance for tourism, sand nourishment and beach stabilization measures should be prioritized in the north.
- Implement interventions to control the longshore sediment transport, e.g. groins, with special attention to adequate rock size and stability of each structure. These structures can create stable small sections of beach systems.
- On the landward side, complement with revegetation of the beach profile.
- Monitor reef health and bathymetry in the northern section, to avoid local erosion and sediment loss.
- South of the headland, contemplate beach and dune rehabilitation with vegetation restoration to reinforce the beach profile. Rock armoring could be necessary but the design must be improved to resist wave action.
- Reef conservation and maintenance of the underwater bathymetry to avoid degradation. Loss of reef and bathymetric complexity can lead to more wave action and flooding and thus enhanced sediment transport and coastal changes.
- Watershed management is critical to maintain healthy reefs (ridge to reef based management).
- Reef restoration and reef breakwaters could be potential solutions.

Malpractices to avoid & factors of special attention to consider in projects:
- Monitor changes in beach width.
- Special attention should be put on rock size, beach closure depth (during design and implementation), and distance between groins.
- Revetments may cause loss of beach sand.

Resources

- JICA. 2014. The study for Coastal Erosion and Flood Control Management in The Republic of Seychelles. Japan International Cooperation Agency (JICA).
- MSTEEA. 2011 Preliminary hazards analysis of sea level rise and coastal flooding in Seychelles islands. Ministry for Science, Technology and Environment, Environmental Agency
- Deltares (2018), Quick-scan runup reduction through coral reef restoration in the Seychelles. PP 54. Commissioned by the World Bank.


Legend
Praslin
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hotel
Elevation contours (m)
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Units Praslin
Buildings
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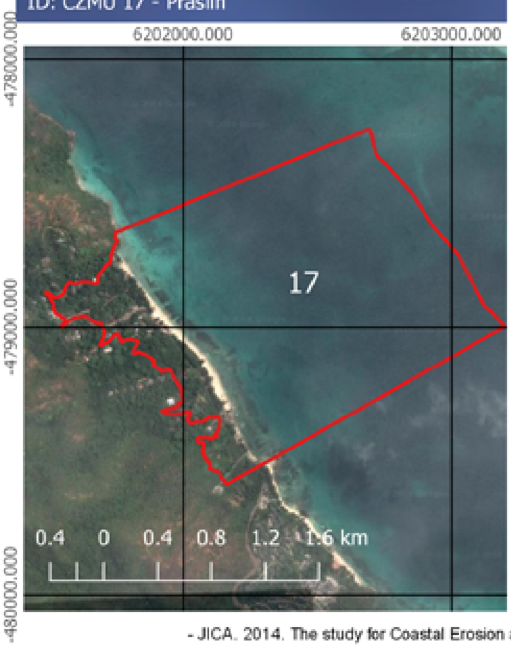
0.1 0 0.1 0.2 0.3 0.4 km



Coastal Hazards and Coastal Processes

Estimated wave runup (Praslin, 1-in-25-yr, MSTEEA): 2.8m
Design conditions: unreported
Level of risk: Low.

Dominant processes:
- The site is protected from offshore wave action but exposed to NW storms.
- The dominant processes are controlled by the regional wave propagation patterns between islands and oblique wave action.

Geomorphology:
- Variable beach width and vegetation cover.
- Two sections of road close to the water's edge, interfere with the active beach profile.
- The southern section presents rocky areas that serve as natural groins and contain sediment transport southwards.
- The northern section presents less beach width.

Current coastal management practices and interventions

Identified problems:
- Erosion in specific road sections.

Projects and current practices:
- Rock armoring and revetments.
- Sandbags
- Pavement built on upper part of the beach profile.

Priorities for Coastal Management

- Revegetation and maintenance of the existing vegetation cover in the upper part of the beach profile. Revegetation interventions should imitate the adjacent sections with no development.
- It is recommended to restore the beach profile (e.g. with revegetation) and continuing monitoring the system.
- Rock armoring is not recommended. Beach stabilization techniques are preferable. These may involve revegetation of the shoreline and respecting the natural beach profile.
- In sections where interventions with hard measures may be required for road protection, project should study effects on adjacent coastal sections and local effects on wave reflection. Sand nourishment may be necessary to restore a natural beach profile, combined with vegetation restoration in front of hard measures (increasing the green buffer seawards).

Malpractices to avoid & factors of special attention to consider in projects:
- Avoid hard measures.
- Do not implement interruption of sediments.
- Monitor changes in beach width across the CZMU.
- Any intervention should attend to the longshore sediment transport and the effects downstream.

Resources

- JICA. 2014. The study for Coastal Erosion and Flood Control Management in The Republic of Seychelles. Japan International Cooperation Agency (JICA).
- MSTEEA. 2011 Preliminary hazards analysis of sea level rise and coastal flooding in Seychelles islands. Ministry for Science, Technology and Environment, Environmental Agency
- Deltares (2018), Quick-scan runup reduction through coral reef restoration in the Seychelles. PP 54. Commissioned by the World Bank.


N
18
Legend
Praslin
roads
hotel
Units Praslin
Buildings
Elevation contours (m)
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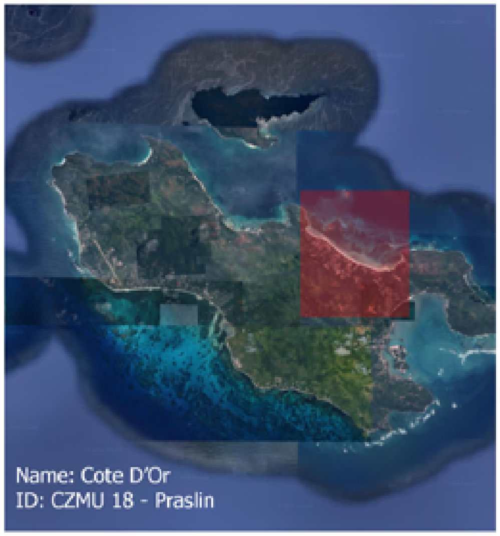

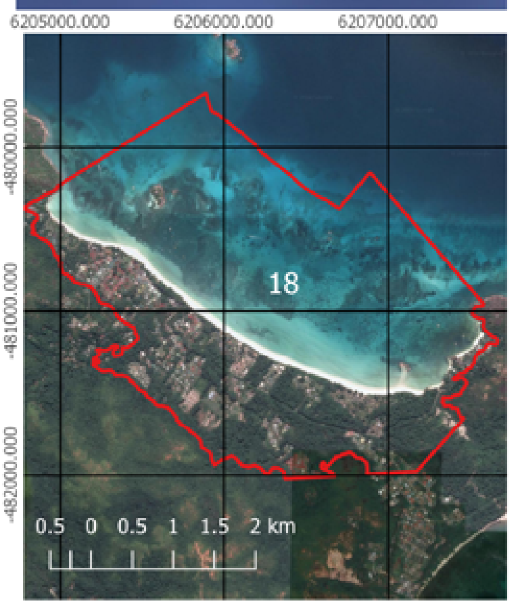

Coastal Hazards and Coastal Processes

Estimated wave runup (Praslin, 1-in-25-yr, MSTEEA): 2.8m
Design conditions: unreported.
Level of risk: Low.

Dominant processes:
- Wave propagation patterns configure the beach system.
- Location exposed to the action of NE and E storms.
- Both longshore and cross shore sediment transport, mostly occurring during storm conditions.

Geomorphology:
- Wide beach areas, very mild slopes
- Beach system with two natural headlands and small island protection (Chauve Souris) that advances the shoreline behind. The beach system is formed by wave refraction and diffraction; these wave patterns create a convergence of longshore drift on the opposite side of the island.

Current coastal management practices and interventions

Identified problems:
- Erosion in the north west section (rest of the beach do not show signs of erosion).

Projects and current practices:
- Rock hardening, different techniques (wooden piling with one or two levels, rock armoring).

Priorities for Coastal Management

- The beach in the northwest is associated to changes in the circulation pattern, north of the headland generated by the offshore island. The specific causes of this concentrated erosion should be studied. Beach restoration techniques should be prioritized.
- Dune restoration
- Beach profile restoration should be prioritized through dune restoration and revegetation, given the small slopes and the long active beach profiles.
- Coastal setbacks could be particularly beneficial.
- Projects should imitate and try to replicate stable sections that present less development.
- Shoreline advancement with sand nourishment may be necessary to avoid hard measures.

Malpractices to avoid & factors of special attention to consider in projects:
- Avoid interruption of longshore sediments (e.g. through the use of groins)
- Avoid shoreline hardening and hard measures.

Resources

- JICA. 2014. The study for Coastal Erosion and Flood Control Management in The Republic of Seychelles. Japan International Cooperation Agency (JICA).
- MSTEEA. 2011 Preliminary hazards analysis of sea level rise and coastal flooding in Seychelles islands. Ministry for Science, Technology and Environment, Environmental Agency
- Deltares (2018), Quick-scan runup reduction through coral reef restoration in the Seychelles. PP 54. Commissioned by the World Bank.


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Legend
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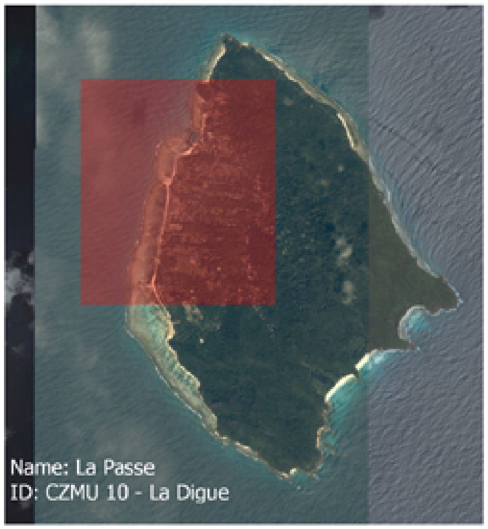

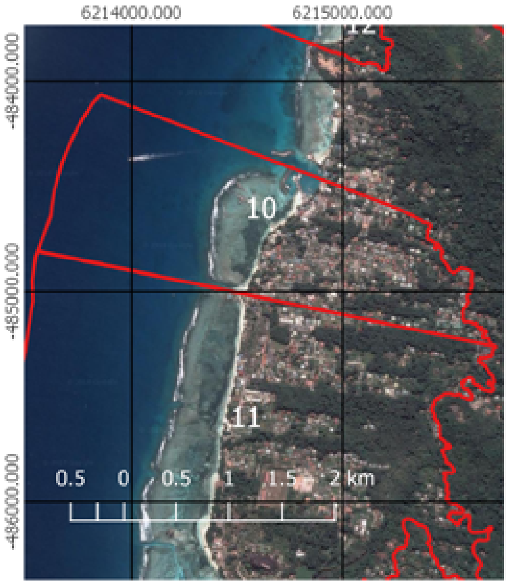

Coastal Hazards and Coastal Processes

Estimated wave runup (La Digue, 1-in-25-yr, MSTEEA): 2.8m
Design conditions (La Passe, La Digue): Hs = 4m, Wave period = 6s, Wave Direction= WSW
Level of risk (JICA): Moderate. Priority Coast.

Dominant processes:
- Hydrodynamics are controlled by an offshore reef system and the detached breakwaters at the harbor (north).
- The circulation is contained between the breakwater at the harbor on the north and the southern reef channel on the south.

Geomorphology:
- Low lying coastal zone
- Complex shallow water bathymetry with different reef and coastal alignments.
- The reef system, at approximately 260m from the shoreline, controls the position of the shoreline through its influence on wave propagation and the circulation in the CZMU.
- A groin in the center of the unit accretes sand from the south, the harbor structures accrete sand on their south face.
- The sediment transport is northwards, driven by the propagation and circulation patterns in the reef lagoon.

Current coastal management practices and interventions

Identified problems:
- Erosion.
- Changes in the shallow bathymetry (e.g. coral reefs) can influence local flooding and erosion.

Projects and current practices:
- Shoreline hardening (rock armoring) in several sections.
- Groins
- Breakwaters to protect the access to the harbor and the navigation channel.

Priorities for Coastal Management

- Monitor shallow water bathymetry and geomorphological changes.
- Restore vegetation in the upper part of the beach profiles.
- Permeable groins can be used to stabilize beach areas.
- Interventions that include shoreline hardening should be avoided.
- Reef conservation and maintenance of the underwater bathymetry to avoid degradation. Loss of reef and bathymetric complexity can lead to more wave action and flooding and thus enhanced sediment transport and coastal changes.
- Watershed management is critical to maintain healthy reefs (ridge to reef based management).
- The protection of existing infrastructure is a priority, e.g. police station, hospital, restaurant, private properties.
- Artisanal fishing management.

Malpractices to avoid & factors of special attention to consider in projects:
- Monitor local changes in beach width and map specific flooding and erosion problems since they will be likely associated with local causes and effects.
- Avoid hard measures (shoreline hardening or interruption of sediments) in the northern section.
- Study the effects of coastal structures in the harbor on the southern reef and the beach system.

Resources

- JICA. 2014. The study for Coastal Erosion and Flood Control Management in The Republic of Seychelles. Japan International Cooperation Agency (JICA).
- MSTEEA. 2011 Preliminary hazards analysis of sea level rise and coastal flooding in Seychelles islands. Ministry for Science, Technology and Environment, Environmental Agency
- EU & UNDP. 2018. Seychelles Global Climate Change Alliance + Climate Change Project. Component B. Shoreline Management Plan. La Digue, Seychelles.
- Deltares (2018), Quick-scan runup reduction through coral reef restoration in the Seychelles. PP 54. Commissioned by the World Bank.


N
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Legend
La Digue
hotels
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Units LaDigue
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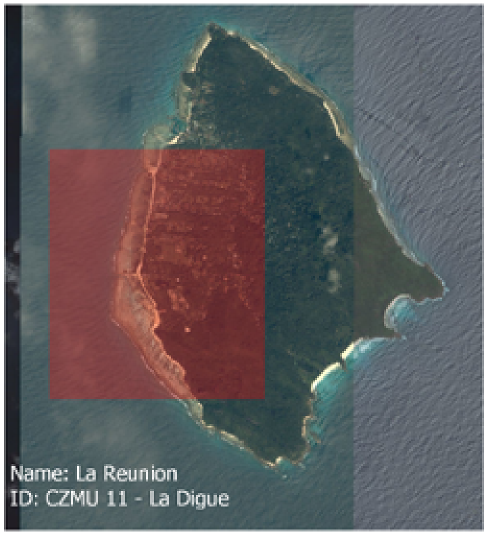
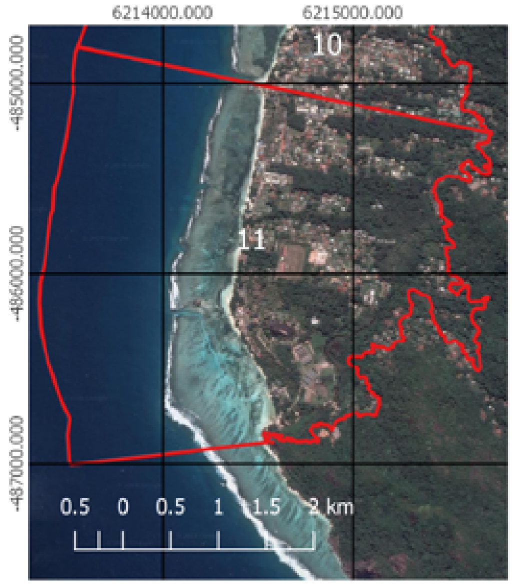




Coastal Hazards and Coastal Processes

Estimated wave runup (La Digue, 1-in-25-yr, MSTEEA): 2.8m
Design conditions (La Passe, La Digue): Hs = 4m, Wave period = 6s, Wave Direction= WSW
Level of risk (JICA): Moderate. Priority Coast.

Dominant processes:
- Hydrodynamics are controlled by an offshore reef system
- Complex shallow water bathymetry with different reef and two main coastal alignments.
- Wave action is oblique to the shoreline, which produces longshore sediment transport, with potential seasonal changes driven by wave direction changes.

Geomorphology:
- Low lying coastal zone
- Reef system parallel to the shore, between 250 to 300 m from the shoreline.
- One reef channel on the north and a natural headland in the south delimit the circulation in the CZMU.
- In the southern end, the orientation of the shoreline changes, and there is a small advancement of the shoreline induced by the effect of an island on the wave propagation.

Current coastal management practices and interventions

Identified problems:
- Erosion.
- Changes in the shallow bathymetry (e.g. coral reefs) can influence local flooding and erosion.

Projects and current practices:
- Small sections of rock armoring vertical walls.
- Artificial islands

Priorities for Coastal Management

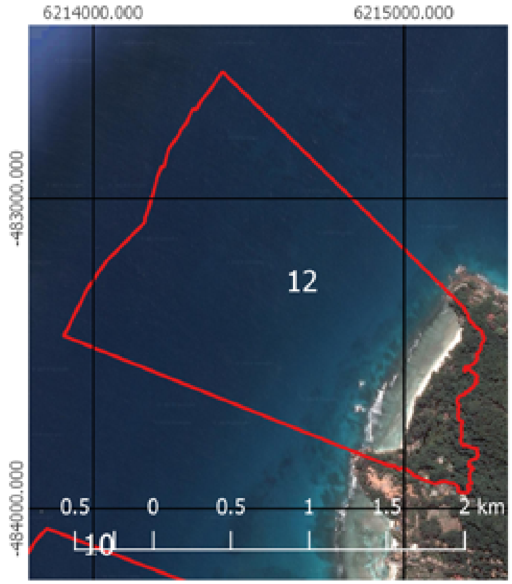
- Monitor shallow water bathymetry and geomorphological changes.
- Restore vegetation in the upper part of the beach profiles.
- Interventions that include shoreline hardening should be avoided.
- It is recommended to stabilize the shoreline with living shorelines and vegetation, with potential small beach stabilization techniques if needed (permeable options are preferable).
- Reef conservation and maintenance of the underwater bathymetry to avoid degradation. Loss of reef and bathymetric complexity can lead to more wave action and flooding and thus enhanced sediment transport and coastal changes.
- Watershed management is critical to maintain healthy reefs (ridge to reef based management).
- The protection of existing infrastructure is a priority, e.g. police station, hospital, restaurant, private properties.
- Artisanal fishing management.

Malpractices to avoid & factors of special attention to consider in projects:
- Monitor local changes in beach width and map specific flooding and erosion problems since they are will be likely associated with upstream/downstream effects.
- Avoid hard measures (shoreline hardening or interruption of sediments).
- Avoid interruption of longshore sediment transport.
- For any intervention, the effects on sediment transport within the CZMU should be studied. Special attention should be put on interventions that can modify the sediment transport within the system, particularly groins.
- Study coastal processes from a system view perspective because changes in the circulation can have large effects downstream from the intervention (longshore effects).

Resources

- JICA. 2014. The study for Coastal Erosion and Flood Control Management in The Republic of Seychelles. Japan International Cooperation Agency (JICA).
- MSTEEA. 2011 Preliminary hazards analysis of sea level rise and coastal flooding in Seychelles islands. Ministry for Science, Technology and Environment, Environmental Agency
- EU & UNDP. 2018. Seychelles Global Climate Change Alliance + Climate Change Project. Component B. Shoreline Management Plan. La Digue. Seychelles.
- Deltares (2018), Quick-scan runup reduction through coral reef restoration in the Seychelles. PP 54. Commissioned by the World Bank.

Detail of the beach profile.



Coastal Hazards and Coastal Processes

Estimated wave runup (La Digue, 1-in-25-yr, MSTEEA): 2.8m
Design conditions (La Passe, La Digue): Hs = 4m, Wave period = 6s, Wave Direction= WSW
Level of risk (JICA): Moderate. Priority Coast.

Dominant processes:
- The reef system configures the wave propagation and circulation in the CZMU.

Geomorphology:
- Pocket beach contained by the natural rocky headlands. The transport of sediment is contained within the CZMU.
- Reef system, about 80-100m from the shoreline.
- Complex bathymetry, the beach is protected by the offshore reef.

Current coastal management practices and interventions

Identified problems:
- Erosion.
- Changes in the shallow bathymetry (e.g. coral reefs) can influence local flooding and erosion.

Projects and current practices:
- Small sections of rock armoring vertical walls.
- Artificial islands.

Priorities for Coastal Management

- Monitor shallow water bathymetry and geomorphology.
- Restore vegetation in the upper part of the beach profiles.
- Interventions that include shoreline hardening should be avoided.
- It is recommended to stabilize the shoreline with living shorelines and vegetation, with potential small beach stabilization techniques if needed (permeable options are preferable).
- Reef conservation and maintenance of the underwater bathymetry to avoid degradation. Loss of reef and bathymetric complexity can lead to more wave action and flooding and thus enhanced sediment transport and coastal changes.
- Watershed management is critical to maintain healthy reefs (ridge to reef based management).
- The protection of existing infrastructure is a priority, e.g. police station, hospital, restaurant, private properties.
- Artisanal fishing management.

Malpractices to avoid & factors of special attention to consider in projects:
- Monitor local changes in beach width and map specific flooding and erosion problems.
- Avoid hard measures (shoreline hardening or interruption of sediments).
- Avoid interruption of longshore sediment transport.
- Given the pocket beach configuration, study the potential shoreline changes in relationship with changes in the wave climate conditions and the nearshore bathymetry.

Resources

- JICA. 2014. The study for Coastal Erosion and Flood Control Management in The Republic of Seychelles. Japan International Cooperation Agency (JICA).
- MSTEEA. 2011 Preliminary hazards analysis of sea level rise and coastal flooding in Seychelles islands. Ministry for Science, Technology and Environment, Environmental Agency
- Deltares (2018), Quick-scan runup reduction through coral reef restoration in the Seychelles. PP 54. Commissioned by the World Bank.


13
Legend
La Digue
hotels
roads
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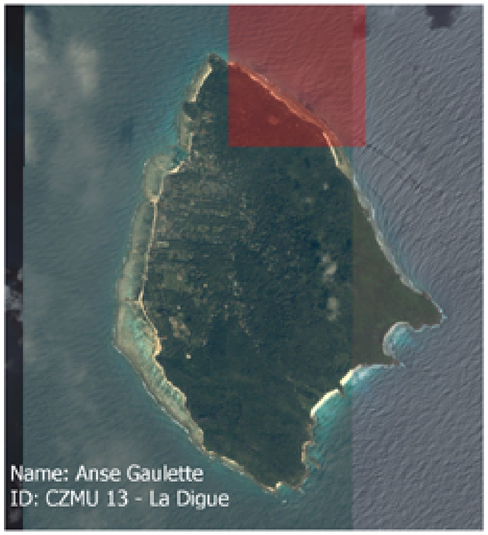
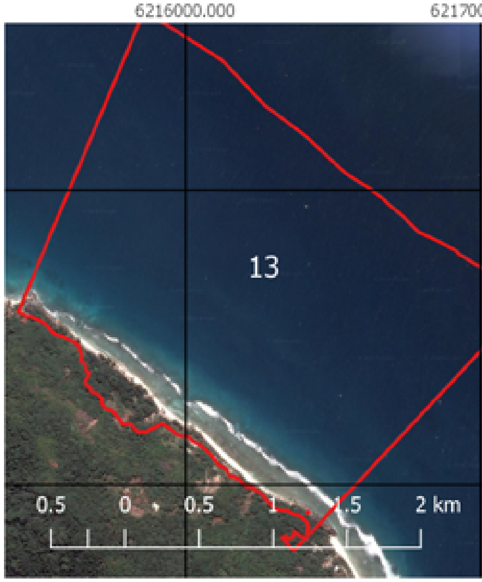




Coastal Hazards and Coastal Processes

Estimated wave runup (La Digue, 1-in-25-yr, MSTEEA): 2.8m
Design conditions (La Passe, La Digue): Hs = 4m, Wave period = 6s, Wave Direction= WSW
Level of risk (JICA): Moderate. Priority Coast.

Dominant processes:
- The site is protected from offshore wave action but exposed to NW storms.
- The reef system configures the wave propagation and circulation in the CZMU.
- The dominant processes are controlled by the regional wave propagation patterns between islands and oblique wave action.
- Dominant longshore transport effects.

Geomorphology:
- Reef system, about 50m to 90mfrom the shoreline, varying in length and complexity.
- Elevated land, with the exception of a section in the center of the CZMU (see topographical map).
- Variable beach width and vegetation cover.
- Two sections of roads are close to the water edge, interfere with the active beach profile (see images).
- The southern section presents rocky areas that serve as natural groins and contain sediment transport southwards.
- The northern section presents less beach width.
- Complex bathymetry, the beach is protected by the offshore reef.

Current coastal management practices and interventions

Identified problems:
- Erosion and flooding in road section, very low lying in the center of the CZMU.
- Changes in the shallow bathymetry (e.g. coral reefs) can influence local flooding and erosion.

Projects and current practices:
- Rock armoring and vertical walls.
- Vertical concrete seawalls in road sections.

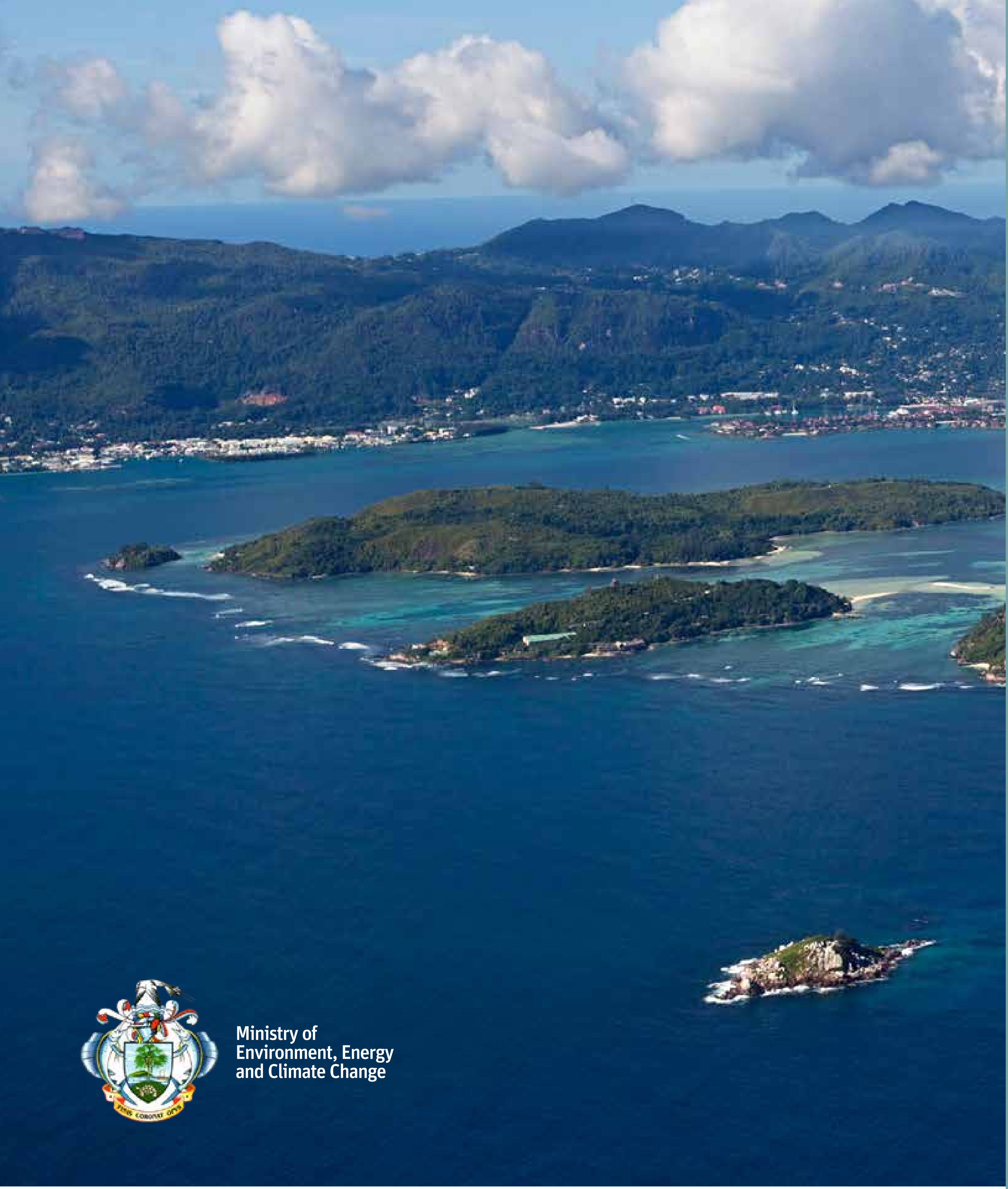
Priorities for Coastal Management

- Monitor shallow water bathymetry and geomorphological changes.
- Restore vegetation in the upper part of the beach profiles.
- Interventions that include shoreline hardening should be avoided, instead restore vegetation and upper part of the beach profile.
- It is recommended to stabilize the shoreline with living shorelines and vegetation, with potential small beach stabilization techniques if needed (permeable options are preferable).
- Reef conservation and maintenance of the underwater bathymetry to avoid degradation. Loss of reef and bathymetric complexity can lead to more wave action and flooding and thus enhanced sediment transport and coastal changes.
- Watershed management is critical to maintain healthy reefs (ridge to reef based management).

Malpractices to avoid & factors of special attention to consider in projects:
- Monitor local changes in beach width and map specific flooding and erosion problems.
- Avoid hard measures (shoreline hardening or interruption of sediments).
- Avoid interruption of longshore sediment transport because it can create effects of larger scale.
- Study the potential shoreline changes in relationship with changes in the wave climate conditions and the nearshore bathymetry, in particular coral reef degradation.

Resources

- JICA. 2014. The study for Coastal Erosion and Flood Control Management in The Republic of Seychelles. Japan International Cooperation Agency (JICA).
- MSTEEA. 2011 Preliminary hazards analysis of sea level rise and coastal flooding in Seychelles islands. Ministry for Science, Technology and Environment, Environmental Agency
- Deltares (2018), Quick-scan runup reduction through coral reef restoration in the Seychelles. PP 54. Commissioned by the World Bank.



Ministry of Environment, Energy and Climate Change

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