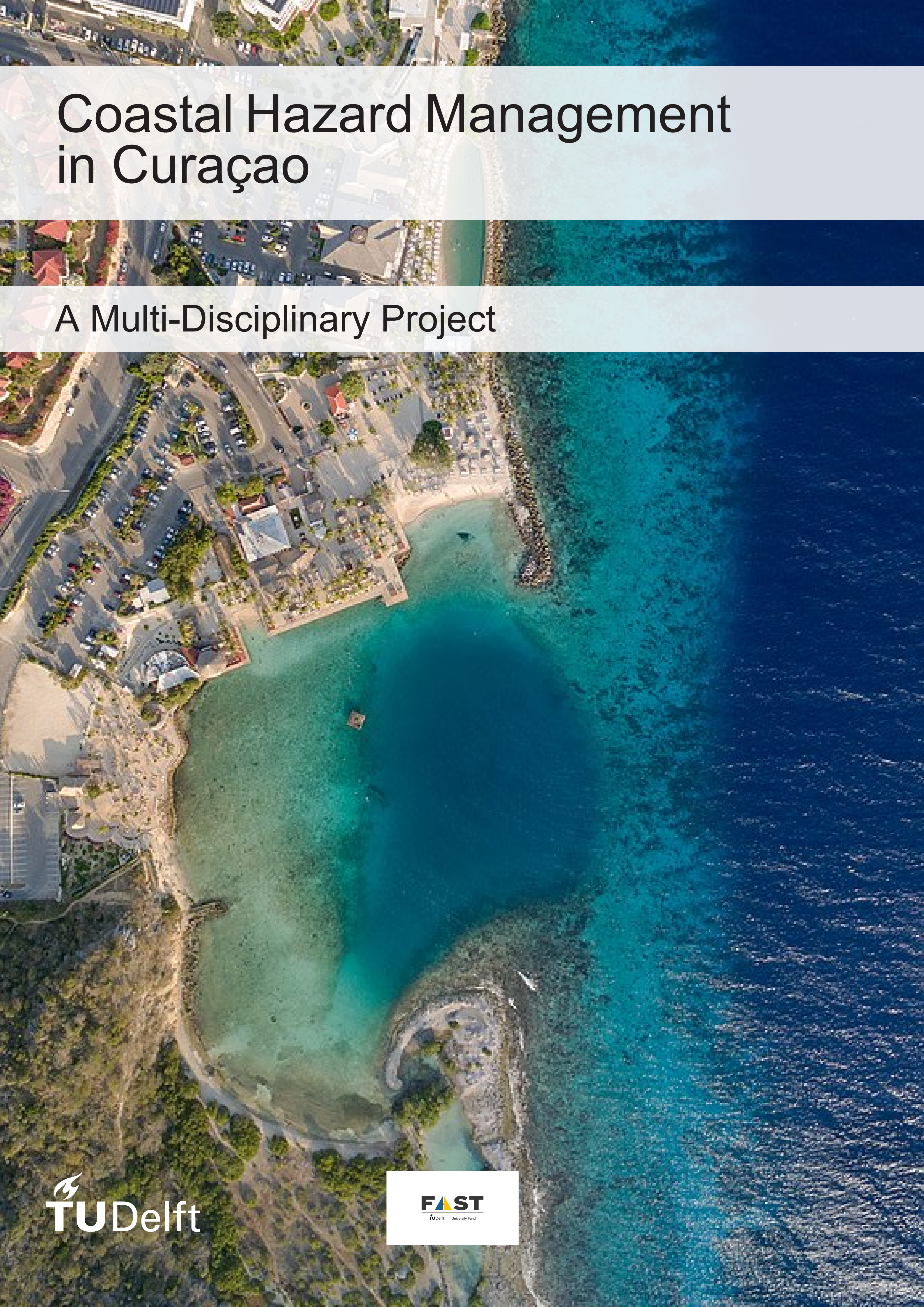
Coastal Hazard Management in Curaçao

A Multi-Disciplinary Project



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A Multi-Disciplinary Project

by

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Preface

The present study was conducted as part of a Multidisciplinary Project on Coastal Hazard Management for the island of Curaçao. The project was initiated in collaboration with the Technische Universiteit (TU) Delft and the Even Groene Vrienden organization, within the scope of the Learning Community on Sustainable Environments in Curaçao. In this context, the aim of this project is to contribute to the understanding of environmental challenges in Curaçao and to support the development of strategies for the sustainable management of its coastal zone.

During the course of this project, we often found ourselves navigating unfamiliar waters, as the broad scope of our research objectives, the new environment, and at times, the limited availability of data on the island, challenged us to think creatively and look beyond our initial assumptions. This process ultimately shaped the direction and outcome of our research into its final form. What was important to us, alongside the technical perspective of our work, was getting to know the island itself. As the project progressed, our explorations made us gain a deeper understanding not only of the coastal system of Curaçao, but also its nature, history, culture, and governance structures, which were initially unfamiliar to us.

A significant part of this learning process came through our interactions with a diverse range of stakeholders, each of whom offered new insights and perspectives, often times contrasting and, at others, affirming of our previous perceptions and understanding. This divergence of perspectives that we came across, reflects the real-life complexity of managing a space that holds ecological, economic, and cultural value all at once and the competing interests that are present within that space. In the end, it made us realize how different experiences and priorities shape the way people relate to the coast, and appreciate the many ways in which the coastal zone of Curaçao is woven into daily life and identity. It also further strengthened our belief in the importance of finding inclusive and adaptive approaches to its sustainable management.

We would like to express our gratitude to our mentors and collaborators for their valuable guidance and support throughout this project. We are especially thankful to Dr. Cornelis Slobbe and Rémi Charton from the TU Delft, for supervising the project. Our sincere appreciation also goes to Ergün Erkoçu, our supervisor from the Learning Community and the University of Curaçao (UoC), for helping us navigate this complex topic and for his invaluable guidance.

We would like to thank the University of Curaçao for providing us with a workspace, and Tamara van Aerde for making us feel at home and assisting us throughout our stay. We are also grateful to Linette Bossen, Barbera Keukens, Saskia Postema, and the team at Even Groene Vrienden for making this collaboration possible, and to the Funding Ambitious Students TU Delft (FAST) Fund from TU Delft for their financial support.

Special thanks go to Pedzi Girigori from the Meteorological Office of Curaçao for her guidance and for providing valuable data, and to Kasper Lendering for his advice, feedback, and for opening many doors for us on the island. We are thankful to Dutch Schrier and Joel Tjong-a Tjoe from the Sea Aquarium for their hospitality and informative discussions, and to Terrence Ching from Mangrove Adoption Program (MAP) Curaçao for sharing with us the stories of the island, its trails, its people, and its nature. Finally, we would like to thank Caribbean Research and Management of Biodiversity Foundation (CARMABI) for providing important data and Eric Houtepen for his valuable help and discussions.

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Curaçao, October 2025

Executive Summary

Curaçao's coastal zones are vital to its economy, environment, and cultural identity, yet they are increasingly threatened by natural hazards and unsustainable development practices. This report provides an integrated assessment of coastal hazards, the impacts of coastal developments, and strategic recommendations for sustainable coastal management, climate adaptivity and resilience in the island of Curaçao.

The study begins with an overview of the geographical, climatic, and ecological characteristics of Curaçao, emphasizing how coastal tourism is the country's main driver of economic growth, but at the same time, a primary source of environmental stress. Existing policies and planning frameworks such as the Eilandelijk Ontwikkelingsplan (EOP), environmental ordinances, and marine management regulations are reviewed to contextualize current coastal governance. A stakeholder analysis identifies the main actors and interested parties involved in coastal management, including governmental bodies, private developers, tourism enterprises, non-governmental organizations (NGOs), and local community groups, highlighting their interests and influence levels.

The Coastal Hazard Analysis section examines the main natural and anthropogenic threats affecting the coastal zone. These include sea-level rise, storm surges, heavy rainfall events, erosion, artificial beach construction, and water quality degradation. Sea level in Curaçao is estimated to be increasing at a current trend of around 3.3 mm/yr [1], with the level expected to increase by around 0.5m by the end of the century. Furthermore, Curaçao is located within the southern fringes of the Atlantic Hurricane belt [2], [3]. Although not frequent, tropical storms due to this location can cause severe social and economic damage. In terms of coastal development the lack of a comprehensive management regulative framework and of technical guidelines on coastal protection design has been found to be detrimental for the coast of Curaçao. Furthermore, the southwest coast of Curaçao is where most of the tourism infrastructure is located, which overlaps with a high coral cover in that area [4]. The shortcomings of wastewater management infrastructure on the island present another major hazard for the coast of Curaçao, with around 84% of it being disposed untreated in the marine and terrain environments due to the overcapacity of the existing treatment plants [5].

Case studies of local coastal developments, including the Baoase Resort, Marie Pampoen recreation area, and the Sea Aquarium, illustrate how development approaches can alter shoreline dynamics and increase exposure to coastal hazards. Lessons drawn from these examples are utilised to inform a broader understanding of sustainable development practices. Key cross-case takeaways include: making the decision process of proposed developments as transparent as possible to improve public trust; assessing development impacts for the entire coastal cell (beyond the project boundaries), rather than treating developments as isolated systems; prioritizing the relationship with the public by defining clear and measurable benefits for the local communities; designing for southwestern storm events; incorporating adaptivity considerations in coastal infrastructure to enable future adjustments in response to climate change; accounting for water quality as a design parameter; and including environmental monitoring during both the construction and operation phases of developments.

Finally, the report presents recommendations and an action plan to strengthen coastal resilience in Curaçao. These are given in the form of suggested policy directions, a proposed coastal monitoring program and examples of good practice from other Caribbean Islands. Key strategies include: improved spatial planning and permitting; enforced regulation and guidelines on technical standards; the integration of nature-based solutions such as mangrove and coral reef restoration; stronger regulation on wastewater management for new developments, and prioritising investments to improve existing infrastructure and raise awareness of current management gaps; review existing legislation to ensure public access to the coast; increase awareness on coastal hazards through education programs, public campaigns, collaboration with local communities and investing in research; and implement a systematic monitoring program to provide up to date and open access data for coastal management.

In conclusion, protection of the coastal zone of Curaçao requires a coordinated, science-based, and inclusive approach that addresses both environmental and socio-economic dimensions.

Contents

List of Glossaries

ABC Aruba, Bonaire, Curaçao. 24

ADCPs Acoustic Doppler Current Profilers. 62

ASVs autonomous surface vehicles. 61

BAU Business as Usual. 10

CARMABI Caribbean Research and Management of Biodiversity Foundation. iii

CCCP Curaçao Climate Change Platform. 54

CCRIF the Caribbean Catastrophe Risk Insurance Facility. 22

CHATA Curaçao Hospitality and Tourism Association. 16

Climaax CLIMAte risk and vulnerability Assessment framework and toolboX. 23

CPA Curaçao Ports Authority. 16

CTB Curaçao Tourist Board. 17

DCNA Dutch Caribbean Nature Alliance. 17

DEM Digital Elevation Model. 21

DEZ Department of Economic Development. 16

DHW Degree Heating Weeks. 7

EIA Environmental Impact Assessment. 14

EOP Eilandelijk Ontwikkelingsplan. v

FAST Funding Ambitious Students TU Delft. iii

GDP Gross domestic product. 11

GMN Ministry of Health, Environment and Nature. 16

GPD General Pareto Distribution. 23

HDPE High-Density Polyethylene. 50

Hs significant wave heights. 23, 71

HWM high-water mark. 65

IMF International Monetary Fund. 12

IPCC Intergovernmental Panel on Climate Change. 25

IUCN International Union for Conservation of Nature. 33

JRC Joint Research Centre. 25

KPIs Key Performance Indicators. 44

LBI Landsverordening belastingfaciliteiten investeringen. 12

LGRO Landsverordening grondslagen ruimtelijke ordening. 43

LMB Landsverordening Maritieme Beheer. 13

MAC Maritime Authority of Curaçao. 14

MAP Mangrove Adoption Program. iii

Meteo Meteorological Department of Curaçao. 4, 16

NAf The Netherlands Antilles guilder. 12

NBS nature-based solution. 49

NGOs non-governmental organizations. v

OECD Organisation for Economic Co-operation and Development. 12

OPEX operational expenditure. 13

pH potential of hydrogen. 8

POO Public Order Ordinance. 14

ppm parts per million. 29

RCP Representative Concentration Pathway. 23

RGB red, green, and blue light. 26

RMO Reef Management Ordinance. 14

RQ research question. 2

RRC Reef Renewal Curaçao. 7

SDB satellite-derived bathymetry. 61

SIDS Small Island Developing States. 22

SPAW Specially Protected Areas and Wildlife. 7, 15

SSE sea surface elevations. 23, 71

SSP-8.5 Shared Socioeconomic Pathway 8.5 Scenario. 21

STDDP Strategic Tourism Destination Development Plan. 11

STORM Synthetic Tropical cyclOne geneRation Model. 23

SWAN Simulating WAves Nearshore. 37

TC Tropical Cyclone. 23

TU Technische Universiteit. iii

UoC University of Curaçao. iii

VVRP Ministry of Traffic, Transportation, and Urban Planning. 14, 16

WTTC World Travel & Tourism Council. 11

1 Introduction

Curaçao is a small island state with a unique coastal environment that plays a central role in its ecological, economic, and cultural identity. The coastline serves as the main area of economic activity, recreation, and tourism and hosts habitats and ecosystems of high ecological significance. However, this zone faces increasing pressures from both natural and human-induced stressors. The island is exposed to tropical storms, increasingly variable rainfall and sea-level rise, while unregulated coastal development and water quality degradation threaten the condition of its ecosystems. In recent years, modifications of the shoreline and the removal of natural habitats to accommodate tourism infrastructure have significantly reshaped parts of the leeward coast.

Tourism, which accounts for a substantial share of the country's national income and employment opportunities, is the main driver of economic growth. However, it is also a primary source of environmental stress. The increasing concentration of infrastructure along the shoreline, combined with a limited coastal regulation and enforcement framework, has intensified risks and exposure to coastal hazards and has reduced the natural protection offered by the beaches and coral reefs. Many developments are located near vulnerable ecosystems, leading to habitat loss and poorer water quality from wastewater pollution and sediment siltation, while the growth of tourism has also limited public access to parts of the coast and changed the landscape for local residents.

In this context, this study examines the main natural and anthropogenic pressures acting on the coast of Curaçao and how these have affected shoreline development over time. The analysis focuses on key hazards such as sea-level rise, storm impacts, erosion, unregulated construction and artificial beach creation, and water quality degradation. Particular attention is given to how the southwestern coast of the island has evolved in the last decades, focusing on three development case studies. These cases are used to understand how coastal projects have been planned and carried out, and what factors have guided current decision-making practices on the island.

In addition to the spatial and environmental assessment of the case studies, a series of interviews with relevant stakeholders, including government representatives, environmental organizations, and professionals involved in coastal development, were conducted. The information gathered from these interviews helped derive insights on regulatory limitations, institutional responsibilities, and local perceptions of coastal hazard risk and development. Through this process, the present study aims to identify existing knowledge gaps and systemic issues in current coastal management practices in an attempt to propose more sustainable ways to guide and regulate future developments.

This project is based on an integrated and multidisciplinary approach that combines environmental, spatial, and governance perspectives to assess both physical and institutional implications of coastal management in Curaçao. It considers the cumulative impacts of coastal developments, as well as the trade-offs between economic growth, environmental protection, and social equity issues. Building on this approach, the report aims to provide directions for more practical and sustainable coastal management on the island. It brings together insights from the case studies and stakeholder analysis to identify key coastal hazards and assess how they are currently addressed. Based on this analysis, it explores ways to improve planning and regulation of coastal developments in the coming years. The final chapter presents recommendations for managing coastal hazards, including policy directions, a monitoring framework, and examples of good practice from other Caribbean islands.

1.1 Research Questions and Objective

This research explores the interactions between natural and human pressures that influence coastal dynamics in Curaçao. It examines how these processes shape the evolution of its shoreline and its exposure to coastal hazards, and how management practices have responded to these challenges so far. Moreover, this study aims to better understand the links between the patterns of development along the coast, and the institutional framework that guides planning and protection measures.

The main research objective is to provide an evidence-based understanding of how natural processes and human activities interact to influence coastal vulnerability in Curaçao in order to form the basis for identifying opportunities to improve future coastal management in a way that supports sustainable development and climate resilience. The study is therefore guided by the following main research question:

How do the combined effects of natural hazards, coastal development, and governance shape coastal vulnerability in Curaçao, and how should they correspond to sustainable management approaches?

To address this overarching question, the following sub-research question (RQ) were defined:

RQ1: What are the main natural and anthropogenic drivers of coastal change in Curaçao?

RQ2: Which areas are most exposed to coastal hazards under current and future conditions?

RQ3: How have recent coastal developments affected shoreline stability and exposure to hazards?

RQ4: What are the main challenges in coastal management in Curaçao, and what are potential opportunities to overcome them?

1.2 Scope of the Project

The scope of the study includes both the physical and governance dimensions of coastal management. On the physical side, the research examines processes related to coastal erosion, flooding, and sea level rise and provides an analysis through satellite observations and a literature review. On the institutional side, it incorporates qualitative information gathered through stakeholder interviews to understand how policies, regulations, and local practices shape coastal development and risk management.

The analysis focuses on the southwestern coast, where tourism and infrastructure are most concentrated and where the combined effects of development pressures are more pronounced. By studying several representative sites along this stretch of coast, the research seeks to identify how physical processes, human activities, and management decisions shape the current state of the coastline, through their interaction. This approach helps reveal the main drivers of coastal change and provides insight into how existing practices can be adapted to better address future risks.

1.3 Report Structure

The report is structured as follows:

Chapter 2 provides the general background of the study area and reviews existing coastal management policies in Curaçao. It also includes a stakeholder analysis.

Chapter 3 presents the coastal hazard analysis. It identifies the main natural and anthropogenic stressors affecting the coast and includes three case studies of coastal developments evaluating their effects on local erosion and exposure to hazards. The analysis utilizes satellite imagery, spatial data, and previous studies to characterize hazards and shoreline changes and concludes with an overview of coastal protection options.

Chapter 4 presents recommendations and an action plan for sustainable coastal management. It discusses proposed policy directions, outlines the proposal of an integrated coastal monitoring program and highlights examples of coastal management practices from other Caribbean islands.

Chapter 5 presents the main conclusions and recommendations for future research. It summarizes the key findings of the study and outlines potential directions for further investigation, including numerical modelling studies, wastewater system upgrades, and governance-related studies.

2

Background of Study Area

This chapter provides an overview of the geographical and environmental context of Curaçao's coastal areas, focusing on the spatial, physical, ecological, and socio-economic characteristics of the island to understand the natural and human dimensions that shape the coastal environment.

Firstly, it describes the geographical setting and climate and oceanographic conditions, which define the natural dynamics influencing the coast. It then analyses the coastal morphology and bathymetry, and the ecosystem characteristics, highlighting the interdependence between physical and biological systems.

The chapter also outlines how terrestrial and marine zones are currently managed and utilized (nature-protected areas and land use patterns sections), and provides an insight into how human activities and settlement patterns have evolved along the coastline (historical and cultural context of coastal development section).

The coastal management policies on Curaçao and broader economic affairs are presented to illustrate the governance and economic framework that influences development decisions, giving special attention to fiscal incentives, such as the Tax Holiday, which may affect investment in coastal zones.

Finally, a stakeholder analysis is provided, detailing the key actors involved in coastal management, their relative power and interests, and potential areas of conflict.

2.1 Geographical Setting

The study area is the island of Curaçao, located in the South Caribbean Sea, approximately 64 km north of the coast of Venezuela (12.2° N and 69.0° W), as seen in Figure 2.1. The island, part of the Leeward Antilles, has a surface area of roughly 444 km² and is home to 156,115 inhabitants [6], making it the most densely populated island in the Kingdom of the Netherlands. Curaçao consists of the main island and a smaller uninhabited islet, Klein Curaçao. The capital city, Willemstad, is situated on the southeastern coast and hosts approximately 90% of the population[1] and the majority of economic activities. In contrast, the western part of the island (Bandabou) remains more sparsely populated, and is characterized by dry tropical vegetation, including scrublands and seasonal desert-like vegetation types [7].

Figure 2.1: Map of Curaçao
2

[1]Willemstad, Wikipedia. Accessed October 2025. https://en.wikipedia.org/wiki/Willemstad
[2]https://www.britannica.com/place/Curacao

2.2 Climate

Curaçao is located in the "Southern Caribbean Dry Zone" [2] and is characterised by a hot semi-arid climate [8]. It has a dry season from February to May, and a wet season from October to January [2]. The annual average rainfall is approximately 570 mm/year [9], with rain events usually occurring in the early morning or evening. In 2022, the total rainfall was 772.5 mm, with the total number of rainy days being 92 in that year [10]. Most of the precipitation is characterised by convective events, which leads to significant local differences [3], [11].

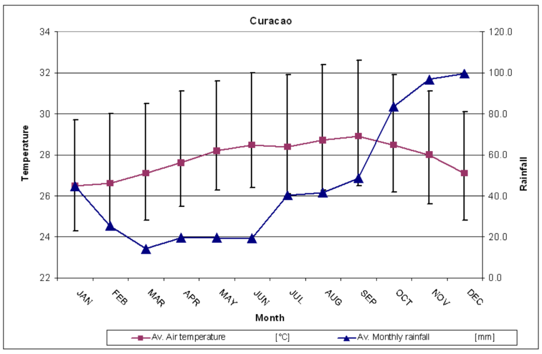

Figure 2.2: 30-year average of monthly air temperature and precipitation (mm) in 1991–2020 [2].

Figure 2.2 shows the summary of the 30-year average of the monthly air temperature and precipitation in the period 1991–2020. It can be seen that the highest and lowest temperatures occur in September and January respectively, and the highest and lowest rainfall amounts occur in December and March respectively.

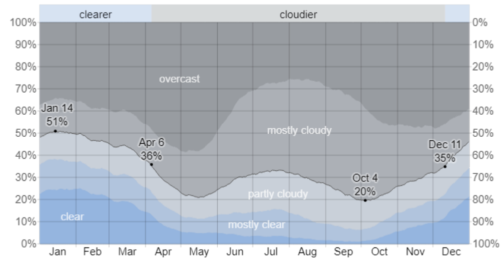

Figure 2.3: Monthly average of the percentage of time spent in each cloud cover band, categorized by sky coverage. Period: 1980–2016 [12].

Temperature varies very little throughout the year and therefore hot and cold seasons are not clearly defined [12]. The annual average temperature in 2022 was 27.6ºC [10]. In the Caribbean islands, temperature is following an increasing trend, with a rise in daily minimum temperature of 0.28°C per decade between 1961–2010 [13].

As seen in Figure 2.3, Curaçao experiences a high seasonal variation in the percentage of cloud coverage [12]. The clearest month is January, with the sky being about 50% of the time clear, mostly clear or partly cloudy. The cloudiest month is October, with the sky being overcast or mostly cloudy around 78% of the time.

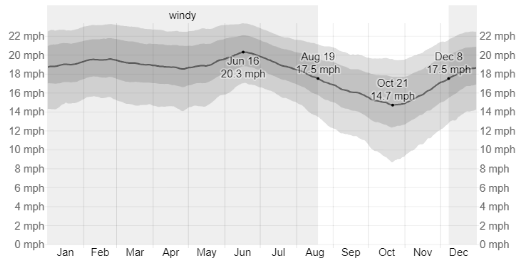

Figure 2.4: Average mean hourly wind speeds (dark gray line), with 25th to 75th and 10th to 90th percentile bands (lighter gray). Period: 1980-2016. [12].

The average hourly wind speed in Curaçao shows seasonal variation (Figure 2.4), with the windiest month being June (average hourly wind speed of 20.1 miles per hour), and the calmest month being October (average hourly wind speed of 15.0 miles per hour). The average wind direction is from the east throughout the year [12].

Sea water temperature experiences some seasonal variation, as seen in Figure 2.5. The months with the warmest and coolest sea water is October and February respectively [12] .

It should be noted that the climate in Curaçao differs from that in the other Caribbean islands since it is dryer and the rainy season occurs in winter rather than summer [2]. There is ongoing research to explain this phenomenon, but the Meteorological Department of Curaçao (Meteo) lists the following three factors as likely:

- Proximity of Curaçao to the southern mainland;
- The northern cordilleras in Venezuela; and
- The Azores subtropical high to the west

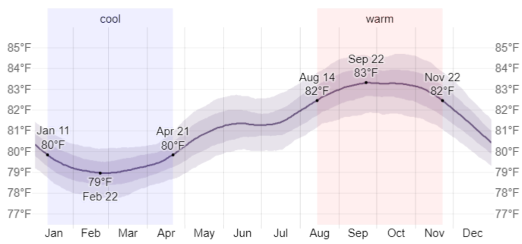

Figure 2.5: [12] Daily average water temperature. Period: 1980–2016.

2.3 Coastal Morphology and Bathymetry

The coast of Curaçao mainly consists of steep limestone cliffs, semi-enclosed bays and inlets, as well as narrow sandy beaches. The southwestern coast, being sheltered by land boundaries, hosts most of the recreational beaches and tourist facilities [14], whereas the northern coast is directly exposed to high-energy wave conditions, resulting in rugged cliffs and minimal presence of sandy shorelines.

Waves

The offshore wave climate per region can be seen in Figure 2.6, which has been generated using Copernicus Marine Service data from the years of 2023 and 2024. The semi-enclosed bays and lagoons, seen particularly on the southern side, providing sheltered environments where mangroves and seagrass beds thrive and contribute to coastal stability.

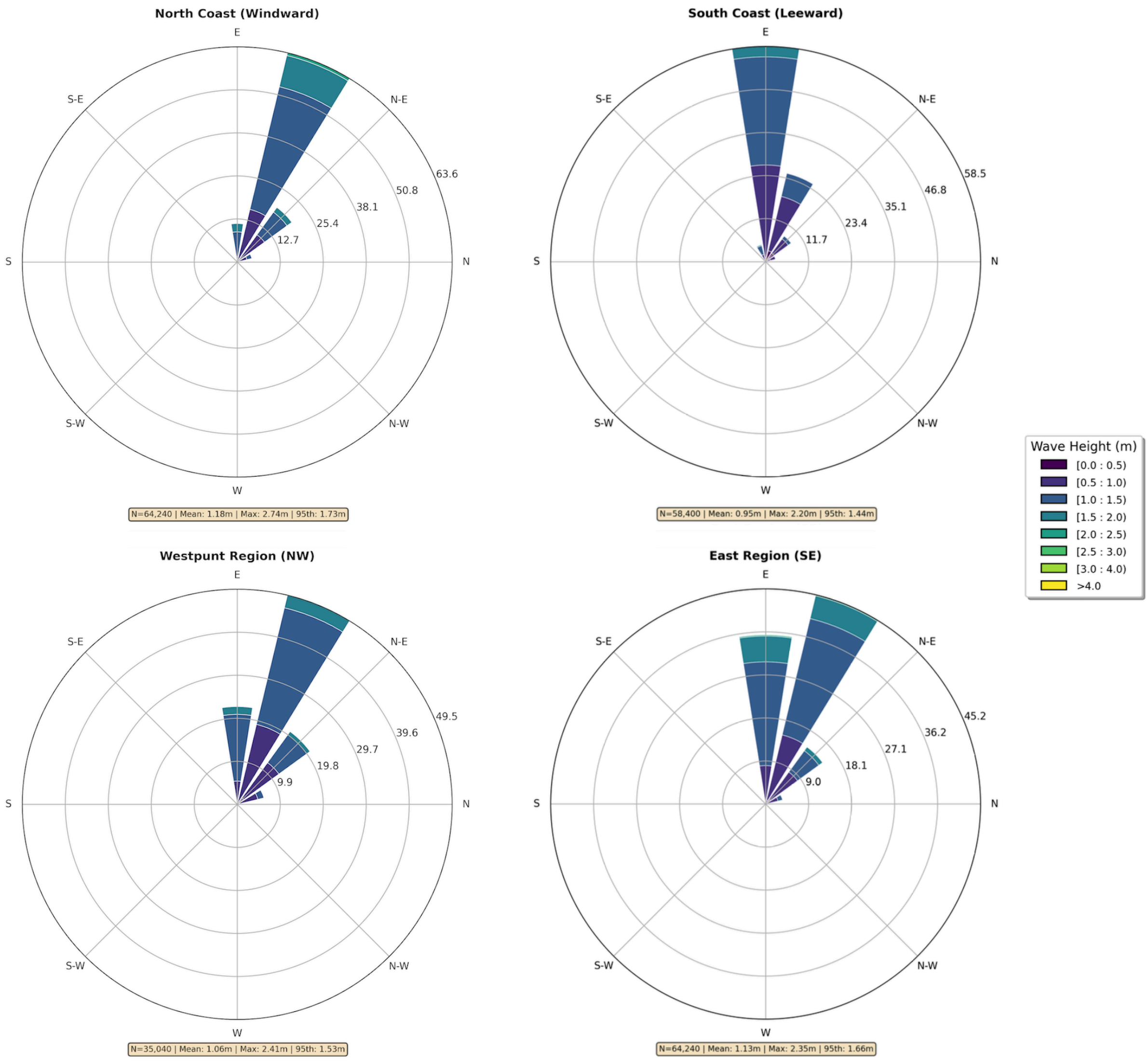

Figure 2.6: Wave roses per region in Curaçao

Bathymetry

In terms of bathymetry, the nearshore area around the island is characterized by a narrow continental shelf and steep bathymetric gradients, particularly along the southern and western coasts where depth increases rapidly within a few hundred metres of the shoreline [15]. A bathymetry map, courtesy of Carmabi, may be seen in

Figure 2.7. A typical cross-shore profile consists of a shallow reef terrace at approximately 5–15 metres depth, followed by a distinct reef crest and a steep fore-reef slope descending to over 50–60 metres before dropping abruptly into deep water [16].

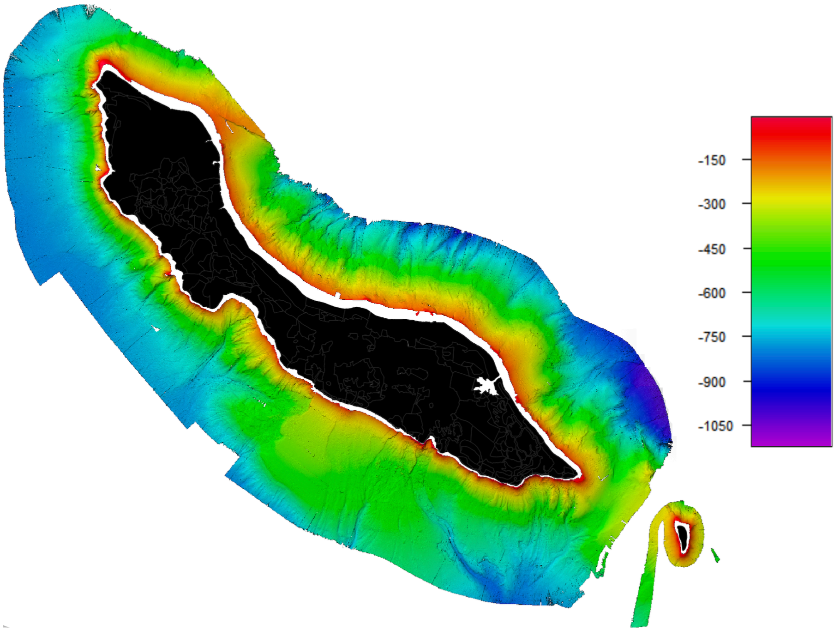

Figure 2.7: Bathymetry of Curaçao, provided by Carmabi, scale is in metres.

In recent decades, human activities on the island have increasingly modified its natural morphology. Several artificial beaches have been created to support tourism, altering sediment dynamics and reshaping parts of the coastline. These interventions, combined with the natural hydrodynamics of the island, can reshape adjacent shorelines and affect alongshore sediment transport conditions.

On the eastern side, the absence of extensive reef terraces and the direct exposure to the trade-wind wave climate result in wave-cut benches and cliffed coasts composed mainly of uplifted limestone formations [17]. These bathymetric and geomorphological contrasts strongly influence wave transformation, nearshore setup, and alongshore current patterns, which in turn control sediment transport and beach stability along the leeward coast [18].

Tides

The tidal regime around Curaçao is predominantly diurnal, with small tidal ranges typical of the Southern Caribbean. Mean tidal amplitude at Willemstad varies between approximately 0.10 metres during neap tide and 0.35–0.40 metres during spring tide [18]. Seasonal variations in mean sea level are modest, averaging about −0.10 metres from February to April and +0.10 metres from October to December, associated with regional wind and barometric pressure fluctuations [19].

Tidal currents around the island are weak, typically less than 0.20 m/s, and are largely overshadowed by wind-driven and wave-induced flows [20]. Longshore currents along the southern coast are generally directed westward under the influence of the prevailing easterly trade winds but can reverse locally depending on coastline orientation and nearshore bathymetry.

For structural and coastal design applications, [18] estimated a representative nearshore design water level at approximately mean sea level + 0.55 metres, which includes both tidal and short-term meteorological effects. This value is consistent with more recent tidal measurements in Willemstad reported by [21], confirming the micro tidal character of the area.

2.4 Ecosystem Description

The coastal ecosystems of Curaçao consist primarily of coral reefs, seagrass beds, and mangrove forests, which are closely interconnected and support a wide range of ecological and socioeconomic functions [22]. The habitats form a continuous system that links the shallow coastal shelf surrounding the island to deeper reef slopes that extend offshore in deep waters. These ecosystems provide critical services both individually and through functional linkages, including primary production, nutrient cycling, sediment stabilisation, and habitat provisioning for commercially important fish species [23], [24].

The interdependence of these ecosystems means that degradation in one component, for example, loss of mangroves or coral reefs due to increased sediment input, can negatively affect the others [25], [26]. Many reef fish species undertake ontogenetic migrations between these habitats, using seagrass beds and mangroves as juveniles before transitioning to coral reefs as adults [27]. This ecological connectivity means that the loss or degradation of nursery habitats can significantly reduce adult fish biomass on coral reefs [23]. Protecting and monitoring these habitats is therefore essential to maintain Curaçao's coastal resilience and biodiversity [28].

Coral Reefs

An important feature of the coastal system of Curaçao is the extensive coral reef ecosystem along the leeward coast. They are typically structured as a double reef system with a nearshore terrace, a shallow reef crest at depths of 5–10 metres, and a fore-reef slope descending to around 60 metres [15].

The coral reefs fulfil several essential functions for the island. Ecologically, reefs are the foundation of Curaçao's marine biodiversity and food web, supporting fish populations and adjacent ecosystems like seagrass and mangroves. Furthermore, together with mangroves and seagrass, coral reefs act as natural coastal protection against wave action and storm surges [24].

Economically, reefs underpin tourism revenue, coastal property protection, and fisheries, and they store large amounts of blue carbon. Studies in the Caribbean show reef restoration projects yield a positive cost–benefit ratio when factoring in avoided storm damages and sustained tourism income [29].

However, coral reefs are increasingly threatened by both anthropogenic and climate-related factors, including land-based pollution, overfishing, eutrophication, and global climate stressors such as ocean warming and acidification [30]–[33]. Sedimentation from coastal development and watershed run-off represents a primary local stressor, as sediment deposition can smother corals and interfere with their ability to feed, grow, and reproduce [25], [34].

Ocean warming drives heat stress and coral bleaching. Corals bleach when water stays ≥1 °C above the local summer maximum for extended periods. Scientists track this with Degree Heating Weeks (DHW):

- DHW ≥ 4 → likely bleaching.
- DHW ≥ 8 → high risk of severe bleaching and mortality.

Repeated bleaching events flatten reef crests, slowing growth and calcification, and reducing long-term dissipation capacity [35].

Curaçao has made progress through its Marine Park, local NGOs (RRC, CARMABI), and regional agreements (e.g., Cartagena Convention, Specially Protected Areas and Wildlife (SPAW) Protocol). However, reefs remain under pressure from coastal development, sewage discharge and overfishing. Effective governance requires not only ecological restoration but also land-based pollution control, enforcement of protected areas, and stakeholder involvement from divers, fishers, and the tourism sector.

Ongoing efforts for coral reef protection and restoration include:

- Reef Renewal Curaçao (RRC): coral nurseries and outplanting.
- CARMABI: research, monitoring, and reef management.
- ECORE International projects in collaboration with local institutions.
- Artificial reef modules (e.g. reef balls at Porto Marie) to enhance habitat and structure.

Mangroves

Mangroves are mainly found in semi-enclosed bays and coastal wetlands, where they act as a transition zone between land and sea. The main mangrove species include Rhizophora mangle, Avicennia germinans, and Laguncularia racemosa. On Curaçao, suitable areas for conservation or restoration include Spanish Water (Spaanse Water), Piscadera Bay, the Marie Pampoen wetlands, the Jan Thiel and Williwood restoration sites, and St. Joris Bay, and there is an established Mangrove Park at Schottegat focused on protection, education, and research [36]. These forests provide vital ecosystem services such as shoreline stabilisation, nutrient cycling, and habitat for fish and bird species [37]. They also filter pollutants and sediments, trap nutrients, and contribute to maintaining the water quality necessary for healthy seagrass and coral ecosystems [37], [38]. Mangrove habitats can enhance the biomass of coral reef fish communities, with several commercially important species functionally dependent on mangroves as nursery habitat [23]. Additionally, mangroves provide biogeochemical buffering services that may help corals cope with ocean acidification by maintaining elevated potential of hydrogen (pH) and aragonite saturation states relative to open ocean conditions [38].

From an implementation perspective, mangrove restoration in Curaçao requires both time and technical effort, as the success of planting efforts is strongly dependent on the knowledge of local environmental conditions. Financially, projects of this type often rely on sustained maintenance and community participation rather than individual investments. Nevertheless, mangrove areas can provide economic and social benefits through ecotourism, education, and can act as fisheries.

Seagrass

Seagrass beds occur mainly in sheltered bays and lagoons along the south-eastern and southern coasts, such as Spanish Water and Piscadera Bay. Curaçao has an estimated seagrass area of 800 ha (Spalding 2003). The most common species are turtle grass (Thalassia testudinum) and manatee grass (Syringodium filiforme), which stabilize the seabed, improve water quality, and provide nursery grounds for reef-associated species [39]. Seagrass meadows serve as important intermediate habitats in the migration pathways of reef fish, with some species utilizing seagrass beds before occupying mangroves and eventually migrating to coral reefs [27]. Seagrasses in Curaçao are often interspersed with patches of macroalgae and are sensitive to nutrient enrichment and turbidity caused by runoff and wastewater discharge [39].

Wet Lands (Saliñas)

In addition to mangroves, Curaçao contains several coastal salt marshes (saliñas), which are shallow saline wetlands formed in natural depressions behind coastal barriers or in former lagoons. These areas are intermittently flooded by rainfall and seawater intrusion and maintain hydrological connectivity to the sea through surface or groundwater exchange. Historically, many saliñas were exploited for salt extraction, particularly during the colonial period, leaving a network of artificial ponds that now function as important ecological habitats [40]. Prominent examples include Saliña di Rif Sint Marie, Saliña Jan Thiel and Saliña di Jan Kok several of which are designated conservation areas due to their biodiversity and role as feeding and nesting grounds for the Caribbean flamingo and other wading birds [41].

Saliñas provide essential ecosystem services, including stormwater retention, groundwater recharge, and filtration of sediments and nutrients before they reach nearshore coral reef systems. They also serve as transitional environments linking terrestrial scrublands, mangroves, and marine habitats. However, many saliñas have undergone degradation due to urban expansion, landfill use, and drainage alterations that disrupt their natural hydrological balance. Eutrophication from wastewater discharge and runoff from surrounding developments has further reduced their ecological quality [15].

2.5 Nature Protected Areas

Curaçao hosts a limited number of officially protected coastal and marine areas, primarily designated under the Ramsar Convention and through national conservation initiatives. The four sites on the island listed as Ramsar wetlands of international importance are:

- **Malpais / Sint Michiel**: a coastal wetland complex of freshwater lakes, a hyper saline lagoon, and nearshore coral reefs supporting both terrestrial and marine biodiversity and contributing to local groundwater recharge.

- **Muizenberg**: an inland wetland area supporting high avian diversity and serving as a natural water retention and filtration basin.

- **Rif-Sint Marie**: a coastal lagoon and salt marsh system with surrounding shrubland and coral reefs that provide habitat for flamingos, seabirds, and endangered marine species such as sea turtles and reef-building corals.

- **Northwestern Curaçao**: the island's largest protected area, encompassing parts of Shete Boka and Christoffel National Parks, including coral reefs, mangroves, limestone terraces, and pocket beaches used by nesting sea turtles[42].

In addition to these sites, the Curaçao Marine Park encompasses approximately 21 kilometres of the southern coastline from the region of Jan Thiel to Oostpunt and extends up to 100 metres offshore. The park was established to protect coral reef ecosystems and associated habitats under increasing ecosystem stressors.

2.6 Land Usage

Curaçao has a diverse pattern of land use shaped by its geography and history. Much of the island is characterized by dry and rocky landscapes. Urban development, tourism, and industrial activities dominate land use, particularly in Willemstad and the coastal zones in the south-east. Alongside tourism infrastructures, Curaçao hosts major industrial sites such as the refinery and port. Natural parks serve as counterbalances by promoting biodiversity conservation. Agriculture occupies a small area, constrained by arid conditions and water scarcity [44].

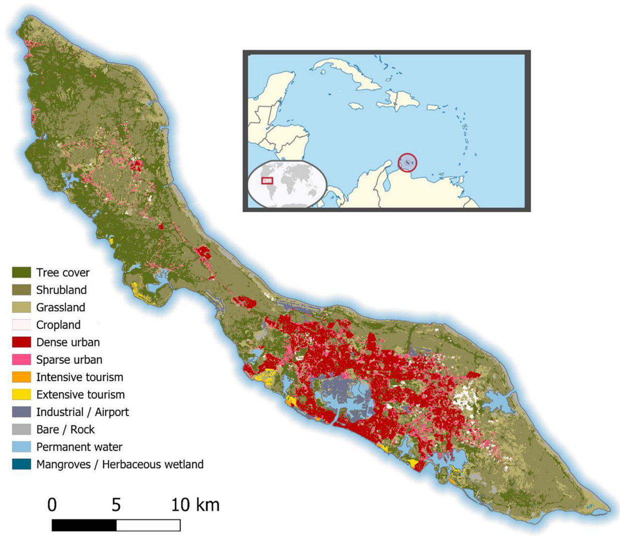

Figure 2.8: Curaçao area map with 2021 land use [43]

A recent study done by Steward, Chopin, and Verburg [43] classifies Curaçao's current land use distribution into urban, tourism, agricultural, and natural categories. Dense urban areas (red) are concentrated around Willemstad, while sparse urban settlements (pink) occur in the hinterland. Intensive tourism zones (orange) cluster along the southwest coast near the city, and extensive tourism sites (yellow) dot other coastal areas. Lush natural vegetation dominates the less developed western region. Urban land is classified into dense urban and sparse urban. Densely built neighbourhoods are those with more than 5 buildings in 75 metres, whereas sparse urban areas have lower building densities and more open space [43]. Figure 2.8 shows this land use classification map from 2021 developed using the world cover 2021 satellite-derived product with a resolution of 30x30 metres [45].

Curaçao's spatial development has been guided by a zoning framework established in the Island Development Plan of 1995, in Curaçao known as the EOP [46]. The EOP was the island's first land use plan, legally dividing the territory into designated zones for specific uses, as shown in Figure 2.9.

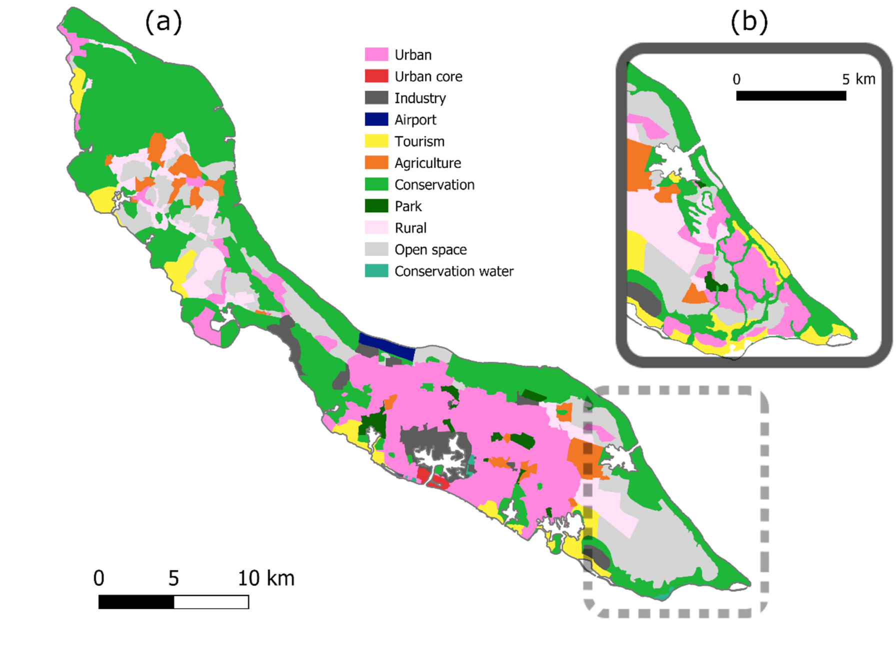

Figure 2.9: Spatial planning options (a) 1995 EOP (b) EOP with proposed revisions. Accessed from [43]

Recent scenario based modelling studies have projected alternative land use futures for Curaçao up to 2050, highlighting the potential impacts of different development and planning regimes [43]. Three key scenarios are given:

1. **Business as Usual (BAU)**: Business as Usual assumes moderate population growth to 180,000 in 2040. Also BAU assumes steady increase in tourism demand, doubling stay over tourist days between 2019 and 2050. Agricultural land use remains constant, while urban expansion occurs primarily around Willemstad.

2. **Agricultural Futures (AgFut)**: envisions a shift toward food security, with cropland area grows from 360 to 1,080 hectares and greenhouse cultivation expanding to 42 hectares. This expansion, if unregulated, risks encroaching into ecologically sensitive inland areas, increasing habitat loss and nutrient runoff.

3. **Tourism Futures (TourFut)**: doubles the growth rate of tourism facilities compared to BAU, leading to extensive coastal development. Without zoning restrictions, this would result in resorts along currently undeveloped shorelines, increasing pollution risks to coral reefs.

The study demonstrates that zoning and spatial planning are decisive in mitigating impacts. Strict adherence to the EOP can reduce the loss of rare vegetation by up to 32% and limit additional nitrogen loading to coastal waters by 22% compared to unregulated growth [43].

2.7 Historical and Cultural Context of Coastal Development

Cultural Ties of Local Population to the Coast

Historically, the coastal zone in Curaçao has played a crucial role in shaping both the patterns of settlement development and the cultural identity of its population. The coast and access to the sea were essential for transportation, defence, and economic functions such as salt production and shipbuilding, but also served as a vital source of food and recreation for the local population [47]. Because the scarcity of water and the arid climate of the island induced difficulties in agriculture, the coast served as an important means of providing sustenance to the local population through fishing and collecting shellfish.

In this context, the interaction between people and the natural environment and the tradition of open public access to the coast have been deeply embedded in the culture of the island. Access to the sea was historically recognised as a public right and institutionalised early in colonial history, with the coastline, referred to as “beaches of the sea", defined as public property under Article 573 of the Civil Code of the Netherlands Antilles [47]. Another expression of the efforts of local residents to maintain access to the coast are the "patruli" footpaths, a network of trails that connected inland areas to the coast. The public nature of these routes was later recognized in the 1971 "Djaoen vs. The People of Curaçao" case, which upheld the right of free passage to the shoreline [47]. This tradition of open access underlines the historical connection between the island's inhabitants and their coastal environment, even as modern development and tourism expansion have increasingly limited public use of the coastline.

Timeline of Coastal Development and Tourist Expansion

Tourism development in Curaçao has been largely shaped by the historical changes in its economic structure, and particularly the transition from an industry-based to a service-based economy following the decline of oil refining As illustrated in Figure 2.10, the construction of hotels and resorts accelerated markedly after the late 1960s, coinciding with the gradual withdrawal of Shell Oil from the island. During this period, tourism was promoted as a main national development strategy, which is reflected in the rapid increase of coastal infrastructure concentrated along the sheltered southwestern coastline where conditions were most suitable for recreation activities.

Tourism growth intensified further after the 2000s, with clear spikes following 2018, when the oil refinery permanently closed, and again after the COVID-19 pandemic as the expansion of tourism became a central strategy in the island's post-industrial economic recovery. In Chapter 3 three representative sites are examined, namely the Marie Pampoen, Sea Aquarium, and Baoase Luxury Resort developments, to illustrate how tourism related coastal development has transformed this stretch of coast in recent decades.

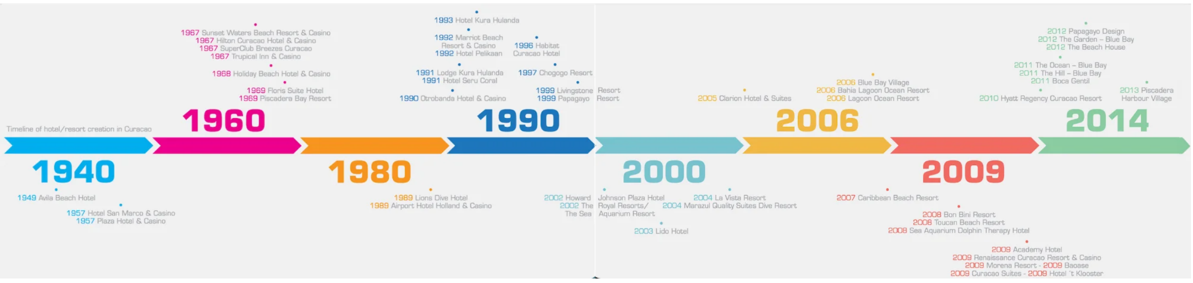

Figure 2.10: Timeline of hotel/resort creation in Curaçao [48].

2.8 Economic Affairs

The World Bank classified Curaçao as a high-income economy with Gross domestic product (GDP) per capita of $21,062 in 2023 [49]. This is partly due to the boost in tourism which had a expansion from approximately 8% of GDP in the mid-2000s to 18% by 2015 [50], and reaching 23% in 2025 according to the Central Bank of Curaçao, contributing approximately Cg. 1.4 billion annually. The sector now supports over 20,000 jobs (25-30% of the workforce), with the World Travel & Tourism Council (WTTC) projecting continued growth toward 30% of GDP by 2033 [51].

The island welcomed 1,570,670 visitors in 2024, overnight and cruise tourists combined, representing a 51.1% increase above pre-pandemic levels, the highest recovery rate in the Caribbean [52]. Further growth is expected and encouraged, as Curaçao's Strategic Tourism Destination Development Plan (STDDP) projects 8% annual growth, potentially doubling current pressures on social and environmental resources [50].

Beyond tourism, Curaçao's economy achieved 5.4% GDP growth in 2024, driven by financial services (contributing 45% of foreign exchange alongside tourism) and port operations [51], [53]. Agriculture represents less than 1% of the GDP, and efforts to expand agriculture remain constrained by limited freshwater resources.

The Paradox of Prosperity

Despite high-income classification and GDP growth, 35.2% of households live in poverty or vulnerable conditions [54]. Average monthly salaries of $1,003 cover only 0.7 months of living expenses, while income mobility stands at just 7%, meaning 89% of households remain trapped in their economic stratum. This disconnect stems from

GDP composition: capital-intensive sectors such as financial services, port operations, and tourism infrastructure generate high value-added but employ relatively few workers while concentrating wealth narrowly. Import dependency further inflates costs while creating persistent trade deficits that drain purchasing power [55].

This notion has been alluded to throughout most the stakeholders meetings and interviews conducted; Curaçao has a high-economy on paper, yet the day-to-day reality is that of a poor country, without funds to work on several lingering critical infrastructure issues. This is a critical consideration that is taken into account in recommendations and in the approach taken in this study, as the existing budget results in projects being broken down into several parts and done as resources become available, such as the Marie Pampoen recreational park analysed in subsection 3.2.3.

Economic Pressures and Vulnerabilities

Government investment capacity has collapsed despite evident needs. While authorities budgeted 204 million guilders for 2025 investments, only 5 million had been spent by mid-year. The International Monetary Fund (IMF) explicitly criticised this "unsustainably low government investment" and absence of multiyear planning frameworks [56].

The healthcare system presents an urgent fiscal crisis, consuming 13% of GDP and annual deficits reaching 6% of GDP it stands among the world's most unsustainable systems [57]. While public debt improved from 89% in 2020 to a projected 54% by 2029 through fiscal consolidation [56], healthcare deficits threaten this stability.

Tourism's expansion reveals critical infrastructure strains. Tourists consume 3-5 times more water than residents, placing severe pressure on desalination capacity in an already water-scarce environment [58]. Recognising these constraints, Curaçao launched a Destination Carrying Capacity Study in March 2025 to examine environmental, social, and economic thresholds [59], though results remain unpublished at the time of this study.

Despite 18% overall unemployment and 40% youth unemployment, critical shortages persist in tourism and construction, with 2,000 to 3,000 workers needed. This reflects fundamental skills mismatches as local education fails to align with rapidly changing labour market demands, while 70% of tertiary-educated workers emigrate to Organisation for Economic Co-operation and Development (OECD) countries [60], [61], indicating severe brain drain.

2.9 Tax Holiday

In Curaçao, the "Tax Holiday" forms part of the investment incentive regime under the Landsverordening belastingfaciliteiten investeringen (LBI). The regime is aimed at attracting large, long-term investments, especially in sectors such as tourism/hotel construction, land development, and selected strategic industries, by granting time-limited tax reliefs.

Benefits

Subject to approval, qualifying projects can obtain:

- A reduced profit tax rate of 3% on qualifying profits for a fixed period (*initial year* plus 5 or 10 following years, depending on the investment size; i.e., 6–11 years in total).
- Exemptions from import duties on specified building materials, equipment and first outfitting (typically for 2–5 years, depending on the category of goods).
- An exemption from real estate (immovable property) tax of 5 or 10 years depending on the total investment amount.
- An exemption from personal income tax on dividends and other profit distributions, if paid within two years after the year the profits were earned [62].

For context, Curaçao's standard profit tax rates are 15% on the first The Netherlands Antilles guilder (NAf) 500,000 of profit and 22% above that threshold [63], [64].

Eligibility

For large coastal/tourism projects, conditions commonly include:

- Hotels/accommodation and land development typically require at least NAf 5,000,000 (for land development: excluding the land value); strategic industries also require at least NAf 5,000,000.
- At least 10 permanent, full-time locally registered employees at start-up for hotels/land development/industry.
- Hotels and accommodations; land development (site servicing, infrastructure, and possibly construction); and designated sectors such as R&D, green energy, transport & logistics, modern agriculture/fishing, IT, etc.
- Substantive operations in Curaçao (staff, operational expenditure (OPEX), compliance) and a clear contribution to tourism or socio-economic goals.

Application & governance

Investors submit a formal request to the Sector Fiscal Affairs (Ministry of Finance). Approval is by decision (*beschikking*; applications should be filed *before* project start (or within short statutory windows)) and include permits and an investment plan; approved cases are recorded in an official register [62], [65].

Debate

Recent commentary questions whether broad tax holidays remain justified amid strong tourism growth, noting potential revenue losses and access barriers for smaller local firms [66]. Advisory and practitioner sources describe the regime as mainly benefiting large, well-capitalized investors [67], [68].

2.10 Current Coastal management policies

Coastal management in Curaçao is governed by a mix of spatial planning ordinances, permitting rules, environmental regulations, and recent nature policies that together define where construction can take place, how coastal activities are authorized, and how ecosystems are protected. As there is not an integrated coastal management policy, the current framework is fragmented consisting of a mix of formal legislations and non binding policy guidelines that are applied in practice.

Spatial planning & zoning

The longstanding ordinance, the Eilandsverordening Ruimtelijke Ontwikkelingsplanning Curaçao [69], provides the procedures and instruments for development plans. Its island wide plan, the EOP [46], designates land uses, including along the coast, and sets binding rules for building and use for both the government and the private sector, as can be seen Figure 2.9. In practice, the EOP's maps and regulations are the first reference for any coastal development or rezoning.

The Blue Halo Curaçao [70] is a partnership formed by the Government of Curaçao and the Waitt Institute in 2015 that advances science based marine spatial planning to optimize ocean uses and expand protected areas based on scientific assessments of ecosystem value and human use.

Coastal development permitting

The two main pieces of legislation that define the requirements for coastal development are:

- Bouw- en woningverordening 1935, containing regulations for building and public housing [71]; and
- Landsverordening Maritieme Beheer (LMB), containing rules for the management of maritime areas in the Netherlands Antilles [72].

As per Article 16 of the Bouw- en woningverordening 1935, the application process for a building permit should include a detailed drawing or description of the proposal. If the development consists of a dwelling (to be constructed or partially renovated), then this drawing should outline (among others):

- "The method of water supply"; and
- "The method of removal of water, dirt and faeces".

As per Article 22 of the Bouw- en woningverordening 1935 a permit can be refused in whole or in part if (among others):

- "The building, also in connection with the construction method used, cannot be considered to possess such solidity that it does not pose a danger to the lives of the residents or users or to the environment"; and/or

- "The building or part of the building, due to its location or construction method, will disfigure the surroundings or will be a nuisance or fire hazard to the surroundings".

Article 30 of the Bouw- en woningverordening 1935 states that "It is prohibited to construct or partially renovate a building or to have it constructed or partially renovate as owner, or to place, install or have any object on land which, according to a decision of the Island Council, is intended for the construction, widening or improvement of a public road in the interest of systematic development in the near future."

Seaward of the shoreline, the LMB [73] requires permits for any construction on or in the seabed, for example piers, land reclamation, pipelines/cables, as well as for activities that could introduce hazardous substances. Permits may be refused where navigation safety or protection of the marine environment would be compromised. The Maritime Authority of Curaçao (MAC) frequently applies this ordinance when regulating coastal and offshore activities.

Pollution control & environmental permitting

The pollution control and monitoring of waste and wastewater is regulated under the Nuisance Ordinance Curaçao 1994 ([74], [75]). This Ordinance applies to commercial activities (e.g hotels, restaurants) and requires businesses to obtain a nuisance license before conducting any activity that could harm the environment. This is done by either: setting specific restrictions for each individual polluter; or establishing general environmental standards to limit the overall impact of pollution. The Public Order Ordinance (POO) 2015 outlines a system of licenses and exemptions regarding waste [76]. Furthermore, The Reef Management Ordinance (RMO) was enacted in 1976 to protect corals and other marine life ([77], [75]). Article 3 of this Ordinance "prohibits breaking, sawing, or loosening corals in any way, or to process, sell commercially, offer, purchase or transport corals from Curaçao". It also "prohibits killing, possessing, purchasing or selling, transporting, or processing any marine fauna, marine animal groups, or plants designated by island decree".

A letter from the Ministry of Traffic, Transportation, and Urban Planning (VVRP) (section A.1) states that an Environmental Impact Assessment (EIA) is mandatory for all construction activities within the territorial sea. The letter outlines that such assessments must include a description of the construction methodology and materials, the equipment to be used, an inventory of local flora and fauna (including the relevant protected species and buffer zones), an analysis of wave and structural interactions, and proposals for mitigation or compensation of potential environmental impacts.

The Nature Policy Plan 2024–2030 [78], however identifies the formalization of EIA procedures as a strategic objective to be achieved through the Nature Protection and Management Ordinance (P.B. 2018 no. 66), suggesting that EIAs are not yet fully institutionalized as law. Stakeholder interviews further indicate that, in practice, the application of EIA requirements is in practice policy-based rather than a legal requirement. The evaluation and approval of coastal developments therefore depend largely on internal guidelines and the discretion of permit reviewers, resulting in uncertainty and inconsistencies in enforcement.

Regarding water quality degradation, as per the letter sent from VVRP (section A.1), a wastewater management strategy is not currently a requirement for construction.

Nature Policy Plan Curaçao 2024–2030

The Nature Policy Plan Curaçao 2024–2030 [78] sets strategic objectives to reduce ecological pressures, sustainably manage natural resources, and move towards "30 by 30" (conserving at least 30% of terrestrial and marine ecosystems by 2030) protection and restoration targets on land and at sea. It provides a long-term strategy to protect natural resources, integrate ecological considerations into spatial planning, and strengthen the institutional and legal basis related to environmental and biodiversity protection. The plan defines a clear strategic direction, with broader goals for climate adaptation and sustainable economic growth, however its implementation remains in an early stage, with limited institutional capacity and enforcement mechanisms.

International commitments

Several international agreements are implemented under Curaçao's regional coastal marine protection duties. These include the Cartagena Convention's SPAW Protocol and its Protocol SPAW, which provide the regional framework for biodiversity conservation and the regulation of marine pollution in the Wider Caribbean Region. Recent advisory documents have used these instruments to guide the designation of new protected areas and buffer zones under the Maritime Management Ordinance and the Nature Protection and Management Ordinance [73], [79].

In addition, the Convention on Biological Diversity (CBD), through the Kunming–Montreal Global Biodiversity Framework, promotes the conservation and sustainable use of marine and coastal ecosystems and establishes the global 30×30 target to protect 30% of terrestrial and marine areas by 2030. The Nature Policy Plan 2024-2030 aims to comply with this framework by setting national objectives for expanding protected areas and enhancing ecosystem resilience.

Beach access

The subject of public access to the coast in Curaçao is a complicated matter in terms of legal definition. When referring to the coast in this context, the areas of interest are mainly the beaches of the island, referred to as "beaches of the sea", as well as certain ecosystem habitats such as mangrove parks and wetlands, as they are the ones providing recreational and economic functions to the local population.

As stated in Chapter 2.3, the morphology of the island, does not naturally favour the formation of long sandy stretches of coast. As a result, sandy beaches in Curaçao are rare and are either found in enclosed inlets or bays or they are artificially constructed and protected by coastal structures like breakwaters. An ongoing debate exists on the definition of what a beach is: while Dutch law refers to a beach as the area between high and low tide, this is unsuitable for Curaçao's geography, where tides are minor and beaches vary widely in form. A 1977 ruling (Court of Justice of the Netherlands Antilles) defined a beach as: "The undeveloped and (largely) unvegetated strip of land between the normal low-water line and the beginning of natural vegetation, sea defences, or traditional buildings" [80].

Regarding beach ownership, the Civil Code of the Netherlands Antilles (Article 5.26) states that "the beaches of the sea" belong to the State, unless private parties can prove ownership by title or possession. These beaches provide recreational and economic functions to the local population, as well as certain ecosystem habitats like mangrove parks and wetlands, due to their culturally historical value. As the owner of the beach, the Country of the Netherlands Antilles has the right to transfer the ownership to private individuals. However, even when transferred to private entities and considering the important public function of beaches, the government should safeguard public access and the public interest (e.g defence purposes or smuggling prevention) through explicit conditions, following the principles of good governance [81].

An additional complication arises from the ownership of land located between public roads and the shoreline. In several cases, the areas above the coast are privately owned, which effectively restricts public access to beaches, even when the beaches themselves are public property. Under the current legal framework, the owner of land between the public highway and the coast has the right to deny access across their property. This can be deemed unlawful in certain circumstances. As per Article 5.26 of the Civil Code, "restrictions on the public access to beaches require special permission granted by national ordinance" [81].

2.11 Stakeholder Analysis

This section presents the stakeholder analysis conducted for the project. It describes the approach used to identify, categorize, and evaluate the key stakeholders involved, as well as to understand their relationships, influence, and potential areas of conflict. The analysis maps each stakeholder according to their level of power and interest, providing a structured overview of their roles and relevance to the project. This mapping enables transparent and inclusive project management by clarifying which stakeholders should be managed closely, which should be kept informed, and where collaboration or communication efforts should be prioritized. The outcomes of this analysis form the foundation for developing a balanced engagement strategy that aligns technical, environmental, and social objectives within the coastal development process.

2.11.1 Stakeholder overview

The stakeholders involved in the project are categorized into five main sectors to provide a clear overview of their roles, responsibilities, and interests. This sector based approach ensures that governmental, financial, research, social, and technical dimensions are all represented in the analysis. A summary of all semi-structured interviews conducted with key stakeholders, including the type of organization and main discussion themes, is provided in the section A.2.

Government and Policy

- **VVRP**
  The Ministry of VVRP holds primary responsibility for spatial planning, land-use regulation, and coastal development control on Curaçao. It ensures that proposed projects comply with the island's zoning policies and building codes, particularly in vulnerable coastal areas. VVRP plays a decisive role in the permitting process and long-term coastal management strategies. Its involvement guarantees that the project aligns with national spatial and environmental objectives.
- **Ministry of Health, Environment and Nature (GMN)**
  The Ministry of GMN oversees environmental protection, public health, and natural resource management. It sets the legal and ecological framework for projects that may affect marine ecosystems, coral reefs, or water quality. The ministry's input ensures compliance with environmental legislation and sustainability principles. Its participation is essential for balancing development with the preservation of natural capital.
- **Meteo**
  The Meteorological Department provides scientific data and forecasts related to weather, wave climate, and tropical storm risk. This information is vital for designing resilient coastal infrastructure and assessing climate related hazards. This Department contributes to the technical evidence base supporting environmental impact assessments and adaptation planning. Its expertise ensures that climate variability is integrated into the project design.
- **Department of Economic Development (DEZ)**
  The Department of Economic Development promotes sustainable economic growth through investment and tourism policy. It assesses how development projects contribute to national economic objectives and sectoral diversification. DEZ provides guidance on aligning private initiatives with broader economic and tourism strategies. Its involvement strengthens the project's socio-economic relevance and investment appeal.
- **Curaçao Ports Authority (CPA)**
  The Curaçao Ports Authority manages port facilities and adjacent maritime areas, including navigation channels and waterfront infrastructure. It ensures safe access and sustainable use of coastal and marine zones that may interact with port operations. CPA evaluates the potential effects of new developments on navigation, sediment transport, and coastal safety. Its approval is critical for projects located within or near managed port boundaries.
- **Maritime Authority of Curaçao (MAC)**
  Administers and enforces the LMB, which governs activities on or below the seabed, including reclamation, dredging, and the construction of piers and breakwaters. The MAC evaluates these projects in coordination with GMN when environmental considerations apply.

Financial and Economic Sector

- **Insurance companies (e.g Ennia)**
  Insurance institutions evaluate the project's exposure to coastal and climatic risks and determine insurability. Their risk assessments influence design standards, safety margins, and financial viability. Collaboration with insurers promotes resilient and cost effective infrastructure solutions. Their engagement ensures that long-term operational risks remain within acceptable financial thresholds.
- **Curaçao Hospitality and Tourism Association (CHATA)**
  CHATA represents the private hospitality and tourism industry on the island. It acts as a key intermediary between the private sector and government institutions, advocating for policies that promote sustainable tourism growth, service quality, and workforce development. CHATA's input ensures that coastal

and tourism-related projects align with the operational realities of local businesses. Its involvement helps maintain a balance between economic development, environmental integrity, and the competitiveness of Curaçao as a destination.

- **Curaçao Tourist Board (CTB)**
  The Curaçao Tourism Board functions as a semi governmental organisation responsible for implementing national tourism policy and promoting Curaçao internationally. CTB focuses on destination management, sustainable development, and the strategic diversification of tourism markets. The board's participation ensures that coastal projects contribute to Curaçao's long-term tourism vision and brand identity. Through collaboration with both government and private stakeholders, CTB promotes a development approach that strengthens economic growth while safeguarding natural and cultural assets.

- **Tourists**
  Tourists represent the end users of Curaçao's coastal and hospitality infrastructure and are a central factor in shaping tourism development. Their preferences regarding accessibility, environmental quality, and recreational experience influence both public and private investment decisions. Sustainable project design must therefore take into account tourist expectations and the carrying capacity of coastal areas. The inclusion of visitor perspectives supports long-term competitiveness and environmental stewardship in the tourism sector.

- **Private Investors**
  Private investors provide the financial capital required to realize and maintain coastal and tourism-related developments. Their decisions are driven by expected returns, regulatory stability, and the island's overall investment climate. As key enablers of implementation, investors influence the project's scale, design standards, and phasing. Ensuring transparent communication and environmental due diligence strengthens investor confidence and contributes to the sustainable growth of Curaçao's tourism economy.

Research and Knowledge Institutions

- **CARMABI**
  CARMABI is Curaçao's leading marine research institute and plays a central role in the study and management of the island's coastal and coral reef ecosystems. Established in 1955, it conducts scientific research on marine biodiversity, coastal ecology, and environmental change, while also managing several protected areas and nature parks. The institution provides data and expert advice to support evidence-based environmental policies and sustainable coastal development. In the context of this project, CARMABI contributes essential ecological knowledge and monitoring capacity, ensuring that coastal interventions align with conservation principles and minimize environmental impacts. Its involvement adds scientific credibility and fosters integration between development and marine ecosystem preservation.

- **Mangrove Adoption Program (MAP)**
  The Mangrove Adoption Program is a local initiative focused on ecosystem restoration, education, and community awareness. It supports reforestation and conservation of mangrove habitats, which are critical for shoreline protection and biodiversity. Its participation strengthens the ecological integrity and community outreach of the project. The program provides a platform for integrating social engagement with environmental restoration.

- **Dutch Caribbean Nature Alliance (DCNA)**
  The DCNA is a regional non-governmental organization coordinating nature management across the Dutch Caribbean islands. It offers scientific support and policy guidance for biodiversity and coastal ecosystem conservation. Involvement of DCNA ensures alignment with regional sustainability frameworks and conservation standards. Their participation adds credibility and ecological oversight to the project.

Social and Community Stakeholders

- **Local residents**
  Local residents are directly affected by changes in coastal access, landscape, and environmental quality. Their perspectives contribute to understanding social impacts and community needs. Inclusion of residents enhances legitimacy, transparency, and long-term acceptance of the project.

- **Non-governmental organisations (NGOs)**
  NGOs represent independent civil society interests focused on environmental protection and public access to coastal spaces. They monitor the project's compliance with sustainability and ethical standards. NGOs act as critical partners in stakeholder dialogue, ensuring accountability and public trust. Their involvement encourages transparency and continuous environmental improvement.

- **Tourism-related entrepreneurs**
  Tourism entrepreneurs, such as dive operators and local business owners, rely on healthy marine ecosystems and attractive coastal areas. Their economic success is intertwined with environmental quality and visitor satisfaction. They provide practical insights into site management and sustainable tourism practices. Engaging this group ensures that the project supports local livelihoods and aligns with market realities.

Technical and Implementation Partners

- **Engineers**
  Engineers translate conceptual designs into technically feasible and durable coastal infrastructure. They ensure structural integrity, stability under wave loading, and compliance with safety regulations. Their expertise bridges scientific modelling and practical construction. Active involvement of engineers guarantees that sustainability principles are effectively embedded in the design process.

- **Contractors**
  Contractors are responsible for the physical realization of the project, including construction, dredging, and site works. Their methods and material choices directly affect environmental impact, cost, and longevity.

2.11.2 Power Interest matrix

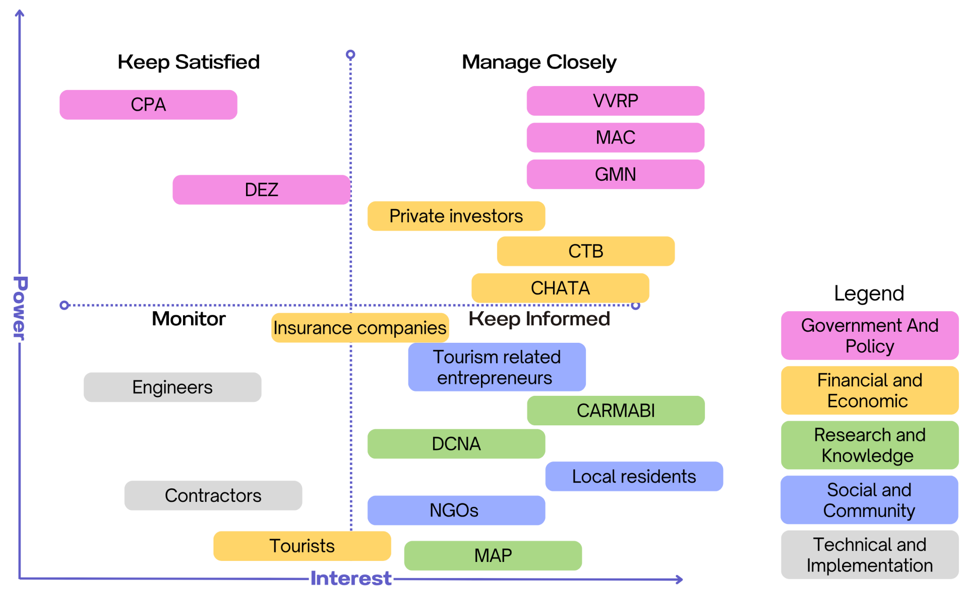

Figure 2.11: Stakeholder Power-Interest Matrix

In Figure 2.11, the project's stakeholders are positioned according to their relative power and interest in the coastal development. Each stakeholder is managed strategically based on their location within the matrix. The bottom-left quadrant (Monitor) includes stakeholders with limited power and interest, such as contractors and engineers during the early planning stages. These parties primarily provide technical assistance and data input. Monitoring their involvement and maintaining an efficient exchange of information ensures technical reliability and continuity once implementation begins.

The bottom-right quadrant (Keep Informed) consists of stakeholders with a strong interest in the project but limited decision-making power. This group includes local residents, NGOs, the MAP, CARMABI, DCNA, and tourism related entrepreneurs. They represent end-users, environmental advocates, and community actors who can significantly influence public perception. Keeping these stakeholders informed and engaged builds transparency, trust, and social acceptance of the development.

In the top-left quadrant (Keep Satisfied) are stakeholders who hold considerable power but have a more indirect or conditional interest in the project, such as the Curaçao Ports Authority, the Department of Economic Development. Maintaining regular communication and demonstrating compliance with regulatory and financial standards ensures their continued support. Should the project diverge from their objectives, their stance could shift toward active opposition, elevating their influence on project outcomes.

Finally, the top-right quadrant (Manage Closely) includes the most powerful and highly interested stakeholders: the Ministries of VVRP, GMN, and MAC, alongside key sectoral partners such as the CTB and CHATA. These actors are central to the project's success, as they combine regulatory authority with strategic influence over tourism, spatial planning, and environmental policy. Continuous dialogue and alignment of project objectives with their mandates are essential to securing approvals and ensuring long-term sustainability.

2.11.3 Competing Interests

VVRP vs Private Investors and Developers

The Ministry of VVRP seeks to uphold spatial planning regulations and safeguard the long-term integrity of Curaçao's coastline. Its mandate emphasizes building setbacks, public accessibility, and risk reduction through responsible land use. Private investors and developers, on the other hand, place a higher priority on profit and site optimization. They often aim to position facilities as close to the shoreline as possible to make it more appealing for tourists. This difference in priorities frequently leads to tension regarding the permissible footprint, coastal buffer zones, and the interpretation of zoning policies. Balancing regulatory compliance with investment feasibility remains one of the project's primary governance challenges.

Local Residents vs Resort Operators and Private Investors

Local communities have a strong interest in maintaining public access to beaches, preserving cultural heritage, and ensuring that coastal developments contribute to local well-being. Conversely, resort operators and investors frequently seek exclusivity to create a premium visitor experience, which can limit public access to formerly open areas. This competition between inclusivity and privatization creates social tension and can erode community support if not carefully managed. Transparent communication, participatory planning, and equitable benefit-sharing mechanisms are therefore critical to achieving social acceptance and legitimacy.

CARMABI, DCNA, and the MAP vs Contractors and Developers

Scientific and environmental organizations such as CARMABI, DCNA, and the MAP advocate for minimizing habitat disturbance and prioritizing nature-based solutions. Their focus lies on long-term ecological monitoring, restoration, and biodiversity protection. In contrast, contractors and developers prioritize timely execution, technical feasibility, and budget control, which can conflict with ecological objectives. These differing perspectives often lead to debate about construction methods, the design of breakwaters or lagoons, and post construction monitoring requirements. Integrating scientific guidance into early design stages helps bridge this gap and supports evidence-based decision-making.

Tourists vs Local Residents

Tourists expect accessible, comfortable, and visually appealing coastal environments that enhance their travel experience. Local residents, by contrast, value peace, cultural continuity, and shared use of coastal areas. The expansion of tourism infrastructure can therefore increase noise, traffic, and environmental pressure on local neighborhoods. This divergence in priorities underscores the need for participatory planning and sustainable tourism design that serves both visitor and community interests. A well managed coastal zone should strengthen Curaçao's tourism appeal without undermining the social fabric of its coastal communities.

Insurance Companies vs Developers and Contractors

Insurance companies assess the project's exposure to natural hazards, sea-level rise, and heavy rainfall. They advocate for conservative design standards, resilient materials, and higher construction costs to minimize long-term risk. Developers and contractors, on the other hand, often focus on financial efficiency and cost control, perceiving these requirements as limiting competitiveness. The resulting tension influences design choices and project financing conditions.

2.11.4 Key Insights and Implications

The stakeholder analysis highlights the range of interests and influence levels that shape coastal development in Curaçao. It shows that governmental institutions such as VVRP, GMN hold the greatest decision-making power, while research organizations and NGOs contribute essential knowledge and environmental oversight. The private sector, including investors and tourism representatives, plays a decisive role in determining financial feasibility and long-term operation, whereas local communities remain key to ensuring social acceptance and transparency. The analysis also revealed several overlapping and competing interests between economic growth, environmental protection, and public accessibility. Addressing these tensions through early coordination, open communication, and integrated planning will be crucial for achieving a balanced and sustainable project outcome.

3

Coastal Hazard Analysis

This chapter examines the primary coastal hazards affecting the study area and evaluates how coastal developments interact with, and sometimes exacerbate, pressures in the coastal zone. The identified hazards, which are induced both by natural and anthropogenic activity, include sea level rise, storm surges and extreme weather events, heavy rainfall events, erosion, unregulated development and water quality degradation. The analysis assesses their impacts on coastal ecosystems, shoreline stability and infrastructure near the coast.

The chapter assesses three case studies of coastal developments (the Baoase Luxury Resort, Marie Pampoen recreation area, and the Sea Aquarium) that highlight how different design and construction approaches influence coastal processes and provide insight into both the challenges and opportunities of coastal management. Lessons learned and cross-case takeaways are summarized to help inform future coastal project design and management.

Potential coastal protection options are discussed, focusing on the engineering measures that can support coastal resilience. Nature based approaches such as the conservation of mangroves and coral reefs, as well as hard engineering solutions, including the use of breakwaters and floating defence systems, are considered for mitigating hazard impacts while accounting for the preservation of ecology.

3.1 Coastal Hazards

The coastal zone of Curaçao is prone to both climate-related and anthropogenic hazards that threaten both the ecosystems and the socio-economic activities taking place in the coast. Climate related hazards include sea level rise, storm surges, extreme weather events (episodic events such as tropical storms and hurricanes), as well as heavy rainfall. Anthropogenic hazards are primarily linked to urban development in the coastal zone, brought by the rapid expansion of the tourism sector. In the absence of a comprehensive coastal management framework, this has resulted in construction projects occurring in an uncoordinated manner along the coastline. In this context, the expected upscaling of such developments could amplify risks to ecosystems and spaces of cultural heritage, while also potentially increasing the exposure of coastal communities and assets to climate change related hazards.

3.1.1 Sea level rise

In terms of sea level rise, there is a difference of up to 2 mm/yr between the north of the Caribbean Sea and the coast of Venezuela and Guyana [82] due to currents in the region. At Bonaire sea level is increasing at a current trend of around 3.3 mm/yr [1], which is assumed to be similar to the rate in Curaçao. This is close to the global sea level trend (3.4 mm/yr). Globally, sea level rise is expected to increase by 24-28 cm in 2050 to 47-86 cm in 2100 for low-high emissions (SSP1-1.9 to SSP5-8.5, IPCC AR6). However, regional sea level rise in Curaçao is expected to be slightly faster due to the Caribbean currents [1], [82].

Figure 3.1 below shows the projected coastlines in the south-west coast of Curaçao by the end of the century in the high emission scenario Shared Socioeconomic Pathway 8.5 Scenario (SSP-8.5). The map shows a large part on the centre of Willemstad (Punda) being under water. Other flooded locations include the area between Marie Pampoen and Mambo beach and the Sea Aquarium. It should be noted that this map was produced using a Digital

Elevation Model (DEM) which is more than 30 years old and therefore any elevation changes due to developments in the past few years are not taken into account [83].

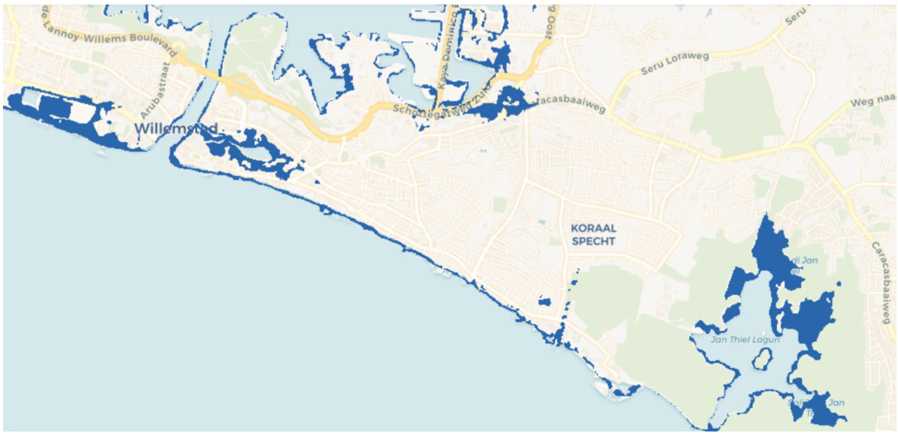

Figure 3.1: Projected coastlines in the southwest of Curaçao in 2100 in the high emission scenario (SSP8.5) [83]

The International Monetary Fund (IMF) carried out an initial study on climate change impacts, for the Central Bank of Curaçao (in 2023). The study highlights the vulnerability of the island to “slow-moving climate risks”, which include sea level rise and “policy spillovers from other countries”. Using the projections from the intermediate emission scenario (SSP2-4.5) - projected sea level rise of around 0.5m by 2100 - the study examined the long-term economic effects of sea level rise, focusing on the potential loss of productive land and its impact on GDP. While only a small share of total land may be physically submerged by a half-meter rise in sea level, the most affected areas are expected to be key business and administrative zones, making the economic impact disproportionately large. Due to limited data, the IMF assumes that 20% of productive land would be lost. Under different scenarios—depending on how easily activities can be relocated or replaced—the estimated permanent GDP loss ranges between 7.5% and 14% in the long run [84].

In spite of the above projections and the predicted impact, interviews with relevant stakeholders suggested that sea level rise is still not being taken into account in development design due to its ”long-term” consequences, with developments usually being implemented for a design life of 20-30 years. Furthermore, there is currently no regulation or technical guidelines related to adaptation measures against sea level rise, which limit the incentive to incorporate measures against and/or increase awareness on the subject.

Strategies to adapt to sea level rise include [85]:

- Planning retreat: relocating or withdrawing development from areas at risk;
- Accommodating to sea level rise through adaptive design, such as elevating roads and buildings or restoring wetlands;
- Protecting against sea level rise through engineered or nature-based infrastructure, including seawalls, mangroves, or “living shorelines.”; and
- Avoiding future development in areas at high risk of sea level rise by restricting or placing conditions.

These strategies are not mutually exclusive and can be applied in combination depending on local vulnerabilities, ecosystem conditions, and socioeconomic priorities.

3.1.2 Storm surges and extreme weather events

The Caribbean region faces disproportionately high economic losses from extreme weather events relative to its economic capacity. Between 1970 and 2020, Small Island Developing States (SIDS) incurred approximately $153 billion in weather-related losses, with the Caribbean bearing a major share [86].

Economically, hurricane strikes slow income growth by about 1.5%, raise public debt by nearly 4%, and can reduce exports by up to 60%, contributing to rising debt levels across the region [87]. Despite the establishment of mechanisms such as the Caribbean Catastrophe Risk Insurance Facility (CCRIF), which has disbursed $245 million since 2007, overall insurance coverage remains insufficient to offset the cumulative economic burden of repeated disasters [88].

Phase 1 of the CLIMAte risk and vulnerability Assessment framework and toolboX (Climaax) [3] analysed extreme water level above mean sea level in Curaçao for different storm events. In the historical period (1985-2014), the recorded water level is 1.5m for the 5-year and 10-year return periods storms; and 1.8m for the 100-year storm. In the future period (2021–2050), water levels are predicted to be 1.5m, 1.6m and 2m for the 5-year, 10-year and 100-year respectively in the high-emission scenario (Representative Concentration Pathway (RCP)8.5). These results were obtained using the Deltares Global Flood Maps, which determines extreme water levels from sea level rise, storm surges, and tidal variations, and global water level statistical and time series datasets from the Copernicus Climate Change Service (2022) [3].

Additionally, a recent study performed a basin-scale analysis that examined Tropical Cyclone (TC)-induced coastal hazards across the Caribbean Sea using 1000 synthetic TC tracks from the Synthetic Tropical cyclOne geneRation Model (STORM) dataset representing 1000 years of present-day climate conditions [89]. The study employed a coupled hydrodynamic-wave model (SCHISM-WWM-III) with spatial resolution of ∼2 km along coasts to simulate both storm surges and wind waves, with return levels estimated by fitting a General Pareto Distribution (GPD) to the data.

The analysis showed 10-year and 100-year return levels of 3.5 m and 6-8 m for significant wave heights (Hs), and 0.4 m and 0.6-1.0 m for TC-induced sea surface elevations (SSE) respectively, in the Curaçao region (Figure 3.2). Storm surge contributions break down as dominantly due to atmospheric pressure effects (60-70%), followed by wind setup (25-35%), and wave setup (<5%). These TC-specific values are consistent with the CLIMAAX Phase 1 total water level estimates, which incorporate tides, storm surges, and sea level rise projections.

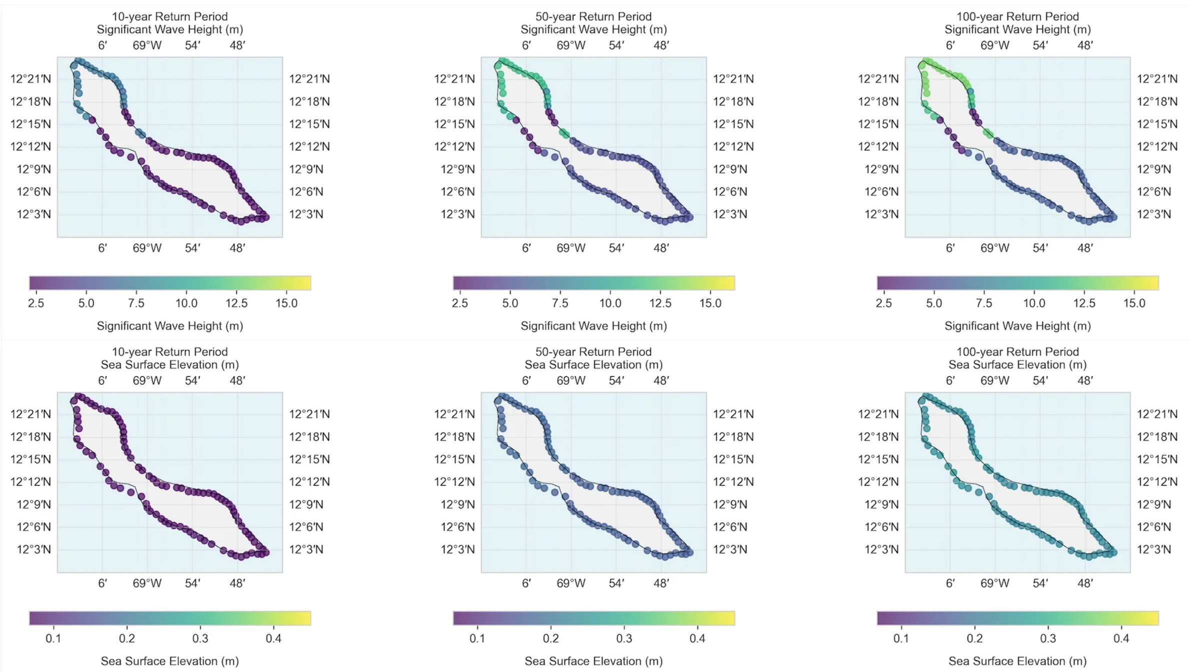

Figure 3.2: Hs and SSE levels for tropical cyclone events in the Curaçao region. The spatial maps show 10, 50, and 100-year return periods derived from 1000 synthetic tropical cyclones representing present-day climate conditions. Source: Analysis based on [89].

The study also confirmed that locations such as Curaçao experience reduced exposure to extreme coastal events compared to the Greater Antilles and Windward Islands. In spite of this, Curaçao is located within the southern fringes of the Atlantic hurricane belt, with a frequency of 1 every 4 years a category 1 hurricane passing within a radius of 250km of Curaçao, and a category 5 hurricane having a 76 years return period (see Figure 3.3) [2], [3]). These storms mostly pass to the north of the island without causing severe weather [90]). Significant tropical cyclones in the recent years include: tropical cyclone Joan (October 1988), Hurricane Lenny (November 1999) and Hurricane Thomas (November 2010). Economic damages range from $1.5 million to $115 million over this 22-year period (1988-2010) [90], [91]. These storms are further analysed in the following subsections to understand the extent to which extreme weather events further coastal, environmental, economical, and social damages.

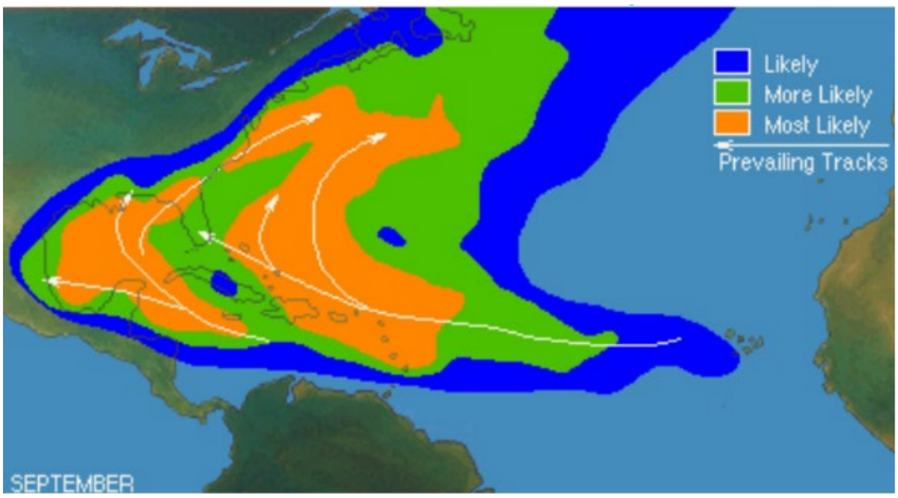

Figure 3.3: Area of origin and general movement of Atlantic tropical cyclones during September, from Meteorological Department Curaçao (2018)

Tropical Cyclone Joan (October 1988)

Tropical Cyclone Joan followed the southernmost Atlantic track since 1933, passing just south of Curaçao on October 16, 1988, with sustained winds of 40 mph and gusts to 55 mph. It exposed southern Caribbean territories to tropical storm conditions for the first time since Hurricane Edith in 1971 [92].

Wulff [93] documented severe impacts on coral reef sponges, finding that nearly half the individuals and biomass of three large erect sponge species were destroyed, with species-specific response patterns to hurricane damage.

Further impacts across the Aruba, Bonaire, Curaçao (ABC) islands included structural damage to several hundred housing units, with approximately 20 roofs destroyed. Social impacts remained relatively minimal with no fatalities recorded in Curaçao, and six minor injuries occurred across the Netherlands Antilles, with limited population displacement [91].

Economic assessment reveals the combined ABC islands experienced $1.5 million in structural damage, representing moderate impact relative to Joan's $2 billion total damage across all affected territories [91].

Response measures involved Netherlands Antilles federal coordination from Willemstad, with the Dutch government contributing $2 million to regional relief efforts and international assistance totalling approximately $10 million [91].

Hurricane Lenny (November 1999)

With an anomalous west-to-east trajectory from November 13 till 23 in 1999, Hurricane Lenny was the first documented reverse-tracking hurricane across the Caribbean basin in 113 years of records [94]. It achieved Category 4 intensity with maximum sustained winds of 155 mph and minimum pressure of 933 mb on November 17, 1999 [95].

Although it passed 200 miles north of Curaçao, it generated 3-6 meter waves that continuously hit protected western shores for 24 hours. Existing infrastructure provided minimal protection to the west-northwest waves, given that the typical wave climate is from the east-northeast, as shown in Figure 2.6. This resulted in catastrophic impacts to the coastal ecosystems that Curaçao is normally sheltered from.

Bries et al. [96] surveyed 33 reef sites around Curaçao and Bonaire, documenting severe damage with coral colonies 2-3 metres high toppled by wave action. Branching and plating corals suffered disproportionately compared to massive species. However, 82-85% of displaced massive corals remained in growth position, and high coral recruitment to sediment-free substrata suggested ecosystem resilience despite severe impacts [96]. CARMABI provided damage documentation for recovery planning, with restoration including reef ball placement and monitoring through April 2000.

Hurricane Tomas (November 2010)

Hurricane Tomas caused severe flooding in Curaçao on November 1–2, 2010, even though the storm's center remained over 100 nautical miles north of the island. Stalled outer rainbands delivered 265 mm of rainfall in 24 hours—the heaviest in four decades—overwhelming drainage systems and inundating urban areas with up to 50 cm of water[90]. The storm reached Category 2 intensity (with 85-knot maximum sustained winds and 982 mb minimum pressure during its approach to the southern Caribbean), and its interaction with local topography concentrated rainfall over eastern districts such as Saliña, Brievengat, Mahaai, Damacor, and Schelpwijk [97].

Damage was primarily hydrological (rather than wind or wave damage, as in the previous two events), with extensive flooding, power outages, and three fatalities. Fires ignited by lightning at the Willemstad oil refinery caused an additional $10 million in losses [90]. Overall economic damage totalled approximately NAf200 million ($115 million USD), with major impacts to infrastructure, businesses, and drainage systems, which required prolonged recovery efforts [90].

3.1.3 Heavy rainfall events

The maximum recorded rainfall amount in 24 hours is 117.8mm, with an estimated increasing trend in intensity [83]. Phase 1 of the Climaax Climate Risk Assessment produced flood depth-damage curves for Central-South America, which were produced based on the Joint Research Centre (JRC) European damage curves. As seen in Figure 3.4, the industrial and the commercial sectors have the largest percentage of damage for lower flood depths, while the transport sector has the lowest damage percentage. For flood depths beyond 3m, the damage is estimated as 100% for all sectors. [3].

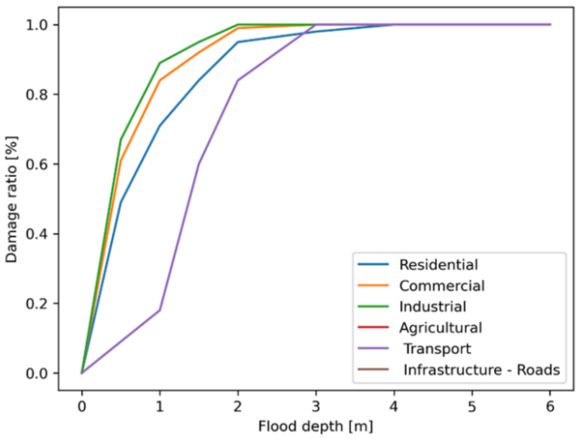

Figure 3.4: Percentage damage for a given flood depth and sectorCLIMAAXKòrsou Project Team [3]

Data from the 15th chapter of 6th Intergovernmental Panel on Climate Change (IPCC) report for the east Caribbean islands estimates that generally they will be slightly wetter with more extreme seasonality. The total rainfall in the wet/dry season in the east Caribbean compared to 1971–2001 will experiment a 5% rise/10% drop and a 8% rise/15% drop by 2080-2100 in the RCP4.5 and RCP 8.5 respectively [13].

The spatial distribution of extreme precipitation (10-year return period) shown in Figure 3.5 indicates a wetting and drying trend in the western and eastern parts of the island respectively in the short term period (2021-2040). For a mid to long term timeline, Climaax [3] found that this trends reverse. It also states that, generally, the intensity of precipitation events will increase [3].

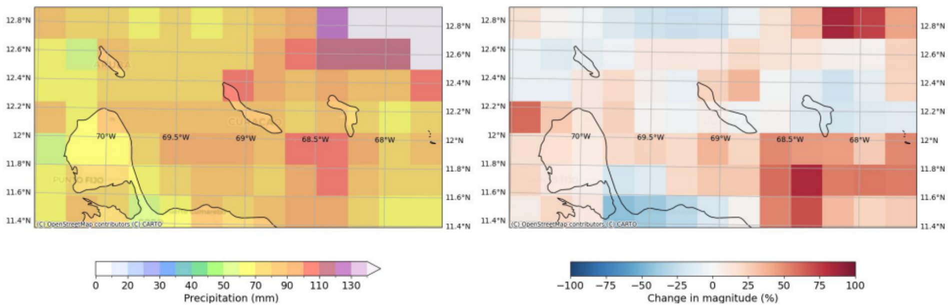

Figure 3.5: Spatial distribution of extreme precipitation (10-year return period) for the short term (2021-2040) in the low emission scenario (RCP 2.6)[3]

3.1.4 Erosion

Coastal erosion represents one of the main natural hazards that affect the coast of Curaçao. Along the windward (north and eastern) coasts, high-energy wave conditions result in continuous cliff retreat and undercutting, while on the leeward (southern) coast, localized beach erosion and sediment redistribution are commonly associated with anthropogenic modifications and coastal development.

Understanding the spatial extent and temporal evolution of erosion is essential for the identification of vulnerable coastal segments. This allows for identification of sections where structural shoreline retreat is taking place, in order to establish erosion baselines that can inform hazard mapping, risk assessment, and the design of coastal protection strategies.

High definition aerial orthopictures of Curaçao for the years of 2018 and 2024 were made available by CARMABI. Furthermore, access was granted to Planet's Research and Education Program, which provided 8-band surface reflectance satellite imagery over the area at a spatial resolution of $3-4m$. Combining both data sources allowed for an algorithm to be devised to extract the shoreline. The 8-band satellite imagery was first resampled to match the higher resolution of the aerial photographs, whilst ensuring alignment was correct via georeferencing fixed points, which effectively adds spectral information to the aerial red, green, and blue light (RGB) data. Strong absorption for water in Near-Infrared (NIR) band led to quick classification of terrestrial and non terrestrial pixels for most of the image, which was refined via computed spectral indices such as the Normalized Difference Vegetation Index (NDVI) to help distinguish vegetated areas from water bodies. Along boundary zones, the detection was refined using RGB characteristics from the aerial imagery, where water typically appears darker with higher blue-to-green ratios. Morphological operations, including dilation, erosion, and closing, were applied to smooth boundaries and remove noise. The final coastline was extracted as the boundary of the water mask through morphological gradient and edge detection, then smoothed and polygonised to allow assessment of erosion and accretion via area differences.

Figure 3.7 and Figure 3.9 depict the result of the algorithm in Pietermaai and from Baoase to Mambo beach, respectively, showing how the coast has changed from 2018 to 2024. Areas in red are areas that were identified in the image of 2018 but not in 2024, thus have eroded over the years. Similarly, the green areas are land zones that were not there in 2018, but were detected in the 2024 image.

Figure 3.6: Aerial orthopicture of Pietermaai in 2024, courtesy of CARMABI

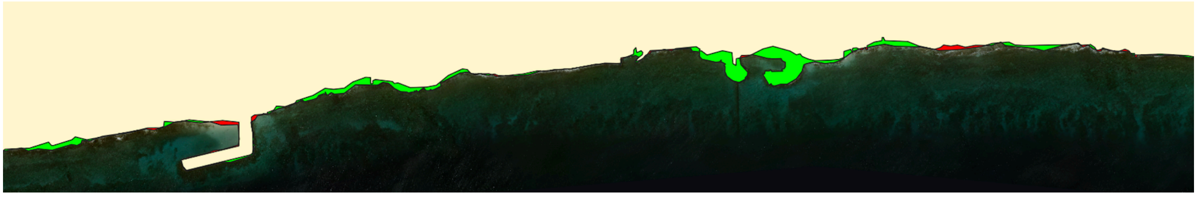

Figure 3.7: Results of coastal detection algorithm in the Pietermaai area

Coastal development is clearly seen in the Pietermaai area, where Scuba Lodge has built an artificial beach. Other areas of land accretion show the upcoming plans to build out to sea, with land preparation already occurring. This alludes to information shared in stakeholder interviews, [subsection A.2.7], mentioning different private parties along Pietermaai to have submitted plans for coastal development which span only the extent of their land ownership; not as an integrated development that protects and improves the entire region. Small areas of erosion were detected, which correspond to areas with lower elevation and sandy patches.

Figure 3.8: Aerial orthopicture of the southwest coast from Baoase to Mambo beach in 2024, courtesy of CARMABI

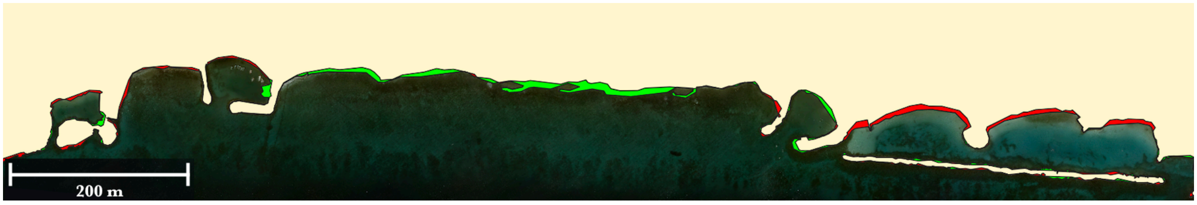

Figure 3.9: Results of coastal detection algorithm in the Marie Pampoen to Mambo beach area

Similar coastal modification can be seen in Figure 3.9 with the development of Marie Pampoen, which is discussed as a case study in subsection 3.2.3. The Baoase luxury resort, seen in the left of the image, shows signs of erosion on the edges exposed out to sea, and a small shoreline retreat in its artificial beach too.

What is also observed is the reduction in Mambo's beach width. Dutch Schriers of Sea Aquarium originally developed the beach and later sold the asset. During an interview (subsection A.2.6) informally discussed how in recent years the new owners have not sufficiently maintained the breakwater, nor re-nourished the beach, leading to a significant shoreline retreat. Indeed, the results of the coastal extraction are in agreement with these claims. This is an area of significant economic and touristic importance to the island, with concentrated hospitality infrastructure, and thus maintaining a wider beach width is crucial for sea flood and damage prevention.

3.1.5 Coastal Development and Artificial Beaches

In recent decades, an increasing number of urban development projects, such as hotels, resorts, and recreational facilities have been constructed along the southwestern coast of Curaçao. This has led to significant alterations of the natural coastline and concentration of economic activity and infrastructure in close proximity to ecologically sensitive areas of the coast. As illustrated in Figure 3.10, the highest percentages of coral coverage is concentrated along the leeward (southern) coast, indicating substantial spatial overlap between development and coral reef ecosystems.

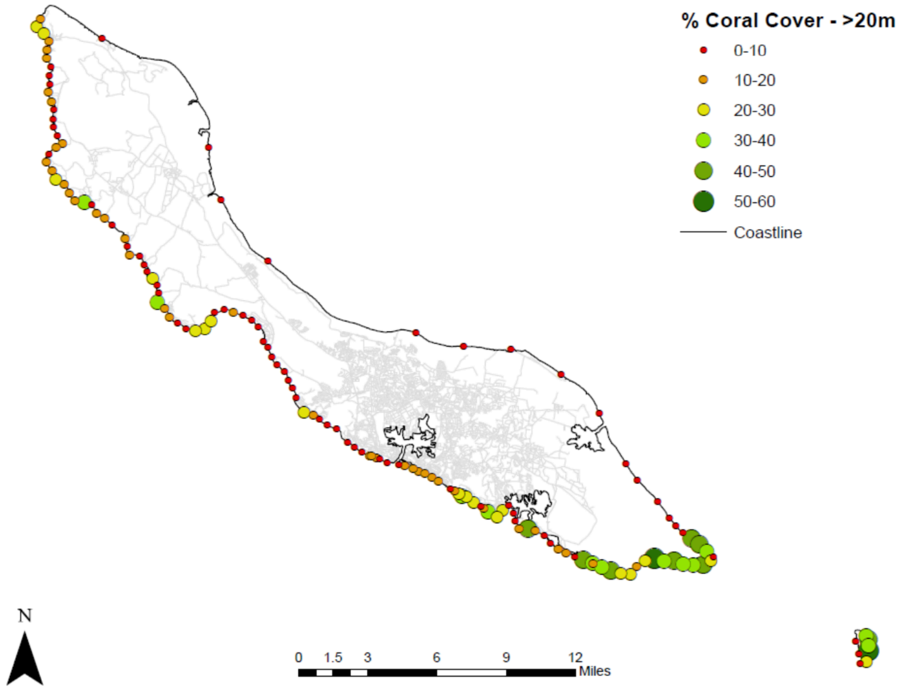

Figure 3.10: Island-scale coral cover (0-20 m) as of 2017 highlighting the concentration of high-cover fringing reefs along the leeward coast, where coastal development is most concentrated (adapted from [4]).

At the same time, while the coastal zone is subject to several individual policies under the jurisdiction of separate governmental entities, an island-wide, comprehensive management and regulatory framework for the development process is currently not in place. In practice, this means that the design and approval of coastal projects is largely dependent on the individual developer and the reviewing authority, rather than on consistent criteria. This fragmented planning approach often leads to a concentration of development in environmentally sensitive zones such as coral reefs and mangrove forests, increasing risks of ecological degradation. Moreover, in the absence of an integrated management framework, projects are often evaluated on an individual basis, without taking into account their cumulative effects on sediment transport, water quality, or ecological connectivity. This is especially relevant given that the projected growth of the tourism sector is expected to further increase development-related pressures.

Artificial beaches in particular, are a type of development that should be taken into account from a zoning perspective. These beaches are typically created using sand extracted from the northern coast, such as the coast of St. Joris Baai, or from the Taffelberg quarry, and are usually enclosed by large L-shaped breakwaters to limit erosion and create calmer swimming conditions. Their construction has intensified in recent years, to support tourism demand, particularly along the southwestern coastline where natural sandy beaches are scarce due to prevailing hydrodynamic and sediment transport conditions.

However, artificial beaches have some times been created without adequate consideration of coastal dynamics, resulting in interventions that may not be sustainable under changing wave climates [98]. The risks of siltation and sediment migration to adjacent coral reefs is also an environmental side effect that should be considered in the assessment of artificial beaches. As there is currently no standardized framework for the design or evaluation of such coastal interventions, and the permitting process does not require feasibility or effectiveness studies prior to construction, designs are often based on the discretion of the developer or as stakeholder interviews revealed, [A.2.2], on trial-and-error approaches, rather than established coastal engineering guidelines. This lack of design standards can undermine the long-term effectiveness of such projects but also increase risks to the valuable coral reef ecosystems.

3.1.6 Water quality degradation

There are currently four sewage treatment plants in Curaçao - Klein Hofje (62%), Klein Kwartier (34%), Tera Kora (3%) and Abbatoir (1%) [5], with the combined capacity been over 5100 m^3/day[99]. These are managed by Public Works Curaçao. 33% of the country's households are connected to one of them, with the remaining 67% using underground septic systems as an alternative with no existing regulation inspection. In 2018, only 16% of the wastewater produced in Curaçao was treated, with the other 84% being disposed untreated into the marine and terrain environments [5]. See Figure 3.11 for a summary of the above.

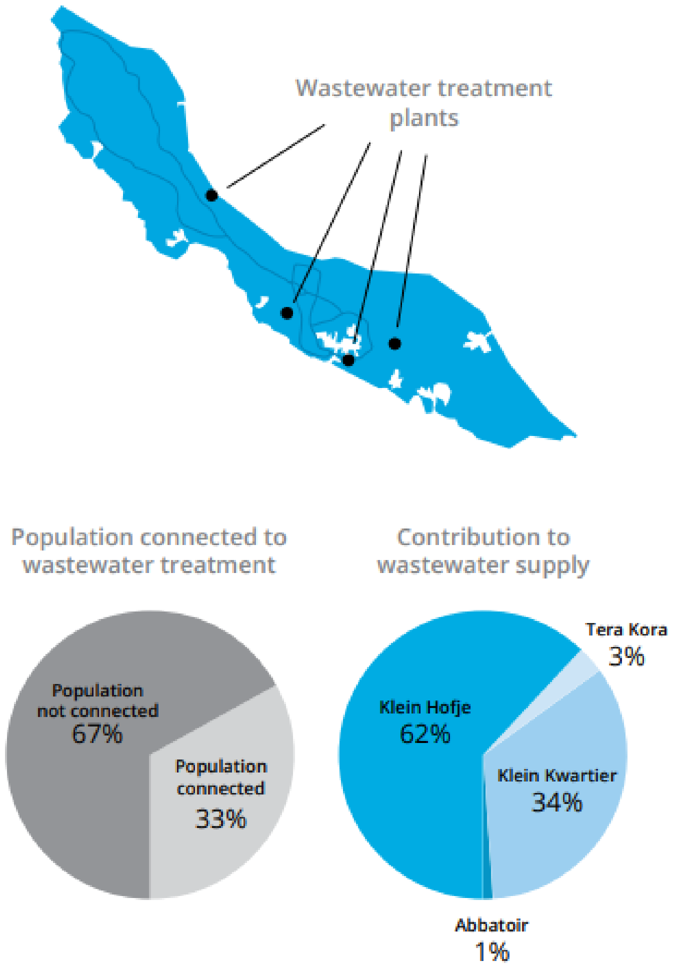

Figure 3.11: Location of the four wastewater treatment plants in curaçao and their supply [5]

Around 80% of the pollution in the marine environments in Curaçao comes from land-sources, including: land clearing and construction, paved surfaces (roads, parking spaces), residential houses, hotel and restaurants, golf courses and port activities [85]. The coast along Willemstad is the area with the highest concentration of infrastructure and sewage discharge. A 2015 study reported that sewage pollution levels near the mega-pier in Willemstad were roughly ten times higher than those measured at other sites around the island [85].

In the Klein Hofje plant, wastewater usually has over 83 ppm of Nitrogen products, which can serve as an indication of other local wastewater [5]. Some wells have recorded values of up to 100 parts per million (ppm) [99]. This is well above the safe level of 20 NO3-N ppm for marine life health, which poses a significant threat to the marine ecosystems, including mangroves and coral reefs [100]. Along the coast of Willemstad and Caracasbaai, the coral reef coverage has reduced from an estimated average of 23% in 1948 to around 14% in 2017 [4]. This stretch of coast is also where most of the development is taking place.

Several proposals have been discussed to address the over-capacity issue in the existing plants, including upgrading the Klein Hofje plant to increase its capacity by 14 m^3/day and plans to build two new treatment plans (in 5-year periods) with a capacity of 5500 m^3/day each. Furthermore, significant progress can be made through more cost-effective and short-term solutions, such as demand management options, with an estimated reduction of 32 million m^3 of untreated water by 2050 through demand-side solutions alone [5].

The construction phase of coastal developments, when insufficiently regulated, is a significant source of water quality degradation and coral reef stress. Activities such as dredging and infilling generate sediment plumes that can smother adjacent coral ecosystems. This is evidenced in the following case studies.

As stated in the policy section above, a wastewater management strategy is currently not a requirement to receive a permit for coastal development. While the government of Curaçao (VVRP and GMN) has approved a wastewater management plan, this plan does not specifically address a strategy for wastewater management along the coast, which is where intensive development is currently occurring in the island. This plan is part of the Pollution Action Plan. Key limitations for the implementation and regulation of this plan include institutional capacity and lack of funding [78].

3.2 Impacts of Coastal developments on the shoreline

3.2.1 Introduction coastal developments

Coastal development has played a central role in shaping the shoreline of Curaçao, particularly through tourism infrastructure, urban expansion, and land reclamation projects. While such developments provide significant economic benefits, they also alter natural coastal processes and can intensify erosion in vulnerable areas. In Curaçao, this tension between development and coastal stability is especially relevant given the island's reliance on its beaches and marine ecosystems for tourism and local livelihoods. By examining specific case studies of recent coastal projects, supported with empirical data collected from stakeholder interviews for the purposes of this analysis, this section explores how different forms of development modify the coast and their implications on the natural ecosystem.

For example, the Punda waterfront in central Willemstad has long been protected by historic seawalls rather than natural beaches. Further east into the Pietermaai area, the coast naturally consisted of a rocky cliff. However, in the past decade small artificial beach coves have been created by hotels, resorts, and beach clubs, such as the Avila beach hotel, which maintains a small artificial beach enclosed by rock breakwaters (Figure 3.12).

Figure 3.12: Satellite photo of Avila beach hotel [101]

Similarly, the Scuba Lodge boutique hotel in Pietermaai constructed a small protected bay using breakwater structures to dissipate wave energy and create favourable swimming conditions for the hotel's guests. These beaches and lagoons did not exist naturally, but were engineered by placing boulders offshore and infilling sand. Figure 3.13 and Figure 3.14 show the evolution of this area from 5 years ago to the present.

Figure 3.13: Satellite photo Scuba Lodge in 2020 [101]

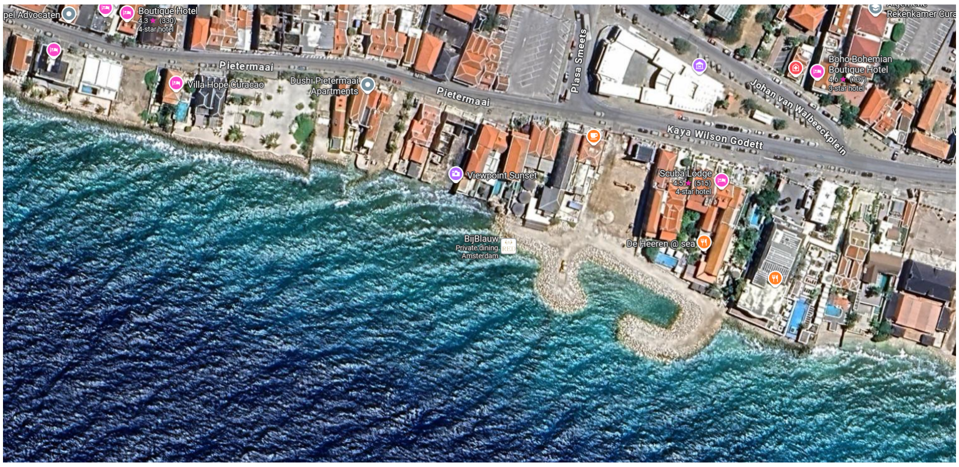

Figure 3.14: Satellite photo Scuba Lodge in 2025 [101]

3.2.2 Baoase resort

Background

Baoase Luxury Resort is an exclusive waterfront hotel in Marie Pampoen, Curaçao, southeast of Willemstad. It opened in 2009 after works that began in 2005. It started with five villas, a master villa and a bar, and has expanded to 23 luxury accommodations with restaurants and a helipad [102]. The development included an artificial beach and sheltered lagoon with rock breakwaters. Earlier coastal works were reportedly done without all required permits, causing coral damage, which set the context for the current controversy over the new proposed expansion.

In 2022–2023, owner Flamingo Development Maatschappij N.V. proposed expanding seaward. A July 2022 letter of intent with VVRP outlined the plan and preliminary government support [103]. In December 2023 the developer filed to reclaim coastal waters east of the resort [103]. The proposal drew swift public scrutiny given the ecological sensitivity of the site and its proximity to local residential areas. Local press coverage in April 2024 highlighted questions regarding the scale, purpose, and impacts of the expansion. Resort representatives chose not to comment publicly until the objection period had ended [102], which critics said made it seem like decisions were already being made without public input.

Figure 3.15: Aerial view of the existing Baoase Luxury Resort in Curaçao [104]

Currently, Baoase plans to reclaim about 2,007 m^2 of seabed to build a small peninsula on the resort's east side [103]. The fill would partly close a shallow bay between the current beach and the Marie Pampoen fishing area, with a rock breakwater around the edge to calm waves. The revetment is designed with a steeper underwater slope to mitigate part of its ecological footprint by avoiding damage to some of the surrounding reef, while still keeping the land reclamation protected [103].

The intended usage of the land reclamation of the resort is to host nine high end tourist accommodation units, oriented towards the sea, to add luxury capacity [102]. The extension site is located immediately adjacent to Baoase's eastern boundary and the public waterfront of Marie Pampoen, which can result in potential conflicts regarding spatial compatibility with nearby residential areas and the preservation of public access to the shoreline.

Construction approach

Two methods of construction were considered: either from the sea or from land. Based on ecological advice, the engineers opted for land based construction to avoid anchoring damage to the reefs [105]. Works involve placing rocks for the revetment and importing filling materials. No separate beach nourishment is planned, though a small side beach may form naturally. The developer also committed to public benefits such as contributing to an upgrade of the nearby Boka Simon beach area [103].

If approved, the project would convert a piece of public water and reef habitat into private resort land. Given multiple permits and possible challenges, the start depends on government decisions and the outcome of objections.

Legal framework

The Baoase coastal expansion must navigate a complex legal and planning framework, encompassing zoning rules, environmental regulations, and maritime permitting requirements in Curaçao. Several key laws and ordinances apply:

- **Zoning / planning.** Under the EOP and the Building & Housing Ordinance, the project requires a building permit and an *aanlegvergunning* [46]. The site lies in an urban residential area, which does not allow hotels; hotels are only permitted in touristic areas. Interpreting recreational zoning as equivalent to hotel use constitutes a misapplication of the spatial plan. Consequently, any project approval would require either a formal rezoning or an explicit exemption decision [46].
- **Maritime permit (LMB).** Article 20 of the LMB prohibits structures on the seabed without a permit; assessments must weigh environmental, ecological, navigation, and maritime heritage impacts [72]. The process must follow Article 20 with public notice and a period, which occurred here [72].
- **Environmental permitting**. The Nuisance Ordinance Curaçao 1994 requires businesses to obtain a nuisance license before conducting any activity that could harm the environment [74]. Furthermore, the GMN

sets coral protection criteria for Curaçao's SPAW species (e.g., *Orbicella*, *Acropora*) [106], which are protected under the Cartagena Convention. Compliance implies mitigation or refusal if endangered corals would be harmed.

- **Reef ordinance & exemption.** Because corals will be impacted, an exemption under the Rifbeheerverordening is required and must align with Nuisance Ordinance conservation principles [77].
- **Process & governance.** Following the submission of the permit application in December 2023, VVRP made the dossier available for public inspection, during which fifteen written objections were submitted [107]. The objectors cited incomplete documentation, arguing that this omission hindered informed public review and fell short of good governance standards [107].
- **Position of VVRP.** VVRP issued a preliminary positive stance with conditions. These include securing all permits, respecting SPAW-listed corals, and implementing coral compensation [108]. The main challenge remains to reconcile environmental and zoning rules with the proposed coastal development.

Environmental impact

The proposed Baoase land reclamation directly threatens a portion of coral reef habitat, and the environmental impacts have been the focus of the research. In early 2023, the developer commissioned EcoVision, an independent environmental consulting firm, to conduct a marine ecological research of the project site [105]. EcoVision's coral reef assessment provides quantitative data on the baseline conditions:

- As seen in Figure 3.16, EcoVision recorded a total of 1,273 coral colonies present [105] within the planned fill area. These include various species of corals attached to the sea bottom that could be damaged or removed by the works. Notably, at least one coral species observed in the area is listed under the SPAW Protocol's protected species [105]. This is presumably the massive star coral or Elkhorn coral, which are known to have protected status.
- EcoVision also categorized the coral colonies by conservation status. Of the 1,273 colonies, 678 were identified as critically endangered species [105]. This refers to International Union for Conservation of Nature (IUCN) Red List status, for example, the Elkhorn coral is classified as critically endangered globally. The remaining colonies were labelled as "other corals".
- An important metric considered was the percentage of live coral cover. The Ministry of GMN has an criterion that at project sites, coral cover should not exceed 5.0% if a construction in the sea is to be permitted [109]. EcoVision's study found that in all the sampled quadrants within the intended footprint, the live coral cover ranged from 6.63% to 7.45%, exceeding the 5.0% threshold [109]. In other words, the site has a coral cover above the limit that environment authorities consider acceptable for construction.

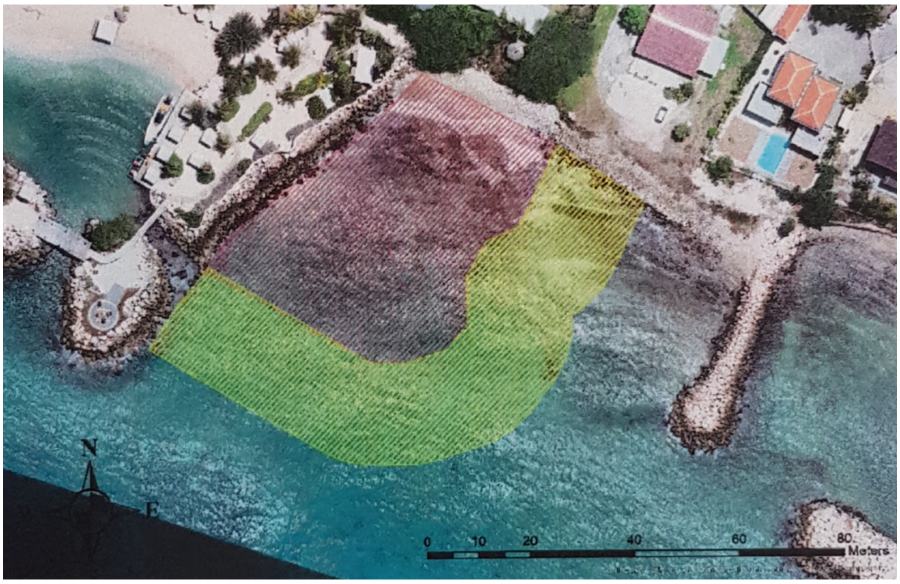

Figure 3.16: Approximate footprint of the proposed land reclamation on the Baoase's property with a buffer zone [105]

The expected impacts include permanent loss of sea habitat, such as coral reefs or algae beds under the new land, as well as degradation of water quality and nearby reef areas during construction. Sediment smothering is a major concern, as filling and earthmoving in water can release plumes of silt that settle on adjacent corals. Figure 3.17 shows Baoase's earlier lagoon construction showing turbid water and sediment covering corals.

Figure 3.17: Photo taken in 2008, showing the effects of the construction activities at Baoase, source: ProMonumento

EcoVision's report did not only mention impacts, it also proposed ways to reduce harm. They presented three alternative design scenarios for the land reclamation that would involve a smaller reclaimed area and different configurations to minimize disturbance to coral habitats [105]. Each alternative had less area of fill than the original plan and was shaped to avoid denser coral patches. However, these alternatives would yield a smaller development area, making them less attractive to the developer. According to Domeinbeheer, all three EcoVision alternatives were rejected, instead opting to simply modify the slope of the shoreline structure as a compromise [107]. To compensate for the ecological damage, the permit application includes a Coral Compensation Plan developed by the proponents. According to EcoVision itself it is probably not efficient as the relocation of corals is specialized work that is very time intensive. The chance of fully succeeding for all corals is very low [105].

Another aspect that raised concerned was the climate resilience and coastal safety. Opponents questioned whether the proposed structures would be able to withstand extreme weather events, citing past hurricanes such as Lenny and Omar as examples of relevant design conditions. In those events, wave action from the south west caused damage to the coastline as mentioned in chapter 3.1.2. Placing hard structures in the coastal area may alter wave and sediment dynamics, possibly causing erosion in adjacent downstream areas [105]. The environmental impact assessment did recommend the project to follow engineering norms, including a wave overtopping limit of 10 litres per second per meter for the structure [105].

Findings from the Shoreline Analysis

A shoreline comparison analysis between 2018 and 2024 reveals visible morphological changes in the vicinity of the Baoase Resort development. Over the six-year period, the total land area decreased from 182,787.28 m² to 182,167.83 m², corresponding to a net loss of approximately 620 m². The analysis indicates erosion along the outer boundaries of the lagoon and in adjacent beach segments, with a total eroded area of 1,743.66 m². An increase of 1,124.22 m² in sediment budget occurred primarily in more sheltered sections in the lagoon. The results can be seen in figure 3.18.

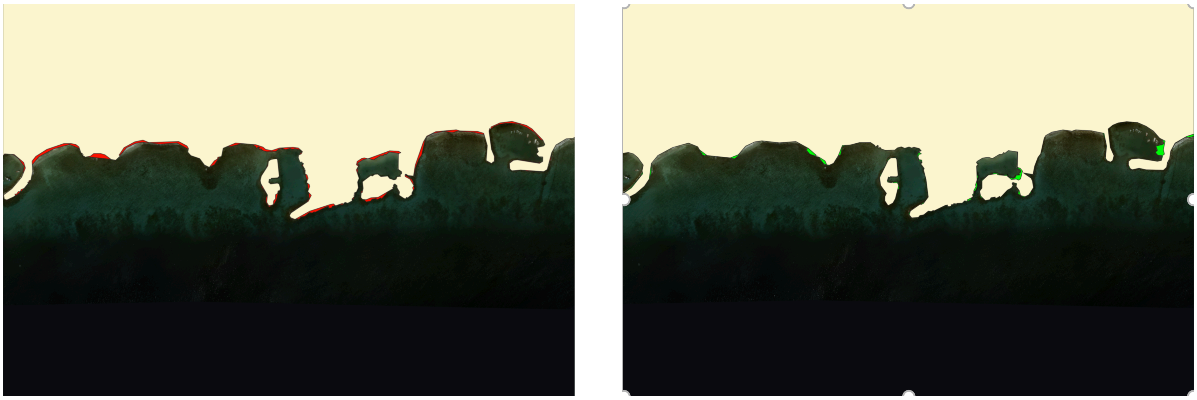

Figure 3.18: Erosion and Accretion in the Baoase Resort Area between 2018 and 2024

Table 3.1: Land area changes at Baoase Resort

Category	**Area (m^2)**
Accreted	1,124.22
Eroded	1,743.66
Net change	**-620**

The areas of sediment increase correspond to the sand nourishments and land reclamation interventions that were carried out during the construction and expansion phases of the resort. These interventions temporarily increased the beach width and lagoon area, however, subsequent erosion along the outer breakwater and adjacent natural shoreline suggests that they were not fully stable under wave forcing and current conditions.

These changes also suggest that while the enclosed lagoon created by the breakwater system retains some sediment internally, it also alters the natural longshore transport processes leading to localized erosion immediately outside of the protected area. The accumulation of sediment inside the lagoon, and the losses along its perimeter are consistent with observations of reduced sediment exchange and are typical of an initial response of the coastal cell to the modified hydrodynamic conditions immediately after construction.

The erosion patterns immediately downdrift of the development suggest a disruption of natural longshore sediment transport, which is already evident within the relatively short time span of six years.

Stakeholder perspectives and Discussion

The Baoase expansion has faced public opposition from environmental organizations, community stakeholders, and citizens. During the objection period in 2024, a total of 15 formal written objections were submitted to the government as mentioned in the legal framework part [107]. These objections can be grouped into main concerns and arguments brought forward by different stakeholders:

- Environmental and ecological concerns
- Legal objections
- Loss of public assets
- Long-term development perspective

From an environmental and technical standpoint, the preference for land based construction to avoid anchor or chain damage on the reef and the adoption of a more compact reclamation design with a steeper slope, are attempts at mitigating some of the direct physical impacts on coral reef habitats.

From an environmental and technical standpoint, the project incorporated several mitigation measures, such as land-based construction to avoid anchor damage and a more compact reclamation layout. However, the objections submitted by environmental organizations and community stakeholders underline deeper systemic issues. Public participation remains largely procedural, with limited opportunities for early engagement or influence on design outcomes. The case also reflects the broader challenge of balancing economic development and conservation:

while tourism expansion drives economic growth, it simultaneously places increasing pressure on ecologically sensitive areas.

In addition, the observed erosion patterns revealed by the shoreline analysis, show that even with technical improvements, there can still be localized impacts affecting adjacent areas of the coast, due to the disruption of longshore sediment transport. This highlights the importance of sufficiently accounting for coastal processes at a larger system scale during the development planning phase.

In this context, the Baoase case reflects both the progress and the limitations of current coastal planning practices in Curaçao. The technical improvements made at the project level cannot fully compensate for the absence of a coordinated approach to coastal management and sustainable tourism planning on the island.

3.2.3 Marie Pampoen recreation area

Background

The Marie Pampoen recreational area is a public waterfront on Curaçao's southern coast, that was redeveloped by the government to combine coastal protection with recreation functions.

Figure 3.19: Satellite photo Marie Pampoen in 2015 [101]

Figure 3.20, shows the area before it was developed. The coastal stretch was characterized by a rocky shoreline with small pocket beaches and a few traditional fishing slipways. A fringing coral reef extends offshore of the area, and the presence of fragmented coral debris along the beach suggests active erosion and transport of coral reef material [110].

The area was historically used for local recreation, but the condition of the public beach was poor, with minimal natural sand deposition. Because the natural processes do not favour the formation of a sandy beach, any sand nourishment efforts face challenges from exposure to wave and current action, that would rapidly erode the unprotected sediment. The combination of high recreational demand and the need of protection from coastal erosion, necessitated an engineering intervention in the area, to make the coast safe and suitable for public use. Moreover, the proximity to the coral reef introduced an additional constraint: from an environmental perspective, the reef was at risk of damage from poorly planned coastal works, while from a practical perspective, the irregular substrate and energetic nearshore conditions made it difficult to establish and maintain a stable sandy beach. [110].

These initial conditions presented a key challenge: how to improve the beach and coastal protection infrastructure at Marie Pampoen, while at the same time preserving the coral reef ecosystem and managing wave impacts. In 2015, the Government of Curaçao launched the redevelopment project of the Marie Pampoen area, appointing the CTB as the project lead [111]. The brief targeted an attractive, publicly accessible beach and swimming area that would improve recreational functions for local communities and for tourism. In this vision, design choices were explicitly tied to the site's natural and cultural setting, so that the redevelopment enhanced cultural identity rather than replacing it [110]. The core design principles emphasized minimal disturbance to the existing reef and marine habitats, with all interventions carefully dimensioned and positioned to reduce the physical and ecological footprint.

Alternatives Considered

During the planning phase, several design alternatives were evaluated. One of the initial concepts involved the construction of a continuous row of shore-parallel detached breakwaters to create a sheltered lagoon suitable for the formation of a new sandy beach. This concept was presented as a preliminary design in late 2015[110] and the layout is illustrated in Figure 3.20. However, it was soon determined to be unfeasible due to the environmental impacts, as it would directly damage the coral reef and alter current dynamics along the reef [110]. The government therefore ruled out this design alternative at an early stage.

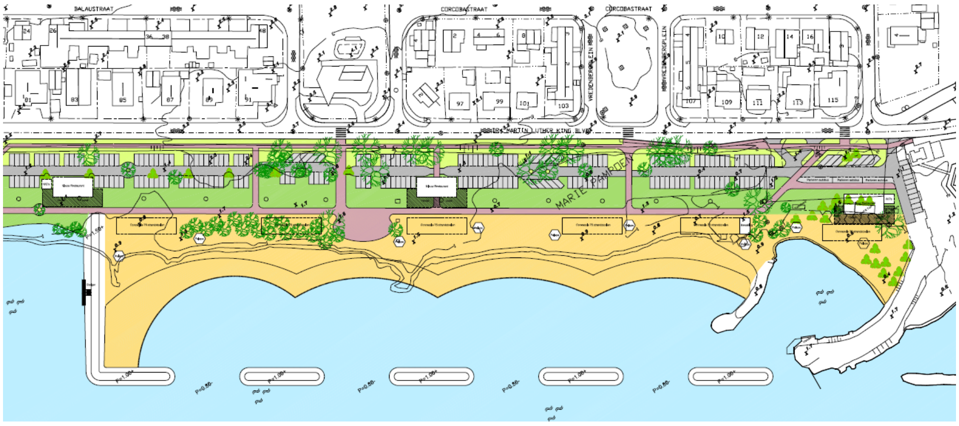

Figure 3.20: Initial Design proposal for the redevelopment of the Marie Pampoen coastal area

In 2016, the design team investigated alternatives aimed at keeping construction activities primarily onshore or immediately along the shoreline. The main objective was to create a safe, family-oriented swimming area while minimizing physical disturbance to the living reef. Two lagoon design concepts were subsequently developed to balance the trade offs between recreational use with ecological preservation. Alternative A envisioned a shallow inland lagoon just behind the beach, separated from the sea by a low crested rock dam set at sea level [110]. In other terms, waves could occasionally wash over and naturally refresh the water, with additional exchange through porous fill. Alternative B proposed a similar lagoon but enclosed by a higher, less permeable barrier. It would provide calmer conditions, but the water quality would rely on engineered culverts to flush out the basin. Both kept construction activities onshore of the reef to avoid direct impacts to the corals.

On the eastern side, an open water swimming bay was designed using a small breakwater configuration to form a sheltered cove. By aligning the structure with existing shoreline projections and a small jetty on the opposite side, the design aimed to minimize the ecological footprint of the intervention compared to an earlier design option that proposed a continuous offshore breakwater [110]. Layouts, orientations, and crest heights were tested using Simulating WAves Nearshore (SWAN) to model the hydrodynamic conditions in the sheltered area, and assessed the required amount of sediment and the stability of the nourishment under the prevailing wave conditions [110].

Figure 3.21 illustrates the final design configuration, while Figure 3.22 shows a current 2025 satellite image of the current state of the area [101].

Figure 3.21: Illustration of the final plan for Marie Pampoen [110]

Figure 3.22: Satellite photo Marie Pampoen (2025) [101]

Engineering studies of groundwater seepage and tidal exchange showed that with just the permeable dam, the lagoon would achieve roughly 17% water renewal per day, and that wave overtopping during moderate seas could increase this exchange to about 27% per day [110]. To further guarantee water quality during calm conditions, the final plan incorporated a set of PVC exchange pipes through the dam as a circulation aid.

An important engineering consideration was how to handle storm water runoff and prevent flooding or pollution of the new recreational areas. The upgrade included improvements to the drainage infrastructure on land. The design integrates the coastal structures with the area's sewage and rainwater systems to ensure that heavy rainfall does not simply flow to the beach or lagoon areas[112]. During design; drainage, sewage connections, and storm overflow studies were conducted to align the project with the water management plan of Willemstad [112].

Given the proximity of the project to a living coral reef, ecology led the design. A baseline marine survey mapped coral cover and species, confirming a moderately diverse community in the area. Since certain protected species were detected, the plan built in clear protection measures for the corals.

The implemented measures can be summarized as follows:

- Minimize impacts through design. The original concept of a continuous offshore breakwater was abandoned in favour of a configuration that confined construction to onshore and shallow rocky areas, thereby minimizing disturbance to the reef.
- Coral relocation. Small and medium coral colonies located within the construction footprint were transplanted by marine biologists to suitable nearby reef areas to mitigate habitat loss [113].
- Control siltation: Silt curtains were deployed around the construction zones in the water, and activities were scheduled during calm weather conditions to limit sediment dispersion periods [110].
- Monitor and manage water quality: Divers regularly inspected adjacent corals for signs of stress or bleaching and monitored levels of clarity in the lagoon [113].
- Ensure oversight and compliance: The GMN and CARMABI supervised the implementation of mitigation measures. Permits required measures like coral relocation, turbidity control, and seasonal restrictions, aligned with the marine protected area rules and the 2008 Maritime Management Ordinance [114].
- Breakwater and Structure Maintenance: The rubble mound breakwaters and lagoon dam will require periodic inspections to check for stone displacement or settlement. The structures are expected to be relatively low maintenance, as they are built for a 50-year storm condition [113].

Wave activity

Offshore wave conditions were transformed to nearshore environments using the SWAN spectral wave model. Due to the orientation of the southern coastline, this area is naturally sheltered from waves approaching from the north-west to east sectors. Model results indicate that 1/100-year easterly waves, with an offshore significant wave height of approximately 5.3 m, refract and attenuate to around 3.0 m in deeper water and further reduce to roughly 1.7 m nearshore, with additional wave growth driven by local winds between the offshore boundary and the coast. Hurricane conditions were simulated using spatially varying NOAA GFS winds and WW3 boundary conditions. Figure 3.23 captures hurricane Lenny driving westerly swell into the normally sheltered south coast at Marie Pampoen [110].

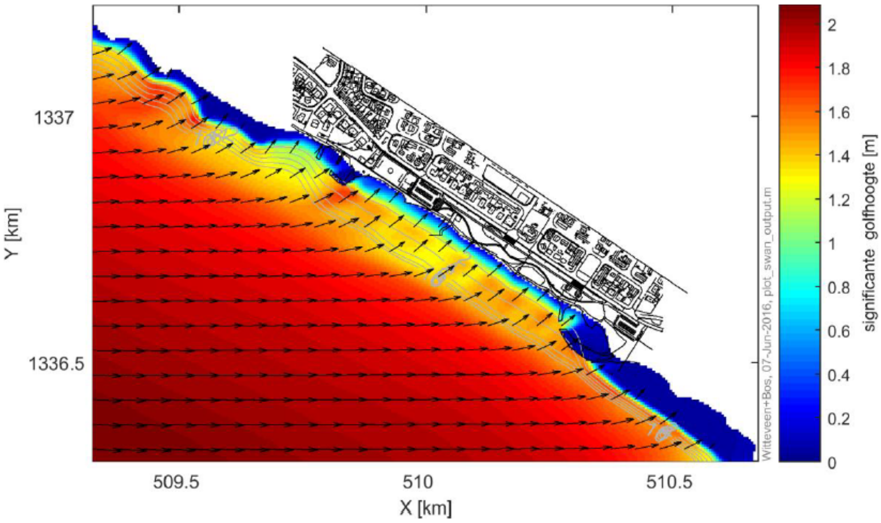

Figure 3.23: Significant wave height under design conditions representative of hurricane Lenny [110]

Findings from the Shoreline Analysis

The shoreline comparison between 2018 and 2024 shows a net land gain in the Marie Pampoen area. The total land area increased from 193,007.72 m² to 194,483.44 m², resulting in a net accretion of approximately 1,475.7 m². The analysis identified 2,937.23 m² of land gain and 1,461.51 m² of erosion along the studied section of coastline and the results can be seen in Figure 3.24.

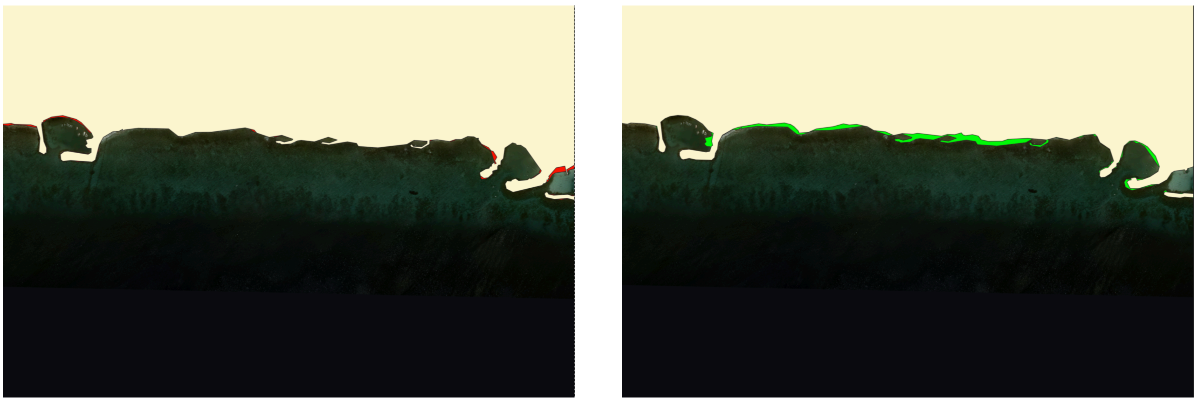

Figure 3.24: Land Gains and Losses in the Marie Pampoen Area between 2018 and 2024

Table 3.2: Land area changes at Marie Pampoen

Category	Area (m²)
Accreted	2,937.23
Eroded	1,461.51
Net change	**1,475.72**

Most of the accreted areas correspond to the beach nourishments carried out as part of the redevelopment project. These interventions have helped increase the available recreational area, while the increase in beach width enhances the natural buffer capacity of the coast, providing protection to the infrastructure located behind it. Limited erosion is observed near the channel openings and downdrift sections, but the time after construction is not sufficient to determine any trends in morphological changes. Continued monitoring will be required to assess the long-term performance of the nourished areas and the stability of sediment transport dynamics under future forcing conditions.

Discussion

The Marie Pampoen project represents one of the recent examples in Curaçao where coastal redevelopment was done with ecological and social considerations. The design process demonstrated a clear direction towards more environmentally sensitive alternatives that were modified to avoid impacts on the coral reef. By limiting construction to the nearshore zone and adopting mitigation measures such as coral relocation and siltation control, the project set a precedent for integrating ecological protection options within recreational coastal developments. In addition, the intervention improved and protected public access and safety, while contributing to urban storm water management.

However, several challenges are still present. Despite the implementation of mitigation measures, some impacts on the coral reefs cannot be fully ruled out, as the long-term survival rates of the relocated corals are uncertain. Moreover, there are concerns about the water quality of the lagoon, as reduced flushing capacity during calm conditions and storm water influx may degrade its ecological health over time. These factors highlight the need for long-term monitoring and management to ensure that the recreational and ecological benefits of the project are maintained over time.

3.2.4 Sea Aquarium

Location and context

Figure 3.25: Sea Aquarium Park.

The Curaçao Sea Aquarium (Figure 3.25), is located at Bapor Kibra on the island's south coast, adjacent to the artificially created Mambo Beach. The site lies within a semi-sheltered coastal cell, as the headlands of Spanish Water Bay and the Jan Thiel headland provide partial protection from the dominant north-easterly trade-wind waves. This reduces incident wave energy under normal conditions, while exposure increases during occasional south-westerly storm events. The fringing reef and narrow lagoon provide a naturally attenuated wave climate dominated by persistent north-easterly trade winds, while occasional south-westerly storm swell can generate reverse wave conditions.

The Sea Aquarium area marked the *first large-scale coastal development* along this section of the south coast; subsequent tourism expansion inland and to the west (Mambo Boulevard, resorts) followed the spatial pattern that it initiated.

Historical development

The Sea Aquarium was founded in 1984, initially consisting of a few open-water basins. The surrounding shoreline at that time functioned as an informal landfill site, which was cleaned and reclaimed for development. Between 1986 and 1987 the adjacent Seaquarium Beach (now Mambo Beach) was constructed through land reclamation and the installation of rubble-mound breakwaters. Subsequent phases in the 1990s and 2000s expanded the complex with lagoons, the Dolphin Academy, and the Royal Sea Aquarium Resort. More recent additions include the *Ocean Lens* (2019) and a new underwater observatory (2025). The project therefore represents the pioneering node of development in the Bapor Kibra–Mambo coastal zone, with continued infilling interventions and commercial development in the hinterland.

Design and coastal engineering approach

The Sea Aquarium applies an "open-water system" that continuously circulates unfiltered seawater through all exhibits. Gravitational pressure differentials drive flow between the open water and the internal basins, maintaining natural oxygen and nutrient levels while minimizing energy use. The coastal protection structures consist of large rubble-mound breakwaters built from natural boulders of approximately 1.5 m diameter, as shown in Figure 3.26. These structures were deliberately over-dimensioned to withstand long-period swell events and to ensure multi decadal durability with minimal maintenance. They separate the marine life lagoons from the open sea, but permit continuous renewal of seawater. Because of limited space and local site conditions, the breakwaters were not designed strictly according to Dutch guideline dimensions, but follow empirical site-specific criteria. The Sea Aquarium maintains a nearby stockpile of large boulders recovered during construction. Prior to forecasted storm events, this material is used to reinforce the breakwater crest and vulnerable sections, thereby minimizing storm impacts. Regular inspection and stone repositioning keep the structures stable; total annual maintenance costs remain below 1% of total income, demonstrating a sustainable life-cycle design. The following section elaborates on how these structures safeguard the coastal frontage and influence adjacent beaches within the Bapor Kibra–Mambo system.

Figure 3.26: Breakwater Sea Aquarium

Coastal zone protection and safeguarding of frontage

Building on the design principles outlined above, this section details how the breakwaters function as the primary coastal defence system protecting both the Sea Aquarium property and the adjacent section of Mambo Beach. Armour porosity and crest levels are selected to withstand trade wind waves while allowing continuous seawater exchange; as mentioned by the owner and developer of the Sea Aquarium in subsection A.2.6, sizing is deliberately conservative to limit overtopping and to resist occasional south-westerly swell. The structures are attached into the reef, with a stable toe and narrow footprint, and are kept in condition through routine stone re-positioning rather than periodic beach nourishments. By reducing nearshore wave energy and interrupting alongshore transport at the eastern boundary of the Mambo cell, the breakwaters shield the Aquarium's basins and land and cast a partial wave-shadow over the nearest segment of Mambo Beach, contributing to its stability. A shallow internal drainage corridor behind the lagoons conveys warm, low-salinity runoff seaward during heavy rainfall, preventing pond formation and avoiding salinity and temperature fluctuations in the animal habitat basins while reducing erosive overland flow onto the property.

Hydrodynamic and morphological effects

The sheltered lagoons behind the breakwaters experience reduced wave heights, creating calm water conditions that protect the artificial beach from erosion. Longshore sediment transport is locally interrupted, resulting in stable but morphologically altered pockets. The rubble structures promote colonization by marine organisms, partially functioning as artificial reefs.

Findings from the Shoreline Analysis

The shoreline comparison between 2018 and 2024 shows a net land gain in the Sea Aquarium area. The total land area increased from 261,356.78 m² to 264,472.52 m², representing a net gain of approximately 3,115.7 m². The analysis identified 2,119.48 m² of erosion and a larger area of land gain concentrated around the enclosed lagoon and reclaimed sections of the shoreline, as summarized in Table 3.3.

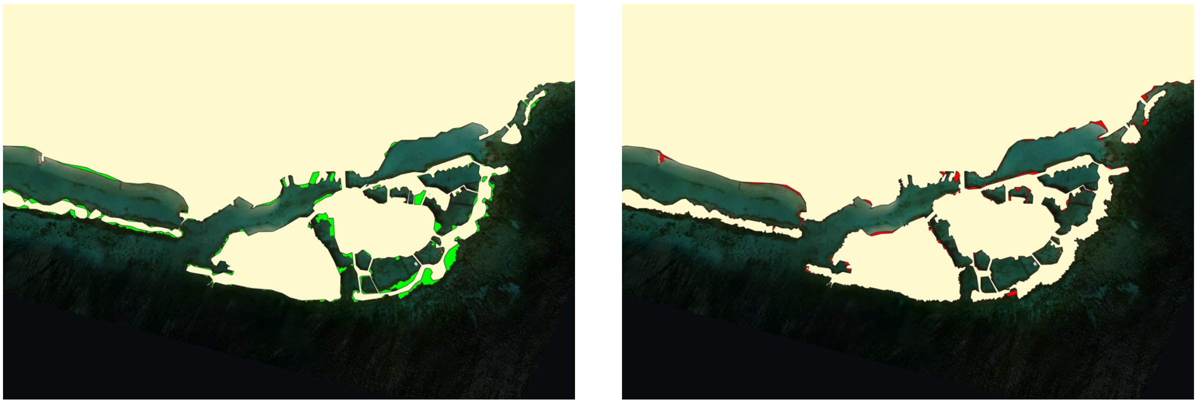

Figure 3.27: Land Gains and Losses in the Sea Aquarium Area between 2018 and 2024

Table 3.3: Land area changes Sea Aquarium

Category	**Area (m²)**
Gained	5,235.22
Lost	2,119.48
Net change	**3,115.74**

As shown in Figure 3.27, the observed differences are largely due to land reclamation and expansion works made by the Sea Aquarium. Over this six-year period, several developments and reinforcements of the breakwaters have taken place. In the right-hand figure, the areas of land loss are visible; although limited in extent, they illustrate how wave action gradually erodes the unprotected sections of the structures.

The limited erosion observed along outer segments and openings between structures is likely related to hydrodynamic adjustments caused by wave reflection and reduced sediment exchange with adjacent coastal cells. In locations where no reinforcement or land reclamation occurred, a small but noticeable amount of erosion can be observed. This comparison highlights the importance of continuous maintenance and reinforcement of the breakwaters to prevent further erosion and stabilize the coast.

Regular monitoring of sedimentation and hydrodynamic conditions would be beneficial to ensure that ongoing infilling does not reduce water circulation or adversely affect ecological conditions within the lagoon.

Governance and permitting context

When construction began, the legal framework was governed by the Landsverordening grondslagen ruimtelijke ordening (LGRO) and the *Eilandsverordening Ruimtelijke Ontwikkelingsplanning Curaçao* (EROC, 1980), as the first spatial planning instruments on the island. The EOP was not yet in force until 1995, implying that the original works were assessed by case, under the general building ordinance and maritime-environmental regulations. Recent expansions, however, must comply with the *Hinderverordening* (1994) and the LMB, requiring construction, nuisance, and maritime permits. The developers reported voluntarily adhering to NOAA coastal-engineering guidelines that are more conservative than current technical standards in Curaçao.

Discussion

The Sea Aquarium development represents a technically sound example of a coastal intervention. The conservative design of the rubble mound structures, for a robust spectrum of forcing conditions including long-period swell waves, increases the structural integrity of the construction under multiple wave conditions. Moreover, the open-water system with continuous renewal of water reduces the risk of stagnation and contributes to maintaining the stability of the adjacent coasts.

However, the location of the project along a heavily developed coastal area reinforces the cumulative nature of anthropogenic impacts. The construction of breakwaters have fragmented parts of the natural reef edge and may have altered local sediment transport processes at the coastal cell scale. These effects can contribute to the gradual transformation of the coastal system, particularly in areas with heavily concentrated tourism infrastructure. Furthermore, the development sets a precedent for continued urban intensification along the coast.

The project also highlights some of the larger institutional and governance challenges associated with current coastal development practices. The design approach was robust from an engineering perspective and achieved its intended objectives of coastal protection and recreation. At the same time it serves as an example for nature-based solutions in coastal engineering due to the naturally occurring flow diversion at the eastern boundary, which protects the reef when storm water runoff introduces pollutants into the sea.

However, its realization relied largely on the initiative and engineering discretion of the developer, rather than the regulatory procedures and environmental policies. This case demonstrates how, without a clear and enforceable management framework, environmental compliance and ecological considerations often depend on voluntary measures rather than on standardized or formal requirements.

3.2.5 Cross-Case Takeaways for Future Projects

Based on the above development cases, several lessons can be drawn to guide future coastal developments. These insights highlight best practices to balance development goals with environmental and public interest, and show how the planning, design and regulation of future projects can improve.

Governance & Process

- **Consider multiple alternatives and ecological impact mitigation measures**: Future coastal projects should research a range of design alternatives that differ in key parameters and make the decision making process open. Comparing different variants helps identify options with smaller environmental footprints. For example, in the Baoase case an environmental study presented three designs to reduce coral damage [105], but these alternatives were ultimately set aside in favour of a larger plan with only minor modifications. Additionally, the construction process must be handled carefully. For example, work should be timed for calm weather windows and with silt control. The Marie Pampoen project follows many of these practices, with authorities carrying out operations like coral relocation and turbidity limits with silt curtains.
- **Assess impacts at the coastal cell scale**: The impacts of a project extend beyond its own boundaries, so assessments should consider the entire coastal cell rather than treating the development as an isolated system. This way, interconnected processes such as longshore sediment transport and hydrodynamic feedbacks can beaccounted for. Assessing at a broader spatial scale helps prevent morphological or ecological impacts on adjacent shoreline segments.
- **Build public trust through transparency and execution**: Earning public trust is critical for the success of a project. Proponents should make complete, auditable documentation of plans enabling stakeholders to

review and understand the basis for the project. Clear documentation of the reasons for rejecting or adopting each alternative in a public dossier can build trust and show that the chosen plan is truly the most balanced option. In the Baoase expansion, the permit dossier was criticized for missing information, undermining confidence in the process.

- **Prioritizing public value**: Developments that occupy or modify public coastal space must demonstrate clear and measurable benefits for the local community. These benefits, including the protection and improvement of public access and recreational opportunities, should be legally guaranteed through zoning conditions. Where private projects use public waters or infrastructure, benefit-sharing mechanisms, such as maintenance contributions, public monitoring data, or public amenities should be required to ensure equitable returns to the local community.

Engineering & Design

- **Design for South-Western storms**: Structural design should explicitly account for rare South-Western storm events, which generate long-period waves and increase wave run-up capable of damaging the protection works. Breakwaters, revetments, and seawalls should therefore be dimensioned and oriented by taking these conditions into account. The Sea Aquarium breakwaters provide a relevant example, having been conservatively designed to maintain stability under long-period swell, as mentioned in subsection 3.2.4.
- **Shore-adjacent and permeable configurations**: Where feasible, coastal protection should be kept as close to the natural shoreline as possible and allow water to flow through or over at intervals.
- **Make provisions for adaptability**: Coastal structures should incorporate flexibility for future adjustments, with stable foundations designed for potential future elevation or extension of the crest, in response to increasing sea-level rise or changing hydrodynamic conditions.

Ecology & Water Quality

- **Water quality as a design parameter**: The hydraulic design of lagoons and swimming bays should include continuous exchange of water and storm water regulation to avoid stagnation and eutrophication. Integrating these functions in the engineering design framework can protect the ecological integrity of adjacent coral reef systems.

Monitoring & O&M

- **Monitor with Key Performance Indicators (KPIs)**: Active environmental monitoring should continue in construction and operation with KPIs that are easy to track. These may include, water transparency, the percentage of living coral, or wave overtopping rates. For each indicator, clear thresholds should be defined that will trigger management actions if exceeded. During the Marie Pampoen construction, for example, divers regularly inspected the adjacent corals for stress and checked the water clarity in the lagoon. Future projects should formalize this approach: if turbidity rises above a limit, construction activities should be halted.
- **Keep essential materials on hand for emergencies**: Coastal infrastructure will face extreme weather, so being prepared with spare materials can speed up recovery and prevent minor damage. Project operators should stockpile supplies, such as armour rocks and sand so it is readily available when a strong storm is forecasted. Sea Aquarium provides a model for preparedness as mentioned in subsection 3.2.4. They maintain a reserve of large boulders, which are used to reinforce the breakwaters and vulnerable sections before an approaching storm.
- **Systematic inspections**: Regular visual inspections with aerial pictures or satellite data, particularly after significant swells or rainfall events, should be conducted at fixed reference cross-sections to document changes in beach morphology and structural performance over time.

3.2.6 Vision for the Redevelopment of the Pietermaai area

Pietermaai is a historic district of Willemstad that has transformed over the past decades evolving into an area filled with hotels, restaurants, and cultural venues [115]. Due to its location directly next to the sea, the area faces several challenges, including coastal erosion and wave action that threaten the integrity of its monumental buildings along the rocky shoreline. To tackle these issues and make better use of the potential of the coastal zone, a comprehensive plan was developed as part of the the Vision for Development of the Southern Coast[116]. This plan proposes the construction of a seaside promenade, the creation of commercial zones along the waterfront, and the addition of new public spaces, as well as the improvement of connectivity with the inner city [117]. This analysis describes the proposed interventions and then evaluates their main advantages and disadvantages.

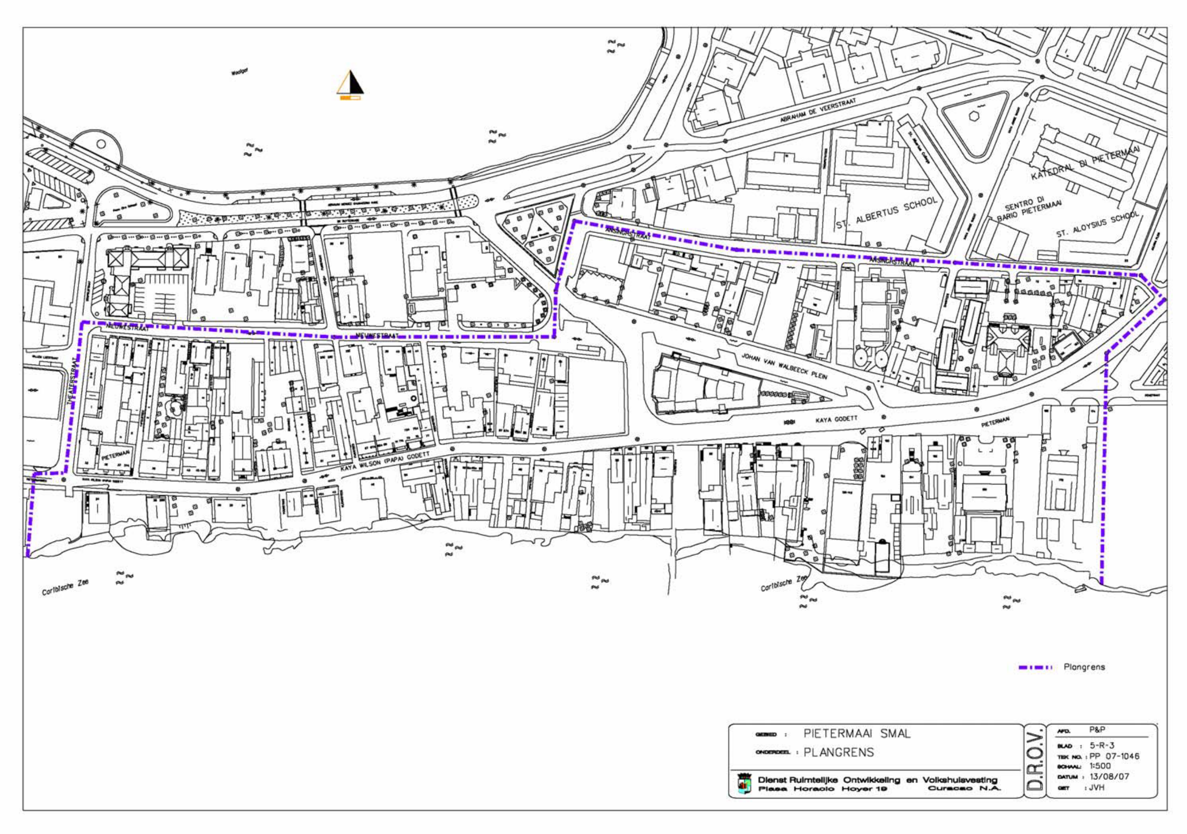

Figure 3.28: Illustration of Pietermaai [118]

Proposed plan

The central proposition of this plan is the creation of a continuous seaside boulevard featuring a broad pedestrian promenade along the Pietermaai shoreline [117]. The walkway, currently planned to be approximately 6 metres in width, would be positioned directly at the waterline. To accommodate the structure and reinforce the existing coastline, between 15 and 20 metres of land reclamation is planned in selected areas [116]. The promenade is intended to extend over a length of approximately 700 metres, from Marichi Beach to the eastern part of Pietermaai [116]. It would include a robust construction with rock breakwaters and a paved walking zone to withstand rough seas [117]. Some parts of the coast have already been widened and reinforced with dams, so the proposed intervention can tie into those sections. The overall objective of the project is to establish an accessible "walk by the water" that links different parts of the inner city [118]. The promenade will be publicly accessible for locals and tourists, with sea views and places to sit and enjoy the area (Figure 3.29) [118].

Figure 3.29: Illustration of proposed plan of Pietermaai

To stimulate social and economic activity in the area, the plan includes commercial zones along the boulevard [116]. On parts of the reclaimed strip, there would be space for terraces, restaurants and cafés adjacent to the boulevard [116]. The width and exact layout must be adapted to the bathymetric conditions, coral reef distribution and marine ecosystems to avoid harming ecologically valuable areas [118]. Terraces are possible only where coral is limited or where an EIA shows impacts are acceptable. Also, no buildings may be constructed on the new strip, permanent structures are forbidden. The land remains under government ownership while private entities may be granted management rights limited to the placement of temporary furnishings [118].

A key component of the plan is strengthening the links between the new coastal works and the inner city. Historically,physical barriers such as walls and boundaries of private property have restricted access to the sea [117]. The existing routes that reach the coast will be connected to the new boulevard, becoming access routes from the city to the sea [117].

Figure 3.30: Coast boulevard example from Barbados [119]

Advantages

- **Protection against erosion:** One of the main motivations for the plan is to protect coastal infrastructure from erosion and wave impacts. Currently, wave run up already reaches the foundations of residential buildings under severe wave conditions, [116]. The function of the proposed coastal reinforcement plan would be to dissipate wave energy[117], to protect important infrastructure in the area from erosion. The new coastal strip is intended to also function as flood protection defence during storms. Additionally, the land reclamation could allow the natural coral reef to recover further offshore, away from vulnerable buildings [44]. In calmer water behind the new strip, new coral growth could be achieved but additional nature management measurements should be applied [118].

- **Holistic vision instead of individual interventions:** At present, coastal protection in the area is largely approached on an individual basis. Each property owner constructs their own protection measures, as is currently the case near the Scuba Lodge area, as mentioned in subsection 3.2.1. However, such isolated interventions often lead to increased coastal erosion on adjacent properties due to dynamic hydraulic conditions. Therefore, adopting an integrated coastal protection strategy is more beneficial than relying on individual solutions.
- **Improved connectivity and accessibility:** The plan would make the waterfront into one continuous route, rendering previously closed sections accessible and creating a coastal promenade starting from the Marie Pampoen area to the city centre [118].
- **Touristic potential:** A new boulevard also represents a promising solution from a touristic development perspective. As of October 2025, the number of tourists in Curaçao has increased by approximately 14% compared to the same period in 2024 [120]. This growth is accompanied by a rising demand for hospitality services and recreational activities. Developing a waterfront boulevard in the city centre could further stimulate this trend and provide a significant boost to both tourism and the local hospitality sector.

Disadvantages

- **High costs:** The estimated costs, which in 2012 for a similar idea amounted to about 1.3 billion guilders for 4.5 km of coastline, are considerable [118]. Although the current plan covers only 0.7 km and includes fewer extras, it still represents an expensive investment. Without clear funding sources or public/private partnerships, realization could be cancelled.
- **Environmental effects:** Land reclamation and construction of a seaside boulevard come with severe ecological impacts. Infilling material in close proximity to coral reefs can lead to habitat loss and alter hydrodynamic conditions or smother nearby reefs with sediment [117]. At Pietermaai, coral and fish populations close to shore could be affected. Previous small-scale works, such as the Scuba Lodge breakwater in 2022, showed temporary turbidity from sediment and debris [117]. Therefore, the plan requires marine and hydrological studies before permits are issued [117]. An investigation on construction methods with minimal impacts should also be conducted.
- **Technical feasibility:** The project is technically complex. Land reclamation on a rocky coast with deep water requires robust engineering and detailed studies on stability, waves and currents, as well as stress testing under storm conditions [116]. Long-term sea level rise may require repeatedly upgrading or extending defences, requiring additional costs and disruptions [117]. Execution is also challenging, as segments built by different owners must align seamlessly, and strict quality standards and additional studies are needed to ensure the structural integrity of different connected sections.

3.3 Coastal management/protection options

The previous section outlined how coastal development along the southwestern coast of Curaçao has progressively transformed much of the natural shoreline through the construction of artificial beaches, breakwaters, and recreational infrastructure. These developments have concentrated activity and investment in a narrow coastal strip that also hosts ecologically sensitive habitats. This section identifies and evaluates coastal protection options for Curaçao in response to erosion, coastal flooding, and sea-level rise. The steep shorelines encountered on the island pose specific design and implementation challenges, while most interventions must remain both economically viable and spatially feasible in high-value coastal zones.

The core analysis compares these options in terms of their effectiveness in risk reduction, costs and expected lifespan, ecological and recreational co-impacts, feasibility including permitting and maintenance, and applicability by coastal segment, with particular attention to exposure to south-westerly storms. The outcome is a decision-oriented synthesis that matches measures to place-specific conditions and investment horizons.

3.3.1 Mangroves

A large body of research, including global meta-analyses, shows that mangroves attenuate waves, stabilize shorelines, and can deliver substantial risk-reduction benefits through restoration. These benefits are typically strongest in intact, mature forests, and outcomes depend on species, forest age, width/density, local hydrology, and restoration method [121].

Restoration of mangroves only succeeds if tidal exchange and hydrology are intact and there is sufficient fine sediment supply; in many cases, channels or culverts must be restored first [122]. Effective belts typically require 50–200 metres in width and 5–15 years to mature, meaning they cannot provide immediate protection but deliver risk-reduction benefits over time. Another disadvantage is that they are vulnerable to hydrological disruption and poor water quality [123].

Much of Curaçao's coastline is steep and exposed to wave action which limits the feasibility of mangroves as a main defense along the open coast. However, mangroves can still have a valuable role as part of hybrid strategies (e.g. paired with offshore reefs or low-crested structures) in sheltered bays and lagoon margins [124].

Although mangroves cannot function as a first line of defense against wave energy in longer stretches of exposed coastlines, they remain highly valuable for localized risk reduction in enclosed or semi-enclosed areas. As discussed in Chapter 2, besides flood and erosion protection, mangroves provide multiple ecosystem benefits, by stabilizing sediments, filtering runoff, improving water quality and biodiversity, and contributing to blue carbon storage that make them a key component of sustainable coastal management [125].

3.3.2 Coral reefs

Healthy reef crests act like submerged breakwaters: they dissipate wave energy before it reaches the shoreline, lowering run-up and erosion. A global meta-analysis found reefs reduce wave energy on average by about 97%, with the reef crest doing most of the work [126].

For the fringing coral reefs in Curaçao, this means maintaining or raising the roughness coefficient and relief at the crest, which can be realized by improving reef health and through targeted restoration. This can contribute to risk reduction, especially along some of the leeward or sheltered segments of the coast. Economic analyses also show positive returns on investment for reef restoration aimed at flood-risk reduction in the Caribbean [29].

The reefs best dissipate wave energy when the reef flats or crests are shallow at high tide and wide enough to induce breaking and energy dissipation.In locations where the nearshore drop off point has a steep slope or the crest is degraded or located too deep, the protective function of the reef combined with hybrid measures is more effective.

The leeward (south) coast of Curaçao features fringing reefs with shallow reef terraces (≈50–100 m wide) that drop steeply offshore. Where reef crests remain shallow, waves break effectively and dissipate energy before reaching the beach. In degraded areas where crests are deeper, risk reduction is limited.

By 2100, sea level around Curaçao is projected to rise by roughly 0.5–0.9 m (with high-end outcomes approaching 1 m). This additional depth reduces wave breaking at the reef crest, allowing more energy to reach beaches and seawalls, raising run-up and erosion risks [127].

Coral reef restoration projects, such as those mentioned in Chapter 2, support both coastal protection and broader reef ecosystem health, but scaling up is necessary to maintain shoreline defense under future stressors [128].

3.3.3 Breakwaters

Breakwaters are offshore or alongshore structures that reduce incoming wave energy by causing waves to break and dissipate before they reach the shoreline. By creating calmer water behind the structure, they help limit erosion, lower overtopping and flooding, and protect beaches, roads, and waterfront assets.

On Curaçao, many sandy beaches along the south coast are artificial pocket beaches, that require protection from wave action which would gradually erode and remove this imported sand. Well-designed breakwaters (with adequate crest height, armor size, toe and filters) create calmer nearshore conditions that retain sand, reduce overtopping and erosion, and help keep these recreational beaches in place. Regular monitoring and maintenance are essential to sustain their performance over time [129], [130].

Policy frameworks should therefore promote the conservation of natural ecosystems and the adoption of solutions that enhance biodiversity and resilience, consistent with nature-based solution (NBS) principles applied elsewhere in the Caribbean. Although rubble-mound breakwaters follow a relatively standard cross-section, their dimensions depend on site-specific conditions, including bathymetry, wave climate, and geotechnical stability. On Curaçao's steep nearshore slopes, conventional designs may result in wide bases and heavy toes, increasing seabed footprint and ecological impact. Design approaches should therefore aim for site-specific optimization, for example using segmented or low-crested configurations, minimizing toe berm width, or combining structural and nature-based elements to reduce disturbance while satisfying stability and overtopping requirements [131].

Breakwater location, design, and permitting in Curaçao

The location and construction of coastal protection structures in Curaçao should, as good practice, avoid live reef crests, minimize turbidity and shading, and incorporate mitigation measures such as pre-construction coral surveys, coral relocation where feasible, and post-construction restoration.

Since November 2023, the Ministry of VVRP and the Ministry of GMN have issued suggested guidelines for the design and application of permits for breakwaters and shoreline protection works in Curaçao [114]. The main procedural and design considerations are summarized below.

Permit framework Breakwater construction typically requires three to four permits:

1. A maritime permit under the LMB, obtained via the MAC;
2. A building permit from the Department of ROP;
3. An exemption under the *Rifbeheerverordening Curaçao*, issued by the Ministry of GMN;
4. If applicable, a *Hindervergunning* (nuisance permit) from GMN.

Application dossier The application is expected to include environmental and technical studies on the coral community, water exchange and ecological impacts, as well as a sewage and drainage plan. A preliminary engineering design and a bathymetric survey are generally required. For larger projects, hydrodynamic modelling may be recommended to assess wave and current changes.

Design principles The expected service life should be at least 50 years, and for large-scale or high-impact projects, 100 years. Stone material should consist of limestone from the *Mijnmaatschappij Santa Barbara*, unless otherwise approved. The design should demonstrate geotechnical stability and incorporate measures to prevent sediment leakage through the structure. Water circulation and quality should remain adequate; wastewater treatment units are required, and septic tanks are not allowed.

Spatial and visual integration The structure should blend with the existing coastline and natural setting, minimizing visual disturbance and preserving sea views and public access. Where relevant, the harbour officials must review the design for navigational safety.

Environmental monitoring If adjacent coastal areas could be affected, seabed and coral conditions should be monitored before construction and for at least two years afterward.

Breakwaters require ongoing maintenance. Under storm and swell, armour stones can shift and lose interlock, crest lines can lower, and toe scour can undermine the seaward edge. Over months to years, units may also settle into sand or soft foundation layers, reducing effective crest height and stability. Design checks should include armour stability, overtopping limits, and dedicated toe design, since toe failure is a common mode of damage [129].

Another way to look at breakwaters is to make them part of public space (e.g., waterfront promenades). Where appropriate, segmented or low-crested systems can double as accessible amenities, provided that design for transmission, overtopping, and ecology is respected.

3.3.4 Floating defence

Floating breakwaters are buoyant structures (pontoons, modular concrete units, linked High-Density Polyethylene (HDPE) pipes, or eco-modules) moored with chains/anchors to reduce wave energy by hydrodynamic reflection, radiation, and viscous losses. They provide calmer conditions on the lee side without a significant seabed footprint, making them suitable for use in areas where the preservation of benthic habitats is a priority.

The floating defense systems are best suited to semi-sheltered south-coast settings where existing reefs and headlands already provide partial wave attenuation. They can be effective at lagoon entrances, marina approaches, and semi-enclosed bays. However, they are less suitable for fully exposed shorelines or west-facing coasts affected by long-period swell events, as the required attenuation capacity and mooring loads become technically and economically challenging. Anchors should be installed on sandy bottoms or dead pavement, avoiding live coral and sea grass beds to minimize ecological disturbance.

In addition to design and siting considerations, the performance of floating defences is influenced by biological and operational factors. Biofouling rapidly colonizes mooring lines and structural modules, adding surface area for small organisms and attracting fish, which may enhance local biodiversity. At the same time, heavy biofouling increases weight and hydrodynamic drag, reducing performance and increasing maintenance requirements due to more frequent cleaning and earlier component replacement. [132].

Another consideration is the slight reduction of natural light beneath the floating structures, which may affect benthic growth directly under the modules. In most semi-sheltered sites, this effect is spatially limited, but should still be considered in the design. Using segmented layouts or allowing light gaps between modules can enable adequate illumination and water circulation.

Advantages

- Low impact on the seabed in comparison to rubble mound structures, which is an advantage in ecologically sensitive habitats (e.g coral reefs).
- Easy to extend the structure in phases and can be relocated.
- Good for short-period and moderate waves. [133]

Disadvantages

- Attenuation drops for long-period swell and severe storm seas.
- Dependence on robust mooring systems; mooring failure can create navigation and environmental hazards.
- Operations require regular inspection and periodic replacement of mooring components. [134].
- Potential visual and navigational impacts that must be considered.

4

Recommendations and Action Plan

4.1 Policy Directions for Coastal Management

This section analyses different areas relevant for coastal management and protection and provides an overview of the current state together with recommendations, key actors and bottlenecks. The subjects analysed include: coastal development management, wastewater management, nature-based solutions integration, public access to the coast, raising awareness, and numerical modelling. Table 4.1 provides a full summary of this section.

4.1.1 Coastal development Management

Integrated Coastal Management Policy should be designed specifying explicit rules and regulations for different development types in the coast. The Environmental Policy Plan 2016-2021 states that restrictions should be put in place when construction is proposed in vulnerable areas, and proposes a “reasonable setback space” depending on the development type to account for the effects of sea level rise and extreme weather [135]. Furthermore, every proposed development on the coast should require a detailed coastal protection strategy, which should be designed in line with enforced guidelines (guidelines on coastal protection design (specifically on breakwaters) were produced by VVRP and the GMN in 2023) [114]. The strategy should have a holistic approach by considering the wider area and accounting for any impacts to/from upstream and downstream of the development (beyond the development parcel boundaries), rather than treating the development in isolation. Wider impacts can include longshore sediment budgets and wave shadowing effects.

Setting clear zoning policies that limit where coastal development can occur (i.e. designate certain coastline segments for development and restrict others) is also crucial to limit unplanned sprawling along the coast and reduce damage to natural habitats and environmental pressures. It was found that with zoned regulated development, rare vegetation loss and nutrient fluxes (e.g. nitrogen, phosphorus) into coast areas could be reduced by an average of 32% and 22% respectively [43]. Unregulated development would, on the other hand, have higher marginal environmental costs per unit of added economic value [43].

As mentioned in the policy section in Chapter 2 above, currently the point of reference regarding spatial planning and zoning for development is the island-wide EOP Curaçao [46] from 1995. However, its limited enforcement and out-datedness has given rise to a debate on its effectiveness in balancing the island’s growth, environmental protection, and ecosystem services [43]. In this sense, a scenario analysis and using spatial regulation tools in the early stages of development planning would help to minimise environmental and social impacts [43].

A strong coastal development program should include:

- Explicit rules and regulations for different development types in the coast.
- Ensure holistic coastal protection strategies for proposed developments considering the wider area rather than assessing the proposed development in isolation.
- Enforced guidelines on technical standards for coastal protection;
- Clear zoning policies that limit where different types of coastal development can occur.

4.1.2 Wastewater management

Water quality degradation is one of the main stressors for the coastal zone in Curaçao. The current capacity of the system is often surpassed due to the increased turnout from the tourist industry. Laws on water quality should be further developed to manage shore and marine pollution by addressing water quality standards and pollution-based controls. Coastal developments should be required to submit a wastewater strategy and specify any actions for treatment of waste water to ensure that no untreated water is discharged into the marine and terrestrial ecosystems. Furthermore, funding/resources should be directed into monitoring water quality degradation in the coastline. Key indicators to measure should include the amount of untreated wastewater, and the amount and type of nutrients present in groundwater. This will help increasing awareness by providing a quantitative assessment, on top of a qualitative one.

The Environmental Policy Plan 2016-2021 highlights the importance of a proper centralised system to treat sewage in a high-density coastal or watershed areas for better management and reduce the risk of harmful substances. Furthermore, treatment plants should be located inland, near agricultural zones, so that the nutrient-rich treated water (containing nitrates and phosphates) can be reused for irrigation. Only low-nutrient water, with nitrate and phosphate levels safe for coral ecosystems, should be used within 200 metres of the coast or watershed areas to prevent marine pollution [135].

For coastal developments within 500 metres of the shore or watersheds The Environmental Policy Plan 2016-2021 suggests they should be connected to a treatment plant at least 1 km inland. Furthermore, the plan adds an exception to this when the density is below 20 ie/ha, with the potential in that case "to use septic tanks or small treatment plants with a septic drain field at least 100 metres from shore" [135].

Stronger regulations during the construction phase of developments is also crucial for avoiding water quality degradation and damaging coral reefs. This includes planning work during calm weather windows to avoid sediment smothering and silt plumes settling on corals.

A strong wastewater management plan to manage the existing burden caused by untreated wastewater should include:

- Upgrading the capacity of existing plants as per government plans;
- Plan for additional plants;
- Promoting changes in household and work practices to reduce the water demand and the toxicity contained in wastewater;
- Stronger regulation during the construction phase of developments and review current legislation (Nuisance Ordinance, Public Ordinance) to address water quality standards and pollution-based controls; and
- Increase awareness

4.1.3 Integration of nature based solutions

Nature based approaches, such as mangrove restoration and coral reef rehabilitation, should be promoted as sustainable initiatives to enhance the resilience of the coast. The discussed coastal hazards (flooding and erosion due to sea level rise and extreme weather, and water quality degradation) can be effectively mitigated through nature-based measures by reducing wave energy, attenuating storm surge, stabilizing shorelines and filtering water. A recent study was done in a Mediterranean coastal lagoon system in Sicily to analyse the efficacy of nature based solutions to protect the coast against flooding and erosion using a hydro-morphodynamic modelling [136]. This study found that flooding can be reduced by a minimum of 16% and 53% using dune revegetation and seagrass meadow reconstruction respectively. Erosion was found to be reduced by up to 75% from seagrass meadow reconstruction, with dune revegetation not found to be as effective.

In addition to flood/erosion control, nature based solutions provide habitat creation, carbon sequestration and recreational value. With the aim of minimising the loss of carbon sinks, coastal developments that require clearing of vegetated land should not be allowed unless a permit is issued. This permit should be supported by strong reasoning. Furthermore, maintenance and adaptability costs of nature based solutions are generally cheaper than hard engineered structures.

For the conservation and proper management of nature, The Environmental Policy Plan 2016-2021 proposes some steps for the creation of a nature plan. These include: develop a "red list" of native species to identify and protect endangered local flora and fauna, complementing species already protected under international treaties; describe and classify the island's habitats to ensure that habitat protection efforts cover all key ecological areas in a representative manner; and conduct an ecosystem services study to evaluate and preserve the benefits nature provides to the island's population and economy [135].

A common understanding and collaboration between the different key actors - government, urban planners, engineering companies, local conservation organisations, investors - is crucial for the implementation of a strong nature-based solution framework for coastal resilience.

Key elements in a strong nature based solutions framework should include [137]:

- Strong governance frameworks and alignment across agencies with maintenance regimes and long-term funding;
- A central knowledge / funding central platform for technical assistance, demonstrate the co-benefits of nature-based solutions and make financing opportunities visible and accessible;
- A standardization and protocol system to monitor ecological and hydrodynamic effectiveness, as well as social, economic, and governance outcomes.

4.1.4 Public access to the coast

Equitable access to the coast should be recognized as a core principle of coastal policy. This recognition may start by reviewing the existing legislation to clearly define key coastal terms such as beach, coastal zone and public access. There is currently no universally accepted definition for public coastal access. While in its simplest form public access can be defined as "people's physical ability to view, reach, or move along the shoreline", the term should also consider its social, cultural, economic, and ecological values and interests. These may include the right to livelihood and the ability to use marine resources for fishing communities, cultural connections, traditions, and identity for indigenous communities, or ecological integrity for environmental advocates [138].

Legal boundaries and mechanisms should be put in place to safeguard long-standing public access routes to the coast, as well as coastal communities' longstanding rights and practices (fishing, gathering, cultural use) which are not usually codified or legally recognized and may be threatened by formal access regimes and entry restrictions from private property [139]. Furthermore, public access to the beach should be equally distributed by considering socio-economic, cultural, mobility, and legal barriers. Even when legal access rights exist, practical barriers (lack of amenities, transportation, cost) may effectively prevent access to certain groups.

Recommendations to promote public access to the beaches include [139]:

- Review existing legislation to clearly define key coastal terms (beach, coastal zone public access);
- Incorporate access planning in coastal development, land-use, and conservation policies;
- Explicitly assess and mitigate barriers for vulnerable groups (e.g. physically impaired persons, low-income communities);
- Involve local communities in designing access so that their values are respected by formalizing or legally recognizing existing customary uses;
- Ensure best practices are used so that access paths/infrastructure do not degrade habitat (e.g sensitive routing, erosion control, low-impact materials). This can involve producing standardised guidelines or a centralised knowledge platform for technical assistance;
- Establish a monitoring program with indicators to evaluate access policies in response to observed impacts, usage patterns, or unexpected changes;
- Consider future scenarios when defining access zones, buffer spaces, and retreat plans, rather than only relying on current shoreline conditions.

4.1.5 Raising awareness through communication, education and research

Increase awareness on the coastal hazards (sea level rise, water quality degradation, unregulated development), through education programs, public campaigns and collaborations with local organizations. These programs should aim to transmit the principles on sustainable development and the idea that "caring for the environment is not a luxury, but necessary for survival for all" [135]. Collaboration with local initiatives is key in this regard to help integrate community knowledge and promote public participation.

In a recent study on coastal cities in Indonesia finds how individuals with higher levels of education tend to have better preparedness to coastal hazards due to improved understanding and access to information Oktari [140]. Access to information can be provided through media community programs. Furthermore, previous experiences with coastal hazards also enhance preparedness, as individuals learn from past events and are more likely to take proactive measures. The study found that education, experience and access to information accounted for 89% of the variability in community preparedness to coastal hazards.

Proper qualitative and quantitative data gathering and analysis is needed in order to implement and monitor appropriate and strong policies. In a speech in 2023, the president of the Central Bank of Curaçao highlighted the knowledge gap on the climate change impacts on the economy of the island [84]. R. Doornbosch highlighted the need to direct investment into researching the effects and consequences of climate change, as well as appropriate mitigation and adaption measures [84]. This means investing in weather-resistance infrastructure and sustainable building practices, and consider projected local climate changes when designing development plans.

Making the decision process of proposed developments as transparent as possible is also key in raising awareness and building public trust, as was learned from the Baoase case study. This should involve having a public dossier with the different development alternatives studied and outlining the reasons for rejection/adoption.

Currently, the Curaçao Climate Change Platform (CCCP), the KlimaKòrsou, and the Nature Policy Plan 2024-2030 are key initiatives raising awareness about coastal hazards. The CCCP publishes reports, maps and technical synthesis on the climate impacts and runs sessions, workshops and stakeholder meetings. Furthermore, they have a group specifically for "capacity building and awareness" to help stakeholders to manage climate-related projects, promote campaigns for policymakers and the public, and engages children and youth in learning about climate resilience through education programs and learning activities. The Nature Policy Plan sets strategic objectives, targets and actions that make coastal hazard reduction a policy priority - putting the topic on official agendas and budgets. Furthermore, projects such as the MAP are key in raising awareness on the importance of preserving invaluable ecosystems and encouraging sustainable coastal management practices.

Initiatives to increase awareness on coastal hazards include:

- Education programs, public campaigns and collaborations with local organizations;
- Investing in scientific research and carrying out proper qualitative and quantitative data gathering and analysis to support policies;
- Making the decision process of proposed developments as transparent as possible;
- Working to reduce the social inequality and ensuring everyone has access to a proper public education level.

4.1.6 Numerical Modelling

The analyses and recommendations presented in this study are based primarily on existing literature and expert consultation. To quantitatively assess the present day coastal conditions, and to design the conceptual designs highlighted in this study, there would be a need for a specific numerical modelling study.

Numerical modelling provides an effective tool for the analysis of coastal processes and testing likely management alternatives under controlled, reproducible conditions. By simulating hydrodynamics, sediment transport, and morphological evolution, models can project coastline reaction to different forcing conditions like sea-level increase, storming, and anthropogenic interference. These models also allow for sensitivity analyses that make it possible to determine the primary drivers of change and relative effectiveness of alternative protection measures. Adoption of a modelling framework would also facilitate scenario planning, through which decision-makers could evaluate trade-offs between ecological conservation, infrastructure resilience, and expense.

To provide necessary data for the purpose, it is necessary to establish a systematic coastal monitoring system that collects recent and reliable estimates of the most important physical parameters. They include wave and current characteristics, bathymetry, shoreline position, and sediment type along representative sections of coast. Reliable and long-term datasets are needed to calibrate and validate hydrodynamic and morphodynamic models that can be employed afterwards for simulating the coastal processes of the island under varying forcing conditions and for assessing the efficiency of planned works. An analytical representation of how this monitoring program could be structured and implemented is presented in Section 4.2.

For the implementation of a strong modelling framework, the following is recommended:

- Develop a systematic monitoring program to provide recent and reliable data on waves, currents, bathymetry,sediment composition, and shoreline change (see Section 4.2);
- Use model results to inform policy, permitting, and coastal protection design, integrating them into a data-driven decision-making process; and
- Promote collaboration between government, research institutions, and international partners to build technical capacity and maintain updated coastal models.

Table 4.1: Policy Pathways for Coastal Management

Policy	Current state	Suggestion	Key Actors	Bottlenecks
Coastal Development Management	**Existing relevant policy for coastal development:** **Spatial planning and zoning:** • EOP (1995) **Coastal development permitting:** • Bouw- en woningverordening (1935) – buildings and public housing • Landsverordening maritime beheer (2007) – maritime areas management **Pollution and environmental permitting:** • Nuisance Ordinance Curaçao 1994 • Reef Management Ordinance • Public Order Ordinance 2015 (for system of licences and exceptions) • Fragmented planning approach: Projects often evaluated individually, without considering their cumulative effects on sediment transport, water quality, or ecological connectivity • No standardized framework for the design or evaluation of coastal interventions (such as artificial beaches)	• Specific rules and regulations for different types of developments in the coast • Ensure holistic coastal protection strategies for proposed developments considering the wider area rather than being individualistic • Enforced guidelines on technical standards for coastal protection • Create coastal buffer zones and clear zoning policies that limit where different types of coastal development can occur.	• Government (VVRP, GMN) • Engineering companies • Private developers	• Difficulty balancing interests of different sectors (private developers, environmental advocates, local communities) • Limited regulations and guidelines

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Table 4.1 – continued from previous page

Policy	Current state	Suggestion	Key Actors	Bottlenecks
Nature Based Solutions integration	• Currently four sites on the island listed as Ramsar wetlands of international importance. Furthermore, the Curaçao Marine Park (21 kilometres along the southern coast and up to 100 metres offshore) originally established to protect coral reefs and associated habitats. • Strategic objectives to reduce ecological pressures, sustainably manage natural resources, move towards "30 by 30" (conserving at least 30% of terrestrial and marine ecosystems by 2030) protection and restoration targets on land and at sea within the Nature Policy Plan 2024-2030. • Projects such as the Mangrove Adoption Programme in Curaçao are key in preserving invaluable ecosystems using the "power of community, environmental expertise, and innovative techniques" [141]. • Not legally enforced yet.	• Strong governance frameworks and alignment across agencies with maintenance regimes and long-term funding • A central knowledge/funding central platform for technical assistance, demonstrate the co-benefits of nature-based solutions and make financing opportunities visible and accessible • A standardization and protocol system to monitor ecological and hydrodynamic effectiveness, as well as social, economic, and governance outcomes	• Engineering companies • Local conservation organisations • Government (GMN, VVRP, Ministry of Economic Development) • Investors	• Small project scales • Limited standardization/guidelines of nature-based approaches and metrics [cite] • Lack of evidence-based communication of the benefits [cite]
Raising awareness on coastal hazards	• Institutions such as CARMABI and the Dutch Caribbean Nature Alliance (DCNA) supporting monitoring and implementation. • Awareness on coastal hazards is starting to grow, with the Curaçao Climate Change Platform, the KlimaKòrsou and the Nature Policy Plan 2024-2030 being key initiatives • Projects such as the Mangrove Adoption Program are key in raising awareness on the importance of preserving invaluable ecosystems and encouraging sustainable coastal management practices [141].	• Education programs, public campaigns and collaborations with local organizations • Invest in scientific research and carry out proper qualitative and quantitative data gathering and analysis to support policies • Conduct assessments on coastal hazards • Making the decision process of proposed developments as transparent as possible	• Government • NGOs • Local communities • Education organisations	• Social inequality resulting in unequal levels of education

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Table 4.1 – continued from previous page

Policy	Current state	Suggestion	Key Actors	Bottlenecks
Wastewater management	• Four sewage treatment plants with a combined capacity • 33% of the country's households are connected to one of them, remaining 67% using underground septic systems as an alternative with no existing regulation inspection • As per 2018, only 16% of wastewater produced was treated • Wastewater management strategy not required for proposed coastal developments	• Upgrading the capacity of existing plants as per government plans • Plan for additional plants • Promoting changes in household and work practices to reduce the water demand and the toxicity contained in wastewater • Stronger regulation during the construction phase of developments • Raising awareness	• Government	• Lack of funding and resources from government
Public Access to the coast	• Unclear definitions on key coastal terms (beach, coastal zone, public access) • Restricted public access to beach where areas above the coast are privately owned	• Review existing legislation to clearly define key coastal terms (beach, coastal zone, public access) • Incorporate access planning in coastal development, land-use, and conservation policies • Explicitly assess and mitigate barriers for vulnerable groups (the physically impaired, low-income) • Involve local communities in designing access so that their values are respected by formalizing or legally recognizing existing customary uses • Ensure best practices are used so that access paths/infrastructure do not degrade habitat (e.g., sensitive routing, erosion control, low-impact materials). This can involve producing standardized guidelines or a centralized knowledge platform for technical assistance • Establish a monitoring program with indicators to evaluate access policies in response to observed impacts, usage patterns, or unexpected changes • Consider future scenarios when defining access zones, buffer spaces, and retreat plans, rather than only relying on current shoreline conditions	• Government	• Limited/outdated regulations and guidelines

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Table 4.1 – continued from previous page

Policy	Current state	Suggestion	Key Actors	Bottlenecks
Numerical Modelling	• Coastal management studies in Curaçao rely mostly on empirical data, expert consultations, and limited site observations. • Available datasets (waves, bathymetry, sediment characteristics, shoreline position) are outdated or incomplete.	• Develop a systematic monitoring program to provide recent and reliable data on waves, currents, bathymetry, sediment composition, and shoreline change (see Section 4.2). • Use model results to inform policy, permitting, and coastal protection design, integrating them into a data-driven decision-making process. • Promote collaboration between government, research institutions, and international partners to build technical capacity and maintain updated coastal models.	• Ministry of Traffic, Transportation and Urban Planning (VVRP). • Ministry of Public Health, Environment and Nature (GMN). • Research and academic institutions • Engineering consultants.	• Lack of recent and consistent monitoring data for model calibration. • Limited technical expertise and computational infrastructure for numerical modelling. • Absence of a centralized, open-access database on coastal data.

4.2 Coastal Monitoring Program

A key obstacle to the development of an effective coastal management framework in Curaçao is the lack of data availability. Implementing a coastal monitoring program would address this problem by generating a publicly available database, with all the relevant information required for applying an integrated systems approach to coastal management. That can only be achieved through a holistic understanding of the natural processes and the unique forcing conditions of the island.

4.2.1 Purpose and Value of the Program

The value of a coastal monitoring program would be to provide developers, engineers, and government institutions with the data needed to carry out feasibility and effectiveness studies before new projects are implemented. This is particularly relevant for beach nourishment projects, as modelling their response based on accurate data would allow predictions of their behaviour and shape, as well as estimates of alongshore sediment transport rates and expected morphological changes along the coast. Such information could also serve as an early warning system, against interventions that are likely to harm the natural ecosystems, by increasing sediment migration and siltation of coral reefs.

In addition, regular monitoring would make it possible to assess storm impacts and quantify the effects of episodic events, which often account for the most significant morphological changes in the coastal zone. These assessments could help predict and prepare for the impacts of such events on coastal infrastructure, especially accounting for climate change which is expected to increase the frequency and intensity of storms.

Moreover, initiatives should be integrated that encourage local community participation in the observation and management of their coastal zone. This can be achieved either through education and awareness programs or through the creation of jobs.

4.2.2 Proposed program Structure

Monitoring data

The proposed monitoring program should focus on the systematic collection of data along the coast of Curaçao. The data to be collected include the following.

- **Oceanographic conditions:** These should include regular measurements of wave height, wave period, wave direction, and sea level obtained from stations strategically placed along different parts of the coast. These could consist of wave buoys and tidal gauges deployed on the southern coast where most development projects are concentrated, as well as at selected points on the northern coast which is most exposed to incoming wave forcing.

- **Sediment Characteristics:** Sediment size (D50) should be measured at representative cross-shore profiles, with sufficient coverage along and across the coast to capture possible spatial gradients in sediment transport and deposition. In addition, the amount of coral sand should be monitored to assess the contribution of coral material to the coastal sediment budget and to detect signs of coral reef degradation.

  Fine sediments should also be analysed for density, grain size distribution, and chemical composition to better understand seabed composition and identify the presence of contaminants or high organic matter content in nearshore areas. Sediment data is important for assessing the physical and ecological state of the coastal zone and can form a basis for the improved design of coastal interventions.

- **Shoreline position and morphological changes:** Monitoring of shoreline position and coastal morphology should be undertaken using GPS and topographic surveys conducted in the regions of interest on the coast, complemented by satellite images and aerial photographs. These observations would make it possible to understand the long-term behaviour of the coastal system and to identify patterns of morphological deformation, thus informing planning, design, and decision-making processes.

- **Bathymetry:** Regular bathymetry scans should be implemented, to track morphological changes in the near shore area. Observations of the changes in bathymetry provide important information about the dynamic behaviour of the coastal system and are also critical for detecting the impacts of extreme storm events. Having an up to date database for bathymetry around the island can also facilitate the integration of numerical modelling studies in engineering studies, that would provide the basis for more reliable design, planning, and management of coastal projects. To minimize environmental disturbance, especially in areas of high coral coverage, low impact surveying techniques should be prioritized. These include multi-beam or single-beam echo sounders mounted on small vessels or autonomous surface vehicles (ASVs) for shallow waters, and satellite-derived bathymetry (SDB) for very shallow or reef-dense areas where direct vessel access could cause damage.

Programme parameters:

Several key parameters need to be defined for the monitoring program to be effective. The spatial and temporal resolution of the data should be carefully selected to capture both short-term processes such as storm impacts and long-term patterns in the behaviour of the coastal system. Shoreline surveys are commonly conducted on a seasonal to annual basis (Boak & Turner, 2005), while bathymetric and sediment measurements are repeated every 6 to 12 months in dynamic environments (Kroon et al., 2007). Continuous data on waves, tides, and currents are typically collected at intervals of 10 to 30 minutes, ensuring sufficient detail to detect rapid changes (Holland et al., 2020).

According to the PIANC–Deltares (2021) guideline for mitigating environmental impacts on coastal plant habitats, it is recommended that monitoring near sensitive ecosystems, such as mangroves and seagrass beds, includes baseline habitat assessments and specific protocols to detect potential disturbance or degradation. Finally, adequate resources should be allocated not only for data collection but also for equipment maintenance, data processing, and communication of results. This ensures that the knowledge generated can be effectively used to guide the planning, design, and management of coastal projects in Curaçao.

Coastal Monitoring Techniques

Monitoring technique	Description	Spatial resolution	Temporal resolution	Advantages	Disadvantages
GPS measurements	Repeated measurements of (fixed) ground points.	0.5 meters	Weeks to years	Accurate (5-10 cm)	Labor intensive, small spatial extend.
Fixed photogrammetry	Repeated photos from a fixes point.	0.5 meters	Minutes to hours	Accurate (1-2 m), low labour intensity.	Needs stable reference points, small spatial extend.
Aerial photogrammetry	Photos taken from planes or drones.	0.5 meters	Months to years.	Accurate (1-5 m), big spatial extend, low labour intensity.	Expensive, weather dependent.
Terrestial LiDAR	Laser scanning from a fixed points to create 3D models	0.1 meters	Months to years	Accurate (0.5 m), low labour intensity	
Airborne LiDAR	Laser scanning to create 3D models.	0.1 meters	Months to years	Accurate (0.5 m), big spatial extend, low labour intensity.	Expensive
Satellite imagery	Use optical or radar data from satellites.	1-30 meters	Days to weeks	Cheap, global spatial extend, much historical data available, easy worldwide access.	Inaccurate (1-30 m).

Figure 4.1: Monitoring techniques for coastal erosion from [142]

To support the design of the proposed monitoring program, it is useful to compare the capabilities of different data acquisition techniques commonly used in coastal applications. These methods vary in terms of spatial and temporal resolution, cost, and feasibility and their selection should reflect the objectives and available resources of the monitoring network. Figure 4.1, adapted from [142], provides a summary of widely used approaches for shoreline and morphological monitoring, including their advantages and limitations.

Station Locations

The proposed monitoring stations are selected to represent different locations around the island in order to capture spatial variability of the forcing conditions. The placement of wave buoys based on international guidelines is recommended to be in deep water conditions, typically between 50 to 100 metres depth, in order to record incident wave conditions before they are affected by breaking or refraction processes (Holmes, 2010). In Curaçao, this corresponds to roughly 1 to 3 kilometres offshore along the southern coast, depending on the local slope. Complementary nearshore instruments such as Acoustic Doppler Current Profilers (ADCPs) or pressure sensors placed in 10 to 20 metres depth are needed to monitor wave transformation, setup, and current patterns closer to the shore (Kroon et al., 2007). The proposed locations are listed below and shown in Figure 4.2.

- **Sea Aquarium:** This site is representative of the dominant incoming wave climate for the south-western coast. The location is also relevant because of its proximity to several recreational beaches and tourist developments, making it useful for assessing how natural wave conditions interact with human activity along this stretch of coast.
- **Piscadera Bay:** Located near the Carmabi Research Institute, a measuring station here could be maintained and utilized by the researchers for long-term data collection and modelling of hydrodynamic processes.
- **North Coast**: A reference station on the exposed northern side of the island would capture the open-ocean wave climate and high-energy forcing from the prevailing trade winds. This data would be valuable for calibrating island-wide wave and sediment transport models. Given the rough coastal morphology and strong hydrodynamic conditions along this coast, the exact location and technical feasibility of installing a buoy should be determined by the responsible coastal authority in consultation with field specialists.

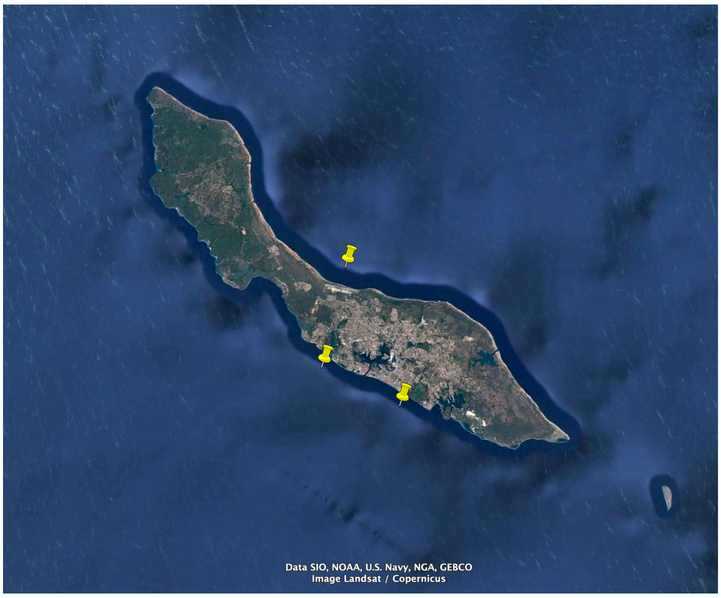

Figure 4.2: Proposed locations for monitoring stations along the coast of Curaçao. The sites represent different exposure conditions.

Inclusion of Local Communities

An additional component of the proposed coastal monitoring program is the systematic participation of local communities and existing conservation initiatives in data collection and observation activities. The inclusion of local communities can serve several functions beyond the data collection scope of the monitoring program, such as awareness and education, creating employment opportunities, and strengthening the cultural connection of the local population to their land and coastal ecosystems. The participation of local initiatives would also help bridge the gap between coastal management institutions and the public. Many residents maintain a direct dependence on the coastal zone through small-scale fishing, tourism services, and informal economic activities. Engaging them in the monitoring process not only builds local capacity but also creates a sense of shared responsibility for protecting the coast.

Moreover the field experience and generational knowledge of the island's natural habitats that local residents possess, can complement scientific observations and help with the continuity of individual research projects.

A recent study was done to assess the balance between local authority and national (or higher-level) frameworks in governing coastal protection. The findings indicated that while local authorities can be more responsive to local conditions and closer to stakeholders, they often lack resources, technical capacity, or legal authority to enforce protective measures or integrate across jurisdictions. National laws can ensure consistency, set minimum standards, provide funding mechanisms, regulate cross-border or large-scale interactions, and resolve conflicts between local units. However, centralization can become inflexible, disconnected from local realities, or slow to respond to site-specific needs or emerging changes (e.g. climate impacts). In this sense, the study highlights the importance of a well-coordinated hybrid approach to coastal management [143].

Regarding local versus overseas volunteers, Reef Care Curaçao outlines the advantages and disadvantages of each in protecting and restoring the coral reefs in the island. (shown in Figure 4.3 below) [144].

Description	Local	Overseas
In favor of local volunteers		
Logistic costs (transportation, housing, equipment)	low	high
Preparation time of involved scientist(s)	limited	high
Time-span fieldwork	long	short (2 - 4 wks)
Response to unpredicted opportunities	fast	slow
Knowledge of local situation	good	poor
Contribution to local awareness	excellent	limited
In favor of overseas volunteers		
Training	continuously	once
Availability of volunteers	mostly weekends/evenings	continuously
Possibilities for socializing	limited	good

Figure 4.3: Advantages and disadvantages of local versus overseas voluneteers in coral reef assessment in Curaçao

4.3 Examples from other Caribbean Islands

4.3.1 The CaribCoast Programme

The CaribCoast project is a monitoring programme for coastal risk carried out by a partnership of both governmental and private institutions. It mainly concerns the French territories of the Caribbean (Guadeloupe, Martinique, and Saint-Martin) where most of the pilot observatories and measurement campaigns are implemented as well as other countries in the region, namely Puerto Rico, Jamaica, and Trinidad and Tobago. The purpose is to provide a shared digital platform for coastal risk management in those areas and is structured of the following components.

Inventory of monitoring actions and knowledge networks

The first component of the program is focused on compiling existing hydrodynamic, meteorological, and morphological data across the participating countries and identifying gaps where new measurements were required. This is also implemented by fieldwork campaigns using instruments such as current speed measuring devices, pressure sensors, and wave buoys, which generate a database of important information on waves, currents, and water levels.

Network of pilot observatories

To better understand erosion patterns and track the developments in shoreline position and coastal ecosystems such as coral reefs and mangroves, CaribCoast established a series of pilot observatories at selected sites. These observatories perform frequent data collection through the local networks and are also used to evaluate the protective role of natural ecosystems for the coastal zone. The information gathered then feeds into the production of a regional guide of good practices that can support coastal management strategies adapted to the specific dynamics of the participating Caribbean islands.

Decision support tools

A final component of the programme has been the development of decision support tools to ensure that the monitoring results are translated into practice. A digital platform has been set up to make datasets and model outputs accessible, while storm impact networks and regional workshops and academic institutions provide mechanisms to validate numerical models, raise awareness, and promote knowledge exchange between territories.

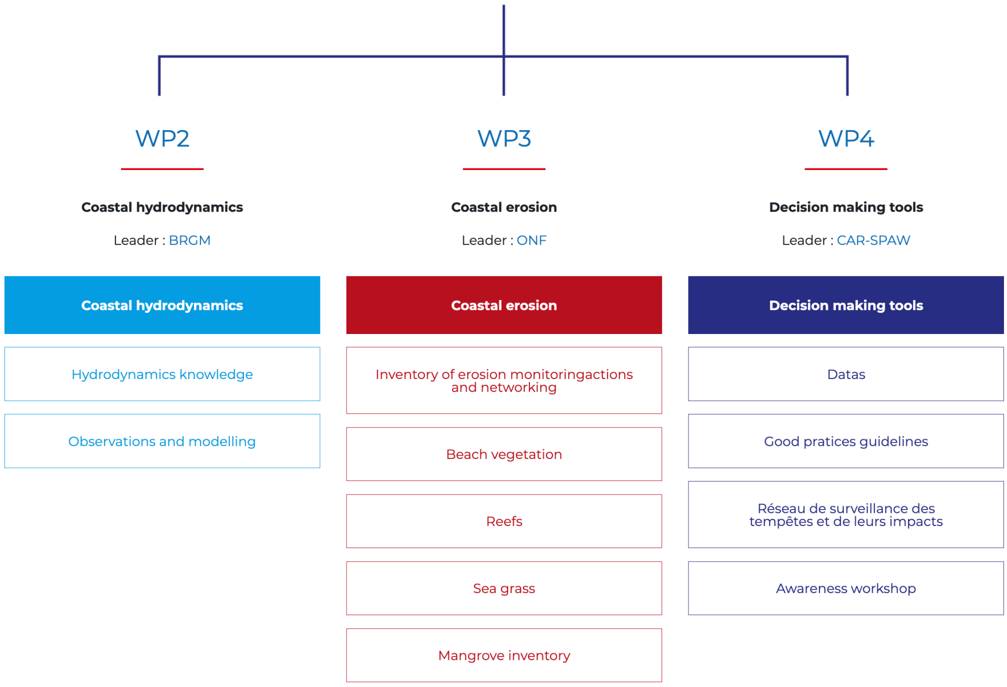

Figure 4.4: Structure of the CaribCoast Monitoring Program [145]

For Curaçao, this structure demonstrates how an integrated monitoring program could combine local pilot sites for shoreline and ecosystem monitoring, in order to create a centralized data platform that could be valuable for coastal management. This approach would provide a model for bridging the current knowledge and data availability gaps and build the required technical capacity.

4.3.2 Coastal zone management in Aruba

A recent coastal zone management study for Aruba [cite], carried out by Deltares in association with Witteveen&Bos, provides a relevant example of coastal planning structure for small island states. The project applies numerical modelling tools (Delft3D and UNIBEST-CL+) to quantify coastal hazards, simulate erosion and water quality processes, and test possible interventions. This modelling framework provides the basis for an integrated coastal zone management plan, which had not previously existed for Aruba.

For Curaçao, the value of this case lies in the methodology. A comparable study could help the island develop a science-based framework for managing tourism pressures, shoreline change, and ecosystem protection. By combining data collection, systems understanding, and modelling for different forcing condition scenarios, Curaçao could move towards a robust long-term coastal strategy supported by design criteria and sustainability principles.

4.3.3 Setback

Coastal setbacks are used throughout the Caribbean to reduce erosion and storm risk while maintaining the natural function of beaches. In most islands, a distance of roughly 30 metres from the high-water mark (HWM) is applied as a practical benchmark. This buffer allows space for seasonal shoreline movement, limits wave run-up impacts during storms, and protects public beach access. Where shorelines are more exposed to open-sea conditions or hurricane waves, authorities often increase the setback or apply site-specific values based on coastal morphology and hazard mapping.

All islands in the region lie within the Atlantic hurricane belt, yet their risk levels differ. The northern and western islands such as the Bahamas, Jamaica, and the Cayman Islands are frequently affected by tropical storms and hurricanes, leading to wider or more regulated setback requirements. The southern islands Aruba, Bonaire, and Curaçao experience fewer direct hits but remain sensitive to long-period swell, localized storm surge, and gradual sea-level rise. Even in these calmer areas, maintaining a sufficient setback remains critical for long-term coastal resilience.

For planning and permitting, a setback of approximately 30 m can serve as an initial guideline. This should be refined through site-specific studies that consider local wave climate, erosion history, and projected sea-level rise, as well as insurance and zoning requirements. Table 4.2 below summarizes typical setback values and relative hurricane exposure across representative Caribbean islands.

For coastal developments in Curaçao, insurance companies apply a guideline requiring a minimum setback of seven meters from the shoreline. Although this rule is not mandatory by law, it is used as a risk-based criterion for insurance purposes. Buildings located within this 7-meter zone are subject to higher deductibles due to the increased exposure to coastal hazards.

Table 4.2: Typical coastal setbacks and hurricane exposure

Country / Island	Typical setback	Hurricane exposure
Barbados	1oo ft (∼30 m)	High
Jamaica (general)	15 m (often ∼30 m)	High
Jamaica — Negril & Green Island	45.75 m	High
Cayman Islands (general)	50 ft (∼15.2 m)	High
Cayman — Seven Mile Beach	∼130 ft (∼39.6 m)	High
Bahamas	60–100 ft (∼18–30 m)	Very high
Aruba	No fixed island-wide setback	Moderate–low
Bonaire	No fixed island-wide setback	Moderate–low
Curaçao	No fixed island-wide setback	Moderate–low

5

Conclusions and Recommendations for Future Research

5.1 Conclusions

This study investigated how natural processes, human activities, and governance structures together shape coastal vulnerability in Curaçao. By combining spatial and hazard analyses, three development case studies, and stakeholder interviews, it assessed both the physical and institutional dimensions of coastal change and management on the island. These methods were all guided by the effort to investigate the main research question of the present study:

> *How do the combined effects of natural hazards and coastal development shape coastal vulnerability in Curaçao and how should they correspond to sustainable management approaches?*

The findings can be summarized by answering the sub-questions defined to address the main research question, as follows:

RQ1: What are the main natural and anthropogenic drivers of coastal change in Curaçao?

The analysis shows that coastal change results from a combination of natural processes and human interventions. Natural stressors such as sea-level rise, storm surges, extreme and increasingly variable rainfall events and erosion due to wave action, continue to alter and shape the shoreline, but their effects are increasingly amplified by human pressures. More specifically, unregulated construction, artificial beach creation and wastewater discharge, lead to the removal and degradation of natural buffers such as coral reefs, wetlands and mangrove forests. The loss of these ecosystems has reduced the resilience of the coastline, leaving many developed areas more exposed to erosion, flooding, and habitat decline. Over time, the interaction of these pressures has reshaped much of the leeward coast and intensified the vulnerability of its most developed sections.

RQ2: Which areas are most exposed to coastal hazards under current and future conditions?

The spatial and hazard analyses, supported by satellite data and relevant literature, indicate that the most exposed areas are concentrated in the south-western coast of the island. In particular, the low-lying area of Punda and the Pietermaai district, where development extends close to the shoreline, show the highest exposure. These areas host most of the island's tourism infrastructure and economic activity. In addition, they are characterised by narrow or artificial beaches, limited elevation, and reduced natural protection from coral reefs and seagrass beds, which limit their ability to dissipate wave energy and increase susceptibility to both erosion and episodic storm impacts. In contrast, the more elevated or rocky sections along the eastern and northern coasts remain relatively stable and experience limited direct exposure due to their geomorphology and lower development pressure. Under future conditions of sea-level rise and potentially more intense tropical storms, exposure levels are projected to further increase. Even under moderate scenarios, sea-level rise will likely amplify wave impacts and undermine beach stability, and therefore heighten the frequency of flooding along the southwestern coast. Artificial sandy beaches will likely require repeated nourishments and structural reinforcement to remain functional. At the same time,the degradation of coral reefs are expected to offer less natural protection, further increasing vulnerability. The overlap between high economic value and physical exposure shows a growing imbalance between development priorities and the natural limits of the coastal system.

RQ3: How have recent coastal developments affected shoreline stability and exposure to hazards?

The analysis of recent coastal developments shows that project design and construction practices have had a direct influence on shoreline stability and exposure to coastal hazards. The three case studies, illustrate how three different types of developments can impact the coastal zone.In all cases, the physical response of the coast was closely linked to how design decisions were made, how environmental impacts were addressed, and how each project affected the status of public access. In general, the coastal response was closely linked to how well each project considered environmental conditions, ecological impacts, and its role within the wider coastal system.

Many developments have achieved their goals of improving safety, recreation or visual quality, but often with side effects. The construction of artificial beaches and protective structures has changed nearshore sediment and wave patterns, creating sheltered areas in some places while causing erosion or habitat loss in others. Environmental effects such as coral disturbance and reduced water quality were observed where construction activities were not properly managed or monitored. In addition, the study found that limited transparency during the design and permitting process has sometimes reduced public trust and created uncertainty about long-term responsibilities.

At the same time, projects that were more environmentally aware and accessible to the public showed more positive results. Designs that maintained natural water circulation, mitigated impacts on coral reefs, and provided open access to the shore helped balance development with ecological and social benefits. These examples show that when projects are planned with both the environment and the community in mind, they tend to be more resilient and better integrated into the coastal landscape.

Taken together, these cases show that the outcome of coastal development in Curaçao largely depends on how well each project combines technical design with ecological and spatial considerations. When interventions take into account natural dynamics and cumulative effects, they tend to result in more stable, resilient, and beneficial interventions for both the environment and the public.

RQ4: What are the main challenges in coastal management in Curaçao, and what are potential opportunities to overcome them?

The review of Curaçao's governance framework and stakeholder interviews indicate that coastal management is shaped by an institutional structure involving several authorities, including VVRP, GMN, DOW, and the CTB. While responsibilities are shared across sectors, coordination between these institutions can be improved to enhance consistency in planning, regulation, and environmental protection. Existing procedures provide a foundation for managing development, yet clearer coastal guidelines. The spacial planning still relies on the EOP of 1995 so zoning and cumulative-impact assessment are uneven. Monitoring and numerical modelling are not yet institutionalised, leaving decisions data-light.

The opportunities to overcome these challenges lie in the development of an integrated coastal management plan that provides clear and practical guidance for future projects. This would entail a policy that incorporates a risk-based zoning and standardized coastal setbacks, adjusted to specific site conditions. The standard technical guidelines of structures in the water should be formally implemented and enforced.In addition, permit templates should require applicants to include wastewater and drainage strategies, specified environmental impact mitigation measures and detailed numerical modelling studies. This should be combined with a modest island wide monitoring program that is focused on waves, bathymetry, shoreline and water quality. Lastly a clarified public-access plan, developed in collaboration with local communities. These steps align economic value, access, and ecosystem integrity with long-term risk reduction.

With the answers for these four sub questions the main research question can be answered and lead to the following conclusion:

Coastal vulnerability in Curacao comes from the combined effects of natural coastal hazards and human interaction, particular where development alters and influences the natural systems. Processes such as sea-level rise, erosion and storm impacts are natural drivers of change, but they can be enhanced when coastal development causes fragmentation of the coral reefs, restricts sediment transport, and reduces the resilience of coastal ecosystems. The case studies show that certain types of development, such as large-scale reclamations or enclosed lagoons, have severely altered the natural shoreline with severe effects for natural habitats. At the same time, projects that were designed to work with natural dynamics and protect ecological buffers demonstrate that development can also enhance safety and public benefit when done thoughtfully.

Overall, the findings point to the need for a change in how coastal development is managed and in the provisions taken to protect the coastal zone. Curaçao has capable professionals and existing institutional knowledge, but a more integrated and transparent coordination between institutions, especially in spatial planning, permitting, and long-term monitoring, will be essential to meet future coastal challenges. To achieve sustainability and climate resilience, Curaçao must adopt integrated coastal planning that aligns development with natural processes, protects ecological buffers, ensures fair public access, and enforces robust environmental standards through transparent governance. This approach not only mitigates potential risks but also supports long-term resilience for both the communities and the ecosystems.

Limitations

This study provides an overview of how natural and human processes shape the coast of Curaçao; however, a few important limitations were also imposed. A key constraint is that the analysis was based mainly on available spatial data, satellite imagery, and existing reports, which limited how precisely shoreline changes and environmental impacts could be quantified. Field measurements and simulations of waves, sediment transport or ecological conditions were also not included, so some physical processes could only be interpreted indirectly.In addition, access to detailed design documents and environmental assessments for certain developments was limited, reducing the ability to assess their performance. Even with these constraints, the combination of spatial analysis, case studies and interviews provided new insights for understanding the main patterns of coastal change and management challenges in Curaçao, and provides a useful foundation for future research and policy development.

5.2 Recommendations for Future Research

5.2.1 Numerical Modelling

This study identified several issues related to different environmental stressors, and the impacts of human interventions along the coastal zone. However, many of the processes described here were assessed mostly based on a qualitative analysis. Further research could utilize numerical modelling tools that can help validate these findings and provide additional quantitative insight into the mechanisms driving coastal processes in Curaçao. These simulations would allow for a better understanding of how the shoreline responds to sea level rise, storm events, and assess the effectiveness and interaction of coastal interventions.

Developing a calibrated and validated numerical model for the southwestern coast would allow for a more detailed evaluation of how specific development projects and management measures influence coastal dynamics. A baseline simulation could be used to test the performance of different interventions and their effectiveness under varying scenarios for storm conditions and sea-level rise. The modelling outcomes could inform practical decisions related to coastal zoning and permitting, such as the identification of areas most prone to risks, and support the design of adaptive protection strategies.

To support the analysis of future modelling predictions, research should also focus on improving the underlying data that describe local coastal conditions. This includes the systematic collection of bathymetry, nearshore wave and current measurements, and sediment characteristics, complemented by periodic monitoring of shoreline position and seabed morphology. Building a robust data and modelling framework would strengthen the technical capacity to evaluate coastal risks and support the design of policies and projects based on quantitative evidence.

5.2.2 Sustainable Options for Upgrading the Wastewater System

A priority for the focus of further research should be the development of sustainable strategies to upgrade the country's wastewater system, which currently presents one of the most significant stressors for the coastal and marine environment. Currently, only a limited portion of domestic and commercial wastewater is treated before discharge, while many coastal properties rely on septic tanks or informal systems. This leads to nutrient enrichment, eutrophication, and coral reef degradation in nearshore waters.

Sustainable wastewater solutions could be explored together with conventional infrastructure improvements. Potential approaches include decentralized or modular treatment systems, the role of wetlands, and the reuse of treated wastewater for irrigation or groundwater recharge. These options could reduce nutrient loads in the sea while providing additional environmental and social benefits.

Addressing this issue requires a multidisciplinary approach, where environmental engineering and hydrology disciplines can contribute to the design and optimization research for treatment technologies suited to local conditions while a management and governance perspective can be applied identify institutional arrangements that support the implementation of those practices. In parallel, marine ecology and environmental sciences can assess the ecological carrying capacity of coastal habitats and monitor the recovery of the ecosystems in response to improved water quality.

5.2.3 Socioeconomic and Governance Studies

This report shows that governance and social dynamics are important for coastal resilience. Unequal access to the coast, limited transparency in permitting, and weak enforcement of zoning laws often create tension between private development and public interest. Coastal hazard management should extend beyond the engineering and ecological considerations, to include questions of who benefits, who participates in decision making, and whose interests are represented. Future projects or MDP groups could further investigate these dimensions.

Different disciplines could be involved, including public administration, environmental policy, urban planning, and social sciences, to better understand how institutional arrangements and community perspectives can be integrated in the decision making process. By linking these insights to the technical and environmental findings, future studies could focus on the development of management strategies that are both socially equitable and environmentally sustainable.

Looking at governance, land use, and equity questions can reveal critical points that can improve the long-term success of coastal management. Understanding how people experience and shape coastal space helps connect technical designs with real world impacts and ensures that management approaches are more inclusive and effective.

5.2.4 KPIs (Key performance Indicators)

KPIs are specific and measurable metrics that show how well a project or organization is working to their goals. They turn objectives into trackable numbers thus this allows one to monitor performance, compare results over time, and decide when to adjust course. A number of KPIs were recommended during this project to measure the success of coastal interventions. For instance, the report emphasized tracking water quality and marine ecosystem health in construction and operation phases. Specific KPIs included water transparency and the percentage of living coral cover near project sites. These indicators provide direct measures of ecological impact. Future MDP groups can set a small list of KPIs with numbers. This makes goals clear, keeps everyone aligned, and will track real progress instead of relying on opinions. Numbers also make projects easier to compare across sites and show when to adjust course. They help with stakeholder trust, and they often make permits and funding easier because it provides proof of value.

ChatGPT statement

We acknowledge the use of artificial intelligence tools, such as ChatGPT and Grammarly, which assisted in improving word choice, sentence structure, English language quality, and the overall organization of this report. After using these tools, the authors carefully reviewed and edited all content as needed and take full responsibility for the final version and the ideas presented in this publication.

List of Figures

A

Appendix

A.1 Letter VVRP

MINISTERIE VAN
VERKEER, VERVOER EN RUIMTELIJKE PLANNING

Aan: Irene Idalgo Castañon

Datum	*Contactpersoon*	*E-mail*	
October 7th. 2025	Giselle Hollander	Giselle.Hollander@gobiernu.cw	
Uw brief d.d.	*Uw kenmerk*	*Ons nummer*	*Zaaknummer:*
Onderwerp:		*Pagina*	*Aantal Bijlagen*
Coastal developments and the marine environment		1 van 3	1

Dear Irene,

In your mail you requested the following information:
General application process to receive a permit for coastal developments, including requirements needed to receive a permit:

a. Standards for: marine archeology, safety for navigation, effect on marine biology, sealevel rise assessment;
b. Documents that need to be submitted (e.g. zoning), building plans of development, methodology, equipment, EIA feasibility study, waste water management strategy, as well as the criteria for these documents to be approved, assessment process of these documents;
c. Legislation/handbooks: discussed to collect these requirements/relevant for coastal developments;
d. Date that the following development received permits: Baoase, Marie Pompoen, Sea Aquarium TUI Blue.

Introduction

The two main legislation the Ministry of Traffic, Transportation and Urban Planning is responsible for, that contain requirements for construction in general and construction in the sea, are:

- Bouw- en woningverordening 1935 en;
- Landsverordening maritime beheer;

Bouw en woningverordening 1935

This legislation contains general conditions for construction of buildings that fall within the applicability of this legislation (gebouw).

Landsverordening maritiem beheer

This law was established for the implementation of the following conventions:

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- VN-zeerechtverdrag (maritime traffic safety);
- Zeeaanvaringsverdrag (maritime safety)
- UNESCO convention (marine archeology)
- OPCR (marine pollution);
- Protocol of 1996 (marine pollution);

Sub a and b

Standards for marine archeology:

The National Archeological Anthropology Management is an independent organization that takes inventory of archeological values around the island of Curaçao. Whenever there is a request for the issuance of a permit, this is sent to NAAM. NAAM then sends advice. This advice generally contains information of the sire and contains the advice to the government to set as a condition in the permit that if there are any archeological findings that the permit holder shall immediately contact the NAAM, so they can investigate.

Safety of navigation:

Depending on the object of the request of permit, we will set conditions for the safety of navigation. Different objects require different safety conditions. If the construction is in the territorial sea, the minimum conditions will be:

1. Location. The applicant needs to give the coordinates of the construction.
2. Dimensions of the construction (length, width and height);
3. Guiding lights on the construction;
4. Bathymetric measurements;

The hydrography service will receive information of the Harbor Master of the construction in order to include this information (location and dimensions) on the hydrographic map.

Environmental impact

Apart from the safety of navigation or maritime traffic and archeology, the Minister needs to assess the environmental impact of the object for which the permit has been requested. The construction method and the construction itself are also part of this assessment. We require the applicant to render the following information:

1. Methodology being used for the construction;
2. Material for the construction;
3. The equipment that will be used;
4. A map and inventory of the flora and fauna in the area in which the construction is planned and also a bufferzone around this area with an indication of the status of protection of the flora and fauna according to international conventions;
5. The condition of the fauna in the area where the construction is planned;
6. The possible effects of the construction, methodology and construction equipment and material to be used;
7. A study on the height, speed force and direction of the waves vs the construction and the effects on the durability of the construction;

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8. Depending on the results of the EIS, we negotiate a compensation or reallocation plan with the applicant;
9. Proposals for mitigation of the possible negative effects of the construction.

Waste water management strategy

Waste water management strategy has not been a part of any requests for construction. The government of Curaçao has approved a waste water management plan, but this plan does not specifically address a strategy for waste water along the coast. The Ministry of Traffic, Transportation and Urban Planning is currently working with the Ministry of Health, Environment and Nature on this strategy and plan. This plan will also address the effects of the increase of the water level, the effects of global warming on marine life and the different diseases that affect the marine ecosystem and the effects thereof.

Sub c

The legislation that is relevant for the permit of construction in the sea has been sent to you. It is the Landsverordening maritiem beheer. This same legislation is used on the BES islands. This legislation is applicable on constructions in the sea and has been enacted since 2007.

I assume you already have a copy of the legislation on construction (Bouw- en woningverordening 1935) If this is not the case, please inform.

Sub d

The information requested under sub d cannot be given to you by me. As informed by mail, a request for information needs to be send either by a Curaçao national or an institution that is established in Curaçao.

Kind regards,
Director of Traffic and Transportation

Giselle N. Hollander, LLM

A.2 Interviews

A.2.1 Carmabi - Erick Houtepen (11/09/2025)

The Caribbean Research and Management of Biodiversity, or CARMABI is a non-profit foundation in Curaçao which works on 4 pillars: Marine and Terrestrial Research, Park Management, Nature and Environment, Education and Consultancy.

The team had contact with Erik Houtenpen, a marine biologist by training who is responsible for Consultancy services. Upon discussing this project's goals with Houtenpen, he emphasised that water quality was of big concern. The wastewater network is extremely overloaded, of not enough capacity and exceeding discharge flows out into the ocean. It was also explained that creating beaches via nourishment was bad to the reefs as the eroding sand coats and suffocates the corals. Breakwaters reduce sunlight and foundations damage the seabed. It was expressed that the island needs improved marine protection and better regulations before furthering any new tourism related coastal builds, if not fully stopping them.

It was also brought to light how flood prone Punda and Otrobanda, UNESCO protected areas of Willemstad are. This region is very low lying and therefor of highest concern when discussing sea level rise on the island, especially due to its historical importance.

Additionally, Houtenpen was able to provide GIS data that has been incredibly helpful to this project. Thanks to him, a DEM, bathymetry, EOP, and aerial orthopictures were obtained, and analysed in REF HERE.

A.2.2 AWA Consulting - Kasper Lendering (17/09/2025)

Dr. Kasper Lendering, originally from Curaçao, obtained his PhD in Coastal Flood Management at Delft University of Technology. After several years of consulting experience in the Netherlands, he returned to Curaçao, where he now works as a real estate developer and flood risk management consultant.

During the interview, he provided valuable insights into the current procedures for coastal development and the practical approaches to coastal protection on the island.

Kasper Lendering explained that Curaçao currently formal hydraulic or coastal development regulations are different from the Netherlands. There guidelines are limited and not always strictly applied. Projects are generally implemented through a “balance of interests” rather than standardized design codes, as existing draft regulations have not yet been adopted. Since the refinery closed in 2018, tourism development along the coast has expanded rapidly.

Lendering explained that the island's reefs lie too deep to provide natural protection, and there is limited shallow water suitable for mangroves or traditional breakwaters. Combined with Curaçao's short, steep wave climate, this makes common coastal defense methods, such as rubble-mound or floating breakwaters, largely unsuitable. Conventional designs would require excessive space and cause coral damage, so most structures are built through trial and error and are not expected to last long.

Most coastal protection structures on the island consist of L-shaped configurations oriented to shield against the north eastern winds that dominated the . These are inexpensive and built with locally quarried rock, but they offer little protection from storms approaching from the south or west, which are becoming more frequent and severe. The only notable exception is the robust system constructed by the Curaçao Ports Authority for the cruise terminal.

Lendering emphasized a pragmatic approach to coral management: if coastal protection is necessary in an area with coral reefs, developers should be allowed to proceed provided they compensate for ecological damage for example, by relocating affected corals. Although no formal regulatory framework exists, developers tend to adhere to international best-practice guidelines, typically designing for a 50-year return period storm and accounting for a sea-level-rise rate of approximately 1 cm per year. Despite this, there is little long-term planning capacity, as Lendering emphasized that “there are not enough resources to plan for more than 20–30 years ahead.” Insurance coverage presents an additional challenge. Damages caused by heavy rainfall, storms, and flooding are generally excluded from insurance policies, meaning developers themselves have the financial risk of not designing correct. This, in turn, creates an incentive for them to make their projects more hazard-resilient.

Finally, Lendering mentioned ongoing and upcoming technical studies, including a watershed management study (conducted with Javier Diaz) and sea-level-rise mapping. He also suggested reviewing the local impacts of past storm events. Specifically Hurricanes Lenny, Ivan, Omar, and Thomas to better understand potential coastal consequences for future development.

A.2.3 VVRP - Miriam Jonker (17/09/2025)

Miriam Jonker, representing the Ministry of VVRP, outlined that the ministry has identified three priority issues for the upcoming years. These are ranked in the following order of importance:

1. Heat management on the island, as both average and extreme temperatures are steadily increasing.
2. Flood hazards caused by heavy rainfall events.
3. Sea-level rise, which will be addressed in later phases as its impacts are expected to become more significant in the future, whereas extreme heat already poses immediate challenges.

Jonker emphasized that adaptation within these areas follows a long-term process, as institutional and regulatory changes are typically implemented in small, incremental steps. Modifying laws and regulations requires extensive coordination and discussion. As an example, she mentioned that a seemingly simple project such as planting more trees to increase shade in the historical inner city of Willemstad involves a lengthy procedure. Before implementation, issues such as sourcing the trees, identifying funding sources, and coordinating logistics must be discussed across several meetings and hearings.

Regarding construction along the coast, Jonker explained that the permitting process involves four main steps:

1. **Maritiembeheer Articles 20 and 23:** All structures built on the seabed require a permit, to be obtained from the Meteorological Department of Curaçao (MAC).
2. **Protection of Coral Reefs:** Activities must not cause damage to coral reefs, with permits issued by the Ministry of GMN.
3. **Government Land Usage:** Assessment of whether the proposed development is situated on government-owned land.
4. **Building Permit:** To be obtained from the Department of Spatial Planning (ROP).

Jonker further noted that there is currently no standardized regulation for developments constructed over the water. Many existing coastal structures have been built illegally or deviate from the original permit plans that were approved. This regulatory gap presents an ongoing challenge for the ministry in managing and enforcing sustainable coastal development practices.

A.2.4 GMN - Pedzi Grigori (23/09/2025)

Pedzi Grigori has extensive experience in climate and environmental governance within the Government of Curaçao. She recently started her role as Strategic Specialist and Program Manager for Water, Climate and Nature, after serving for over twelve years as Chief Operations Officer at the Meteorological Department of Curaçao.

Pedzi Grigori discussed the ongoing climate risk assessment and coastal management efforts in Curaçao. She confirmed that Phase 1 of the CLIMAAX Climate Risk Assessment was completed in March 2025, while Phase 2 is now being contracted and will provide a more technical overview of the island's local climate. She offered to share this report once available, along with any bathymetric data and aerial imagery that could support the case studies.

Regarding current coastal projects, Grigori highlighted that the St. Tropez project is politically complex and therefore difficult to advance. She recommended that the team focus on the areas of Marie Pampoen and the coastline between Punda and the Sea Aquarium, where practical coastal management solutions can be developed and demonstrated.

Although a formal permit process for coastal development does exist, she emphasized a significant gap in knowledge and implementation capacity. The island lacks a clear operational framework for applying coastal management options in practice, and this framework needs to be optimized. According to Grigori, the team's deliverables should therefore include guidelines for a monitoring framework, outlining how coastal changes and management measures could be systematically observed and evaluated over time.

Given the scarcity of data, proposed solutions should not depend heavily on complex modelling but remain practical under data-limited conditions. Grigori also highlighted that "there are currently no eyes on the coast," stressing the need for active coastal monitoring. Existing EOP guidelines date from the 1980s and lack climate change considerations, so it is in need of updated research and policies.

A.2.5 ENNIA - Ralph Diaz & Lennard Jake (24/09/2025)

ENNIA is one of the largest insurance companies in Curaçao, providing a wide range of services in property, health, and life insurance across the Dutch Caribbean. The company plays an important role in assessing and managing risks related to coastal and urban development on the island.

Ralph Diaz and Lennard Jake from ENNIA provided an overview of how climate and coastal risks are assessed and insured in Curaçao. They explained that most buildings on the island are constructed from reinforced concrete, which makes full structural collapse extremely rare. However, facade damage is relatively common, particularly during heavy rainfall or localized flooding.

They noted that climate-related risk factors are not yet systematically included in insurance assessments or short-term planning. For developers, insurance coverage is mandatory when projects are financed through mortgages, but coverage for developments over water is limited, typically only including damage caused by fire. Because that is the lowest level of insurance for a structure. The main risks currently covered in coastal areas are fire (mostly from human negligence), burglary, and water damage from internal piping.

Proximity to the coast influences both coverage conditions and land value. Properties located closer to the shoreline generally receive a higher percentage of coverage for storm surge or wave damage, though they are also more valuable and exposed. A minimum setback distance of seven meters from the coastline is generally applied in development standards. ENNIA may raise the deductible for projects without adequate construction plans or structural safety measures.

Diaz and Jake highlighted examples of flood-related issues, including the Hofi Mango flooding, where water entered a garage that was not part of the approved building plan and failed to meet drainage standards. Following Hurricane Tomas, government actions focused on cleaning drainage systems and increasing public awareness during the wet season to reduce such incidents.

In cases of large-scale losses, ENNIA applies co-insurance, outsourcing a portion of damages exceeding 40 million guilders to other insurers. They also noted that in Sint Maarten, ENNIA avoids insuring properties located directly along the coast due to the high hurricane exposure. This is something that could become relevant for Curaçao in the future as climate change increases the likelihood of hurricane impacts. The Crisisbeheersings & Rampenbestrijdingsorganisatie (CRBo) provides practical government support and coordination during catastrophic events.

A.2.6 Sea Aquarium - Adriaan "Dutch" Schrier & Joël Tjong-a Tjoe (24/09/2025)

Dutch is the founder of Sea Aquarium, a welder by training, with no technical engineering background. As a young boy at the age of 7 in Zeeland, he experienced the flood of 1953, to which their family home was destroyed, and the following year they emigrated to Canada.

He spoke strongly of his love for the oceans, seas, and coast; for all the land he has ever owned in his life, none was not in a coastal area. When he began developing sea Aquarium, original shoreline was an area of regular trash disposal, and old rotten wood that was deposited by the sea. This was cleaned, and the land developed.

The Bapor Kibra site was specifically chosen for its direct ocean access and natural harbor protection from Spanish Water Bay, elevated 0-5 meters above sea, allowing for what they have defined as an "Open Water System" that pumps fresh seawater continuously through all exhibits without pre-filtering. By eliminating energy-intensive filtration equipment, the system significantly reduces operational energy requirements. Gravitational pressure differentials move water through exhibits, while the continuous ocean connection maintains natural nutrient and oxygen levels. However, outside of the day-to-day required water refreshing, there is also the case for run-off water that was considered. Curacao has no infrastructure in place to retain and repurpose rainwater onshore. During wet season, all water flows out to the sea, and Sea Aquarium receives a lot of dirty, warmed from the land, run-off freshwater. This is made worse since the drainage systems overflow when it rains, thus that also gets sent out to sea. This floats above the colder saltwater, and due to the analysed wave climate, they have decided to “release the pressure point” at the edge of the complex, making a natural pathway behind the lagoons with animals, where the wave energy will lead that lower density water through that path. This allows runoff water to flow through an inner channel which then gets cleared out later into the open sea.

The aquarium’s construction methods reflect both coastal engineering and practical constraints. Rubble mound breakwaters using large rock boulders separate animal lagoons from open ocean while allowing continuous seawater flow. Upon asking, it appears whilst very well-thought out, these structures are not necessarily designed as per international design guidelines standards. As per coastal engineer Kasper Lendering, indeed, there is not sufficient space for the dimensions the design guidelines made in mainland Netherlands result in. Then, other solutions must be engineered. The founder emphasised the use of large natural stones, of 1.5m diameter, rather than concrete for the breakwaters. He also noted that maintenance is crucial for the upkeep of breakwaters, that as the stones settle in the bottom of the sea, and waves may erode and topple stones on top, few stones have to be replaced or repositioned throughout the year, but that work at the base was not necessary if when upon first building, it was built with intention. Emphasis was also placed that maintaining the breakwaters meant also not requiring upkeep of artificial beaches via nourishing. It was stated that the word “maintenance” seems to be a “dirty” word on the island; no one wants to do it, and the dominant attitude appears to be to deal with issues as they come rather than prevent them. At sea aquarium, it was stated that their annual maintenance costs of the waterbreakers and other coastal protection constructions are less than 1% of the income generated. This is considered by them a sustainable design.

This design philosophy is of working with rather than against coastal processes. In their opinion, ceasing coastal construction is not possible in the current economy, and an unrealistic expectation to have. Their stance thus far has been to protect via commercialisation and through responsible actions. They stated regulations in Curaçao are not up-to-date, and so for their new constructions they abided by NOAA guidelines, with the mentality that they go above and beyond what Curaçao’s government demands, but will result in a more future-proof design justifying the higher costs.

A.2.7 GMN - Javier Diaz (30/09/2025)

Javier Diaz is a Nature Specialist Advisor at GMN. With a long-standing background in environmental management, research coordination, and permitting, he plays an important role in connecting scientific knowledge with practical coastal and nature conservation efforts on the island.

Javier Diaz provided insights into the current procedures and challenges of coastal development in Curaçao. He suggested to look into KLM aerial images and contacts for obtaining more data and existing coastal development guidelines to support the project. He noted that Giselle Hollander oversees all constructions built over water and should be a valuable person to interview.

Several project cases were discussed to illustrate current practices and challenges: the Scuba Lounge, which required reinforcement of its coastal protection due to storm risks; and Baoase, which initially obtained a permit to protect an existing breakwater but later expanded the development beyond the approved scope.

He emphasized that many coastal developments reflect individual developer visions, and noted the need for a cohesive island-wide coastal plan rather than isolated projects. According to Diaz, coral protection should remain a public responsibility to ensure that coastal areas can eventually be restored for community access. He also referred to the Cartagena Convention, which sets out regional commitments for coral reef and marine habitat protection.

In terms of governance, he explained that the government currently receives permit applications individually, without an integrated framework, and suffers from a shortage of in-house engineering expertise and funding. As a result, much of the technical assessment and coastal protection work is outsourced to private consultants and developers. He advised that the propose practical implementation and monitoring solutions.

A.2.8 Mangrove Adoption Program - Terrence Ching(01/10/2025)

The interview focused on the ecological, social, and economic importance of mangroves in Curaçao. Mangroves were described as essential for filtering wastewater, improving water quality, and supporting coral reef health.

They host fish species that help with pest control and are important for biodiversity and ecosystem balance. In many instances deep water mangroves are removed due to coastal developments and mangroves in current management practices serve mostly as filter for water quality purposes. In summary of the main functions and value of mangroves are presented below:

- Ecosystem and biodiversity functions as they filter out the wastewater, they host species for fishing and pest control (fish that eat the mosquito larvae). Necessary for water quality and coral reef health.
- Protection against storm damage and coastal erosion.
- Also important for the wellbeing of local communities as they provide food sovereignty and security and provide secondary economic functions (local fishermen, market sellers) and cultural heritage (connection of local population to their native land and to nature).
- Connection between locals and natural habitats: local generational knowledge of the history and evolution of the landscape, locals are skilled in field reconnaissance and should be included in managing these spaces, their voice should be heard due to their historical connection and co-existence with them.

Moreover the discussion showcased that even though tourism is the main economic activity, there are also secondary economies of locals, such as small scale fishing, that are not taken into account. Removal of locals from the coastal zone and changes in land usage, results in dispossession of those resources.

The Tax Holiday for resorts and its implications were also discussed. The issue is that the largest share of income from big tourist investments goes to other countries doesn't effectively contribute to the country's economy, besides the creation of jobs and general increase in demand for tourism services. However, the trade-off between the removal of the direct economic function of the coast for locals and the actual benefit of tourism for them is not studied.

Developments also put a strain on locals as they remove mangroves, they alter the natural ecosystems and increase the load of the wastewater management facilities. Currently mangrove park is government owned but privately managed.Entrance fee for locals raises questions about free public access to nature spaces and gatekeeping coastal zone from them.

The discussion also touched on power dynamics, the colonial past, and how local voices are often left out of decision-making. Local communities don't have access to resources, tools and knowledge on how to make their grass roots conservation movements official and secure funding to institutionalize their participation in managing coastal habitats and the zone to contribute their local knowledge.

External contributions from European universities can be helpful, but the lack of continuation of those projects doesn't let projects evolve, making an essential impact. Involvement of local students in issues concerning their own land enhances connection with their heritage and should be encouraged.

Finally, the interviewee noted that locals trying to protect mangroves face difficulties getting official recognition and funding. COIA, established in 2023, was mentioned as one of the first local-led efforts. The interview ended by highlighting the difference between preservation and conservation. Conservation involves the sustainable and responsible use of natural resources for human benefit, while preservation focuses on protecting areas from human intervention and development, aiming to keep them in their pristine, untouched state. It was also noted that public access to the coast is legally required but not always respected.

A.2.9 VVRP – Chalrinela Conradus & Giselle Hollander (3/10/2025)

The Ministry of Spatial Planning, Infrastructure and Environment (VVRP) is the governmental body responsible for land-use planning, building permits, and environmental regulation in Curaçao. The ministry plays a central role in evaluating and approving coastal developments in coordination with other agencies such as the Ministry of Health, Environment and Nature (GMN).

VVRP stated that there is more development is upcoming on the west coast (Bandabou), including several unauthorized developments in the past year.

They suggested TUI Blue as a potential case study, as it is a big development along the coast. For new coastal projects, an Environmental Impact Assessment (EIA) is required to obtain a permit.

A new coastal development policy has been drafted (developed externally) but is not yet implemented. VVRP asked that we email Chalrinella to receive the draft. Standard permit requirements for building along the coast include: applicable zoning (EOP), detailed building plans, methodology and equipment, EIA, feasibility study, and a wastewater management strategy. The legal framework draws on international conventions.

Applications must also address marine archaeology, maritime navigation safety, marine ecology impacts, and a sea-level-rise assessment. These materials are reviewed jointly by VVRP and the Ministry of Environment. VVRP indicated there are handbooks detailing these requirements/guidelines.

A.2.10 CTB – Faisol Ayoubi (8/10/2025)

Faisol Ayoubi from the Curaçao Tourism Board (CTB) explained that the organization, while primarily government-funded, operates as an independent foundation since 36 years, which has made its processes more efficient compared to when it was a government agency. The CTB oversees tourism planning and development across the island, including projects such as Marie Pompoen, which it manages from planning to contracting and is currently awaiting funding for Phase 4.

Tourism is at the moment Curaçao's main economic driver, with key markets in the countries with the direct flight routes. While most of the tourist come from the Netherlands, they target and see a growth in the United States (New York, Miami, Atlanta), Canada (Toronto, Montreal), and Latin America (Colombia, Argentina, Panama, Venezuela, Brazil). Following the Covid pandemic, tourism has grown by 20–30%, outpacing neighbouring islands. This rapid growth, however, is creating infrastructure bottlenecks such as traffic congestion. Plans are underway to moderate growth while ensuring continued economic benefit.

A Carrying Capacity Assessment and a five-year Strategic Tourism Development Plan have recently been finalized and are expected to be published next year. These documents aim to guide a sustainable tourism model, emphasizing stricter coastal development regulations, improved sewage management, public awareness, and ensuring that local communities also benefit directly through employment and public investment. Faisol also noted that Environmental Impact Assessments (EIA) are required for certain categories of tourism development.

A.2.11 CCM Engineering - Martin Koopman (10/10/2025)

Martin provided the finalized coastline guidelines on coastal protection, specifically breakwaters, which is currently the main coastal protection currently in Curaçao. These are to be implemented by VVRP. Martin also provided a document outlining the vision for the Piscasdera – Sea Aquarium stretch of coast (dated July 2020). We discussed about the requirement of an Environmental Impact Assessment in coastal development, with Ecovision being the main company producing this type of assessment. Martin noted that there is currently no regulation on wastewater management due to lack of funding and awareness, and suggested to look at wastewater management in Bonaire to get recommendations. Furthermore, regarding coastal development it was noted how an approach of looking at individual developments is normally followed rather than a holistic one.

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