

# CLIMATE RESILIENT COASTAL SOLUTIONS IN THE CARIBBEAN CONTEXT

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## BACKGROUND

Caribbean Small Island Developing States (SIDS) face a unique set of development challenges and are exposed to some of the most extreme weather events. While the Caribbean region has a limited contribution to climate change drivers, such as greenhouse gas emissions, the region is significantly impacted by the effects of climate change, especially sea level rise, increase in tropical storm intensity, and ocean warming and acidification.

Climate-resilient coastal infrastructure design and management require an integrated approach including environmental, socio-economic, and physical considerations. Based on experience and lessons learnt from projects such as the Barbuda Redevelopment Master Plan, the Saint Lucia Point Sable Marine Protected Area Coastal Stabilisation, and the Turks and Caicos Islands Climate Resilient Coastal Protection and Management, the team developed a roadmap to maximize value of coastal design projects from an engineering consultancy perspective. The proposed roadmap relies on frequent communication with parties and stakeholders involved, and also in knowledge sharing and capacity building. In contrast to previous studies, this roadmap focuses on the applicability and the ability to integrate climate resilient solutions into the Caribbean context.

The objective of this study is to describe key SIDS case studies completed in recent years, including challenges and opportunities, and to highlight the unique characteristics and lessons learnt that led to the development of the design framework.

## METHODS

1. Data collection and analysis - Combination of publicly available resources, direct communication with governments, local institutions, funding agencies, and dedicated field monitoring campaigns.
2. Stakeholder engagement - Addressing the needs of key stakeholders in a complex and ever-changing environment, where social, gender, political, and other priorities have conflicting interests.
3. Define key project targets - Based on data, knowledge gaps, and consultation outcomes, establish priorities and level of effort of each component of the project to maximize value and benefits.
4. Develop modelling framework - Adaptable modelling framework incorporating key processes identified in the previous steps, including extreme water levels and wave driven impacts, causing coastal flooding and erosion. This is especially challenging within the Caribbean context with a multitude of (complex) coastal process and unique coastal environments.
5. Design of coastal solutions - Phased approach from conceptualization of alternatives, risk assessment, and evaluation matrix, ending on the detailed design. It is key

to involve stakeholders at all design stages and develop cost-effective, island compatible, and preferably nature-based solutions.

6. Knowledge sharing and capacity building - Joint development of data and information repositories, viewers, tools, and procedures that are easy to access, use, and update, including training of local staff for continued monitoring and understanding beyond the duration of the project.
7. Development of implementation framework - Define, in collaboration with governments, investors, and clients, a methodology for implementation of proposed solutions with clear timelines, procedures, and evaluation steps to ensure the success of the project.

## CASE STUDIES

### Barbuda Redevelopment Masterplan

Hurricane Irma made landfall in Barbuda leading to severe damage and destruction of 95% of the buildings. After the storm, there was no water or communications and residents had to evacuate to the neighbouring island of Antigua. Since 2021, CBCL has been working with the Maya Blue consortium to develop a technically feasible, economically viable, socially inclusive, environmentally sound, and climate-resilient development plan. This project is focused on listen to the needs of the local community and promote stakeholder engagement at all levels.

The most populated areas of Barbuda are located in the west and southwest areas of the island, which are naturally protected from the dominant waves. The city of Codrington is situated along a coastal lagoon separated from the sea by a long and highly dynamic barrier, which was breached during Hurricane Irma.

The focus of this study was to characterize the key coastal processes on the island and to provide risk reduction recommendations based on data analysis and numerical modelling. Three models were developed: a hydrodynamic model (Delft3D-FM, Figure 1), a wave model (SWAN), and a beach erosion and wave run-up model (XBeach). The hydrodynamic model was calibrated against tide gauge measurements during Hurricane Irma, which registered a water level of 2.4 m (above mean sea level) at the peak of the storm.

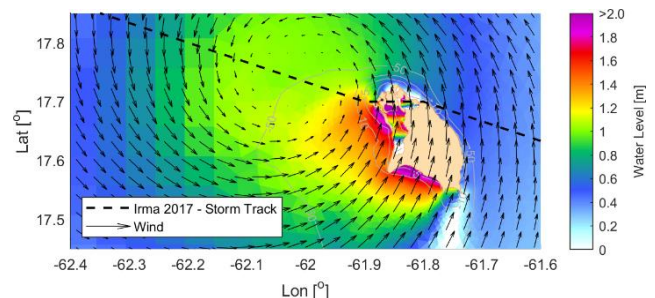


Figure 1 - Simulation of Hurricane Irma 2017 around Barbuda.

In addition to providing a general description of (historical and future) coastal conditions around the island, other specific outcomes of this study included: an assessment of currents, waves, and water renewal capacity of the Codrington lagoon (considering both conditions with or without breach); confirmation of existing setback distances based on the morphological model, coastal flood maps; and establishment of coastal design elevations.

We provided recommendations and guidance to specific developments around the island to promote the vision of the ongoing redevelopment masterplan and to ensure stakeholder engagement.

Saint Lucia:

The Pointe Sable Environmental Protection Area (PSEPA) is a coastal strip on the southeast coast of Saint Lucia consisting of a combination of natural and built assets, including sensitive ecosystems such as mangroves, sea grasses, and coral reefs. In recent years, the area has experienced localized coastal erosion and a severe accumulation of sargassum. The consultancy project objectives included identifying the causes of coastal degradation, designing coastal stabilization solutions, and improving climate resilience of natural resources and ecosystems within the PSEPA.

To achieve the objectives, we developed a baseline of the coastal conditions and identified key coastal areas and at-risk assets in PSEPA through field investigations, stakeholder engagement, data analysis and numerical modelling. Next steps of this ongoing project comprise the development of coastal stabilization solutions with a strong focus on nature-based solutions. This work is being done in cooperation with local consultants with extensive experience in the area, including the design and implementation of nature-based solutions such as dune restoration.

During the field visit, a wave buoy and a tide gauge were deployed, and a series of stakeholder consultations and discussion sessions were hosted. Two numerical models were developed for this study: a coupled hydrodynamic-wave model (Delft3D-FM) and a series of beach erosion and wave run-up models (XBeach). The models were calibrated against waves and water level measurements and the magnitude of the erosion and flooding during key simulated events were verified by locals who experienced first-hand the impact caused by such storms.

The PSEPA area is exposed year-round to waves associated with the easterly trade winds and swell waves, mostly generated in the North Atlantic (Figure 2). Although the site is located within the Caribbean hurricane belt, most weather systems with hurricane potential that affect Saint Lucia are not yet fully developed and relatively weak in comparison to storm events that develop further north in the region. Nevertheless, Saint Lucia is still exposed to these types of events, more frequently to categories 1 or 2 hurricanes. The strongest hurricane to hit Saint Lucia was Hurricane Allen in 1980, which passed south of the island as a category 4 hurricane.

Given that surge levels are highly dependent on the hurricane track, simulations were performed using synthetic storms in order to estimate the impact of different hurricane categories on nearshore conditions. The synthetic storms were built based on Hurricane Allen's track with storm characteristics scaled to typical values for each category.

The existing patch coral reefs provide some protection to the shoreline due to wave breaking and dissipation over the reefs. However, the reefs are not continuous, leaving some areas along the coast vulnerable to wave action. Nearshore wave heights are modulated by the tide, due to increased dissipation during low tide. Extreme events, such as tropical storms and hurricanes, lead to high waves near the coast especially due to the combination of high surge levels generated by the low pressure, high wind speeds, and wave setup. Numerical model results indicate that wave setup is an important contributor to local storm surge, accounting for 30% of the total surge.

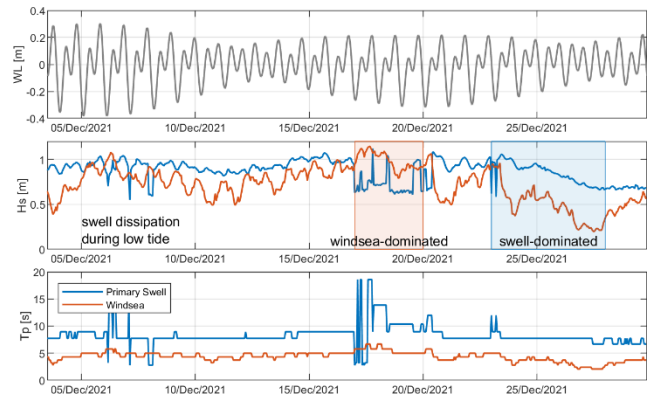


Figure 2 - Modelled Wave Conditions at PSEPA.

The comparison and correlation of satellite images and wave conditions indicate that erosion is mainly storm-driven during easterly and north-easterly swell events in the winter season and due to hurricanes/ tropical storms. Based on satellite images, some recovery of the beaches likely occurs during the calmer months in the spring and summer.

A series of recommendations for best management of the coastal area was proposed, including establishing set-back distances and design flood elevations for new developments, maintaining healthy beaches, dunes, and reefs, developing post-storm contingency beach nourishment plans, and developing climate-resilient sargassum collection plans.

Turks and Caicos Islands:

The Turks and Caicos Islands (TCI) has one of the fastest growing populations and tourism-dependent economies in the Caribbean. Critical infrastructure situated in the coastal zone supports most economic activity and social security in TCI and is severely vulnerable to climate-related hazards, including extreme precipitation and flooding, drought, sea level rise, and storm surge associated with tropical hurricanes. Within the context of climate-resilient development of TCI's coastlines, CBCL has been tasked with providing sustainable coastal protection solutions at three locations including an environmental, social and

gender impact assessment. The overall project is being done in cooperation with numerous local and international experts and includes a climate risk and vulnerability assessment, and the development of a shoreline management plan.

Several site visits were undertaken to conduct extensive stakeholder engagement sessions and to perform field work as well as knowledge transfer with local professionals from the Department of Environment and Coastal Resources (DECR) and the Public Works Department (PWD), of the Turks and Caicos Government, to allow continuation of the monitoring program after the project is completed.

Data analysis and numerical modelling were performed to derive design conditions for the three sites. A coupled hydrodynamic-wave model of the area was developed using Delft3D-FM as well as a standalone SWAN wave model. Sixteen storms were selected to represent hurricanes with different categories and various tracks. The surge levels for each of those storms were fitted into a Generalized Pareto Distribution to estimate return periods at each of the project sites (Figure 3).

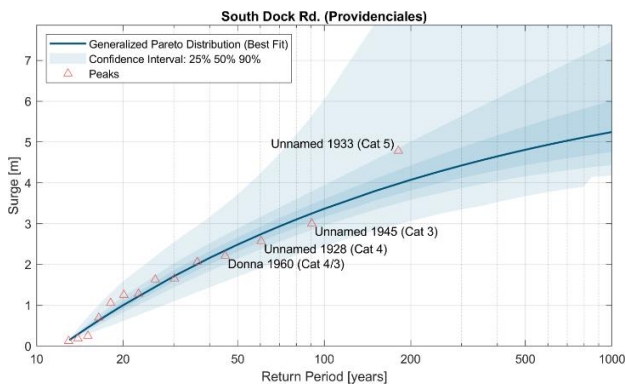


Figure 3 - Extreme Surge Levels at Providenciales.

Each of the three sites has different characteristics and design considerations. For each location we developed various design alternatives and performed a high-level feasibility assessment to select a preferred solution. Scoring was based on different criteria, including effectiveness and resilience, social and amenity value, environmental benefit or impact, constructability, and costs.

South Dock Road in Providenciales experiences significant coastal (and pluvial) flooding. The area is fairly protected from wave action but prone to extremely high surge levels during tropical storms, especially due to the adjacent shallow Caicos Bank. Model results indicate total water levels of 2.5 m above mean sea level in this area during Hurricane Irma, which is in line with anecdotal evidence by locals. The preferred design alternative consists of pre-cast concrete seawall with an improved drainage system to reduce risk and duration of coastal and rainfall-driven flooding.

The project coastal section at Grand Turk is composed of a combination of groynes, seawalls, and sandy beaches. Located in the west coast of Grand Turk, the area is naturally protected from the dominant easterly waves. The most important forcings in the area are the northerly swells and hurricane-generated waves. Those events can have

significant wave impact to the infrastructure and cause wave overtopping, flooding, and sand transport over the existing seawall. The design solutions focused on dissipating wave energy to minimize overtopping. The preferred option consists of a set of three detached breakwaters with orientation, length, and spacing developed taking into consideration wave dissipation efficiency and circulation.

Like the Grand Turk site, Salt Cay harbour is protected from easterly waves. The design component of the project focused on the inner seawall which is severely damaged. This inner seawall is typically protected against the dominant north swell by an outer seawall. To derive design conditions, a diffraction analysis was performed. The proposed design solution consists of a precast concrete seawall.

Climate resilience was the key focus of the development of the solutions. However, due to the harsh coastal conditions in the project areas, a higher risk tolerance had to be considered including a phased approach for the design solutions. Additionally, recommendations were proposed to integrate the other coastal assets and infrastructure with the proposed design solutions.

## FINDINGS

Each SIDS, and regions within, has its unique characteristics and challenges; therefore, a clear but flexible methodology is essential in the development of climate resilient coastal solutions. Key findings of the on-going work include:

1. Climate change disproportionately affects SIDS and must be considered in the design of coastal infrastructure.
2. Limited resources and capacity of local governments to guide decision-making processes during design often result in solutions that are not resilient in the long-term.
3. The lack of data availability and effective data transfer poses a significant challenge. Planning cost-effective monitoring programs and making use of local knowledge and anecdotal evidence whenever practical is important.
4. The definition of design criteria, modelling needs, and methodology framework must account for site-specific processes and characteristics.
5. Coastal solutions should consider all the relevant physical stressors (i.e. hurricanes, storm surge, bi-modal seas, long swell waves), and also be suitable to address social and economic inequality issues in the Caribbean.
6. The design of climate-resilient coastal solutions should be adaptable, including a phased implementation approach, ensuring compatibility with present and future conditions and potential lack of available resources.
7. The use of integrated coastal zone management, long-term planning, and strictly enforced development policies is critically important to eliminate inadequate coastal infrastructure, to protect the natural environment, and to maintain natural coastal processes where possible.

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