Caribbean Weather Impacts Group
Supporting risk based decision making

Coastal Zone Management

Summary for Policymakers

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1 Importance of the Sector to National Sustainable Economic Development

The coastal zone is well endowed with resources which are utilized by different sectors of the economy. It is extremely important for the livelihoods and economic development of Small Island Developing States (SIDS) and developing countries. In the context of an island that has an area of 166 square miles, the Caribbean island of Barbados can be considered almost entirely to be a coastal zone. Although Belize is attached to mainland Central America, it is still considered a part of the Caribbean and has a very important coastal zone system with the second longest barrier reef system in the world, which allows the nation to partake in international trade. The coastal zone is very important for the continued economic stability of all nations in the Caribbean Region. Most industries in Belize and Barbados and by extension the Caribbean are either directly or indirectly reliant on some component of the coastal environment to function and contribute to the overall growth of GDP. The presence of a Coastal Zone system facilitates countries to partake in activities such as:

- Foreign trade – Industries such as agriculture, aquaculture, and petroleum use the coastal waters to transport their products, thus allowing them to engage in overseas trade. It is estimated that $350 to $400 million BZD is generated directly through resource-based economic activity in the Belize coastal zone. Additionally, more than 50% of approximately $650 million BZD worth of imports entered the country through the sea ports in 2010 (CIA 2012; Clarke et al, 2013). Of the three main ports, Belize City acts as a main entry point and this port received approximately 251 container ships in 2007 (Clarke et al, 2013). Furthermore, it is estimated that more than 80% of Barbados's revenue is generated within the legally defined coastal zone management area and this is even more applicable to the greater Caribbean region.
- Tourism and Recreation – The major economic sector of all Caribbean territories including Barbados and Belize is coastal tourism. The coasts and cayes attract large numbers of visitors to their white sand beaches, aquamarine waters and diverse coral reefs. Therefore, the tourism accommodation partners have located their hotels, condominiums and villas on the coast. The recreation and entertainment elements of tourism are also sustained by the coast. The Coastal Zone contains numerous attractions and is a major ecotourism zone that draw numerous visitors from around the world. The Belize Tourism Board's 2008 Statistical Digest found that the tourism sector generated $264.4 million USD and welcomed 842,396 visitors, 597,370 of which were from cruise tourism (BTB 2008; Clarke et al, 2013). There is great potential for growth in the tourism industry for the Caribbean region thereby maintaining and improving the nations' economic growth and development.
- Fisheries/Export industry – With respect to marine areas, there are also direct gains for livelihoods and the economy. The Caribbean Region inclusive of

Belize is famous for commercial, recreational and subsistence fishing which is a multi-million dollar industry. The fisheries sector plays a significant role in food security, as well as providing jobs for both fishers and processors. In 2010 the fishing industry in Belize generated $23.2 million BZD with the exportation of the three main marine products lobster, conch, and finfish. Additionally, for Belize, approximately $450 to $500 million BZD are transported through the coastal zone area in exports (sugar, citrus, bananas, timber, and other agricultural products) (Clarke et al, 2013). Major investments in the offshore petroleum sector have already occurred for some Caribbean islands and this industry is expected to be transformative.

- Labour force - The tourism industry is the major employer of the Caribbean region workforce both directly and indirectly, driving construction of airports, urban areas, and ship ports. In Belize, the fisheries industry supports the livelihoods of over 2,500 registered fishers and their families (Clarke et al, 2013). Arkema (N.D.) reported that the tourism industry employs over 25% of workforce, which drives the construction of airports, urban areas, and ship ports.
- Aquaculture support– The Belize Coastal Zone provides appropriate habitat for the development and functionality of large aquaculture farms including shrimp farms, tilapia farms and cobia farms bringing a revenue of approximately $39.7 million BZD in 2010 (Clarke et al, 2013).
- Real Estate and Urbanization – Coastal land is highly desirable and very valuable, with up to 90% of the population of the Caribbean region settling along the coast and these settlements are continuously growing. A Belize Real Estate and Auto Rental 2006 report stated that land parcels near the coast start at about $80,000 Belize dollars per parcel in some areas Therefore, it is of utmost importance that development within the coastal zone should be monitored and effectively regulated and the infrastructure needs to be resilient to future changes in weather conditions. Many manufacturers, utilities, retailers and major urban centres are all located on the coasts. In Barbados, the rum industry is the oldest in the world, and is coastal, contributing significantly to national gross domestic product. Almost all of the power-generating stations in the countries are on the coastline. Most of the capital cities are also coastal. Additionally, it is very important to note that almost all of the airstrips and ports of entry lie within the coastal area.

The coastal zone is not a separate entity and is affected by stream discharge points and subsurface channels that allow rainfall, wastewater, and all their constituents to reach the coast, causing major impacts on its resources. On the other hand, the coast also influences upland terrestrial areas through inundation during extreme wave events.

Summary policy points

- Develop and improve policies regarding interagency cooperation for the proper exchange and collection of important climate information

- Develop policies to guide or facilitate future development plans in various sectors with the use of technical studies to provide scientific support for the plan.
- Introduce policies that emphasize the need for capacity building in order to effectively utilize available scientific tools.
- Encourage stakeholder sensitization to the availability and accessibility of scientific tools.
- Revise policies when shortcomings in existing policies are discovered with the help of new scientific tools
- Encourage the need for revision and updating of existing policies (e.g. building codes may need to be revised so as to increase resilience to future changes in climatic conditions).

2 Application of the Tool to Determine Outputs

Belize City is the economic and tourism hub of the country of Belize. Due to its flat elevation and poor drainage system, Belize City like other Caribbean cities is prone to flooding events particularly when there is heavy rainfall. The coastal zone of Barbados is also a hub for socio-economic activity on the island and is a zone of transition where the land and the sea meet which extends seaward to the edge of the continental shelf and inland to the first major change in topography above the reach of major storm waves.

For the Belize case study, by analysing past extreme weather events, a detailed list of days with heavy rainfall was compiled. From this list, some indication of flood risk was realized, although a one-to-one, linear relationship was not discovered. The CARIWIG Weather Generator (WG) was chosen for this study based on this analysis. The availability of intact weather data set for 30 years is extremely crucial to run the WG. With this intact data, the WG could then provide daily time series at a point location in the study area. In the Belize City study, plots of 100 WG runs each were produced for three different future scenario periods: 2020s (2011-2040), 2050s (2041-2070), and 2080s (2071-2099). As was shown in this study, analysing past weather events and using this as an input for newly developed tools such as the Weather Generator can help to identify critical rainfall thresholds. These thresholds can then be used to explore future changes in extreme rainfall events and so help city planners determine best ways of dealing with floods and inundations that the city may possibly face in the future. Plots for basic climate variables such as minimum temperature, maximum temperature, average temperature, mean wet day precipitation plus additional extreme variables including warm nights (percentage of days when daily minimum temperature is above the present-day 90th percentile), warm days (percentage of days when daily maximum temperature is above 90th percentile), and maximum 5-day rainfall amount were also developed. The availability of the plotted outputs for these variables for future scenarios can help policy makers

anticipate weather events that will affect the coastal areas in the future. Being able to anticipate weather events for the future can drive policies regarding infrastructure and development of these coastal areas.
For Belize City, it was found that rainfall threshold plots showed increased variability in October and November which could possibly bring about more intense rainfall for this area and resulting in flooding in the city. Plots also showed that there will be increased number of warmer days and nights in the future scenarios.

Barbados' coastal zone is highly vulnerable to small changes in climate such as sea level rise, variation in wind activity and increased sea surface temperatures. Within the island's coastal zone, ecosystems such as reefs, beaches, sea grasses and mangroves can be found. These play a significant role in Caribbean's and Barbados' socioeconomic activity. Much of the region's development also inhabits the coastal zone with the vast majority of the hotels and restaurants located on the coast. The number of critical facilities are also within that high risk zone. Several activities providing livelihoods for the Caribbean people such as fisheries and tourism based ventures also occur within the coastal zone. The case study highlighted the period December to March as during those months, the island and the region is impacted by wind and wave activity resulting from winter storms further north. Because of the heightened wind and wave activity during this period, infrastructure and livelihoods are extremely vulnerable. Therefore, the WG and Threshold Detector can be used to provide relevant climatic outputs and thresholds that can inform policies with regards to socio-economic activities and critical coastal infrastructure.

Baseline wind data for the months December to March for a period 1981 to 2010 was collected from the meteorological station at the Grantley Adams International Airport, plotted and a wind speed threshold of $8ms^{-1}$ chosen. The Regional Climate Models (RCMs), *echam5* and *aenwh* were used to generate three scenarios: 2030s (2011-2040), 2050s (2041-2070), and 2080s (2071-2099). Wind plots were then produced which showed significant increases in the frequency of threshold exceedance over each scenario. It must be noted, however, that the wind direction change was negligible and the wind continued to blow from the East-North-East.

The wind plots from the three scenarios produced show that the $8ms^{-1}$ threshold would increasingly be exceeded and it can be inferred that there would be changes to the wind speed during the other 8 months. Bearing this point and the hurricane season (June to October) in mind, the Tropical Storm Simulator was run and similar tracks, catergory (3) and forward moving speed (17kmh) were selected for each storm (Dean; Katrina; Ivan). The outputs from this model were plotted to determine the variation in wind speed as the hurricanes passed over the island and the charts used to give an idea of potential storm surge activity and wind damage to the coastal zone. The model outputs were also analysed in conjunction with the RCM projections to determine the potential impacts of the storm activity coupled with increased wind speed.

3 General Issues Emerging from the Application of the Tool

Stakeholder involvement - The involvement of different stakeholders and their participation in a short survey was very encouraging for the Belize City case study. They were always willing to provide opinions and inputs at different stages of the case study process. Their inputs allowed for exploration of issues from different perspectives and development of meaningful recommendations.

Highly technical – the use of the portal and tools were very complicated at first. With proper guidance and training, however, interpreting outputs became easier. Guidance and training is therefore of high necessity. The technical guidance provided enabled the plotting of graphs using outputs from the Weather Generator and Threshold Detector and allowed for better understanding of the outputs and adequate guidance in the right direction.

There were several issues with downloaded files from the CARIWIG tools portal, which had corrupted files that could not be utilized for analysis.

Initially the Tropical Storm Simulator was difficult to understand as the model was incomplete and only storm (Dean) was available. However, when it was complete, using the simulator proved to be much easier as it is laid out in a series of comprehensive steps. After the simulation is complete, the process becomes a bit more technical. Independent of which variable is selected, choosing markers along the storm track was a trying exercise. Later it was explained that it is quite random for a marker to be on the track because selected markers correspond to fixed data points in the centre of grid boxes, giving an area average for each grid box.

Uncertainty – the outputs can't be used as the sole source of information. There are large uncertainties between climate models and so more models and scenarios need to be included to reflect this uncertainty.

In the case of Barbados, due to fact that the data for the baseline period was both readily available and mostly complete, it was easy to obtain the future scenarios from the Regional Climate Model. However, with the two models used, there were some levels of ambiguity in the outputs obtained which could not be explained. This made analysis of the resulting plots a bit complicated.

Also, because the tools do not provide a direct means of converting the wind output to wave information, the effect of the projected increases in wind speed on wave activity had to be inferred.

Data recording – observed data needs to be sufficient to be able to apply the tool. For the WG, there is a need to have intact data for a 30 year period. Data cannot be extrapolated or utilized uniformly (eg. Rainfall varies across the country, the presence of recording stations in different areas is of great importance to be able to gather data. In reality, some stations can be more reliable than others).

In the Belize case study, high resolution hydrological mapping would have aided greatly in mapping a better flood risk overview of Belize City which would have greatly helped in exploring future impacts of increased rainfall levels and extreme weather events. Having information on sea level rise and storm surges could have helped in projecting future scenarios for these parameters. The Barbados case study could have used projections of sea level, storm surges and wave height/energy as well as wind speed and direction. If these parameters were available, the study could have focused on deeper analysis of RCM-simulated winds – extending the analysis to more models and emissions scenarios to better encompass the uncertainties.

4 Other Sectors to which the Tool(s) can be Applied

The tool is applicable to a variety of sectors, for example:

Agriculture – Agriculture is a major sector of the economy for Caribbean countries. The profitability of this sector depends on the production of successful crops which in turn depends on ideal weather conditions. Therefore, it is very important to be able to monitor and plan for the future weather conditions that might be favourable to crop productivity. Conversely, higher rainfall may cause crops to drown and higher temperatures may impact plants that may not be able to tolerate it. The tools developed by CARIWIG can be used to investigate future weather conditions and the resulting effects on crop productivity, suitability and changes in seasonality. The results can be used to advise farmers about planting seasons or to develop management plans and explore funding initiatives for climate resilient crops that can thrive in future weather conditions.

Water resources sector – the streams and rivers on Caribbean islands and in Belize are very important for the supply of potable water to citizens. An increase in temperature can result in water scarcity which can affect the health and livelihoods of communities especially those in rural communities. Meanwhile an increase in rainfall and its intensity can increase flooding occurrence and damage to infrastructure. Flooding events and landslides are some of the greatest threats to Caribean communities, especially those with mountains and hills that have been damaged by erosion. Being able to monitor rainfall and temperature levels in the future using CARIWIG tools can help determine the flow and the availability of water to communities. Water scarcity can result in developing desalination plants in coastal communities of the Caribbean. Additionally, the tools may help in monitoring rivers and investigate if there is a connection between river flow and flooding in large communities or coastal settlements which can help develop policies regarding infrastructure and emergency planning.

Tourism – is the major economic driver and foreign exchange earner of Caribbean small island communities. Thus this is a very important sector. Any impacts from weather events such as hurricanes, tropical storms, droughts, flooding, etc. can affect the amount of visitors to an area. Having outputs from the CARIWIG tools can help stakeholders anticipate future weather conditions and plan accordingly regarding infrastructure and disaster prevention and management. Warmer temperatures may impact the resources that attract visitors (coral reefs, sport fishing, etc.). Adaptation planning and proper management of natural resources can possibly be done so as to limit the amount of natural resources that are impacted by changing climate events.

Infrastructure and Urban development – Extreme weather events and flooding can negatively impact infrastructure such as roads and bridges. Being able to predict the intensity and rate of occurrence of weather events can help develop policies regarding building codes, sea wall construction and urbanization of coastal communities. The CARIWIG tools can play a role in developing such plans and policies.

Health sector – A change in climate conditions can affect the health of communities by increasing the transmission of communicable diseases such as dengue, malaria, etc. The Weather Generator could be used to help provide projections on numbers of persons presenting at specific clinics and hospitals with a particular illness, based on wind patterns. However, the wind patterns must be matched with satellite imagery that detects blooms of bacteria and viruses in a locale, then use the tool to identify dispersion patterns. The Weather Generator can also show changes in temperature and rainfall which can help determine the survivability of various viruses that are temperature and rainfall dependent.

Alternative Marine Energy – The alternative marine energy sector is growing in the Caribbean as climate change mitigation efforts increase. Future wind scenarios will be utilized in the development of technology such as Ocean Thermal Energy Conversion, ocean cooling, offshore wind, and tidal differentials.

Petroleum Sector – The location of oil and gas platforms in deep water, as well as coastal petroleum installations will also require predictions on storm event impacts as well as wind-driven waves. Being able to have these predictions can help in building the infrastructure and avoid oil spilling events which can destroy fragile coastal resources.

5 Policy Implications for the Use of the Tool in Decision Making

The outputs developed from the use of the CARIWIG Weather Generator, threshold detector, and tropical storm model have revealed various problems that coastal areas of Belize and Barbados may experience due to changing weather variables. These problems can possibly affect planning and future development of these coastal areas The outputs and implications from these case studies can possibly be extrapolated to the Greater Caribbean region.

An increase in temperature and decrease in rainfall in June, July, and August months may result in decreased water availability in Belize City with effects on infrastructure.

Flood risk may increase due to drainage channels becoming blocked with garbage and increased dust and debris would reduce the natural flushing or cleaning effect when it does rain along with the fact that increased dust can exacerbate respiratory illnesses.

City officials may have more work to clear up debris and clear drains increasing the need for manpower.

Increased presence of garbage may ultimately present health risks and rodent infestations, all the while reducing the efficiency of drainage canals.

There might be increased intensity and amount of rainfall in Belize City inthe months of October and November. This may result in more flooding events in Belize City which can endanger the living conditions of many residents due to poor housing and road infrastructure.

If the small changes projected in wind speed in the Barbados study are realized, they have the potential to cause more significant impacts in Barbados because the beach slope is less than in other small islands. Wave setup in Barbados is dependent on wind which responds to typically insignificant changes, and consequently, produces relatively high waves. Although the waves impacting the island are not locally generated, changes in wind speed may affect the energy associated with these waves when they enter local waters, potentially leading to instances of “above normal sea swells” during the December to March period.

Historically, Barbados has been relatively safe from hurricanes and tropical storms. However, the latest tropical storm has demonstrated the significant property damage that can be experienced as a result of strong winds.

The projected increases in average wind speed and the frequency of threshold exceedance for the December to March period increase possibilities for elevated wave energy affecting the island, so that the swash zone may become a more significant factor in sediment transport along beaches during winter months.

The coastal aquifers of the Barbados Water Authority would be at risk of saltwater intrusion, reducing the quality of pumped water to residents.

Water sports' operators may possibly benefit from any projected increase in wind speeds no matter how small, where activities such as sailing, surfing and wind surfing may increase in popularity.

Recommendations

- The need for proper interagency cooperation is of high importance so as to interpret and use tool outputs in decision making. The use of these tools depends on having the relevant weather information complete and available from the country of interest. Proper data collection and recording is critical for this to be done. Additionally, researchers need to be able to communicate with policy makers so that the outputs and information can be properly distributed. The tools can produce outputs that can benefit different sectors and this can be facilitated by cooperation between personnel.
- There is a need to develop policies, that would guide or facilitate future development plans in an area or sector, to include the use of technical studies to provide scientific support for the plan bearing in mind that outputs should be used as guidance only. Future development plans for such areas as Belize City need additional technical studies in order to identify mechanisms to control the City's development. These studies should be accompanied by city-wide consultations on the findings, and should lead to more effective Land-Use, Governance and Finance Plans for the City. A Land-use plan should also provide consideration of the economic, social and environmental factors that the city faces.
- There is a need for capacity building in order to effectively utilize available scientific tools. The tools are highly technical and to be able to understand the outputs, there is a need for proper training to be done. Once training is completed the tools will make more sense and can be utilized to understand outputs and plots generated from these tools.
- Encourage stakeholder sensitization to the availability and accessibility of scientific tools. The CARIWIG tools have recently been developed and improved. They provide valuable information on weather variables that is able to aid in planning for the future of different sectors in a country. There is a need to encourage stakeholders to explore new tools that are constantly being developed and improved so as to have the best available information in their decision making.
- The use of these tools can show shortcomings in existing policies, encouraging the need for revision and updating of these policies. The potential for inundation of low lying coastal infrastructure such as businesses, homes and hotels may require the Town Planning Department to revisit existing legislation, introducing changes to the Building Code in response to more events of threshold exceedance, increased extreme weather events and by extension, intensified wave activity. In preparing for the potential landfall of hurricane of any category and forward moving speed, the Town Planning Department may introduce legislation requiring the new structures to be

resilient to hurricane-force winds and flying debris while compelling existing properties to implement similar adaptation measures. Furthermore, new legislation may be introduced which might require new construction to include adaptation measures such as building on pillars to allow the inundation of seawater through the ground level. There is a need to effectively plan for and control population growth and expansion of unplanned housing units within the coastal limits. A policy to prevent development in vulnerable areas may be drafted and enacted, resulting in the relocation of some properties.

- In order to use natural shoreline protection mechanisms such as reefs and mangroves to help to dissipate wave and wind energy, there needs to be conservation, restoration and protection of reefs while mangroves which act as natural tropical storm mitigation mechanisms should also be regrown and restored to increase resilience of the coastal zone.
- The Department of Emergency Management of Barbados in conjunction with CZMU may use the projections of increased wind speed and the “what if” tropical storm scenarios to work towards the quantification of storm surge flooding risk, as well as drafting of an evacuation map.

The science-policy interface can be bridged by tools such as the Weather Generator and the Storm tool. They have the potential to move Belize, Barbados and the Caribbean towards science-based decision making in respect of economic development in hazard-prone areas such as the coastal zone. Once data is translated into usable, easily accessible information by policy makers, the setting of policy itself could be transformed by such tools. However, the data and information generated must have an acceptable level of accuracy, in order to be trusted by policy makers.

6 Gaps and Further Work to be Undertaken in the Refinement of the Tool and its Application

6.1 Constraints/Limitations

- Detailed explanation about time periods and scenarios/models used are not available on the portal.
- The lack of intact weather data can possibly cause more error in analysis of data; it is necessary that the data utilized is reliable and intact so as to provide better analysis outputs.
- Being able to use the tools with the fewest amount of steps would greatly encourage more people to use them. At present the tools provide data that needs to be downloaded and analysed by an individual. Once the analysis can be done on the portal for the Weather Generator and threshold detector and just download the results, users might find it easier to use.

- Full assessment of the flood prone areas needs to be undertaken and mapped to provide a graphic image of the vulnerabilities of coastal cities. Eventually a country wide flood assessment may be done focusing on coastal areas where larger settlements or important tourism areas are located. Flood assessments may be done in conjunction with Tropical storm simulator where storms can bring high intensity rainfall that may result in intensive flooding. Vulnerability assessments of infrastructure in coastal areas should be considered so as to incorporate resilience of infrastructure in future development plans.
- In terms of Coastal Zone Protection, the tools used do not provide any means of converting the wind outputs into storm surge or wave activity which are two very important variables to be considered in coastal zone protection. The tools also do not allow easy extrapolation to vulnerability and risk assessment maps or evacuation zone maps and these should be considered in the future especially in conjunction with the Tropical Storm Simulator. The tropical storm model is quite weak for use in coastal management, with the model unable to simulate changes in bathymetry and therefore variations in coastal inundation cannot be projected. Changes in hurricane parameters over water should also be considered, as the ocean influences extreme atmospheric events significantly. Possibilities should be explored for coupling Weather Generator and surface ocean models.
- Also, another case study should be undertaken as it is important to evaluate the changes in wind speed and direction for the entire year, rather than December to March.

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