Inception Report

Bermuda and Climate Change: Impacts from Sea Level Rise and Changing Storm Activity

Prepared for:

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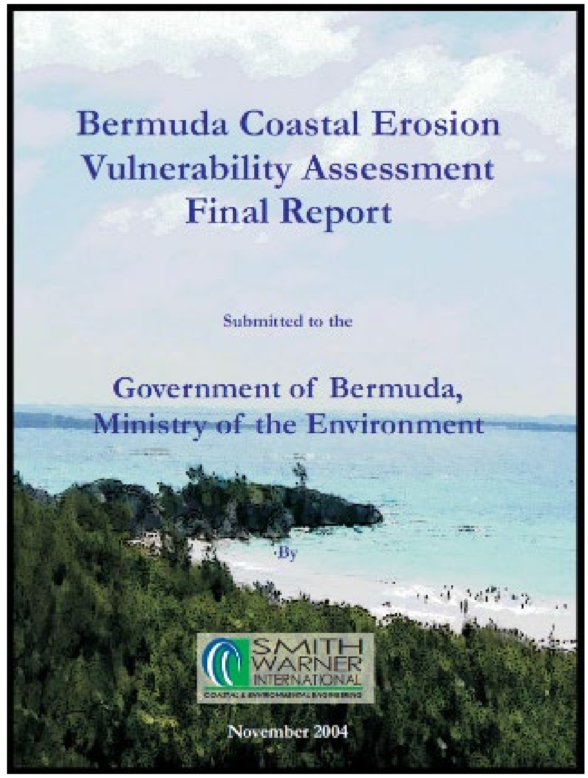
1 Introduction

1.1 Project Background and Objectives

In 2004, the Government of Bermuda (GoB) contracted Smith Warner International (SWI) to prepare an assessment of the vulnerability of Bermuda's coastline to erosion[1]. The 2004 study identified shorelines that were most vulnerable to erosion and storm inundation from potential wave run-up at select locations.



This present study is intended to update the 2004 study in light of the recent projections of sea level rise and other anticipated climate change impacts, and includes the following:

- Current predictions of global warming in the context of sea level rise, combined with expected more severe weather events. The predictions specifically for Bermuda will contain a projection timeline for best- and worst-case climate change scenarios over short-, medium- and long-term time frames.
- Effects of coastal erosion and sea level rise on the mean sea level (MSL) benchmark.
- Identification of Government and critical infrastructure and facilities located at or close to the shoreline that are at risk from erosion or inundation. Undertaking of a vulnerability assessment for major infrastructure i.e., airport, ports, public highways, power plant, subterranean utility cabling, waste (i.e., Tyne's Bay incinerator, sewage management systems, etc.).
- Identification of what effect sea level rise will have on waterways, inshore ponds, marshes, from an ecological perspective.
- Identification of saltwater inundation of agriculture areas (soil salinization), within the context of food security and continued ability to cultivate fields.

[1] Government of Bermuda (2004). Bermuda Coastal Erosion Vulnerability Assessment and Final Report. Prepared by Smith Warner International for the Government of Bermuda, Ministry of the Environment. pp. 148.

- Update coastal erosion and flood inundation projections for the offshore islands, bays, beaches, and dunes, especially during storms and hurricanes.
- Identification of coastal areas prone to hydraulic erosion and / or destabilization of cliff faces or the island's shoreline areas.
- Mapping of projections for inundation island wide, identifying:
  a) low-lying coastal areas that will be periodically or permanently inundated by seawater, and
  b) low-lying freshwater resources that could be impacted, i.e., saltwater intrusion into freshwater lens.
- Recommendations for products / construction methods that are effective in controlling or reducing the effects of erosion. e.g., cliffs, beach dunes, including "green" or hybrid approaches.
- Identification of 'no go' areas for future development based on predicted flood zones and areas identified as being susceptible to high erosion.
- Identification of critical infrastructure components that will be at risk over the near-, medium- and long-term time frames.

1.2 Project Delivery Outline

The project began with meetings in Bermuda (notes from site meetings are included in Appendix A) and a data collection exercise. A fair amount of historical data has been collected throughout various agencies, including the Department of Planning, Department of Environment and Natural Resources, Department of Parks, Ministry of Public Works, Works & Engineering Division, Bermuda Weather Service, and the Bermuda Institute of Ocean Sciences. All of this data will contribute significantly to understanding Bermuda's complex coastal system. Concurrently with the data collection, we are engaging key individual stakeholders within the abovementioned list and beyond to better understand the historical context, as well as the needs and wants of the project.

This deliverable – *Inception Report* – documents the work plan intended for later phases of the project (largely adopted from our proposal) with a comprehensive schedule for delivery. It also details the results of the early works, including the ongoing data collection and desktop literature collection, the initial site visit, and project-related risks we have identified and will mitigate.

Concurrent with this *Inception Report*, we will continue to collect and review/analyse additional desktop research and data, including the available surveys (LiDAR topography and bathymetry in 2004 and 2019/2020), water quality, sediment samples, aerial and benthic mapping. Land use mapping and shoreline types will be delineated from 2022 satellite imagery, and we will identify changes in the shorelines (beach or coastal cliff erosion) from historical imagery. A second site visit is planned that will include our coastal modellers and our specialists in hydrogeology and coastal cliff erosion. We intend to commence our met-ocean campaign with this trip as well, which will measure waves, currents and water surface elevations for two months on the north shore followed by an additional two months on the south shore. The information from this phase will constitute our *Baseline Conditions Report*.

Our modelling phase of the project follows. The latest climate projections will be derived from available historical data. Using both previous and *in-situ* data, we will conduct detailed modelling of waves and currents to provide insight into the coastal dynamics and identify erosion and inundation risk and vulnerabilities. We will analyse and map beach and cliff erosion projections and assess the impacts of sea level rise on the hydrogeological landscape. From these models, we will qualitatively assess the ecology of coastal habitats and the species therein. This exercise will be documented in a *Modelling Report*.

The next stages involve conceptualizing the vulnerabilities in and around the coastal zone through derivation of a coastal vulnerability index. The index will be visualized in a GIS-based platform, with individual maps for each scenario modelled. With the index produced and the information gathered, we will conceptualize appropriate solutions to the coastal problems, focussing on natural or nature-based concepts, where applicable. These will be presented in a *Climate Change Report*.

2 Work Plan

Our work plan is largely reproduced from our proposal with additional information added were applicable.

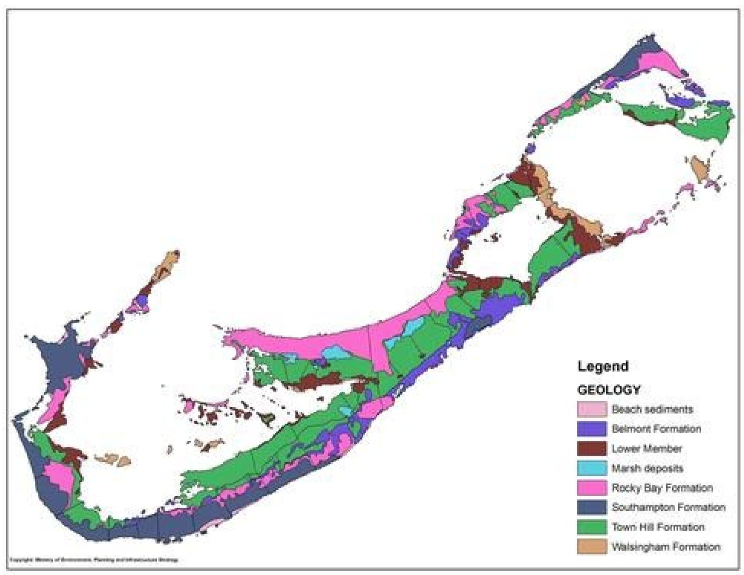
2.1 Baseline Coastal Studies

To fulfil the objectives of this study, various baseline studies are required. Several of these will require data collection, analysis and interpretation, while others rely on modelling, mapping and interpretation of all data (newly collected or existing information). All reports and data, which are documented in our File/Document Register (Appendix B), are filed electronically on our servers and available to the GoB on request.

The baseline data collection activities will evolve in close collaboration with the stakeholders to maximize the outputs given the shoreline stabilization objectives, time and budget constraints. It is anticipated that some level of prioritization will be required so that the most meaningful outputs can be obtained, while still meeting the project time constraints.

2.1.1 Desktop Research and Review of Existing Technical Information

The development of this project must be based on sound evidence and understanding of strategic and site-specific data and information. There will be much to learn from previous undertakings, including data and information contained in the *Coastal Erosion Vulnerability Assessment Report (SWI, 2004)*. As an initial task, SWI will commence services by reviewing information from this report as well as all relevant and readily available information gathered from other sources, including charts, maps, aerial photography, client reports, previous data acquisition, and environmental and marine reports. The data review will be followed by a data gap analysis, leading to recommendations for additional data acquisition including field measurements. These desk-based studies are critical to ensuring that the vital information on past and present behaviour and future plans for the respective coastlines are taken into account.



SWI visited GoB's offices and met with other key stakeholders in our initial site visit (Appendix A) and are planning another site visit in the coming month. The information vital to our project includes:

- historic maps and photographs (including aerial photographs);
- bathymetric and topographic data;
- offshore and nearshore wind and wave data;
- navigational maps of the area of interest;
- any available data on the extent, depth and frequency of previous flooding and erosion events;
- frequency, volume and cost of past works;
- plans and drawings of existing structures;
- locations and values of property and infrastructure;
- beach level and sediment data;
- current speed and direction data;
- previous reports on coastal investigations in the project area;
- all of the latest policy documents on policy, strategy objectives and priorities within the coastal zone;
- water level records;
- potential sources of materials and access routes to site for any proposed coastal works;
- land ownership records; and
- future development plans.

Sources of this data include both long-term and spot measurements taken over the years during private and public projects such as primary research and environmental studies supporting coastal development projects. SWI will source this data through consultation with key agencies including, but not limited to, the following:

- Department of Planning
- Department of Environment and Natural Resources
- Department of Parks
- Ministry of Public Works, Works & Engineering Division
- Bermuda Weather Service
- Bermuda Institute of Ocean Sciences

Given the importance of the marine and coastal natural environment to Bermuda, this area has been the subject of a substantial amount of research and study, which provides a baseline of understanding.

The output of this task will include:

- Data register to track information requests and receipts to the various organizations and responsibility for reviewing data (Appendix B);
- Critical review of this data, identifying gaps in the baseline and monitoring data and future recommendations for Bermuda (Baseline Conditions Report);
- List of coastal risks and related ecosystem services (Baseline Conditions Report); and
- Baseline definition and description; the reviews undertaken for this task will be used for subsequent tasks and deliverables will feed into the (Baseline Conditions Report).

2.1.2 Site Inspection (select locations island-wide)

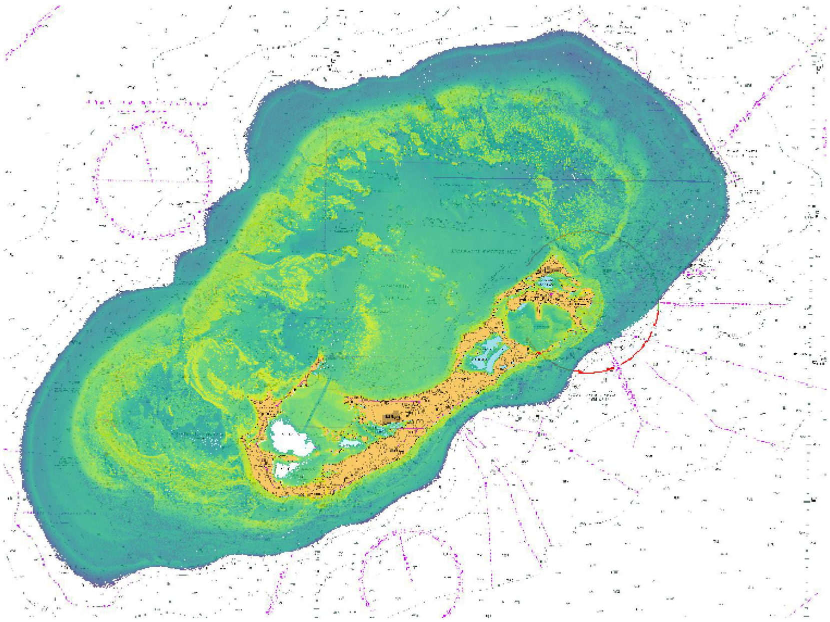
SWI's first task was to undertake a site inspection, which was conducted by land and boat from 1-3 March 2022 (Appendix A). A follow-up site visit is planned for the week of 21 March 2022.

Considerable information can be gained during a series of site inspections. The site visit will allow:

- Our coastal engineers to familiarize themselves with the various coastlines and view evidence of existing shoreline condition including erosion/accretion and changes in the shoreline to facilitate the assessment of shoreline changes in combination with the shoreline records from historical photographs.
- Our hydrogeological specialist to meet with the GoB's hydrogeologist and others including personnel at the Plant Protection Laboratory and gather pertinent data, tour to observe pertinent features such as locations of freshwater lenses, ponds, desalination and waste disposal facilities, and locations of buried infrastructure.
- Our cliff erosion specialist to visually evaluate present conditions and to collect data including rock hardness (Schmidt hammer) and rock dip, and to collect photos of representative erosional processes. This data will in turn be applied to the cliff erosion assessment described in the relevant section below.

2.1.3 Bathymetry

We were recently made aware of a LiDAR survey for bathymetry undertaken by Fugro on behalf of the UK Hydrographic Office (UKHO) in 2019/2020 (Figure 2.1). We are also aware of a Tennix Lads LiDAR survey from 2004, which contained bathymetry and topography for the south coast. We assume both datasets are available and will be provided by the GoB and have not included costing for this effort.



2.1.4 Topography

As part of the same UKHO programme identified above, topography was also collected. We assume this data (as well as the Tennix Lads LiDAR survey from 2004) is available and will be provided by the GoB and have not included costing for this effort.

2.1.5 Aerial imagery

As part of the LiDAR project, the UKHO also assembled a composite of images of the entire shelf of the Bermuda waters in 1x1 km tiles. We assume this data is available and will be provided by the GoB and have not included costing for this effort.

2.1.6 Sea Floor Classification

SWI is aware of previous monitoring efforts on the benthic environment, including benthic mapping dive surveys (2006-2008), seagrass monitoring and water quality monitoring conducted by the Department of Environment and Natural Resources. This data will be very useful in our study.

The UKHO also provided information of "seabed textures", which we assume will be provided by the GoB. This mapping will be critical to gage the contribution of Bermuda's benthic habitats toward coastal protection. For example, we intend to perform sensitivity testing on parameters that represent coral reefs, to replicate changes in the reef structure (in both structure and rugosity) from degradation (e.g., from Stony Tissue Coral Disease or otherwise). With this, we will gage the impact specific habitat degradation will have on the wave energy reaching the shorelines.

2.1.7 Land Use Mapping

A 1 km buffer along the coast will be identified for this task. Our nominated satellite data provider, EOMAP, will undertake a satellite-based interrogation of the land use using a similar methodology to that presented above. The proposed classification schema includes land use/land cover such as road network (transportation), buildings (residential / commercial, industrial), agricultural areas, forest, meadows, bare ground (open land), inland water, wetland, marina, etc.

2.1.8 Delineation of shoreline types

The project shoreline will first be classified into sub-cells based on orientation, type, exposure, degree of enclosure, using aerial or satellite imagery. The following units will be assessed based on the formatted satellite data:

- **Coastline** (Rocky, Unconsolidated, Anthropogenic)
- **Backshore** (Beach, Tidal Salt Marsh, Dune)
- **Foreshore** (Tidal Flat / Intertidal Plain, Tidal Stream, Mudflat)

EOMAP will use object-based geomorphological classification according to texture and spectral characteristics, linking this to identified classes of geomorphological units. This will be translated into metadata (XML) with results presented as geomorphological classification (ESRI polygon shapefile), including relevant attributes. Ground truthing of this preliminary categorization will then be achieved by walking and/or boating along the shoreline. The results of this work will be used to aid the qualification and understanding of the risk to coastal erosion and flooding along the various morphological cells.

2.1.9 Historical beach, cliff and shoreline changes

For this task we will use the LiDAR imagery, satellite imagery and any other relevant and available georeferenced aerial imagery provided by the GoB, Google Earth and/or archived satellite imagery. For example, in Google Earth there are numerous images of Bermuda from 1984 to 2020. The georeferenced imagery will be overlaid to allow an interpretation of the trends in shoreline movement. This analysis will provide a time series of shoreline positions over the available period to identify historical changes, including erosion and accretion patterns.

2.1.10 Inventory and condition of engineering structures

Site visits will be conducted along the shoreline to document existing major engineering structures. These will be evaluated, photographed and assessed to determine their condition and their locations. A standardized structure inspection form will be developed and completed for each structure, to which a photographic record will be added. Aerial imagery will be used to identify and estimate structure dimensions. For each structure's 'General Assessment Rating', we intend to employ the UK

Environment Agency's 2012 'Managing Flood Risk – Condition Assessment Manual', which sets out a clear picture and text-based descriptions of five condition grades specific to the wide range of structures found along the shoreline.

2.1.11 Nearshore and marine sedimentology

Sediment samples will be collected from beaches and nearshore sandy areas. They will then be subject to grain size analysis.

2.1.12 Hindcast wind, wave and water surface elevations

The statistics applied to determine wave and surge elevations in the 2004 report will need to be updated, especially considering the increase in tropical storm frequency and severity over the last 10 years.

SWI will update records of tropical storms and hurricanes within the Atlantic Ocean that have passed near the site from 1850 to the present day using data from NOAA's National Hurricane Center.

We will also retrieve continuous wave and surge hindcast data from an appropriate global wave model (e.g., ERA5, OWI, UK Met Office, NOAA station) to provide the deep-water operational wave climate. Wind data will be provided from the GDAS data assimilation system for the GFS weather model.

An example plot of NOAA's GFS simulation is shown in Figure 2.2 for the Atlantic basin.

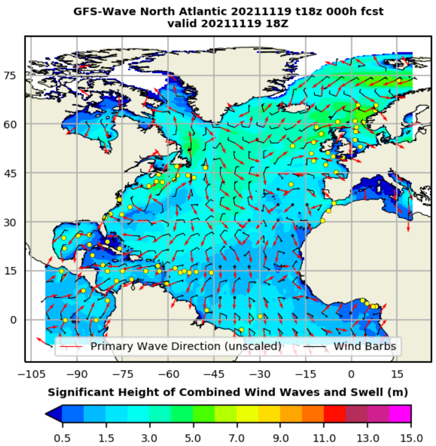


Figure 2.2 Example from NOAA's GFS hindcast wave simulation

2.1.13 MetOcean Data Collection

To reduce uncertainties in wave modelling, which is an important component of the investigation, SWI will carry out a programme of wave and current measurements. Much of this uncertainty stems from the fact that specific parameters associated with modelling algorithms that compute wave transformation from deep water, over the reefs that ring Bermuda, and into the nearshore coastal zones, may not be sensitized to adequately account for the physics of the energy dissipation process. The recommended wave and current measurement programme is intended to provide insight to these parameters to better replicate this wave transformation phenomenon.

Based on our previous study and available offshore wave climate information, Bermuda experiences two main seasons with opposing wave directions, shown in Figure 2.3 in wave roses from hindcast (virtual) deep water wave data. Between May and September, the primary wave direction is from the east-southeast to southeast (i.e., approaching primarily the south coast). Between October and April, waves primarily approach from the west-northwest to north-northwest (approaching the north coast), with secondary waves spread somewhat evenly from other directions. During that latter winter period, wave heights are approximately four times what they are during the summer period.

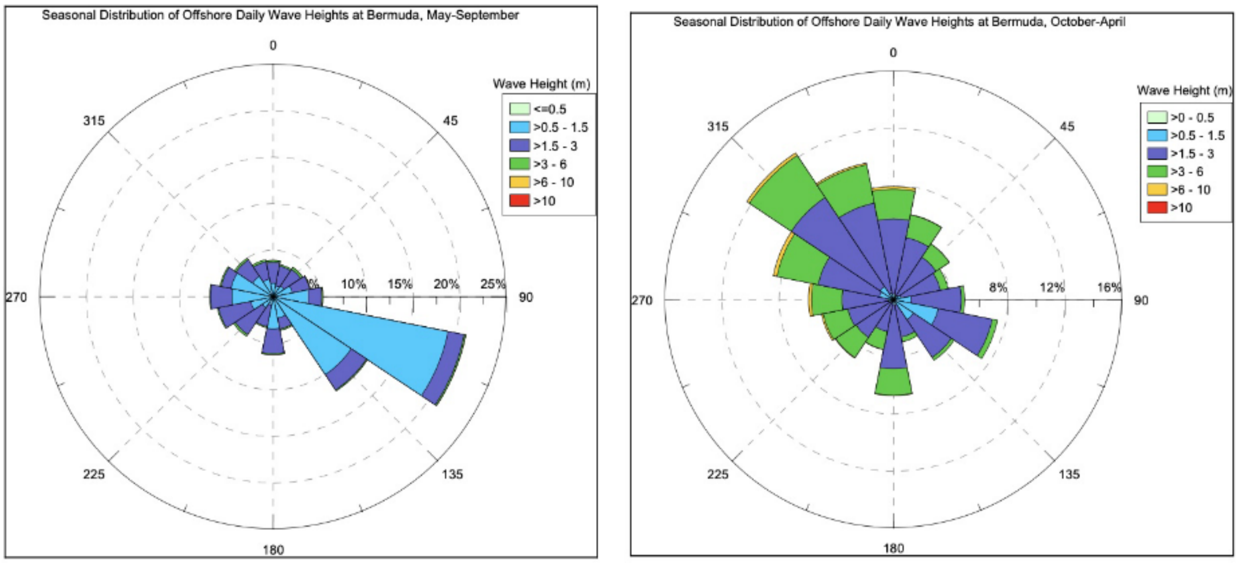


Figure 2.3 Wave roses showing seasonal variations in Bermuda offshore waters

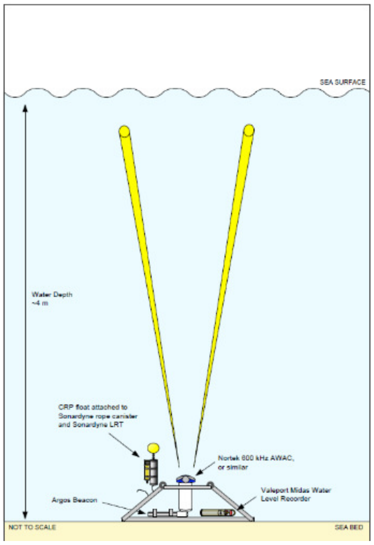
This omni-directional spread of wave conditions suggests that wave and current measurements should occur on both the north and south coasts and should span at least two months so that representative periods of these two seasons can be measured.

There are various options for measuring waves and currents, including bottom and surface mounted instruments. For this project we will use the Teledyne RD-WHS0600, a bottom-mounted ADCP instrument. These instruments use acoustic Doppler current profiling to measure currents through the water column and simultaneously compute wave conditions by a combination of surface water tracking, near surface current measurements, and/or pressure variations. They provide accurate, reliable measurements for reasonably long periods (up to six weeks at a time). The Teledyne RD-WHS0600 units (two) will be deployed, serviced (cleaned) and retrieved by open water scuba divers using a small recreational dive vessel. SWI has carried out numerous successful wave and current measurement campaigns throughout the West Indies with very few instrument malfunctions or data loss events.

The instruments will be deployed for a 3 to 4-month monitoring campaign, set up similar to what is shown in Figure 2.4. The units will measure tide levels and currents throughout the water column at 20-30-minute intervals and waves at 2- or 3-hour intervals. The campaign will be broken into two phases: we will deploy the two gages on the northern side of Bermuda during the week of 21 March

2022 to capture wave events generated within the north Atlantic waters. After two months, we will retrieve and service the gages and re-deploy them on the south side of Bermuda to measure wave transmission on the south coast.

We assume data from the permanent tide gages installed by the UKHO at Somerset and St. Georges will be provided by the GoB.



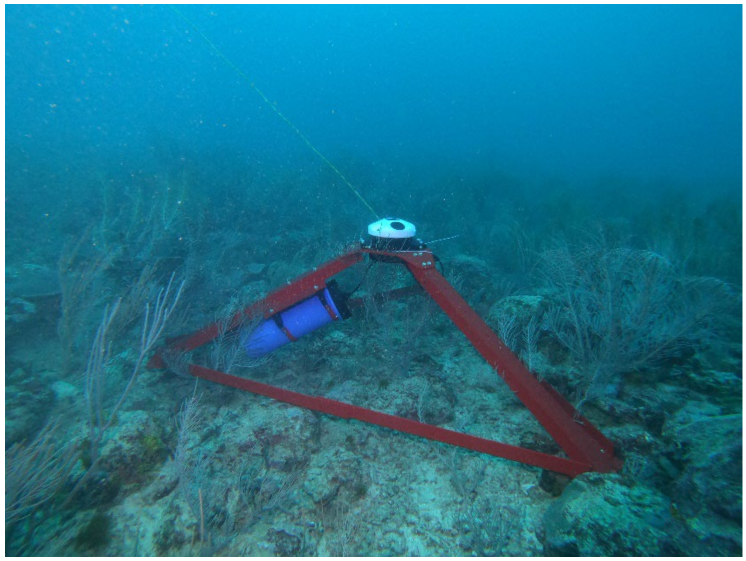


Figure 2.4 ADCP deployment examples

2.1.14 Stakeholder Engagement and Participation

Participatory modelling in coastal management involves interactive and adaptive planning, in which stakeholder participation and the development of models (i.e., conceptual, simulation, physical, etc.) and communication tools go hand in hand. For this project, participatory modelling refers to the integration of four distinct approaches for decision support:

i. coastal planning;
ii. the use of scientific and technical knowledge;
iii. stakeholder engagement (local knowledge); and
iv. cooperation in the sense of negotiation.

We consider these four linked pillars the basis for effective and sustainable coastal management. Consistent stakeholder engagement enhances the exchange of perceptions and consensus building and plays a central role in balancing interests for sustainable coastal management.

Stakeholders will be selected through document review and initial discussions with the Department of Planning. As part of this process, all those affected by the activity, who have influence or power over it, or who have an interest in its conclusion will be identified.

The participatory modelling approach in this project will support the process of creating an integrated overview of problems, develop stakeholder knowledge and improve cooperation among stakeholders through collective knowledge sharing. This is especially valid as specific interest from the industrial sector and from the local communities might be conflicting. Examples of this are, for instance, addressing the development of floodplains and areas prone to erosion for which the tourism industry would have to consider withdrawing potential investments, low-lying areas for which it might be also necessary to consider giving up development and urbanization plans, or coastal community relocation, etc.

Possible visualization and support tools will be used where appropriate. This will enhance and support stakeholder engagement through active participation.

Two stakeholder engagement sessions are planned for this project: one at the onset (in conjunction with the site visits – notes from these meetings are included in Appendix A) and one following the modelling tasks, where we will present the modelling output. We expect the engagement following modelling will be in a group setting.

2.2 Modelling and Assessments

2.2.1 Climate Change Modelling

The climate change assessment for Bermuda will be conducted using a combination of literature review, analysis of observed historical climate data as well as climate model outputs. The variables to be investigated and the associated time periods will be subject to data availability and client approval, however, it is envisaged that the analysis will include key climate variables such as temperature, rainfall, wind, and sea level rise for mid and end of century timelines.

The climate change modelling methodology includes the following steps:

i. **Literature review**. A review of authoritative works and recent studies on climate change and climate variability for the Caribbean, and specifically as it relates to Bermuda will be conducted. These works include those by the Intergovernmental Panel on Climate Change (e.g., The IPCC's Fifth and Sixth Assessment Reports and the Special Report on Global Warming of 1.5^{o}); The Caribbean Community Climate Change Centre; The Caribbean Institute of Meteorology and Hydrology and the Climate Studies Group, Mona.

ii. **Historical Data Analysis**. Available historical observed data will be used to (i) characterise the climatology of relevant variables describing the climate of Bermuda and (ii) examine variability and trends for climate variables. This will be completed using available station data from the National Meteorological Service but will also make use of other applicable and available datasets. Quality control checks will be performed to verify data quality prior to commencing analysis. Special focus will be given to any locations that are of priority to the Project, provided data is available. Where historical data is unavailable or lacking, literature review will be used to address data gaps.

iii. **Projections of future climate**. Projections of future climate change will be examined for key variables for time slices in the future (e.g., 2040s, 2060s and end of century). Information will be gathered from literature, data generated from modelling (using global and regional climate models) and from statistical downscaling (contingent on the availability of daily meteorological station data). Comparisons with past trends will be made where appropriate.

   a. ***GCM Data.*** A review of existing projections data generated *at the country* level will be done for select time slices in the future. The data will be mined from Global Climate Models (GCMs) ensembles (accessible through, for example, the IPCC database) run under Representative Concentration Pathways (RCPs). For the purposes of this work, RCP4.5 and RCP 8.5 will be emphasized.

   b. ***Dynamical* downscaling**. This method employs a regional climate model (RCM) driven at its boundaries by the outputs of Global Climate Models (GCMs) to give *sub-country* level projections. Data will be provided at a minimum resolution of 25km for mid to end-of-century and using RCM(s) validated for use in the Caribbean.

   c. ***Review***. Guidance from literature and analysis of available datasets will provide information on future changes in sea level rise. Use will also be made of SIMCLIM for extracting sea level rise data.

iv. ***Statistical* downscaling**. Statistical downscaling enables the projection of a local variable using statistical relationships developed between that variable and the large-scale climate. The relationships are premised on historical data and are assumed to hold true for the future. Statistical downscaling is especially useful for generating projections at a location (e.g., at the community level), once sufficient historical data are available. Statistical downscaling work will be facilitated using the Statistical Downscaling Model (SDSM) (Wilby et al. 2002) and available historical time series of climatic variables. This method is contingent on the availability of daily meteorological station data for a sufficiently long period, e.g., 1960-1990.

SWI is aware of the six different Shared Socioeconomic Pathways ('SSP') produced in the most recent IPCC AR6 report[2]. The SSPs are qualitative narratives describing alternative socio-economic developments. Each SSP analysis is intended to provide data on national population, urbanization and GDP (per capita) representations.

Our Climate Change expert, Dr Michael Taylor, has revealed there are still too few downscaled SSPs for the region, which precludes specific quantitative analysis on the various SSP scenarios. Our assessments on the SSPs will therefore be limited to qualitative comment in the narrative, drawing from the IPCC AR6 report and atlas.

[2] IPCC (2021). Masson-Delmotte V, Zhai P, Pirani A, Connors SL, Péan C, Berger S, Caud N, Chen Y, Goldfarb L, Gomis MI, Huang M, Leitzell K, Lonnoy E, Matthews JB, Maycock TK, Waterfield T, Yelekçi O, Yu R, Zhou B (eds.). Summary for Policymakers (PDF). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge (UK): Cambridge University Press. p. SPM-18. Archived from the original (PDF) on Aug 19, 2021.

2.2.2 Wave Assessment and Transformation Modelling

The collected hindcast wave data described above will be processed in a statistical extreme value analysis. Our analysis includes a parametric hindcasting routine to produce estimates of deep-water waves for each storm. A statistical approach will then be adopted to determine the hurricane or storm event equivalent to a 20-, 50-, 100- and 150-year probability of occurrence. SWI will similarly process the wind and surge record to achieve the respective corresponding extreme values.

We will also statistically analyse the wave record to isolate trends in individual storm events. In doing so, we aim to investigate seasonal and long-term variations in coastal forcing (e.g., waves, tides, currents, and sea level rise) that may contribute to varied erosion and accretion trends, including:

a. "North swell" events, considering wave heights, periods, and direction, and

b. Tropical, sub-tropical, and extra-tropical storm activity.

With the hindcast data processed, we will numerically transform deep-water wave, wind and surge conditions to the nearshore coastal zone of Bermuda. The purpose of this wave transformation modelling is to develop a working representation of the wave and current environment throughout Bermuda to aid in the various risk and vulnerability assessments.

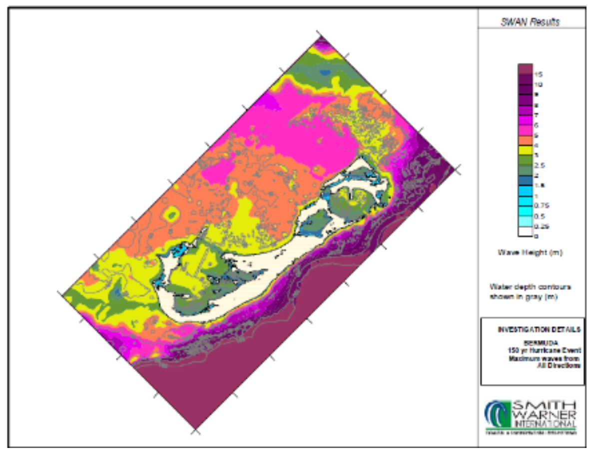


Figure 2.5 Wave transformation modelling from SWI's 2004 report

A wave transformation model developed using the software package MIKE 21 SW FM by DHI (MIKE by DHI, 2016) will be used. This model is a state-of-the-art numerical tool for simulating the growth, transformation and decay of wind waves and swell. The model accounts for refraction, shoaling, and diffraction as well as energy dissipation due to white-capping, bottom friction and wave breaking. The model also accounts for non-linear effects such as wave-wave and wave-current interaction. The wave model will be calibrated to measured data and driven by hindcast wave data purchased from the most appropriate source. Wind data will be sourced from L. F. Wade International Airport or hindcast sources.

2.2.3 Hydrodynamical Modelling

Hydrodynamic coastal modelling will be carried out using the MIKE 21 Hydrodynamic (HD) FM module (MIKE by DHI, 2016), and will be applied to represent water flow. The model will be set-up and calibrated against measured water levels and currents. The hydrodynamic model will then be nested with the wave model to represent expected tide, storm surge and inundation levels. The models will extend from the offshore waters to the maximum expected storm/run-up elevations on land.

We will also include surface water modelling and an assessment of the canal leading from the interior of Hamilton to Mill Creek, which is understood to experience flooding during rainfall events and/or higher tide levels. *We have assumed that groundwater effects are independent to the flooding and, as such, this model will focus on the interaction between climate change induced rainfall events and elevated sea levels only.*

2.2.4 Beach Erosion Modelling

The first and best-known model relating shoreline retreat to an increase in local sea level was that proposed by Per Bruun (1962). The IPCC reports that a 1cm rise in sea level erodes beaches about 1m horizontally. This becomes a large issue for developed beaches that are less than 5m from the ocean (IPCC, 1998). The Bruun rule states that a typical concave-upward beach profile can be represented by a parabolic function whose parameters are entirely determined by the mean water level and the sand grain size, and correlates sand erosion from the beach face to deposits in the nearshore area. The Bruun rule will be applied to estimate erosion from sea-level rise where applicable (open beaches with relatively straight and parallel bathymetric contours). The derived hazard footprints will be used to assess impacts, damages, and integration into risk (erosion risk mapping).

2.2.5 Cliff Erosion Assessment

The vulnerability of Bermuda's coastal cliffs will be qualitatively assessed for 20-, 50-, and 100-year time horizons for the two sea level rise scenarios selected. Future cliff vulnerability will be primarily evaluated using available data sources including: present and future wave exposure and run-up conditions, geologic conditions and lithology, foreshore setting, presence of coastal protection, and historical coastal erosion and change. As noted in the site visit section earlier, we will collect some representative data on site including rock hardness (Schmidt hammer) and rock dip. The 20-, 50-, and 100- year time horizons will be compared to historical and current baseline conditions to evaluate future changes.

Overall qualitative vulnerability will be assessed using weighted criteria including wave exposure, rock hardness, adverse geologic conditions, erosional processes, historical erosion rates, and foreshore setting. Exploratory conceptual models may also be used. Cliffs will be broadly characterized by site setting, geologic conditions, and onsite assessment. The spatial scale of the cliff groups and vulnerability analysis will be based on available data, resolution, and the onsite visit.

2.2.6 Hydrogeologic Assessment

Following the site visit and review of all relevant documents and maps, SWI will analyse reports and data with the view to determining hydrogeologic impacts that result from climate change. The methodology to be employed is described following.

Fresh Water Lenses

a) Obtain all information on wells that tap the lenses such as location and elevations, static water levels, pumping rates, chemistry;

b) Look for evidence of upconing while pumping and disturbance of the saltwater interface;

c) Plot water table in relation to sea level;

d) Examine the literature for derived aquifer parameters from pumping tests, total average pumping rates, well interference and tracer tests if they have been carried out;

e) Examine groundwater protection areas; and

f) Assess climate data over the years of record to note trends in precipitation, evaporation etc.

Fresh and Saltwater Ponds

From literature and available data, note elevation and depth of water and fluctuations in levels, changes in chemistry.

General Methodology

- Collect data on other groundwater monitors that may exist around the island such as in the vicinity of the incinerator.
- Note the locations and specifications of desalination plants that have been installed, including methods of disposal of waste brine such as deep well injection.
- Obtain inventory of buried infrastructure, which may be adversely affected by the corrosion effects of increased salinity, and determine elevations of these features in relation to sea level.

Results of the study will be included in the *Modeling Report.*

The climate change scenarios will be considered and compared with the existing (present day) hydrologic data network to determine the impacts of sea level rise on Bermuda's water resources and water supply infrastructure. Mitigation and adaptation measures will be researched, and recommendations provided in the *Climate Change Report.*

2.2.7 Ecological Assessment

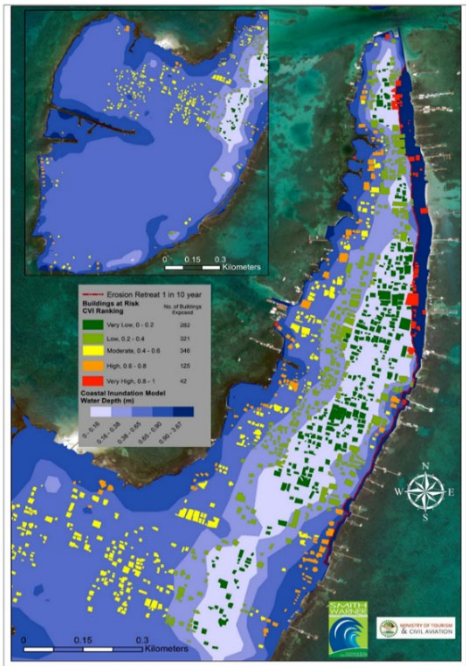
Bermuda's coastal habitats – beaches and sand dunes, brackish ponds, caves, coastal forests, coral reefs, freshwater marshes, inshore bays, mangroves, coastal cliffs, salt ponds and marshes, and seagrass beds – will all likely be at risk from the effects of climate change.

Under this task we will carry out a watershed characterization to include discussion of land cover/land use, hydrology and water resources and ecosystems. We will develop a site description and assessment as it relates to the wetlands, carry out mapping of wetland ecosystems, map generation and data analysis and interpretation.

Based on our assessments, we will provide qualitative identification of coastal habitats and the main species therein that will be at risk for the various scenarios considered. We will also identify further, more detailed studies to quantify ecosystem vulnerability.

2.2.8 Coastal Vulnerability Index Mapping

The understanding presented in the coastal processes analysis, together with the results from the extreme sea level analysis, will be used to perform a coastal vulnerability assessment. This will include a review of the potential for flooding and erosion of coastal areas, and the potential for extreme events that would disrupt other coastal and marine activities.



Buildings Exposed to Multi-Hazard
1 in 10 Year Scenario, South Island Caye Caulker

Figure 2.6 SWI's coastal vulnerability index in Caye Caulker, Belize

To analyse potential solutions that may be appropriate to mitigate the effects of coastal erosion, SWI will employ the concept of "geomorphic units". The coastline will be divided into geomorphic units or "sediment cells" that define relatively self-contained units within which sediment circulates. The net balance between sediment inputs and losses from within each geomorphic unit determines, to a large extent, whether a coastline is retreating or advancing.

The mapping and assessment will be used to develop and apply a Coastal Vulnerability Index (CVI) to rank the severity of erosion and flood threats along the coastline. The mapping will identify government and other critical infrastructure that may be at risk, including:

- Utilities
- Fuel pipeline routes and landing points
- Cables – telecoms
- Docks/marinas/ landing points – commercial docks - ferries, fish landing
- Marina fuel stations and tanks
- Bridges and causeways e.g., Flatts Bridge into Harrington Sound, Somerset Bridge, Causeway
- Reverse osmosis intake and outfalls
- Tourism infrastructure
- Underwater fuel storage
- Water lines

The criteria to be used in the CVI will incorporate:

- Shoreline characteristics;
- Sediment transport patterns;
- Wave conditions (operational and extreme);
- Climate change expectations.

The CVI will also be used to assess the vulnerability of critical infrastructure in the short-, mid- and long-term time frames.

2.3 Recommendations

With the combined understanding of the sediment dynamics of the coastal areas of Bermuda with coastal vulnerabilities based on the modelling and mapping tasks described above, SWI will consider and advise on measures or combinations of measures that may be appropriate to mitigate the effects of coastal erosion or inundation.

SWI will focus on natural or nature-based solutions that tend to be more sustainable in longer term timescales. Activities and outputs will tend to follow the *Building with Nature* key principles[3], and will heavily rely on the Bermuda Biodiversity Country Study[4]. We will also consider potential cost reduction initiatives, adaptive features of solutions and creating additional functionalities that can benefit coastal communities.

Measures could include *inter-alia*:

- *Restoration of natural sediment transport.* Coastal erosion can be reduced through the restoration of longshore transport near the coast, or restoration of the natural sediment transport from either coral reefs or estuarine discharges to the coast.
- *Re-use of dredged material.* The various shipping and navigational channels of Bermuda's harbours require maintenance dredging where large volumes of sediment may be disposed of in deep water, rendering it lost for supply to the coastal system. The dredged material from both maintenance dredging and capital dredging projects can help to fill the sediment supply needs of the coast.
- *Application of sand nourishment.* Sand nourishment aims to recover the sediment balance by supplying beaches and shore faces with sand from the continental shelf or, alternatively, from

[3] De Vriend, H.J. and Van Koningsveld, M. (2012) Building with Nature: Thinking, acting and interacting differently. EcoShape, Building with Nature, Dordrecht, the Netherlands

[4] Government of Bermuda (2001). Bermuda Biodiversity Country Study. Available at: https://static1.squarespace.com/static/501134e9c4aa430673203999/t/55393543e4b0b0c454552cb2/1521553251120/Bermuda+Biodiversity+Country+Study.pdf. Accessed Nov 21, 2021.

inland sandstone quarries. Sand nourishment will help to restore beaches and can reduce storm damage to coastal structures.

- *Rehabilitation and reestablishment of mangroves.* Mangroves constitute a barrier against structural erosion and to extreme events, such as storm surge, spring tides and tsunamis. The tree root systems stimulate sedimentation and prevent erosion. The rehabilitation of mangroves requires the restoration of hydrology and salinity conditions, replanting of trees and restoring the sand barrier in front of the mangrove forest. Hungry Bay Mangrove Swamp, the largest example of the most northerly mangrove swamp in the Atlantic, has significantly degraded from the effects of sea level rise, damage from hurricanes, and the dredging of a boat channel some 40-50 years ago[5].

- *Re-shaping cliffs.* This measure aims to slow down the erosion of steep cliffs by re-shaping them to a slope with an angle of less than 15º. A smooth profile may dissipate wave energy more gradually, reducing or even halting coastline retreat.

- *Protection, rehabilitation, and development of coral reefs.* Hard structures (like wrecks) on the sea bottom can provide a suitable settlement substrate for coral polyps. Reefs provide a complex habitat to a wide variety of marine species, including fish. The development of coral reefs to reduce erosion is a long-term solution.

- *Smart use of hard structures.* Smart use of hard measures may include re-designing and up-scaling of several small groynes by fewer larger ones or the construction of offshore breakwaters.

- *Proper spatial planning.* Spatial planning can define a buffer between the coastline and urban development in order to reduce the risk of coastal flooding and maintain the resilience and natural appearance of the coastal zone in the long term. An effective measure is defining a minimum distance from the shoreline to where new buildings or infrastructure can be developed (set-backs).

Recommendations of measures will likely differ for each study area. Several measures may be used in all areas (spatial planning, sand nourishment) while others are suitable on a more site-specific basis (regrading cliffs, development of coral reefs, etc.). The measures recommended for shoreline stabilization will also consider goals of protecting people, ecosystems, properties, public, and infrastructure and at stimulating economic (tourism) development.

We will also address recommendations to address the impacts on the hydrogeology. Mitigation recommendations could include pumping fresh water into the aquifers, desalinating ocean water and storing it, building levees and dikes to prevent the salt water from reaching the fresh water; however, it is likely that these measures are prohibitively expensive.

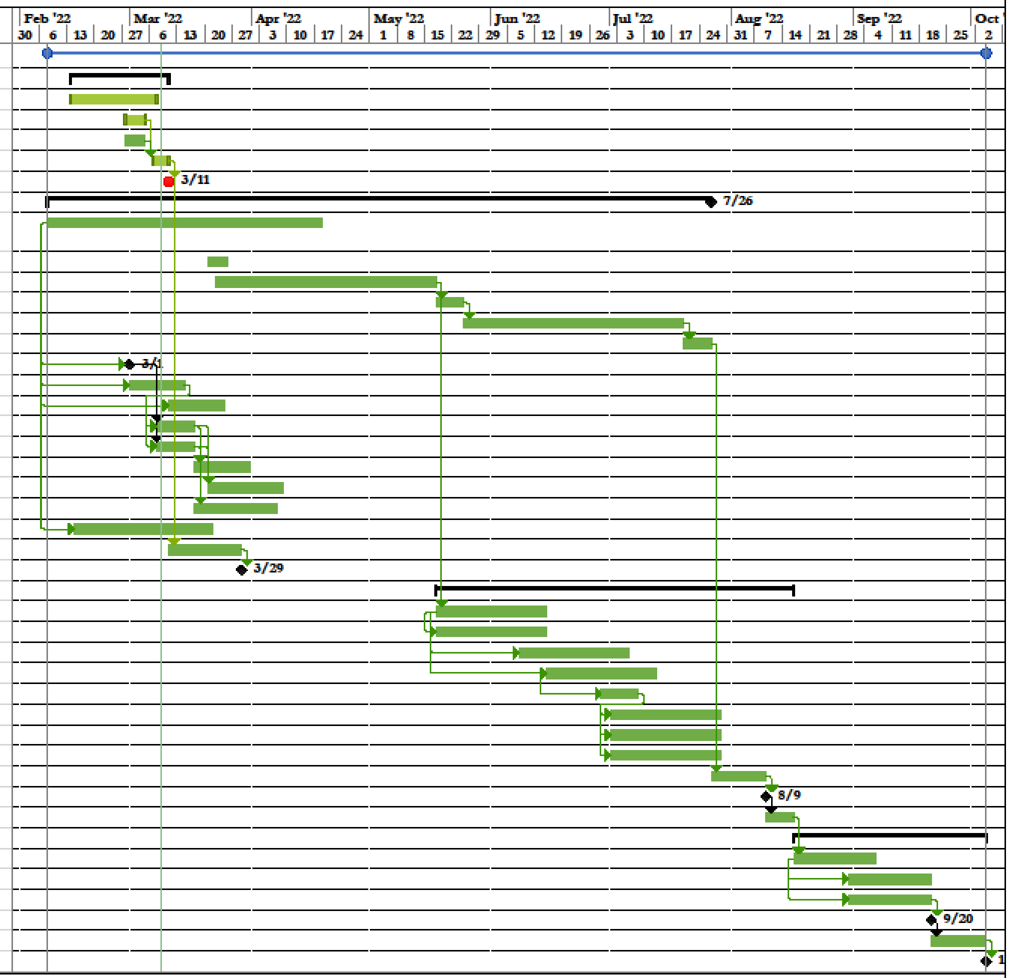
[5] Ramsar, 2021. Hungry Bay Mangrove Swamp. Available at: https://rsis.ramsar.org/ris/987. Accessed Nov 21, 2021.

3 Project Schedule

Our project schedule, presented on the following page, is the same as that presented in our proposal but with additional detail and changes as necessary to the workflow. We expect that the schedule, along with the document register, will be updated throughout the project duration.

Bermuda - Climate Change Study (2021-2022)
Wed 3/9/22

ID	Task Name	Duration	Start
1	Bermuda Climate Change Study (2021)	171 days	Tue 2/8/22
2	Project Inception	19 days	Mon 2/14/22
3	Subcontracts	16 days	Mon 2/14/22
4	Site Visit #1	5 days	Mon 2/28/22
5	*Stakeholder Engagement - 1*	*1 wk*	*Mon 2/28/22*
6	Inception Report Preparation	4 days	Mon 3/7/22
7	Deliverable: Inception Report	0 days	Fri 3/11/22
8	Baseline Studies	121 days	Tue 2/8/22
9	Desktop Research and Review of Existing Technical Information	10 wks	Tue 2/8/22
10	Site Visit #2	1 wk	Mon 3/21/22
11	Metocean Data campaign 1	8 wks	Wed 3/23/22
12	Instrument Retrieval	1 wk	Wed 5/18/22
13	Metocean Data campaign 2	8 wks	Wed 5/25/22
14	Instrument Retrieval	1 wk	Wed 7/20/22
15	Bathymetry (provided by client)	0 wks	Tue 3/1/22
16	Topography (provided by client)	2 wks	Tue 3/1/22
17	Sea Floor Classification (provided by client)	2 wks	Fri 3/11/22
18	Land Use Mapping	1.5 wks	Tue 3/8/22
19	Delineation of shoreline types	1.5 wks	Tue 3/8/22
20	Historical beach, cliff and shoreline changes	2 wks	Thu 3/17/22
21	Inventory and condition of engineering structures	3 wks	Mon 3/21/22
22	Nearshore and marine sedimentology	3 wks	Thu 3/17/22
23	Hindcast Wind, Wave and Water Surface Elevations	5 wks	Tue 2/15/22
24	Report Preparation	2.5 wks	Fri 3/11/22
25	Deliverable: Baseline Conditions Report	0 days	Tue 3/29/22
26	Modelling	65 days	Wed 5/18/22
27	Setup and Calibration	4 wks	Wed 5/18/22
28	Climate Change Modelling	4 wks	Wed 5/18/22
29	Wave Transformation Modelling	4 wks	Wed 6/8/22
30	Hydrodynamical Modelling	4 wks	Wed 6/15/22
31	Beach Erosion Modelling	1.5 wks	Wed 6/29/22
32	Cliff Erosion Assessment	4 wks	Fri 7/1/22
33	Hydrogeologic Assessment	4 wks	Fri 7/1/22
34	Ecological Assessment	4 wks	Fri 7/1/22
35	Report Preparation	2 wks	Wed 7/27/22
36	Deliverable: Modelling Report	0 days	Tue 8/9/22
37	*Stakeholder Engagement - 2*	*1 wk*	*Wed 8/10/22*
38	Coastal Vulnerability Mapping and Assessment	35 days	Wed 8/17/22
39	Coastal Vulnerability Index Mapping	3 wks	Wed 8/17/22
40	Recommendations	3 wks	Wed 8/31/22
41	Report Preparation	3 wks	Wed 8/31/22
42	Deliverable: Draft Climate Change Report	0 days	Tue 9/20/22
43	Client Review & Report Updates	2 wks	Wed 9/21/22
44	Deliverable: Final Climate Change Report	0 days	Tue 10/4/22



Page 1

4 Project Risk Register

The following risk register documents potential risks that may be encountered during the project.

Project Risk Register

Government of Bermuda, Department of Planning
Bermuda Climate Change Project

Status Date: 9-Mar-22

			Current Status							
			Control Dates		**Most Likely**			**Action**		
Risk No.	**Risk Category**	**Risk Description:** **Cause, Threat/Opportunity, and Effect**	**Identified**	**Status**	**Impact**	**Probability**	**Overall Risk Ranking**	**Treatment Type**	**Treatment Plan**	**Risk Owner**
1	Schedule	C: Due to the potential for weather delays for metocean gages O: There is a threat that metocean deployment/service/retrieval/data collection is delayed E: Which could result in additional fees/schedule	2-Mar-22	Active	Medium	Medium	Medium	Avoid	Weather patterns should dictate metocean visits	SWI
2	Cost	C: Due to the remote location of Bermuda O: There is a threat that gages have a difficult time getting to site E: Which could result in schedule impact	2-Mar-22	Active	Low	Low	Low	Share	Arrange shipping beforehand, arrange customs clearance beforehand	SWI/ GoB
3	Cost	C: Due to the number of subconsultants O: There is a threat that not all can attend the kickoff/site/project meeting or deliver their inputs in time E: Which could result in delays and difficulties in incorporating subs work into our reports	2-Mar-22	Active	Medium	Low	Medium	Accept	PM responsible for team progress	SWI
4	Quality	C: Due to uncertainty in technical information provided (e.g. survey differences) T: There is a threat that our additional technical information needs to be procured E: Which could result in unexpected costs and delays	2-Mar-22	Active	Low	Low	Low	Accept	Early detection of data gaps in literature reviews	SWI

5	Schedule	C: Due to the need to change personnel on the project O: There is a threat that the change will create disruption to the design process E: Which could result in additional cost/time	2-Mar-22	Active	Low	Medium	Medium	Accept	Resourcing plan needs to be secured by SWI management well in advance	SWI

Appendix A Site Visit Memo: 1-3 March 2022

Smith Warner International Limited
Unit 13, Seymour Park,
2 Seymour Avenue
Kingston 10, JAMAICA
www.smithwarner.com

memo

SMITH WARNER INTERNATIONAL

To:	Miles Harris
From:	Edward Albada, David Smith
CC:	
Date:	4 March 2022
Re:	Bermuda Climate Change – Site Visit Report: 1-3 March 2022

This memo details notes and observations made during the initial project visit to Bermuda by Smith Warner International (SWI) representatives David Smith and Edward Albada. Two field visits were conducted on 2 March 2022 by land and by sea and on 3 March 2022 by land to view coastal areas and infrastructure vulnerable to climate change and exhibiting evidence of coastal erosion. Meetings were also held throughout the entire visit with key stakeholders.

Notes from Meetings Held

	Meeting Particulars	Attendees
1	**Sean Patterson, Chief Land Surveyor** Date: 1 March 2022	• Victoria Pereira, Director, Department of Planning • David Smith, SWI

- The new LiDAR data set has revealed previously uncovered shipwrecks.
- Topographic data is referenced as Land Datum, and bathymetric data are referenced as Marine Datum. The two datum references are to be harmonized.

- A 4TB external drive was identified as being required to download the LiDAR dataset.
- This dataset also contains aerial photography at a 10cm pixel resolution, as well as contour data at 2m contour intervals. More detailed resolution may be extracted from the raw data.
- It was noted that the seabed around Bermuda was mapped (benthic mapping) under the Benthic Ocean Prosperity Programme (BOPP). This data is to be obtained.
- It was noted that a Chinese fishing vessel, the Xing Da, had been sunk off the north-west coast of the island to provide a dive destination. The currents at that location proved to be so strong that the vessel was torn apart within a year and reduced to a pile of metal plates.
- To the best knowledge, current meters have not been deployed offshore Bermuda.
- There used to be a tide gauge on the Esso pier, run by NOAA. This was in operation for 19.5 years. It was decommissioned and relocated within the lagoon at the Bermuda Institute of Ocean Sciences (BIOS) station. Data from this gauge can be obtained online from the NOAA website.
- The UKHO gave the Survey Department two (2) tide gauges. One on Ordnance Island, St George's and the other by Summerset Bridge (although this was not properly related to a datum).
- It was mentioned that NOAA has been looking at re-establishing the tide gauge on the Esso pier.
- The Survey Department does not have a copy of the Tennex Lads LiDAR data from 2004 and would like to receive a copy from SWI. This data set is to be brought to Bermuda by Philip Warner on 20 March 2022.
- We should note building footprints from the recent LiDAR data, as well as observed hurricane flooding locations.
- Has tsunami risk been examined for Bermuda? A tsunami exercise was modelled by NOAA in 2016. This may be seen on the NOAA Natural Hazards Viewer.

2	**Mark Guishard, Director** **Bermuda Weather Services** **Date:** 1 March 2022	• Victoria Pereira, Director, Department of Planning • Jeanie Nikolai, Dir. Of Energy • David Smith, SWI

- There has been recent flooding in the square of St George due to tidal excursions and rainfall.
- Caribbean Renewable Energy Forum (CREF) Director of Energy, Jeanie Nikolai, has been working on a "Resiliency Scorecard".

- SWI to have a chat with people from Building Services. How resilient are buildings (offices and residences) to hurricane winds? The Building Code is being updated.
- The wave model used by the BWS is applied in a predictive mode. It was written expressly for the BWS.

3	**Dr Geoff Smith, Director Dept. of Environment** **Sean Lavis** **Patricia Hollis** **Date:** 1 March 2022	• Victoria Pereira, Director, Department of Planning • Jeanie Nikolai, Dir. Of Energy • David Smith, SWI

- The Dept. of Environment has a lot of information and operate as regulators.
- Many underground storage tanks are believed to be within the hazard zone.
- A recent study by Princeton University has shown that nitrates from cesspits go into the groundwater and likely affect the coral reefs. [We need to obtain the Princeton study].
- Treated effluent is typically discharged to the sea.
- Dr Geoff Smith agreed to send their PowerPoint presentation to the Department of Planning for sending on to us.
- We will also get from the Department of Environment the metadata base of GIS shape file coverages and we can indicate the areas of interest.
- We should include the solar farm installation.

4	**Victoria Pereira, Director, Department of Planning** **Date:** 1 March 2022	• Kenny Campbell, Snr. Planning Officer; Paul McDonald, Development Manager; Mandy Shailer, GIS • David Smith, SWI

- There is a desire to see flood risk mapping for storm surge and for rainfall inundation.
- There is a Coastal Development Policy.
- There is a Climate Change Report from the National Trust.
- There is a Sustainable Drainage Policy, which mirrors the policy approach adopted by the UK.
- The concept of sustainable return periods (e.g. 1:50, 1:100 and 1:200 etc.) should be examined.

- GIS department (Mandy Shailer) can get us the ESRI shapefiles that we want. They have an Enterprise License with ESRI.

5	**Minister and Permanent Secretary in the Ministry of Home Affairs** **Date:** 2 March 2022	Attendees: • The Hon. Walter H. Roban, JP, MP, Minister of Home Affairs • Rozy M. Azhar, Permanent Secretary, Minister of Home Affairs • Victoria Pereira, Director, Department of Planning • David Smith, SWI • Edward Albada, SWI

- Hon. Minister Roban and PS Azhar welcomed SWI and expressed enthusiasm for the coastal study.
- Hon. Minister Roban identified that some of the owners of the coastal lots acquired these lots via inheritances from relatives who purchased (or were granted) lots at a much less value than they are today. With the appreciation in the value of the land over time, the present owners seek to develop on the lots as a means to improve their financial standing. However, recent understanding of the vulnerability of the coastlines in light of climate change (through this study, for example) may lead to planning constraints on developments (e.g. within nature reserves or with footprints too close to the coast), thereby minimizing the return potential. The new planning constraints may create discomfort to these developers.
- Given that much of Bermuda's infrastructure has been developed throughout history in the coastal zone, a blanket approach of coastal retreat to all areas is neither feasible nor a viable consideration. There may be areas where other mechanisms should be considered, such as coastal hardening/protection or adaptation.
- PS Azhar identified some important areas of the study including the effects of coastal climate change on the water table, agriculture, subsea infrastructure, fuel tanks, fibre optic cables, etc. The study should identify the critical areas and indicate prioritization for action based on vulnerability.
- Hon. Minister Roban accepted that the study would not necessarily result in a "quick fix" solution, and the intent it that the study will be applied for longer term planning purposes.
- Public awareness opportunities were discussed to raise enthusiasm for the project.

6	**Tynes Bay Industrial Complex** **Date:** 3 March 2022	Attendees: • J. Tarik Christopher, Principal Engineer, Ministry of Public Works • Victoria Pereira, Director, Department of Planning • David Smith, SWI Edward Albada, SWI

- There are 4 desalination/RO plants on Bermuda under Government control:
  - Tyne's Bay, where water is produced from energy derived by the adjacent Incinerator
  - Fort Prospect
  - Tudor Hill
  - Fort Victoria

  Of these, only Tyne's Bay has coastal infrastructure and extracts seawater.
- Another private producer of RO water exists, Watlington Waterworks. The infrastructure for Watlington Waterworks is separate from Tyne's Bay.
- Concerns of coastal-related climate change with regard to Tyne's Bay include the potential for impact on:
  - Tyne's Bay three seawater wells, which are on the coast adjacent to the plant.
  - The approximately 200 freshwater wells scattered throughout the island.
  - Tyne's Bay cooling water intake and discharge infrastructure.
- The plant recently completed a demand forecast as part of a water and wastewater master plan.
- The main plant (other than the coastal infrastructure) is located approximately 6m above sea level.

Site Visit Observations

<table>
<tr><th></th><th>Images</th><th>Notes</th></tr>
<tr><td colspan="3">Site visit conducted via land on 2 March 2022 between 9:30 am – 12:00 pm with:
• Victoria Pereira, Director, Department of Planning
• Austin Kenny, Senior Structural Engineer, Department of Works and Engineering
• David Smith & Edward Albada, SWI</td></tr>
<tr><td>1.</td><td>
</td><td>Pembroke Canal, Hamilton

The visit was conducted at 9:30 am, approximately 1 hour after high tide. Water level in the canal is at the level of the road, with some pooling of water onto the road in lower elevations.

Sparse mangroves exist at the downstream side of the canal leading to the bay.</td></tr>
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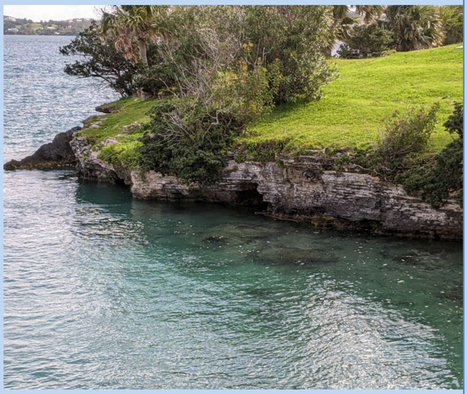
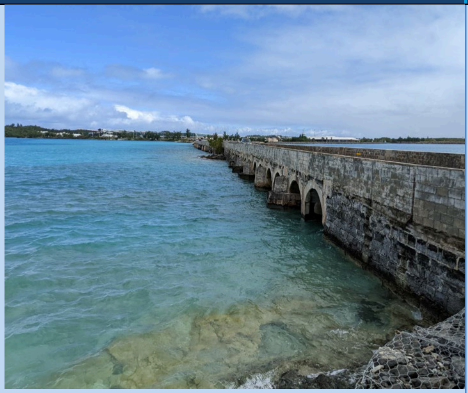
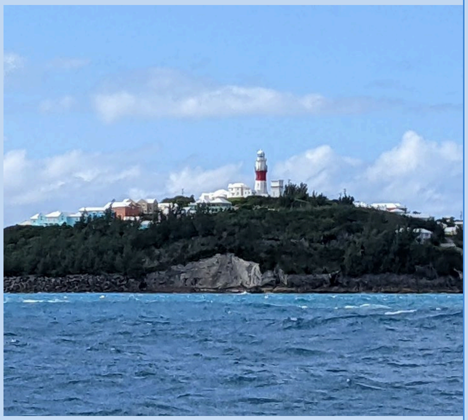
	Images	Notes
2	 	**Flatts Bridge, Hamilton** Bridge over tidal inlet showing aggressive tidal flow. There is evidence of bioerosion undercutting the banks, in particular on the bay side.
3		**Shelley Bay** Beach protected in parts with rock-filled gabion baskets. The gabions are in good condition despite being over 10 years old. Adjacent to the beach a rocky shoreline protects a footpath that has been connected with aluminium bridges in places. The rocky shoreline is disjointed with the gaps allowing wave energy to penetrate to the shoreline. Shoreward of the beach/footpath lies the main arterial road. There is evidence of recent (and imminent) failure of the roadway slipping

	Images	Notes
	 	seaward, repaired with a concrete seawall. Apparently two brush islands existed within the bay, which were cut for firewood.
4		**Causeway** The causeway connects the mainland of Bermuda to the airport and Banjo Island and is considered vital infrastructure for medical emergencies and air-related evacuations. The causeway is approximately 150 years old and failed in parts during the last major hurricane. During subsequent repairs, a layby was built that included protection using gabion baskets. Due to its low-lying nature and fragile condition, the causeway is closed

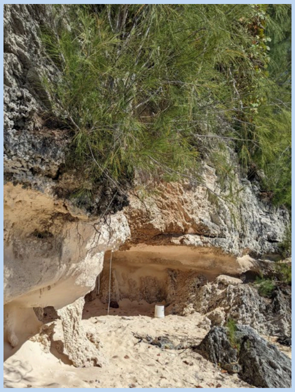
	Images	Notes
		during severe storm events such as the passage of tropical storms. A proposal to replace the causeway with a pier structure was considered in 2010.
5		**Landfill** The landfill site appears to be subject to ad-hoc reclamation by pushing of fill into the shallow nearshore area.
6		**John Smith Beach** John Smith Beach is a sandy beach formed within a crenulate bay. The beach itself appears quite healthy with a well-defined vegetated upper dune. However, there is evidence of undercutting of the sandstone rock in the cliff face presumably caused by wave action during storm events.

	Images	Notes
		
Site visit conducted via sea on March 2nd between 12:30 pm – 3:30 pm with: • Craig Smith, Bermuda Coast Guard • C.J. Richardson, Bermuda Coast Guard • David Smith & Edward Albada, SWI		
7		**Tynes Bay Incinerator and Water Treatment Plant** The infrastructure associated with the incinerator and water treatment plant appeared quite elevated.

	Images	Notes
8		**North Shore Residences** Some residences on the north shore were subject to wave action on their protective seawalls.
9		**Sol/Rubis Fuel Terminal** The fuel terminal appeared to be in good working condition. The infrastructure at the shoreline showed signs of corrosion from wave action.
10		**Interior protected waterways** Bioerosion is presumed evident in the undercutting of the rock strata within the interior waterways.

	Images	Notes
11		**St David's Lighthouse** A large coastal cliff failure occurred close to the lighthouse on the eastern end of St David's Island just east of the end of the airport runway.
12	 	**South Shore Coastal Cliff Failures** Several coastal cliff failures were seen from afar; some appeared to be very close to residences and infrastructure.

<table>
<tr><th></th><th>Images</th><th>Notes</th></tr>
<tr><td></td><td>
</td><td></td></tr>
</table>

Site visit conducted via land on 3 March 2022 between 9:30 am – 12:00 pm with: • Austin Kenny, Senior Structural Engineer, Department of Works and Engineering • Kenny Campbell, Planner, Forward Planning, Department of Planning • Paul McDonald, Senior Planner, Development Management, Department of Planning David Smith & Edward Albada, SWI		
13	  	**Marley Beach** Marley Beach appeared to be one of the more exposed beaches on the south shore, evidenced by relatively large waves (~1m high) on the shore and the presence of a surfer. At Marley Beach, approximately 0.5m of ground cover (organic soil) sits on top of a relatively weak sandstone formation that is easily crumbled to the touch. There are some "columns" of harder rock, thought to be fossilized tree roots. A large coastal cliff failure has occurred under a new development of three apartment blocks. A concrete seawall was built at the toe of the cliff to protect from further erosion.

Reports/data requested:

1) Causeway replacement modelling/design reports (2010).
2) Tyne's Bay water/wastewater master plan, specifically the demand forecasting.

Appendix B Document Register

Topics	Title	Authors	Date Received	Date of Publication	Source	Document Name	Size
Hurricanes		Not Stated	January 18, 2022	June 11, 2021	Mark Guishard, Airport Authority	Bermuda_Hurricanes_to 2020.xlsx	Spreadsheet
Hurricanes	Development of a simple, open-source hurricane wind risk model for Bermuda with a sensitivity test on decadal variability	Pinelopi Loizou, Mark Guishard, Kevin Mayall, Pier Luigi Vidale, Kevin Hodges, Silke Dierer	January 18, 2022	Not Applicable	Mark Guishard, Airport Authority	Loizou_etal_accepted_Sept2021.pdf	18 pages
Hurricanes		Not Stated	January 18, 2022	Not Applicable	Mark Guishard, Airport Authority	TCs_Withiin100nm.xlsx	Spreadsheet
Rainfall	ANALYSIS OF THE RAINFALL VARIABILITY IN THE SUBTROPICAL NORTH ATLANTIC REGION: BERMUDA, CANARY ISLANDS, MADEIRA AND AZORES	Irene Peñate de la Rosa	January 18, 2022	November 1, 2015	Mark Guishard, Airport Authority	20160420TESISIRENE.pdf	343 pages

Topics	Title	Authors	Date Received	Date of Publication	Source	Document Name	Size
Rainfall	Flooding threshold rainfall events in Bermuda	Michael C. Johnston, Mark P. Guishard, Irene Peñate and Ian D. Currie	January 18, 2022	September 1, 2018	Mark Guishard, Airport Authority	Johnston_et_al-2018-Weather.pdf	5 pages
Rainfall		Not Stated	January 18, 2022	May 4, 2021	Mark Guishard, Airport Authority	Precip_MonthlyTotals_1949_2020.xlsx	Spreadsheet
Rainfall		Not Stated	January 18, 2022	April 29, 2021	Mark Guishard, Airport Authority	Rainfall_to2020.xlsx	Spreadsheet
Sea Level Rise		Not Stated	January 18, 2022	February 27, 2017	Mark Guishard, Airport Authority	BermudaMeanSeaLevelTrends_Jan19.xlsx	
Sea Level Rise	Hurricane Storm Surge and Sea Level Rise Exposure Assessment in Bermuda	Ximena Boza, Bermuda Institute of Ocean Science	January 18, 2022	January 1 2019	Mark Guishard, Airport Authority	Boza_Surge_SLR_FINAL-REPORT.pdf	39 pages
Sea Level Rise		Not Stated	January 18, 2022	February 27, 2017	Mark Guishard, Airport Authority	SLR_ClimateCentral_StGeorges.xlsx	
LIDAR	Report of Survey (Lidar)	Fugro USA Marine	January 25, 2022	March 9, 2020?	Kevin Mayall, Locus Ltd.	HI1665_Bermuda_ROS_V3.pdf	84

Topics	Title	Authors	Date Received	Date of Publication	Source	Document Name	Size
LIDAR	Overseas Territories Seabed Mapping Programme	UK Hydrographic Office	January 25, 2022	January 1 2019	Kevin Mayall, Locus Ltd.	OTSMP_Bermuda_ALB_Data_Brief_Aug 21A.pdf	29
Climate Change	Interannual variability of the oceanic CO2sink in the subtropical gyre of the North Atlantic Ocean over the last 2 decades	Nicholas R. Bates	March 1, 2022	September 19, 2007	Online	https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2006JC003759	26
Hurricanes	Atlantic Subtropical Storms. Part II: Climatology	MARK P. GUISHARD* AND JENNI L. EVANS	March 1, 2022	July 1, 2009	Online	https://doi.org/10.1175/2008JCLI2346.1	21
Hurricanes	Bermuda subtropical storms	M. P. Guishard, E. A. Nelson, J. L. Evans, R. E. Hart & D. G. O'Connell	March 1, 2022	March 14, 2007	Online	https://link.springer.com/article/10.1007/s00703-006-0255-y	15
Hurricanes	Increasing tropical cyclone intensity and potential intensity in the subtropical Atlantic around Bermuda from an ocean heat content perspective 1955–2019	Samantha Hallam, Mark Guishard, Simon A Josey, Pat Hyder and Joel Hirschi	March 1, 2022	September 19, 2007	Online	https://iopscience.iop.org/article/10.1088/1748-9326/abe493	11
Sea Level Rise	Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites	Robert E. Kopp,Radley M. Horton,Christopher M. Little,Jerry X. Mitrovica,Michael Oppenheimer,D. J. Rasmussen,Benjamin H. Strauss,Claudia Tebaldi	March 1, 2022	August 21, 2014	Online	https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2014EF000239	25

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Sea Level Rise	New elevation data triple estimates of global vulnerability to sea-level rise and coastal flooding	Scott A. Kulp & Benjamin H. Strauss	March 1, 2022	October 29, 2019	Online	https://www.nature.com/articles/s41467-019-12808-z	12
Sea Level Rise	COASTAL RISK SCREENING TOOL LAND BELOW 1.0 METERS OF WATER	Climate Central	March 1, 2022	Not Applicable	Online	https://coastal.climatecentral.org/map/12/-64.765/32.3348/?theme=water_level&map_type=water_level_above_mhhw&basemap=roadmap&contiguous=true&elevation_model=best_available&water_level=1.0&water_unit=m	Online Map
Hurricanes	Topographic Speed-Up Effects and Observed Roof Damage on Bermuda following Hurricane Fabian (2003)	Craig Miller, Michael Gibbons, Kyle Beatty, Auguste Boissonade	March 1, 2022	August 29, 2012	Online	https://journals.ametsoc.org/view/journals/wefo/28/1/waf-d-12-00050_1.xml	
Hurricanes	Resolution Dependence of Future Tropical Cyclone Projections of CAM5.1 in the U.S. CLIVAR Hurricane Working Group Idealized Configurations	Wehner, M., , Reed, K. A., Stone, D., Collins, W. D., & Bacmeister, J.	March 1, 2022	January 18 2015	Online	https://journals.ametsoc.org/view/journals/clim/28/10/jcli-d-14-00311.1.xml	
Geology of Bermuda	The Geological Map of Bermuda	The Ministry of Works and Engineering	March 9, 2022	January 1, 1989	Shaun Lavis, Hydrogeolist	Geological map 300 dpi.pdf	