

Modelling Projections of Potential Sea Level Rise Impacts on Some Caribbean Communities: Is it Worth the Effort?

Michael SUTHERLAND (Trinidad & Tobago), Keith MILLER (Trinidad & Tobago), Dexter DAVIS (Trinidad & Tobago), Amit SEERAM (Trinidad & Tobago) and Demi SINGH (Trinidad & Tobago)

Key words: Mean Sea Level; Sea Level Rise; Tidal data; P3DM; GIS Predictive Models

For Peer Review and Consideration by Commission 4

SUMMARY

The Caribbean historically experiences a variety of natural disasters including hurricanes, earthquakes and volcanic eruptions, droughts among other things. Climate change is reported to potentially exacerbate many of these extreme events in the region, and add persistent sea level rise as another threat to Caribbean coastal communities. GIS-based sea level rise predictive inundation models have been, and are being, used to assess potential physical and socioeconomic impacts on coastal communities in the Caribbean and other geographic areas. The results of these models are expected to form part of the information base used to develop appropriate adaptation and mitigation strategies. The veracity of the models' results, and the usefulness of the models, are questioned because more often than not the models are constructed with less than ideal data, especially in developing regions such as the Caribbean where there is often a paucity of long term dependable spatial data, including tidal data to determine mean sea level and, as well, coastal deformation data among other things. Within the context of all the foregoing, this paper presents three case studies where GIS-based sea level rise inundation models are produced relevant to selected Caribbean communities. It was found that the models at least have utility in raising awareness, and support for the development of appropriate adaptation and mitigation strategies.

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1. INTRODUCTION

Historically in the Caribbean, volcanoes, earthquakes and hurricanes have caused devastation through destruction of dwellings and the immediate supply of food (Watts, 1993; Charvériat, 2000). Such events are unpredictable and recovery is a long, slow process. The more recent threat of sea level rise is longer term, and with better appreciation for the situation appropriate community plans could be developed to adapt to, or mitigate, the threat (IPCC 2007a, 2007b). However, lack of information on which to base decisions makes preparation difficult. The development of sea level rise inundation models based on geomatics techniques can provide some of the information needed (Poulter and Halpin 2008; Mcleod et al., 2010). However, the paucity of long term tidal and coastal deformation data can cast doubt on the veracity of the models' results. In this paper, Caribbean case studies are presented where the outcomes are sea level rise models designed to support the development of appropriate sea level rise adaptation and mitigation strategies. The models are discussed in terms of data accuracy, amount of information needed for suitable assessment of sea level rise impacts, and the models' utilities considering their construction using less than ideal data.

2. CASE STUDIES

This section describes three recent Caribbean case studies that employ the use of sea level rise projections as part methodologies for analysing sea level rise possible impacts on Caribbean coastal communities' socioeconomic and physical environments. Three case studies presented purport to provide information to support the development of relevant adaptation and mitigation strategies. As no long term measurements of sea level exist, short term tidal measurements from tide gauges are used as to reference current sea level to topography.

2.1 Creating a P3DM for Roxborough, Tobago

Participatory 3-Dimensional Models (P3DM) are subsets of Public Participatory Geographic Information Systems (PPGIS) or Participatory Geographic Information Systems (PGIS). These systems utilize cartographic techniques together with analogue and digital GIS technologies to facilitate the communication of local spatial knowledge by community groups (Jankowski and Nyerges 2003; Corbett and Keller, 2005; Corbett and Keller, 2006; Elwood, 2006; Vajjhala, 2006; Brown 2012; Pocewicz et al., 2012; Gaillard et al., 2013).

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The Tobago Emergency Management Agency (TEMA) has the mandate to coordinate and direct agencies and efforts directed towards disaster management in the island of Tobago, part of the twin island State of the Republic of Trinidad and Tobago. TEMA has engaged in the mapping of inundation zones in the island, and supported the development of the P3DM for Roxborough, a community that was not assessed for inundation threats including that from sea level rise.

The community of Roxborough was first engaged, through the president of the Roxborough Village Council, before the model was developed. It is necessary to expose local participants to P3DM and sea level rise concepts, obtain local support for the project, and to gain access to important and relevant local spatial knowledge, especially that residing in the elders of the community.

A physical model of the region was constructed, chosen to be represented at a horizontal scale of 1:5000 to facilitate ease of local knowledge representation, and at a vertical scale of 1:2000 to support adequate and acceptable exaggeration of contours. There are no long term tidal measurements related to the coast adjacent to Roxborough. Estimations of mean sea level, required to determine the spatial extent of selected projections of sea level rise at Roxborough, were obtained through tide gauge measurements and precise levelling. In this case, five weeks of tidal measurements were collected and processed to produce a mean sea level contour for the study site. A printed contour map of Roxborough was glued to a table and the contours traced onto carbon paper, which was then glued to cardboard sheets. Individual contour representations were then cut and pasted together, and covered with crêpe paper to produce a physical representation of Roxborough's topography.

After the initial P3DM model was built, community members used coloured pins and woollen yarn, and acyclic paint to depict point, line and polygon features representing various aspects of local knowledge. Other information representing the spatial extent of urban and forested areas were also added to the model. Figure 2.1 shows the final P3DM. A high resolution digital camera was used to photogrammetrically capture an image of the P3DM which, through digitization and geo-referencing techniques, was input into ArcGIS. Various thematic local knowledge features were then extracted as ESRI shapefiles. Inundation polygons representing various sea level rise projections were then created and overlaid onto the local knowledge features to determine potential impacts (Figure 2.2).

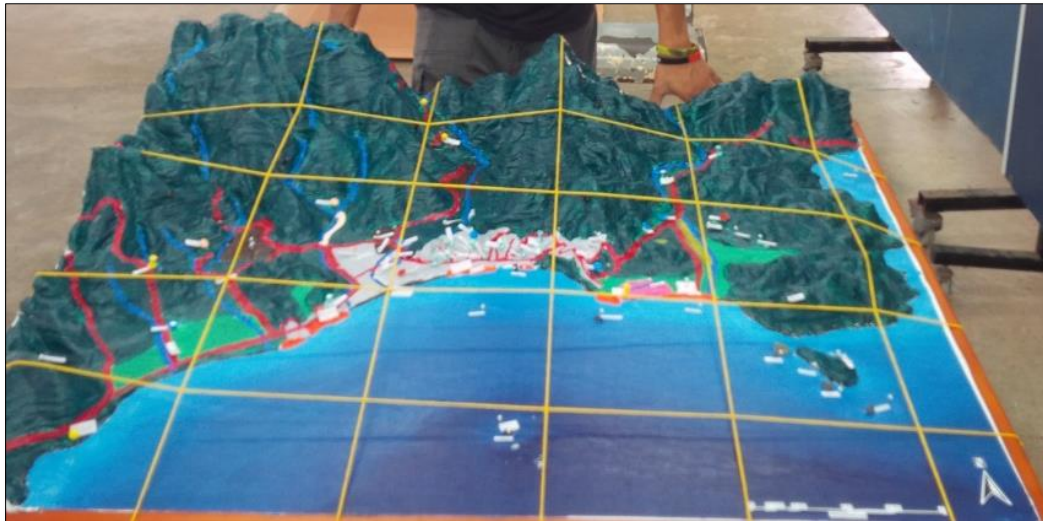


Figure 2.1 Complete P3DM Model of Roxborough depicting local knowledge

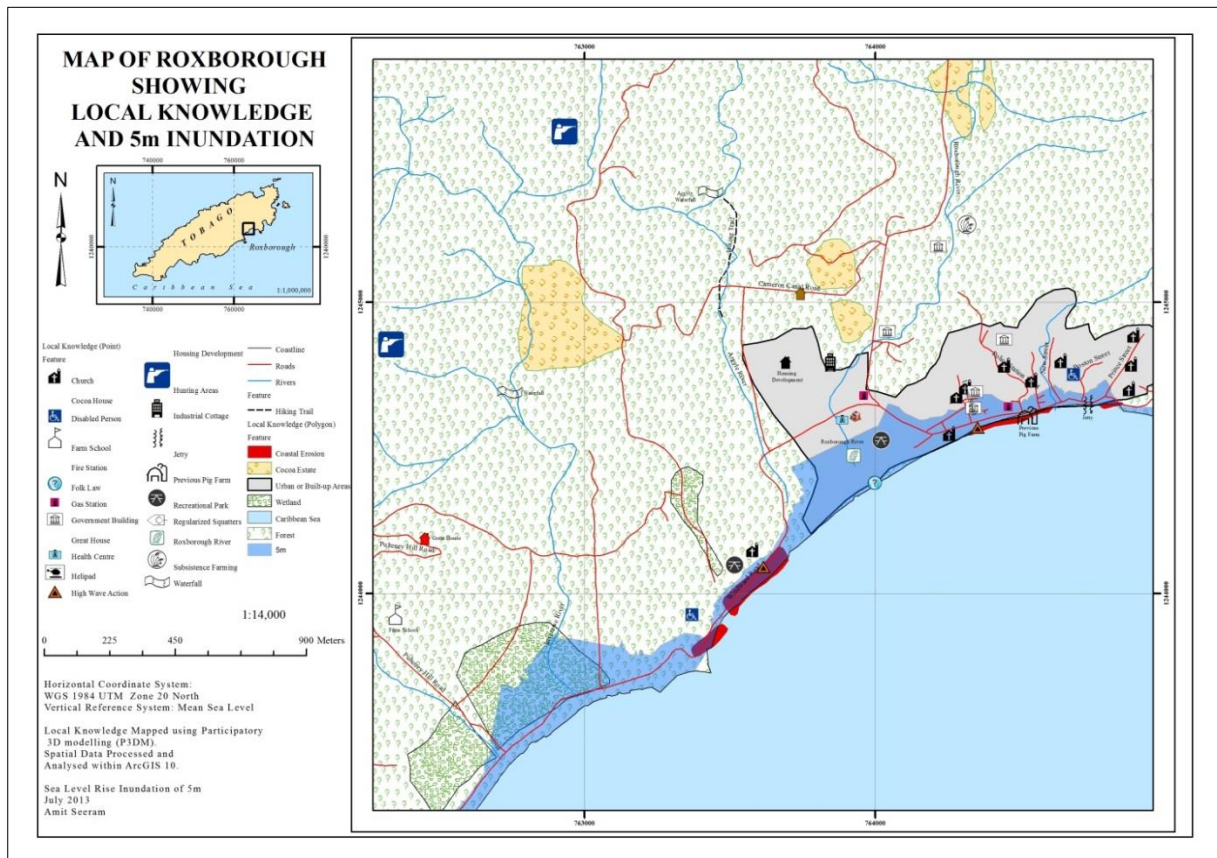


Figure 2.2: Local knowledge features being inundated by projected 5m SLR above MSL

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2.2 Sea Level Rise Model – Grande Riviere, Trinidad

As reported by Sookram and Sutherland (2011), Sutherland (2012) an ongoing project commencing in 2009 and titled “Managing Adaptation to Environmental Change in Coastal Communities: Canada and the Caribbean” produced sea level rise models of Grande Riviere, Trinidad and Tobago. The project is funded by the Social Sciences and Humanities Research Council (SSHRC) and the International Development Research Centre (IDRC) and focuses on socioeconomic impacts of climate change on coastal communities in Canada and the Caribbean. Grande Riviere is the largest nesting site for leatherback turtles in the Caribbean and loss of nesting habitat due to inundation by sea level rise not only affects the turtles but the socioeconomic wellbeing on the community that depends upon related tourism.

Grande Riviere is located in North East Trinidad and offers a beach that narrows by a river. The beach is exposed to Atlantic swells and is therefore subject to high energy wave action and changes in the profile are expected under variation in weather conditions. Locals were able to identify the spatial extent of features that are now covered by the sea, or are covered at times, but used to be permanently exposed land. Developments near the beach to facilitate tourism associated with leatherback turtles are under immediate threat of sea level rise or beach retreat. This is an interesting community where harvesting of turtles and their eggs was common practice, but efforts within the local community have almost stamped out this activity and the community is now dependent on tourism.

Sutherland and Seeram (2011) and Seeram (2011) describe the development of GIS sea level rise models for Grande Riviere. The resulting models are combinations of primary and secondary data. Raster and vector datasets, including aerial photography, and datasets representing contours, buildings, roads, property rights boundaries, coastline, a river and vegetation comprise the secondary data used. Primary data collection includes topographic survey data, GPS spot heights, and short term tide gauge data (*via* tidal datum transfers from the village of Toco, where a tide gauge was located at the time of the surveys). Tidal measurements were observed over a 1-day period. ArcGIS (i.e., ArcMap and ArcScene) was used to process the collected data and to produce sea level rise scenarios for Grande Riviere, based on selected IPCC Fourth Assessment projections, e.g., simulated 0.4m, 0.5m, 0.6m, 0.8m, 1m above mean sea level (IPCC, 2007a and 2007b). The reported horizontal accuracy of the digital terrain model used in the simulation is $\pm 0.02\text{m}$, and its vertical accuracy is reported to be $\pm 0.20\text{m}$. Figure 2.3 shows a resulting simulation of 0.4m sea level rise above mean sea level at Grande Riviere Beach, which if it occurs results in some loss of turtle nesting habitat.

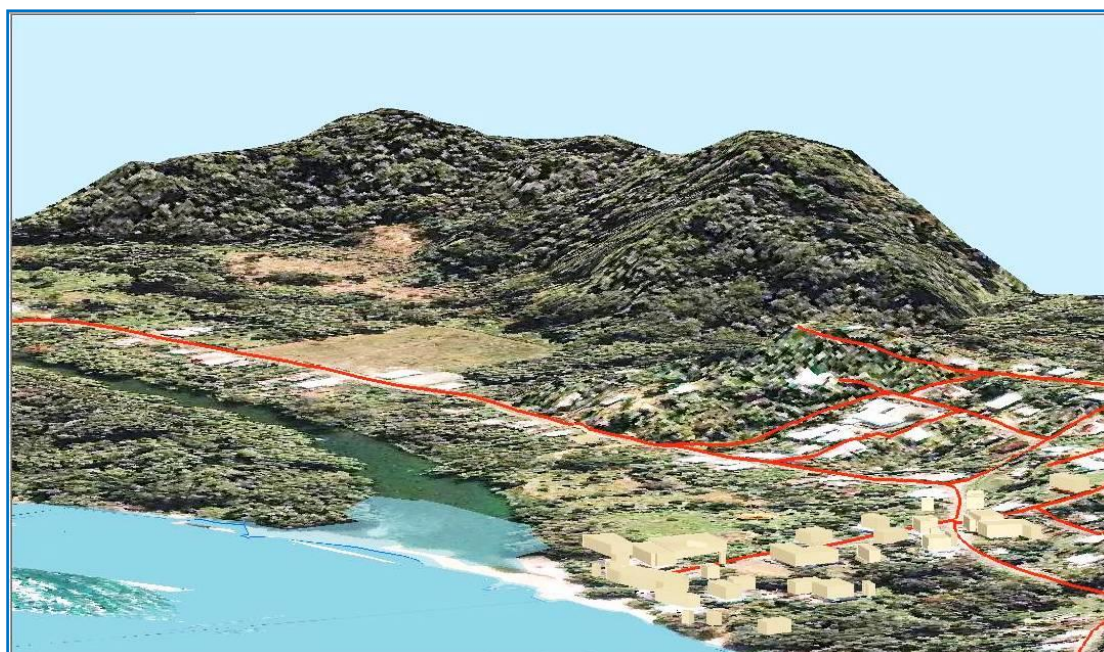


Figure 2.3: GIS Model of 0.4m above MSL at Grande Riviere Beach
Source: Sookram and Sutherland (2011)

2.3 Sea Level Rise Model – Bequia, St. Vincent and the Grenadines

Sea level rise models of Bequia were produced as part of the “Managing Adaptation to Environmental Change in Coastal Communities: Canada and the Caribbean” project described in Section 2.2, and also as part of postgraduate studies (M.Sc. in Geoinformatics) in the Department of Geomatics Engineering and Land Management, Faculty of Engineering, University of the West Indies, St. Augustine, Trinidad and Tobago (Singh, 2013). Singh (2013) was funded in part by the project. The methodology for producing the Bequia model is similar to that outlined in Section 2.2, except that two sites on Bequia were targeted: Port Elizabeth; and Adams Bay. The latter is shown in Figure 2.4 with leading lights for the airstrip, which was built on reclaimed land, located in the sea. Tide gauge data collection continued for one month.

As a volcanic island, the land mass of Bequia rises more steeply out of the sea than that at Grande Riviere. Beaches are therefore narrow. These low lying areas extend inland for short distances before land elevation rises steeply. Development occurs on the hillsides and down onto the foreshore, almost to the water in places. During a topographic data collection exercise, locals identified an area of sea in Adams Bay that used to be permanently exposed land and where potatoes used to be farmed. The beach in that location is now almost non-existent. Due to the nature of the terrain the only option for building the airstrip was by reclamation of land. Figure 2.5 shows a sea level rise model of Bequia and with an increase in

sea level of 1.4 m above mean sea level. According to the model, at that sea level the airstrip would be inundated.



Figure 2.4 – Tide gauge being installed at Adams Bay, Bequia
Photo: M. Sutherland (2012)

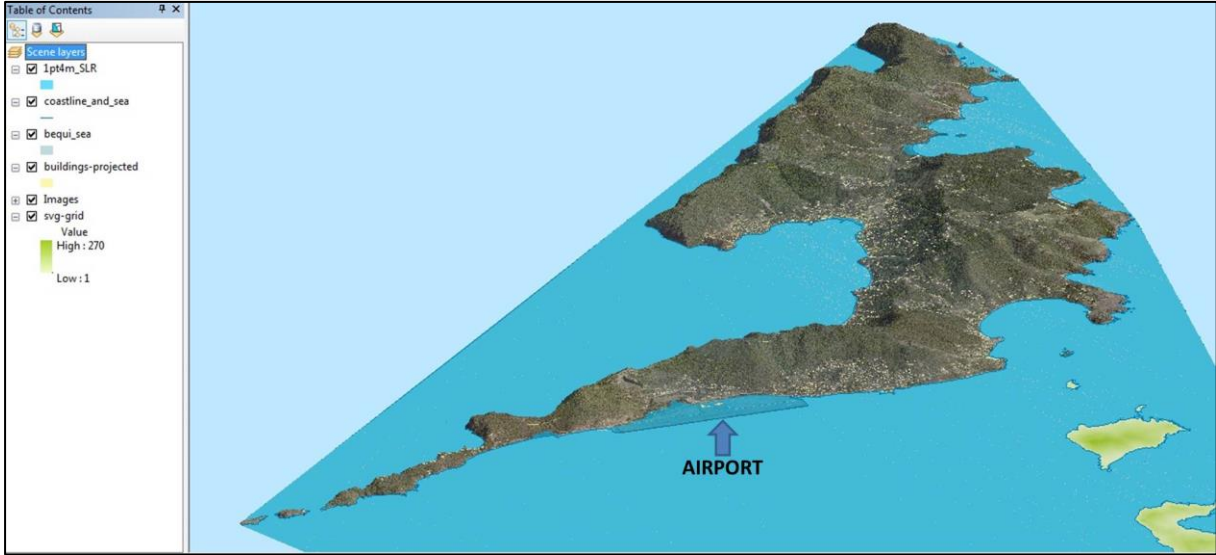


Figure 2.5 – Sea Level Rise Model of Bequia (1.4m above MSL)
From: Davis et al. (2013)

3. DISCUSSION

Within the Caribbean region 50% of the population live within 2 km of the sea, many depending on the coast for their livelihood (Adger et al., 2005; IPCC, 2007b). Activities such as fishing and tourism clearly relate to coastal activities, but in addition much of the agriculture is undertaken on low lying coastal flats. In the three case studies presented each local community is to some extent dependent upon the coast for survival. Different strategies were undertaken for assessment of the impact of sea level rise and these will lead to different approaches to mitigation. However, these results need to be placed into context and the purpose here is to examine whether sufficient information has been acquired to give cause for concern.

The scientific community agree that sea levels are rising globally and that the rate of change is increasing on that determined from historical records. Variation in results from different models presented by Bindoff et al (2007) demonstrate that the rate at which the increase is taking place is less certain, and different models give rise to different trends. Consequential flood hazard mapping and inundation modelling cannot depend on archive sea level data and need to assess scenarios based on the different predictive models. There are differing views on the reasons for sea level change and hence the scenarios for future impact are diverse. In a complex environmental problem with numerous associated modelling dimensions and parameters, the relationships and impacts have yet to fully understood.

Models used in the assessment are predictive and consider scenarios for sea level rise in conjunction with existing topography. The topography itself is measured with reference to mean sea level, which makes the comparison with sea level rise easy, i.e., assuming that sea level is accurately determined in the first instance. Within the Eastern Caribbean the tidal range is 1.4 m as a maximum and towards the North of the island chain this reduces to 0.6 m. There is an annual variation in sea level of ± 0.1 m about mean sea level, so short term sea level observations used to determine mean sea level need to consider annual variation. It is also shown by Miller, Hart and Sydney (2012) that variations can occur by up to 0.3 m for periods of up to two weeks and these incidents are random in terms of timing. A short term sea level data set acquired over a period of 30 days, which is the minimum considered necessary to estimate mean sea level could then introduce an error in the estimate of mean sea level of 0.15 m. Use of existing datums to relate topographic data to MSL is also subject to error. Many vertical datums of the Caribbean were determined using short term data, typically three months, and were established several decades ago. Furthermore, mistakes exist in records and sea level has changed relative to the land mass, with an example of this also being documented within Miller et al (2012).

In addition to the sea level rising the land mass is also deforming. All of the study areas are located within fault zones (Miller, 2006) where vertical deformation of the land mass can change considerably within a few kilometers. In order to make a full assessment of impact the rate of change of sea level relative to localised land movement would ideally be considered. Repeat observations with Global Navigation Satellite Systems over several years are required

to extract vertical land deformation, or alternatively sea level records could be used together with repeat levelling, but this would take even longer. Due to the localised nature of movement a single reference point on each island is insufficient. Existing records are sparse in the Caribbean, particularly in the smaller states that are governed independently. The time scale of sea level change needs to be considered in alignment with data acquisition, with the latter being a costly process, beyond the immediate priority budgetary objectives of the individual states. Where support has been provided from external sources the local capacity for maintenance to sustain data acquisition has not always been available and shortly after installation the measurement systems have failed (Henson, 2005; Sutherland, Dare and Miller, 2008).

Oral tradition and community involvement offers an alternative approach to data acquisition whereby local residents offer information concerning change within their lifetime. With knowledge of the terrain through observation of levels on the shore supported by visual inspection, the historical trend might be extrapolated. In addition to empirical data being acquired, this technique also creates local awareness. This qualitative approach enables rapid assessment, but without quantitative foundation is subject to different interpretation. What is perceived as inundation due to change in sea levels by local residents could in reality be erosion, or change in sediment movement along the coastline. Disappearance of former agricultural land in Bequia for example could be due to sea level rise, or alternatively change in the equilibrium state of sediment budgets brought about by construction of the airstrip through reclamation.

Results obtained from simulations studies through application of the bathtub model must also be questioned in the context of shoreline change. It is acknowledged that a rapid increase in sea level results in a change in the gradient of the sea bed within the surf zone with sand will be taken offshore. Storms have such an effect, and deeper waters adjacent then leave the remaining coastline susceptible to erosion from higher energy wave impact. There is some concern about this same effect occurring under a rise in sea level. However, when the sea level changes slowly, the beach will have a chance to adapt and change (Crooks 2004). Depending on the makeup of the foreshore and sediment sources available, the beach may simply recede. Morphology of the shoreline is not accurately modelled by just increasing sea level. As with the prediction of sea level change, the science and modelling of geomorphology is a complex process.

4. CONCLUSIONS

Within the Caribbean region there is a scarcity of data relating to detailed topography of coastal regions and sea level that is necessary to investigate impact of sea level change. Work undertaken at the selected sites has used a minimum of information and different approaches have been adopted. Topographic surveys of the coastal region offer a bare minimum of data required to consider impact of sea level rise where the latter is given by global trends and scientific predictive models. The reference surface used to represent mean sea level is difficult to establish to a sufficient accuracy in the short term. Also, connection to existing survey

reference points is problematic as they are subject to error introduced by time, original recording of values and the use of short term data sets in the first instance. Anecdotal evidence of historical change may also be used to consider further impact, but the reliability of information offered in terms of cause of coastal change does not offer conclusive evidence in terms of sea level change. Locals appreciate that change has occurred in their lifetime without appreciation for the reason and easily mistake inundation for erosion. Within the assessment of data that is acquired, use of the bathtub model for inundation modelling does not necessarily represent coastal geomorphology that may occur to accompany a slow change in sea level.

The dissemination of research results to communities through the presentation of scenarios based on short term data, which can support the development of plans to prepare for the worst, might be considered an appropriate course of action. However, instilling insecurity in coastal communities is not in their best interest. In terms of mitigation strategies, oral tradition exemplifies previous experiences of communities who have coped with events in the past. A dilemma then exists as to a suitable course of action based on uncertainty in the accuracy of data and results from modelling. Regarding government infrastructure, inundation of the airport in Bequia and beach loss would have a direct effect on the economy. International aid that has been provided to countries of the Caribbean, through the provision of instrumentation to acquire data for impact assessment, has not proved sustainable. In view of this, the more direct, but less accurate techniques are being assessed. In view of the limitations discussed, the more basic forms of assessment using less than perfect data at least provide the basis for the development of adaptation and mitigation strategies, and raise a general awareness on climate change issues.

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BIOGRAPHICAL NOTES

Dr. Michael Sutherland is currently Chair (2011-2014) of Commission 4 (Hydrography), International Federation of Surveyors. He is also a lecturer in land management, and Deputy Dean (Undergraduate Affairs), Faculty of Engineering, University of the West Indies, St. Augustine, Trinidad and Tobago. He is a member of the Canadian Institute of Geomatics and the Institute of Surveyors of Trinidad and Tobago, and is an elected member of the Royal Institution of Chartered Surveyors. In 2012 he was appointed Adjunct Professor in the Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada.

Dr. Keith Miller is a lecturer in geodesy and hydrography at the University of the West Indies. He is a member of the Chartered Institution of Civil Engineering Surveyors and of the International Board of Surveying Competencies in hydrography and nautical cartography. International experience through working at universities in the UK, Egypt and Australia contributes toward his teaching and research. Current research interests focus on the provision of reference frame at national level for Caribbean states.

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Dr. Dexter Davis holds a B.Sc. in Land Surveying from the University of the West Indies and a Ph.D. in Surveying Science from the University of Newcastle upon Tyne. He is currently a lecturer in the field of geodesy GNSS and geodetic surveying and is also Programme Coordinator of the B.Sc. of the Geomatics Engineering Programme in the Department of Geomatics Engineering and Land Management, University of the West Indies. He is a member of the Institute of Surveyors of Trinidad and Tobago as well as the ASPRS. His current research interests include geomatic techniques for hazard monitoring and mapping, including sea level rise and earthquake monitoring.

Amit Seeram is currently a postgraduate student at the Department of Geomatics Engineering and Land Management, Faculty of Engineering, University of the West Indies, St. Augustine campus pursuing MSc Geoinformatics. His thesis research involves assessing the potential impacts of Sea Level Rise within the coastal community of Roxborough, Tobago. This is being explored using topographical data collected through Geomatics and local knowledge collected through Participatory 3D modelling (P3DM) and Coastal Collaborative GIS (CCGIS). Amit holds a BSc Geomatics (2010) from the same Department and his undergraduate research was the development of a GIS model of Sea Level Rise for Grande Riviere, Trinidad.

Demi Singh attained a Bachelor of Science Degree in Geomatics at the University of the West Indies, Trinidad and Tobago in the year 2010. She is currently pursuing a Master of Science Degree in Geoinformatics at the same university. She previously worked on an International Community-University Research Alliance (ICURA) project dealing with the effects of climate change on coastal communities in Canada and the Caribbean. Ms. Singh has also worked on a marine cadastre project at the Land Management Division, Ministry of Agriculture, Land and Marine Affairs, Government of the Republic of Trinidad and Tobago.

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