Technical Report
TR 98002

"Coastal Vulnerability Assessment for Sea-Level Rise: Evaluation and Selection of Methodologies for Implementation"

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November 1998

A Publication of the
Caribbean Planning for Adaptation to Global Climate Change (CPACC) Project

Component 6:
Coastal Vulnerability and Risk Assessment

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EXECUTIVE SUMMARY

i. Coastal countries in the Caribbean are highly dependent on their coastal zones. Therefore, sea-level rise and climate change are an important threat which needs to be understood and then responded to, as appropriate. This report was completed as the first step in the implementation of CPACC's Component 6, *Coastal Vulnerability and Risk Assessment.* Three countries are participating in this pilot component, Guyana, Barbados and Grenada. The purpose of the component is to apply and improve vulnerability assessment (VA) methodologies for the Caribbean within the context of climate change and sea-level rise.

ii. The concept of vulnerability to impacts can be confusing, but it is an essential concept to understanding and responding to the integrated impacts of sea-level rise on the coastal system. Vulnerability is a multi-dimensional concept, encompassing biogeophysical, economic, institutional and socio-cultural factors and is usually defined as a system's *ability to cope with stress and shock.* In the context of coastal zones, vulnerability has been defined as "the degree of incapability to cope with the consequences of climate change and accelerated sea-level rise". Thus, vulnerability assessment includes the assessment of both the anticipated impacts and the capacity to adapt. In this study, the definition of vulnerability presented by Klein and Nicholls (1998) is used throughout, including as a reference to assess the different VA methodologies.

iii. Regional and national vulnerability assessments conducted in the Caribbean have demonstrated the great potential for adverse impacts to these countries. For example, studies for the islands of Nevis and Antigua stress the concentration of economic activities, including tourism, on the coast, which are the most hazardous situations for sea-level rise impacts. Possible increases in hurricane activity are also of concern. Engineering responses appear rather expensive and a planned retreat from the present shore via planning mechanisms such as building setbacks might be prudent. In Guyana the population is concentrated on a low-lying coastal plain which is already vulnerable to flooding and protected by dikes. The capital, Georgetown, is reported to be subsiding, exacerbating Guyana's vulnerability to global sea-level rise. However, all these studies require further work and need to be followed up with more detailed analysis and development of appropriate responses to these threats.

iv. Six potential VA methodologies and approaches are critically assessed in terms of their utility in the Caribbean:

- the IPCC Common Methodology (IPCC CZMS, 1992)
- the US Country Studies Program (Leatherman and Yohe, 1995)
- the UNEP's Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies (Burton et al., 1998) (henceforth the UNEP Handbook Methodology)
- the South Pacific Island Methodology (Yamada et al., 1995)
- the Caribbean Disaster Mitigation Project (OAS)
- the Research Institute for Knowledge Systems (RIKS) decision-support methodology

v. In the evaluation, the vulnerability assessment framework is distinguished from the vulnerability assessment tools. Some of the approaches are found to confuse the framework with the tools. The methods are also assessed against the definition of vulnerability of Klein and Nicholls (1998).

vi. The UNEP Handbook Methodology was selected as the most appropriate one for CPACC and the Caribbean. Aspects of the other approaches might be useful as part of the UNEP Handbook Methodology. For instance, the Caribbean Disaster Mitigation Project provides some good VA tools, while the South Pacific Island Methodology provides a structured approach to using expert judgment.

vii. Implementation of the UNEP Handbook Methodology is discussed. VA requires large amounts of data, and the VA studies will need to liaise with Components 2 and 3 of the CPACC, as these are focussing on GIS-based data. Some additional data collection will be necessary. VA demands a multi-disciplinary approach, and a three-person team is recommended for each study, comprising an environmental scientist or engineer, a socio-economist and a policy analyst. To liaise with government, a steering committee structure is recommended.

viii. In terms of the areas and issues to be studied, this remains to be decided. However, a qualitative screening assessment is recommended as a first step for the three countries. This would identify key socio-economic sectors and most vulnerable areas to be impacted by sea-level rise that could form the main focus of a quantitative vulnerability assessment. In the case of Guyana, a first national vulnerability assessment has already been completed, and this study could be used as a firm foundation. Given the problems of subsidence at Georgetown, combined with its rapid growth, a case study of the capital and its environs would be a useful study.

INTRODUCTION

1. This report is the first step in the implementation of Component 6, *Coastal Vulnerability and Risk Assessment, o*f the Caribbean: Planning for Adaptation to Global Climate Change (CPACC) project. The objective of this pilot component is to conduct vulnerability assessments for three countries: Barbados, Grenada and Guyana, and use these results to raise the level of awareness in the region concerning coastal vulnerability to climate change within each country. In parallel with these efforts, methodologies for vulnerability assessment (VA) are to be evaluated and then one will be adapted for application in the Caribbean, as appropriate.

2. Grenada and Barbados are small Caribbean islands which are quite similar in size (63 and 72 km of coastline, respectively). No previous VA for climate change has been conducted. However, Barbados has developed a detailed GIS-based inventory on coastal resources, while Grenada has much less data on its coastal resources. Guyana has a much longer coastline, about 500 km, that is supplied with sediment from the Amazon Delta, 1,000 km away. It has been the subject of several earlier vulnerability assessments, the most recent being Kahn and Sturm (1995). Therefore, in two cases Component 6 is establishing the first vulnerability assessment for sea-level rise, while in the third case, it is building on established studies.

3. In what follows, firstly the present understanding of the likely magnitude of sea-level rise is briefly reviewed. Secondly, the impacts of sea-level rise and the concepts of impacts and vulnerability to sea-level rise are reviewed, with a special emphasis on the problems of small islands. Thirdly, six possible methodologies to assess the impacts of sea-level rise are critically assessed against the systems model of vulnerability to sea-level rise of Klein and Nicholls (1998). Having selected the UNEP Handbook Methodology as the best approach, the implementation of this method in the Caribbean is considered. Finally, there is a discussion of the data, equipment, human resources and institutional arrangements which will be necessary for these studies.

THE PROBLEM OF SEA-LEVEL RISE

Future Sea-Level Change

4. Global sea levels may rise between 20 cm and as much as 1 meter in the coming century due to anthropogenic global warming (Warrick et al., 1996). This study only estimated the portion of global sea-level rise caused by anthropogenic climate change, excluding other factors such as natural variability, groundwater depletion and ocean basin changes. In addition, published models of future change underpredict historic sea-level rise from 1880 to 1980 (see Douglas, 1991; 1997) by about 1 mm/yr (Warrick et al., 1996; Titus and Narayanan, 1996), so this discrepancy alone adds about 10 cm of uncertainty to future projections to 2100. Therefore, while we expect a rise in global sea level, its magnitude has a large uncertainty. Mitigation policies to reduce or stop the growth of greenhouse gas concentrations in the atmosphere would slow, but not stop climate change even given stabilization of greenhouse forcing in the next few decades (which seems an optimistic goal). Therefore, there is a "commitment to sea-level rise" (Warrick and Oerlemans, 1990; Wigley, 1995) which suggests that some adaptation to sea-level rise will be essential during the next century.

5. Two other factors add to this uncertainty concerning future sea levels at the national and smaller scales relevant to vulnerability assessment within CPACC. Firstly, vertical land movements affect sea level. Relative sea-level rise - that is, the level of the sea in relation to that of the land - rather than global sea-level rise causes the impacts of sea-level rise. Land uplift will counter any global changes in sea level, while land subsidence will exacerbate global changes in sea level (Nicholls and

Leatherman, 1996). Secondly, there are dynamic effects resulting from existing oceanic circulation, wind and pressure patterns, and ocean-water density differences that cause variations in the level of the sea surface with respect to the geoid - that is, the surface that the ocean would exist in the absence of oceanographic and meteorological dynamics. According to experiments using coupled ocean-atmosphere models (e.g. Mikolajewicz et al., 1991; Gregory, 1993), climate-change-induced changes to these processes could cause significant departures from the global mean change in sea level (Warrick et al., 1996). Therefore, ocean dynamics add an additional component to relative sea level and further uncertainty to the magnitude of future change in relative sea level rise.

6. While these uncertainties could be taken as a reason for inaction, or `wait and see', a more practical view is the need to assess a range of scenarios within vulnerability assessment. These scenarios need to embrace the range of likely change.

Other Climate Change

7. In addition to sea-level rise, other aspects of climate are expected to change due to anthropogenic warming. However, unlike sea level, even the direction of that change is often uncertain. Sea-surface temperatures are certainly expected to rise and in the context of small islands, this will raise temperatures on the neighboring land areas. Many other changes of interest, such as windiness or precipitation cannot be resolved within General Circulation Models (GCMs), at this point. The possible consequences of climate change on the tracks and intensity of tropical storms and hurricanes is very important, particularly in the context of the Caribbean where they are a major hazard (Maul, 1993). It is often stated that the frequency and intensity of tropical storms and hurricanes will increase and this gives great cause for societal concern (Bijlsma et al., 1996). However, while the possible maximum storm intensity will increase in a globally-warmed world (Emanuel, 1987; Gray, 1993), this does not answer the question about regional changes in storminess, which could see both increases or decreases.

Impacts of Sea-Level Rise and Vulnerability to These Impacts

8. A relative rise in sea level, from whatever cause, will have a range of biogeophysical (i.e. physical and ecological) impacts. The major biogeophysical impacts are as follow (Bijlsma et al., 1996):

    - Inundate and displace wetlands and lowlands;
    - Erode shorelines;
    - Exacerbate coastal storm flooding (even if storminess does not increase);
    - Increase the salinity of estuaries, threaten freshwater aquifers, and otherwise impair water quality.

9. These impacts in turn will have socio-economic impacts on human activities in the coastal zone, such as human settlements, agriculture, freshwater supply and quality, fisheries, financial services and human health (see Watson et al., 1996).

10. The nature of the impacts of sea-level rise will vary from place-to-place and country-to-country due to a variety of factors, reflecting that certain settings are more vulnerable than others. This conclusion is widely supported by all the available studies (Bijlsma et al., 1996). Small islands, deltaic settings and coastal ecosystems appear particularly vulnerable.

11. The actual magnitude of impacts will depend on a range of factors and is in some sense a function of the *vulnerability* of the entire coastal system to sea-level rise (Bijlsma et al., 1996). While the concept of vulnerability to impacts can appear abstract and confusing, it is an essential concept to

understanding and responding to the integrated impacts of sea-level rise on the coastal system (IPCC CZMS, 1992; Bijlsma et al., 1996; Klein and Nicholls, 1998). Vulnerability is a multi-dimensional concept, encompassing biogeophysical, economic, institutional and socio-cultural factors and is usually defined as a system's *ability to cope with stress and shock*. In the context of coastal zones and climate change impacts, vulnerability was defined as "the degree of incapability to cope with the consequences of climate change and accelerated sea-level rise" by the IPCC Common Methodology (IPCC CZMS, 1992). Thus, by definition, vulnerability assessment includes the assessment of both anticipated impacts and available adaptation options. A simple impact assessment might not consider adaptation options to facilitate rapid analysis, but any comprehensive impact assessment must consider adaptation options, as adaptation potential will influence the magnitude of the actual impacts.

DEFINITION OF VULNERABILITY

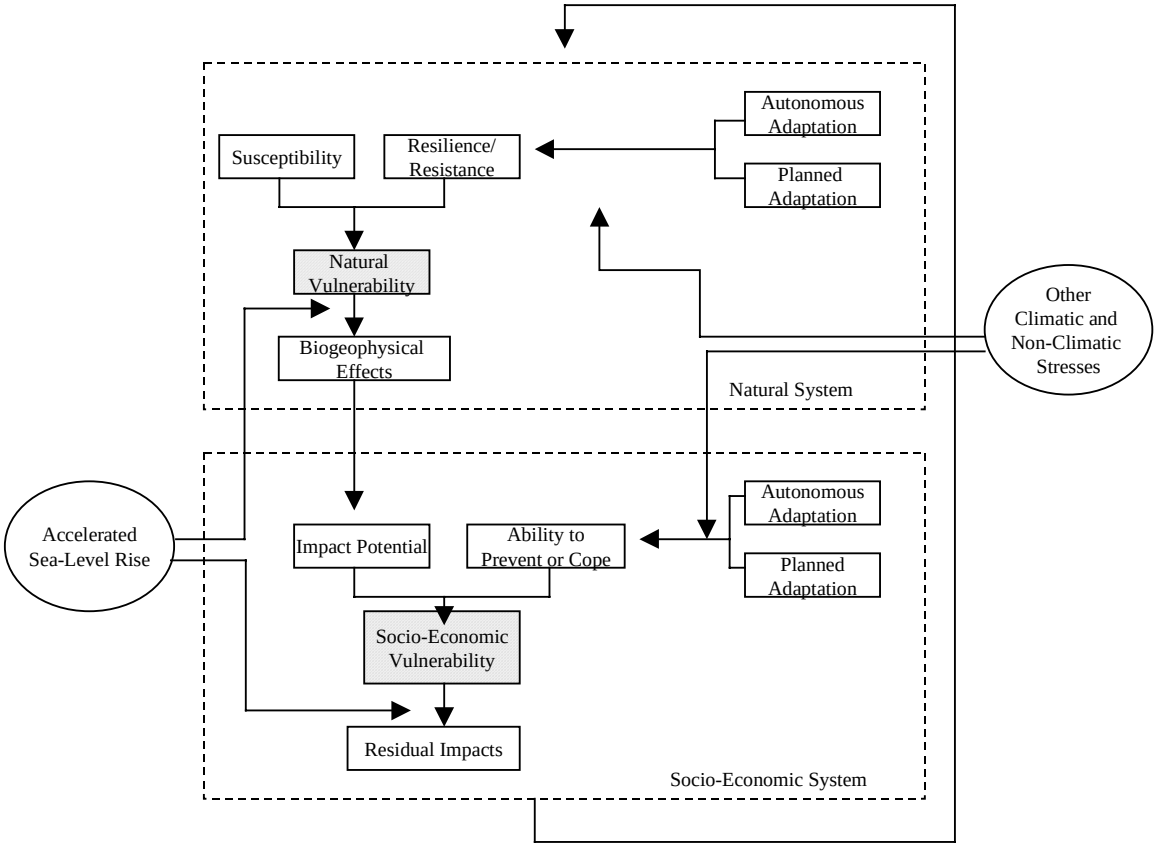
12. Klein and Nicholls (1998) defined vulnerability using a system-based framework, as shown in Figure 1. This framework is followed throughout this report and it helps to define the various concepts involved in vulnerability assessment and shows how these are related. It is also a useful reference to evaluate methods for vulnerability assessment. Firstly, it distinguishes between the *natural-system vulnerability* and the *socio-economic-system vulnerability* to climate change, even though they are clearly related and interdependent. Secondly, a proper analysis of socio-economic vulnerability to sea-level rise requires a prior understanding of how the natural system will be affected. Hence, analysis of coastal vulnerability always starts with the natural system response. Lastly, other climatic and non-climatic stresses are acknowledged, indicating that sea-level rise is not happening in a vacuum and that the coastal system will evolve due to factors other than sea-level rise.

13. Looking to the natural system, the biogeophysical effects of sea-level rise will depend upon the system's *susceptibility* (or sensitivity) to those effects, and its natural capacity to cope with these effects (*resilience* and *resistance*). Susceptibility simply reflects the coastal system's potential to be affected by sea-level rise (e.g., a low-lying, erodible coast versus a cliffed, unerodible coast), while resilience and resistance describe the natural system's stability in the face of perturbation. Resistance describes the ability of the system to avoid perturbation, while resilience describes the speed with which a system returns to its original state after being perturbed. Susceptibility, resilience and resistance collectively determine the coastal system's *natural vulnerability* to the biogeophysical effects of sea-level rise. Resilience and resistance are functions of the natural system's capacity for *autonomous adaptation*, which represents the coastal systems's natural adaptive response to sea-level rise (e.g., if sea levels rise, then wetlands respond by accreting upwards more rapidly which *might* stop the inundation that a simple 'bath-tub' model would suggest). As opposed to susceptibility, which is largely independent of human activities, resilience and resistance are often sensitive to human activities. Human influence often has negative consequences, but in contrast, *planned adaptation* can serve to reduce the natural vulnerability by enhancing the system's resilience and/or resistance and thereby enhancing the effectiveness of autonomous adaptation.

14. The biogeophysical effects of sea-level rise are likely to give rise to a range of potential socio-economic impacts. This *impact potential* is the socio-economic equivalent of the natural system's susceptibility, although unlike susceptibility, it is dependent on human influences. In parallel with a coastal zone's natural vulnerability, which is a function of susceptibility and resilience/resistance, *socio-economic vulnerability* is determined by the impact potential and society's technical, institutional, economic and cultural *ability to prevent or cope* with these impacts (i.e., its capacity to adapt within the timescale of natural changes). As with the natural system's resilience and resistance, the potential for *autonomous adaptation* and *planned adaptation* determines this ability to prevent and cope. Finally, it is important to acknowledge the potential for dynamic interaction between the

natural and socio-economic systems. Instead of being considered as two separate systems that exist independently of each other, natural and socio-economic systems are increasingly being viewed as developing in a co-evolutionary manner (Turner, 1996), although the extent of this interaction under different circumstances remains to be quantified (Nicholls and Branson, 1998). This co-evolution is shown in Figure 1 by the feedback loop from the socio-economic system to the natural system.

Figure 1. A conceptual framework for coastal vulnerability assessment (taken from Klein and Nicholls, 1996)



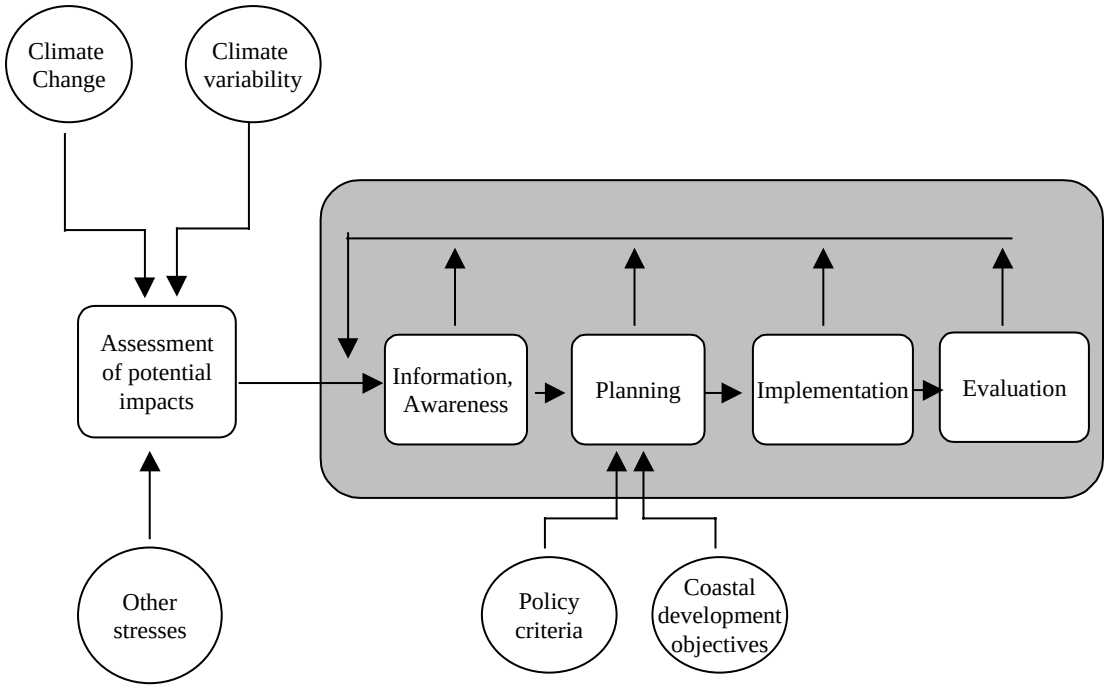
15. In practical terms, it is unlikely that all these system properties will be fully assessed in a vulnerability assessment. However, this model offers a goal of what a comprehensive vulnerability assessment could try and quantify.

ADAPTATION AND VULNERABILITY ASSESSMENTS

16. While the IPCC Technical Guidelines have an explicit adaptation assessment step, there is limited experience with adaptation to climate change and sea-level rise. Given CPACC's goal of fostering adaptation to global climate change, including sea-level rise, vulnerability assessment should proceed to clear recommendations on further action. Experience with the IPCC Common Methodology shows that many studies have not progressed to this stage for a range of reasons such as a lack of information, or uncertainty about how to consider adaptation (Nicholls, 1995a). Klein et al. (1998) have examined the process of adaptation to sea-level rise and considered how it might be better placed within the framework of vulnerability assessment. Both conceptual and empirical information from developed countries shows that coastal adaptation embraces more than simply selecting one of

the "technical" options to respond to sea-level rise (retreat, accommodate or protect) as defined in earlier reports (IPCC CZMS, 1990; Bijlsma et al., 1996). It is also important to recognize that coastal adaptation is likely to be an iterating process with a series of policy cycles, and therefore, the first attempt at adaptation will be followed by opportunities to modify and "tune" these adaptations, as appropriate. To be effective, an expanded adaptation framework involving four steps is suggested by Klein et al (1998), including (*i*) information and awareness raising; (*ii*) planning; (*iii*) implementation; and (*iv*) evaluation (Figure 2). This model suggests that just providing information is part of adaptation, and therefore, completing impact or vulnerability assessments are part of the adaptation process. There are potential feedbacks in the adaptation process at each stage. Each of these steps is now considered in turn.

Figure 2. A conceptual framework showing the iterating steps in coastal adaptation to climate change



(taken from Klein et. al., 1998).

17. Information is indispensable for coastal adaptation, and the more relevant, detailed and accurate the information that is available, the more targeted and effective adaptation strategies can be developed. The climate-related information required for coastal adaptation falls into four categories:

    - Anticipated impacts of climate change;
    - Anticipated trends of other potential stresses (*e.g.*, population increase, land-use changes);
    - Anticipated interactions between climate-related impacts and non-climatic developments;
    - Anticipated autonomous adjustments to combined climatic and non-climatic impacts.

18. Normally, this information would be produced by a vulnerability assessment. In practice, however, the first two types of information are most readily developed, while the assessment of any interactions between climate change and non-climatic stresses and of expected autonomous adjustments has proven more difficult. This is partly due to data deficiencies and partly due to a lack of concrete guidance. A recurring problem in coastal impact assessment is the incompatibility of time horizons over which climate-related impacts are assessed with those over which socio-economic developments can be projected. Because of these practical problems uncertainty remains considerable and decisions

on adaptation will have to rely on imperfect information.

19. Planning for adaptation must start before all uncertainties (concerning knowledge) are reduced to a minimum (otherwise it will never start). As stated above, adaptation is an iterating and continuous process and the cycle shown in Figure 2 is likely to be repeated a number of times over the next few decades as new information becomes available. In view of the iterating nature of the adaptation cycle, adaptation strategies must be designed and implemented in a flexible way such that they can be adjusted to include new knowledge and insights. Public education, participation and awareness is likely to be an important element of effective planning

20. Planning involves deciding which action could best be taken, and where, when and how this could best be implemented. Most VAs have focussed primarily on the first of these four considerations (*which* action), which requires some pre-implementation evaluation (examine constraints; quantify measures/formulate alternative strategies; weight objectives/evaluate trade-offs). Issues of spatial and temporal planning, however, are not generally raised, so the questions *where*, *when*, and *how* remain largely unexplored. Geographical information systems (GIS) and various decision techniques (*e.g.*, cost-benefit analysis, cost-effectiveness analysis, multi-criteria analysis) are available to assist in this type of planning. An important point is that the extent to which planning for coastal adaptation can benefit from these tools and techniques is an indication of a country's adaptive capacity, and should therefore be part of adaptation assessment. This also applies to the extent to which coastal adaptation could be integrated with other aspects of coastal management.

21. Implementation occurs after an adaptation strategy has been selected. As indicated by Bijlsma *et al.* (1996), an adaptation strategy can comprise one or more options that fall under the three broad categories *(planned) retreat, accommodate* and *protect*. However, an important issue is the context in which these technical measures are implemented. Technical options can only be implemented effectively in an appropriate economic, legal and institutional context. Thus, a successful adaptation strategy will comprise a mix of various adaptation approaches, tailored to the particular needs of the area at risk and aimed at reducing implementation constraints. In coastal adaptation assessment, it is therefore important to consider the context in which implementation of technical options takes place. This will give information on the effort required to allow adaptation to be successful.

22. Implementation has several other dimensions. Firstly, adaptation can be either *reactive* or *anticipatory* (Klein and Nicholls, 1997; Smit *et al.*, 1998). While the boundaries are often fuzzy, reactive adaptation takes place after impacts of climate change have become manifest, while anticipatory (or proactive) adaptation takes place before impacts are apparent. Secondly, adaptation may be considered to be *autonomous* or *planned* as already discussed in connection with the definition of vulnerability (Figure 1). Autonomous adaptation takes place without intervention of an informed decision-maker, while planned adaptation requires informed and strategic actions. Adaptation by natural systems is always reactive and autonomous, whereas adaptation in socio-economic systems can be either reactive or anticipatory, and autonomous or planned. However, anticipatory planned adaptation could include increasing the capacity of natural systems to adapt autonomously (*e.g.*, by creating space for wetland migration or nourishing beaches). Klein and Nicholls (*1997*) evaluated the range of options and found that most options require strategic action, while few will occur autonomously. Further, options to protect against sea-level rise can be implemented both reactively and proactively, while most retreat and accommodation options are most effective if implemented in an anticipatory manner.

23. Evaluation of the performance of any implemented measures against the stated goals is a key step in any management strategy (National Research Council, 1995). This process is illustrated in Figure 2 by the feedback loop from evaluation. Such evaluation can yield new insights and information, which

can allow the management process to "learn" and hence improve itself. There is limited experience of such evaluation at present, but it is evident in Britain and the Netherlands (Klein et al., 1998). The continuous need for evaluation implies that coastal adaptation assessment should include consideration of how the performance of suggested adaptation options can be measured.

24. Evaluation can be seen more broadly than occurring at the end of the adaptation process. It should be an ongoing activity at all stages (Figure 2). This is indicated by the three short arrows linking the three earlier stages with the evaluation feedback loop.

Discussion

25. Klein et al. (1998) identified a number of elements of adaptation that are not considered in existing VA guidelines. Important elements which have not been assessed include:

    - The interaction between climate change and other pressures in determining impact potential;
    - Public perception and awareness of climate change and its impacts;
    - Spatial and temporal planning of adaptation measures;
    - Mechanisms for public involvement;
    - Non-technical (*i.e.*, economic, legal, institutional) aspects of adaptation;
    - Tools and procedures to evaluate adaptation performance.

26. Including assessment of these elements within VA or adaptation assessment will give a more complete picture of a country's adaptive capacity and hence of the actions required to reduce its vulnerability. As shown above, these actions may well comprise more than the implementation of technical options to retreat, accommodate or protect. An important practical difficulty, however, is that little to no concrete guidance presently exists to assess the above elements of coastal adaptation. Incorporation of some of these deficiencies in future VA studies is an urgent priority.

SMALL ISLANDS, THE CARIBBEAN, AND SEA-LEVEL RISE

27. Small islands are widely considered to be vulnerable to sea-level rise (Pernetta, 1992; IPCC CZMS, 1992; Bijlsma et al., 1996; Nurse et al., 1998). Common factors are a low resource base, over reliance on a few sectors within the economy such as tourism or agriculture, a high population density and a tendency for that population to be concentrated in low-lying coastal locations which will be impacted by sea-level rise. Increasing human pressures, lack of resources, and the limited size of the islands also limits adaptation options (Bijlsma et al., 1996). While less critical, deltaic coasts such as Guyana -- its coastal processes are linked to the Amazon delta -- are also considered to be highly vulnerable (Bijlsma et al., 1996).

The Global Vulnerability Assessment

28. The overall vulnerability of small islands, including the Caribbean, becomes apparent in the regional analysis of Hoozemans et al. (1993). This work used the Common Methodology which was applied at the country scale to develop regional and global results (The national results are not considered reliable). It was assumed that sea-level rise is the only climate factor which changes. The Caribbean, Pacific Ocean and the Indian Ocean islands are all vulnerable regions in terms of population that could be affected by storm surges given a 1-m rise in sea level and the relative costs of protection. The results for the Caribbean region are summarized in Table 1, although note that Guyana is not included in this region.

Table 1. Flood Impacts of Sea-Level Rise on The Caribbean Region (from Hoozemans et al., 1993).

Scenarios			People in the Hazard Zone (PHZ)		People at Risk (PAR)		Adaptation Costs (US $)	
Sea-Level Rise (m)	Popu-lation	Adapt-ation	Number ($*10^3$)	% Total Population	Number ($*10^3$)	% PHZ	Cost ($*10^9$)	% GNP
0	1990	No	1,200	3.6	40	3.3	0	0
1	1990	No	2,600	7.9	110	4.2	0	0
1	2020	No	3,300	7.9	160	4.2	0	0
1	1990	Yes	2,600	7.9	20	0.8	12.6	21

32. People in the Hazard Zone (PHZ) are those people living at elevations below the corresponding ones to the 1 in 1,000 year storm surge. Given a 1-m rise in sea level and no population changes, it is estimated that this number will be about 2 million people. Population growth will exacerbate these numbers. People at Risk (PAR) is the number of people who experience flooding due to storm surges in an average year. It is a function of PHZ and the level of protection which exists. A 1-m rise in sea level will produce a roughly three-fold increase in PAR. If adaptation measures are taken to counter sea-level rise and reduce PAR to "acceptable" levels, the cost would be substantial -- $12.6 billion dollars at 1990 prices, which amounts to 21% of the 1990 GNP, or 0.21% of the GNP if you presume that adaptation costs are distributed uniformly over 100 years (which is a rather simple assumption!). These cost estimates assume an instantaneous rather than a progressive response and do not consider erosion in non-tourist areas or the costs of water management and drainage. Therefore, they are most useful as a relative rather than an absolute cost.

33. Wetland losses could also be substantial. If Cuba is excluded, more than half the coastal wetlands in the Caribbean could be lost due to a 1-m rise in global sea level (Hoozemans et al., 1993).

National Assessments

34. Several national assessments of the impacts of sea-level rise are available, including Antigua and Nevis (Cambers, 1994), Antigua and Barbuda (James and Jeffrey, 1997), and Guyana (Kahn and Sturm, 1995). These studies also suggest a high vulnerability to sea-level rise.

Guyana

35. Kahn and Sturm (1995) stress the importance of the coastal zone to the Guyanese people and economy. About 90% of the population live in the coastal zone and most agriculture land occurs on reclaimed land in polders which are drained by gravity at low tide. Therefore, unusually for much of the developing world, significant parts of the coast are already artificially defended. The coast is dominantly composed of silt and clay with most sediment being supplied from the Amazon, about 1,000 km to the southeast. Cycles of erosion and deposition are common, although it is argued that erosion dominates. Subsidence has been estimated to occur at the capital, Georgetown, at a rate equivalent to 1 m/century -- i.e. probably more than the expected global rise in sea level by 2100. All these characteristics suggest a high vulnerability to sea-level rise.

36. Kahn and Sturm (1995) used the IPCC Common Methodology (or CM) (IPCC CZMS, 1992) to examine the vulnerability of Guyana to accelerated sea-level rise. The full seven steps of the CM is successfully applied for both a 0.3-m and a 1-m global rise, giving an overview of some of the key issues raised by sea-level rise. Given a 1-m rise in sea level and present conditions, 400,000 people (rising to 600,000 people in 2020) would require relocation, while billions of US dollars of assets would be lost, assuming no human response. Protection appears feasible, and it would cost US $200 million to raise the existing defenses by one meter. These costs do not consider improved drainage of the polders and urban areas, or the ecological implications. However, large areas of coastal wetlands would be lost given this protection due to *coastal squeeze* -- the process by which wetlands are squeezed between a rising sea level and a rigid defense (Bijlsma et al., 1996). A number of potentially important impacts such as salinization and backwater flooding on estuaries and rivers are not evaluated. Identified needs are numerous including more elaborate vulnerability assessment. The potential benefits of regional collaboration with the neighboring countries of Surinam and French Guiana is also identified, as these three countries have similar coasts and hence, face similar problems given sea-level rise.

Nevis

37. Cambers (1994) examined the vulnerability of Nevis and Antigua (see below) to both sea-level rise and increased flooding due to more intense hurricanes using arbitrary scenarios. The Common Methodology was employed and despite the lack of much data, useful results were developed. These islands were selected because they both depend heavily on tourism, but they manage their coastal resources in different ways. In 1991, Nevis passed a setback policy which prohibits development within 37 meters of the high-water mark, with major development having to be 91-meters from the high-water mark. (Antigua had no such policy when Cambers conducted this research).

38. Losses of coastal resources could be significant with agricultural, sand production, tourism and urban areas being impacted by land loss and increased flooding. Most sand production is by beach mining, which seems in conflict with sustaining the tourist industry! This use of beaches reflects the lack of alternative sources of sand and is apparent in the price: the average cost of sand is >$25 per cubic meter, plus transport costs. In terms of response, Cambers notes that there are large opportunities for a managed or planned retreat from the shoreline given the present level of development. Hard protection would be undesirable in tourist areas and beach nourishment to maintain tourist beaches is likely to be an expensive option, at least when compared to prices in the United States (see Nicholls et al., 1995). Therefore, Cambers recommends that Nevis use their new setback law to maintain space so that sea-level rise can be managed in a flexible manner. More broadly, dealing with sea-level rise will be a big challenge for Nevis and external assistance will be required. This will include developing coastal zone management and monitoring and improving institutional capability.

Antigua and Barbuda

39. Existing problems on Antigua and Barbuda are numerous as outlined by James and Jeffrey (1997) and include hurricanes and associated storm surge, beach erosion and beach mining and mangrove destruction. Further there is overdevelopment of the coastal zone, including sites that are vulnerable to existing hazards (and hence sea-level rise). The economy depends heavily on agriculture and tourism, the latter factor being a great pressure for more coastal development. Therefore, sea-level rise and climate change will exacerbate existing problems; the case in most of the the world's coasts).

40. Cambers (1994) followed a similar approach on Antigua to her work on Nevis. Similar issues emerged and the impacts would be similar, although wetland loss may be a more important issue on Antigua. As with Nevis, the potential to move back from the coast today is quite high. However,

while a small (17-meter) statutory setback has existed since 1977 (James and Jeffrey, 1997), there is no planning process to encourage its enforcement or recommend bigger setbacks. Cambers recommended that Antigua develops coastal zone management, including building setback policies to deal with both existing problems of erosion and future impacts of sea-level rise. The broader issues of assistance and capacity building raised for Nevis are equally applicable to Antigua.

41. James and Jeffrey (1997) examine the vulnerability of the two island-nation of Antigua and Barbuda, following to some extent the work of Cambers (1994). The methodology which was applied by James and Jeffrey (1997) for the vulnerability assessment is not clearly referenced or defined. Looking at the main report is not illuminating as to the precise methodology, although anecdotally it is based on the UNEP handbook. (Klein and Nicholls, 1997; 1998) based on the IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations. Further an adapted version of the sustainable capacity index method of Kay and Hay (1993) which was developed for the Pacific islands is also used (see also Yamada et al., 1995). Therefore, the analysis can best be described as using a hybrid methodology.

42. As already noted, the approach of James and Jeffrey (1997) is qualitative to semi-quantitative and focuses on five representative study areas rather than the entire island. Climate change scenarios of a 1.25^{o}C rise in temperature, an increase in the number and intensity of tropical storms (which has important implications for rainfall) and a sea-level rise of 3 to 4 cm/decade, with an extreme rise of 10 cm/decade. These climate changes are superimposed on a densely populated coastal zone (40% of the population), an existing trend of increasing coastal development, increasing coastal engineering such as jetties, retaining walls and other embankments and the destruction of mangroves. Based on existing trends, it is unlikely that mangroves will not survive for many more decades, so the impacts of sea-level rise may not be an issue. The possible effects of climate change on sea grasses and coral reefs are uncertain and these systems are also stressed by human activity. A rise in seawater temperature may have more adverse effects than sea-level rise as corals in Antigua (and much of the tropics) are growing near the upper limit of their temperature tolerance (cf. Bijlsma et al., 1996). In terms of more direct impacts, erosion, flooding and in some cases saltwater intrusion will be important consequences of sea-level rise.

43. James and Jeffrey (1997) consider both short- and long-term responses for Antigua and Barbuda. In the short-term protection seems the inevitable response to the existing problems of erosion and flooding. It must be noted as being a little perverse to be considering beach nourishment at sites where beach mining is a current problem. In the longer term, with better planning which will steer coastal developments away from the more hazardous areas, it should be possible for planned retreat and accommodation to be the major responses to sea-level rise. To be possible, this needs to be accompanied by changes in coastal zone management today (cf. Cicin-Sain et al., 1997). These include more active conservation of marine areas, implementation of coastal setbacks for all future building, long-term planning of coastal infrastructure such as roads, and identification of alternative water sources, especially for Barbuda. To support these changes, a serious of institutional and educational recommendations are made.

44. While this study is essential qualitative to semi-quantitative, James and Jeffrey (1987) further the need for initiating action and planning for climate change which was initiated by Cambers (1994). Clear and feasible recommendations are made. Surprisingly, further and more detailed vulnerability assessments are not identified as a requirement.

Discussion

45. These studies show that several different approaches have produced useful results in the Caribbean region. In Guyana, the IPCC Common Methodology was applied and a set of quantitative results were developed which help to guide further research and adaptation within a broader context (Kahn and Sturm, 1995). Cambers (1994) applied the Common Methodology to both Antigua and Nevis. She found a number of difficulties, particularly a lack of the necessary data. However, as in Guyana, a range of important issues and further activities are identified. In Antigua and Barbuda, a more qualitative approach that is more reminiscent of some of the South Pacific Island studies was applied subsequently by James and Jeffrey (1997). Despite the qualitative nature of the study, precise and feasible recommendations are produced and it builds on Cambers (1994) and related studies.

VULNERABILITY ASSESSMENT METHODS FOR SEA-LEVEL RISE

History of Vulnerability Assessment

46. Impacts of sea-level rise have been assessed for the last decade or more. The first studies were in developed countries which felt particularly threatened by sea-level rise, such as the Netherlands (Louisse and van der Meulen, 1991; Peerbolte et al., 1991), and the USA which looked at the implications of climate change on all sectors, including the coast (Smith and Tirpak, 1989; Titus et al., 1991). In both cases these studies have lead to changes in policy, most clearly in the Netherlands where a policy of dynamic preservation of the coast now has legal authority (Koster and Hillen, 1995), and more informally in the USA, with important differences between states.

47. These earlier Dutch and US studies had a strong influence on the first generic VA methodology -- The IPCC Common Methodology (CM). First released in 1991 with a Dutch-US authorship, the only easily accessible form today is the 1992 revision (IPCC CZMS, 1992). It comprises a seven-step approach to the vulnerability assessment culminating in Step 7, "Identification of Future Needs." Similar approaches emerged in parallel with the CM in the early 1990s such as those described in Nicholls and Leatherman (1995). The CM and similar approaches had been applied in more than 24 national assessments and one global assessment by 1993/94 (Nicholls, 1995a) and many subsequent studies, including the Dutch country studies programme,. The US Country Studies Program used a broadly similar approach to the CM for coastal assessment (Leatherman and Yohe, 1996). While the CM and related methods generated large number of results, it also stimulated a major debate on the appropriate methods and frameworks to assess climate change impacts in coastal areas (e.g., McLean and Mimura, 1993; Bijlsma et al., 1996). Criticisms of the CM were numerous (as discussed below). It was considered by some to be particularly inappropriate for small islands in the South Pacific due to their subsistence-based economies and lack of the most basic data among other factors. As a result, alternative approaches to vulnerability assessment were developed specifically for these islands (Kay and Hay, 1993; Yamada et al., 1995; Nunn et al., 1996).

48. At the same time, and seemingly uninfluenced by the debate about vulnerability assessment in coastal zones, the generic IPCC Technical Guidelines for assessing climate change impacts and adaptations were developed (Carter et al., 1994; Parry and Carter, 1998). They also comprise a seven-step approach to vulnerability assessment for any sector or setting, be it a city, a forest, or an island. A comparison of the seven steps shows that they are not simply equivalent to the CM (Klein and Nicholls, 1998). The IPCC Technical Guidelines imply much less of the vulnerability assessment process, and yet they allow the user complete freedom in terms of selecting scenarios and detailed methods. They are presently being transformed into the UNEP Handbook with more specific guidelines for a range of different sectors (Burton et al., 1998), including coastal regions (Klein and Nicholls, 1997; 1998).

49. The experience of all these methodologies show that there are still barriers to conduct comprehensive impact and response analyses due to a number of factors, including:

    - incomplete knowledge of the relevant processes affected by sea-level rise and their interactions;
    - insufficient data on existing conditions;
    - difficulty in developing the local and regional scenarios of future change;
    - the lack of appropriate analytical methodologies;
    - questions raised by different socio-political conditions.

50. These issues will not be overcome rapidly, although significant progress can be made simply by recognizing these shortcomings and hence having realistic expectations of VA. These are some of the challenges that the CPACC studies need to overcome. After developing some basic criteria for assessment of VA methodologies, a review of the range of possible VA methodologies which could be used in the CPACC studies follows.

Assessing Vulnerability Assessment Methodologies

51. Before discussing existing methodologies, it is useful to consider what we are assessing. Any vulnerability assessment methodology comprises two distinct elements:

    - the VA framework -- a set of fundamental questions or steps, whose answer assists the VA assessment, and collectively constitute some overview of a coastal area's vulnerability to sea-level rise;
    - the VA tools -- a method to accomplish one fundamental step, or answer one fundamental question posed by a VA framework.

52. Therefore, these elements are hierarchical, and the VA tools are "hung" on the VA framework. In general, there are a number of VA tools available for each step/question produced by the VA framework, although a VA framework may recommend a specific VA tool or approach. Examples of such tools are (1) the Bruun Rule for beach erosion, (2) coastal engineering design methods to estimate potential response costs, and (3) cost-benefit analysis to choose between different response options. VA methodologies which confuse the VA framework with the VA tools are considered to be inherently flawed.

The IPCC Common Methodology (CM)

53. The CM was first proposed in 1991 and a revision was produced based on experiences with the first studies in 1992 (IPCC CZMS, 1992). (Although not strictly following the CM, similar methods emerged at about the same time, such as those used in Nicholls and Leatherman (1995)). The CM comprises seven generic steps as follows:

    Step 1. Delineate the case study area;
    Step 2. Inventory study area characteristics;
    Step 3. Identify the relevant socio-economic development factors;
    Step 4. Assess the physical changes;
    Step 5. Formulate response strategies;
    Step 6. Assess the Vulnerability Profile;
    Step 7. Identify future needs.

54. Different types of impacts are assessed and inventoried including values at loss, values at risk (to flooding), and values at change (where the sense of change is uncertain) such as:

- socio-economic value at loss: land, property and population in inundated areas;
- socio-economic value at risk: land, property and population in flooded areas;
- socio-economic value at change: land use pattern, additional financial expenditures;
- loss of ecosystem: total area of inundated wetlands, areas of important ecosystems;
- loss of cultural and historical heritage: number of historical sites.

55. Impacts are determined both with and without response strategies and then assessed using a vulnerability profile. This has pre-defined boundaries between low, medium, high and critical impacts. As these boundaries were selected in an arbitrary manner, the results should be treated in a relative rather than an absolute sense. The final judgement on what and what is not a critical impact is better derived from a more participatory process.

56. The CM is an example of a well-structured VA framework -- clear generic questions are posed by each step in a logical sequence. Issues of timescale and sea-level rise scenarios are tightly prescribed, although it is worth noting that the CM has been significantly adapted by some users (e.g. Turner et al., 1995). This was in response to a deliberate mismatch in timescales between the climate change and socio-economic scenarios. The former assumes a global rise in sea level of 0.3 or 1 meter (and no other climate change, although a user could create other climate change scenarios if desired), which corresponds to the range of likely change by 2100, while the socio-economic scenarios are based on today and 30 years in the future. This reflects the difficulty of developing socio-economic scenarios for 100 years in the future, but raises the legitimate concern that the results produced with the CM overstate the effects of sea-level rise and understate the influence of other changes. This concern is amplified by the fact that few studies projected socio-economic conditions at all and they present the impacts of sea-level rise on a today's world (Nicholls, 1995a). Such results are still useful, but they need to be interpreted with this limitation in mind.

57. In terms of VA tools, little or no guidance is provided and there is an implicit assumption that the user of the CM is familiar with all the different VA tools. If a consultancy from a developed country conducted the VA this is true, but without such support, the CM is difficult to implement without a supporting handbook, or substantial training in appropriate VA tools.

58. The CM has helped to focus the attention of many coastal nations on climate change and it has contributed to longer-term thinking about the coastal zone -- VA studies are one possible trigger of increased efforts towards integrated coastal zone management (ICZM). It also provided significant data in a form suitable for the syntheses presented to the UNCED Meeting in Rio (IPCC CZMS, 1992) and within the IPCC Second Assessment Report (Nicholls, 1995a; Bijlsma et al., 1996). On the other hand, a number of problems have been raised concerning the CM through the experiences of vulnerability assessment case studies (WCC'93, 1994; Yamada et al., 1995; Bijlsma et al., 1996):

    - Many case studies that have used the Common Methodology have faced a shortage of the accurate and complete data necessary for impact and adaptation assessment. In particular, it has often been difficult to determine accurately the impact zone in many countries owing to the lack of basic data, such as the coastal topography.
    - Many studies have been directed towards a single global scenario of sea-level rise (1meter by 2100), often owing to a lack of more detailed data on coastal elevations, while most studies have ignored the spatial distribution of relative sea-level rise and other coastal implications of climate change, owing largely to a lack of regional climate scenarios.
    - Although the Common Methodology encourages researchers to take into account the biogeophysical response of the coastal system to sea-level rise, lack of data and models for describing the complicated non-linear coastal processes have hindered detailed quantitative impact assessment. Many case studies have carried out a simple linear, first-order assessment

by shifting the coastline landward by an amount corresponding with the sea-level rise scenario.

- As to adaptation, the Common Methodology has been less effective in assessing the wide range of technical, institutional, economic and cultural elements present in different localities. There has been concern that the methodology stresses a protection-orientated response, rather than consideration of the full range of adaptation options.
- Market-evaluation assessment frameworks, as applied in the Common Methodology, have proved inappropriate in many subsistence economies and traditional land-tenure systems.
- While the susceptibility of coastal systems is well-assessed, the resilience and ability to cope are largely unevaluated (see Figure 1).

59. Some of these problems such as lack of data are generic to all VA efforts. Other problems such as the perceived bias towards a protect response, or market-evaluation assessment frameworks are a function of the methodology and can be improved if so desired.

60. In summary, the CM (and its sister approaches such as Nicholls and Leatherman (1995)) provided an important start to VA, including rapidly developing a large body of broadly comparable results and a better understanding of the problems raised by VA. It remains a useful framework to think about the problems of sea-level rise, but it requires more realistic assumptions on timing, user-freedom to select scenarios and guidance on the range of appropriate VA tools. The UNEP Handbook is tackling this.

US Country Studies Program (Leatherman and Yohe, 1996)

61. The US Country Studies Program has an overall approach which draws on the early versions of the IPCC Technical Guidelines and stresses that the method provided is only a suggestion of one possible approach that is feasible within the resources provided to each study (Benioff et al., 1996). However, the guidance provided for the coastal regions (Leatherman and Yohe, 1996) references the CM and closely follows the method used by Nicholls and Leatherman (1995) with a more sophisticated economic analysis module. As noted by Leatherman et al. (1995) and Nicholls et al. (1995), the approaches that were used can be viewed as one approach to obtain the data necessary to follow the CM. The only hazards evaluated were erosion and inundation due to a range of global sea-level rise scenarios and these were assumed to impact today's world (i.e., no socio-economic changes are considered).

62. The method of Leatherman and Yohe (1996) in outline comprises four steps:

    Step 1. Preliminary Screening
    Step 2. Aerial Videotape-Assisted Vulnerability Analysis (AVVA)
    Step 3. Economic Analysis
    Step 4. Adaptation Analysis

63. Key steps defined in the CM such as define the study area are stated in the general documentation (Benioff et al., 1996), but they are not restated by Leatherman and Yohe (1996). In many respects the methodology is muddled as it confuses the VA framework with the VA tools. Step 2 should really be two steps in a VA framework: (1) coastal characterization, and (2) land loss estimation. To accomplish these two steps, a set of tools are recommended which have been collectively termed AVVA. In practical terms coastal characterization is accomplished using oblique aerial videography as the major tool to acquire coastal data, combined with other data sources such as charts. Land loss is estimated using a few simple models such as the Bruun Rule.

64. The sequence of the economic and adaptation analysis is confused as the economic analysis uses results from the adaptation analysis. The adaptation analysis simply consists of determining the costs of four protection scenarios against sea-level rise using a combination of port upgrade, beach nourishment and sea walls, depending on the coastal use. The decision on which of these protection scenarios is most sensible is made in a simple manner within the previous step of the economic analysis. This uses an inventory which balances losses (in the 1990s) against the likely costs of protection (against sea-level in 2100). This defines three classes of coastal area: (1) those where protection is likely, (2) those where abandonment (a planned retreat?) is likely, and (3) those where the response is uncertain. This analysis should not be confused with a cost-benefit analysis -- see Turner et al (1995) for a cost-benefit analysis applied to sea-level rise.

65. For application, Leatherman and Yohe (1996) provide a work book in an appendix (this is a standard feature of the US Country Studies Program). In contrast to the CM, VA tools are laid out for a user and despite the methodological problems raised above, it is more likely that a developing country would produce some results working alone using this method than the CM. (The US Country Studies Program generally sent experts for in-country visits, so users had more guidance than the Manual alone).

66. In conclusion, the VA methodology of Leatherman and Yohe (1996) has produced results in a number of countries, but many of the same criticisms of the CM can also be raised, including (1) a mismatch in time scales, (2) an overemphasis on market-based analyses, (3) an over-emphasis on protection, and (4) an overemphasis on assessing susceptibility characteristics rather than resilient characteristics. Further, the methodology only deals with two of the hazards produced by sea-level rise (erosion and inundation), while other impacts of sea-level rise may more important in certain settings. Lastly, there are fundamental problems with the approach as a VA framework. While the workbook approach can be commended, the US Country Studies Program could usefully review its methodology for coastal regions.

The UNEP's Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies (Burton et al., 1998)

67. The IPCC developed Technical Guidelines for Assessing Climate Change Impacts and Adaptations (Carter et al., 1994). These guidelines offer a generic framework consisting of seven main steps of analysis which is designed to be applicable to any natural and socio-economic system potentially affected by climate change. These steps are:

    Step 1. Define the problem;
    Step 2. Select the method;
    Step 3. Test the method;
    Step 4. Select scenarios;
    Step 5. Assess the biogeophysical and socio-economic impacts;
    Step 6. Assess the autonomous adjustments;
    Step 7. Evaluate adaptation strategies.

68. Based on these generic IPCC Technical Guidelines, the United Nations Environment Programme (UNEP) recently published a preliminary version of a handbook that provides an elaboration of the guidelines for nine important physiographic systems and socio-economic sectors (Burton et al., 1998), including coastal zones (Klein and Nicholls, 1997). The handbook is envisaged to provide practical guidance to country studies that, in accordance with the Framework Convention on Climate Change, aim to assess the potential consequences of climate change and identify options to respond to these effects.

69. The VA framework proposed by the Technical Guidelines should not be confused with the seven steps of the IPCC Common Methodology. This reflects that the Technical Guidelines are designed to serve as a more generic framework for any natural or socio-economic system. Therefore, some of the steps outlined in the Technical Guidelines do not appear in the Common Methodology. For example, the definition of the problem and the selection of the method are steps 1 and 2 of the Technical Guidelines, while they are only implied in the Common Methodology. Testing the method is not an explicit step in the Common Methodology. Further, the assessment of autonomous adjustments (Figure 1) is considered explicitly in the Technical Guidelines, but not in the Common Methodology. The final step of the Technical Guidelines, the evaluation of adaptation strategies, is again made up of seven consecutive steps, which approximate steps 5, 6 and 7 of the Common Methodology. Development of an adaptation strategy (Step 7 of the Technical Guidelines) has the following seven sub-steps:

    Step 7a. Define objectives;
    Step 7b. Specific important climatic impacts;
    Step 7c. Identify adaptation options;
    Step 7d. Examine constraints;
    Step 7e. Quantify measures and formulate alternative strategies;
    Step 7f. Weight objectives and evaluate trade-offs;
    Step 7g. Recommend adaptation measures.

70. Therefore, the Technical Guidelines are outlined in a similar fashion to the Common Methodology, but less steps are implied and less prior knowledge is assumed. Further, the Common Methodology is prescriptive in the choice of scenarios, but gives little detailed discussion of specific tools and techniques to conduct the actual analysis. In following the seven steps of the Technical Guidelines, Klein and Nicholls (1997) present a range of alternative tools and techniques that can be employed in identifying coastal vulnerability for the range of coastal hazards associated with sea-level rise, and discuss these in detail. They make extensive use of the experience gained in using the Common Methodology to elaborate the Technical Guidelines. The problems raised by the Common Methodology are fundamental and the work of Klein and Nicholls (1997; 1998) should be seen as one step in an ongoing process of upgrading VA frameworks and tools rather than as an endpoint. In the immediate future, more attention will have to be given to the effects of changing frequencies, intensities and areal occurrences of extreme weather events. At this stage, however, climate models cannot give conclusive results as to the direction and magnitude of such changes (Houghton et al., 1996).

71. Given the freedom to select scenarios, the Technical Guidelines allow a wide range of climatic and non-climatic changes to be considered. Further these can be divided into environmental changes and socio-economic developments. Therefore, the user is encouraged to examine the *relative importance* of a range of climate change scenarios, including sea-level rise versus each other, and versus other plausible changes. Lastly the interaction of different scenarios can be examined. Sea-level rise may not be the most important climate change -- storminess causes much concern, while sea-water temperature may be the key impact variable for coral reefs (Bijlsma et al., 1996). In cases where there are no accepted climate change scenarios, arbitrary scenarios are suggested to allow for sensitivity analysis.

72. Different levels of analysis can also be explicitly considered. As already noted, many vulnerability assessments have been hindered by the limited availability of data. Sometimes there has also been a mismatch between the available data, the level of effort, and the sophistication of the models utilized in vulnerability assessments. This has sometimes led to inappropriate expectations concerning the outcomes of the assessment studies. In most countries, an iterative approach is most useful. The first vulnerability assessment will provide a range of useful results, including providing a foundation for

subsequent studies of the impacts of sea-level rise. To help to structure the approach, to optimize the level of effort, and to make the likely outcome of studies more explicit, it is useful to consider three levels of increasingly complex assessment (Klein and Nicholls, 1998; Nicholls, 1998):

- screening assessment (SA) (least complex);
- vulnerability assessment (VA);
- planning assessment (PA) (most complex).

73. Analysis in the framework of a country study should start with SA. The results of the SA can then be used to plan how VA might be most effectively implemented. VA will provide broad concepts and ideas concerning impacts and possible adaptation. PA can be viewed as the link between VA and detailed coastal planning and management. PA is a response to more detailed and precise management questions and aims to produce management recommendations concerning possible adaptation measures. SA and VA can all be repeated a number of times, if appropriate, while PA is considered to be an ongoing process within coastal zone management.

74. The Technical Guidelines (subsequently the UNEP Handbook Methodology) of Klein and Nicholls (1997) offer a significant improvement compared to the IPCC Common Methodology and the US Country Studies Program in terms of a structured and flexible VA framework. While some VA tools are recommended, the approach is not prescriptive and the full range of VA tools can be used as part of the Methodology.

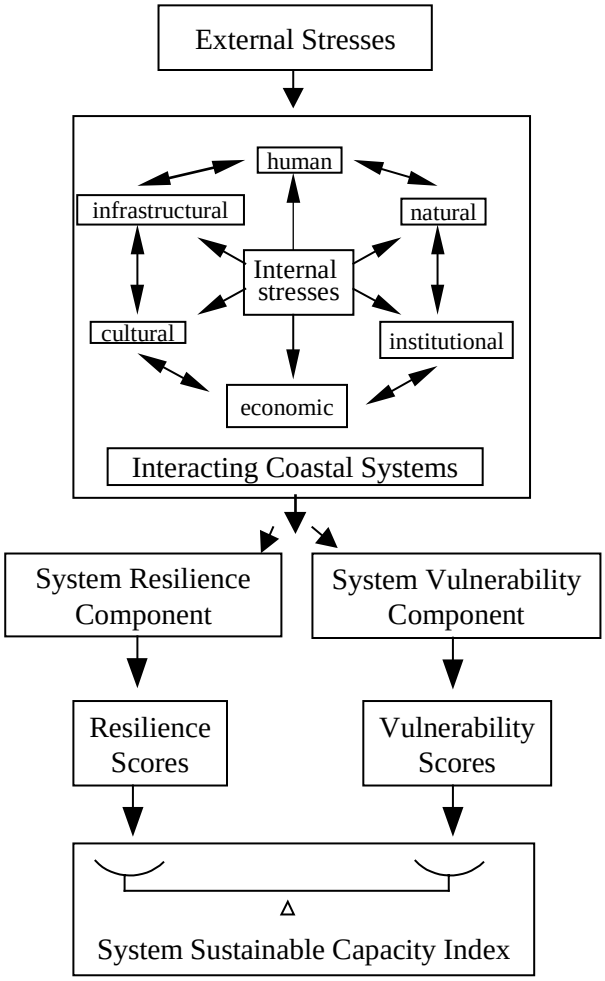
The South Pacific Island Methodology (Yamada et al., 1995)

75. Application of the CM raised more problems in some parts of the world than others, reflecting different levels of development and socio-cultural conditions which challenged the fundamental assumptions of the CM's originators. This problem was greatest for the small islands of the South Pacific due to the limited availability of basic data and more particularly the traditional subsistence economies and patterns of land tenure which make market-based assessment approaches meaningless (McLean and Mimura, 1993; Nurse et al., 1998). To overcome these problems, an index-based method was developed for these locations (Kay and Hay, 1993; Yamada et al., 1995).

76. The model which Kay and Hay (1993) used to describe the methodology is shown in Figure 3. The goal is to evaluate the coastal vulnerability and resilience (equivalent to the susceptibility and resistance/resilience, respectively, of Klein and Nicholls (1998)). The coastal zone is viewed as a set of six interacting systems. These systems can be hard or soft. The three "hard" systems comprise the tangible elements of the coastal zone: (1) the natural environment, (2) the people, and (3) the human-made infrastructure; while the three "soft" systems encompass the less tangible elements of the coastal system: (1) the institutions, (2) the socio-cultural factors , and (3) the economic system. These systems receive impacts from external and internal stresses and also interact with each other.

77. Each of these systems can be further divided into a number of sub-systems. While the potential number of sub-systems is large, in practice a relatively small number has proved sufficient to define all the key components as illustrated in Table 2. A key point is that the sub-systems should always be selected by local experts. Each sub-system is given a vulnerability and a resilience score from -3 to +3, based on expert judgement, for the following scenarios: (1) today's situation; (2) the future with sea-level rise and no management; and (3) the future with sea-level rise and optimum management. For each sub-system, these two values can then be combined to produce a sustainable capacity index for each scenario.

Figure 3. The sustainable capacity index approach as applied to South Pacific Islands (taken from Yamanda et. al, 1995).



78. As this method measures susceptibility and resilience/resistance, the approach is methodologically consistent with Klein and Nicholls (1997; 1998) and the sustainable capacity index can be looked on as a form of vulnerability index. Using this method in South Pacific countries such as Fiji (Yamada et al., 1995), it has been possible to conduct first-order vulnerability analyses and even select broad response options that might be appropriate given sea-level rise. However, questions remain as to the scoring within each sub-system and the relative importance of each sub-system -- by implication, each sub-system has equal weighting in the present form of the methodology.

Table 2. Coastal Systems and Sub-Systems for South Pacific Islands (following Yamada et al., 1993).

System	Sub-System
Natural	Physical
	Biological
Human	Population
Infrastructure	Individual Assets
	Communal Assets
	National Assets
Institutional	Settlement
	National
Cultural	Communal
	National
Economic	Cash
	Subsistence

92. More recent developments of the methodology on Fiji have tested the scores between operators and found them to be similar, which gives confidence in the validity of the method (Nunn et al., 1996). However, the lack of data and the need for experts hinders the application of the approach. Therefore, GIS databases of coastal geomorphology have been developed as one possible input. More data on precise coastal elevations at a 0.5-m vertical resolution is also required. Therefore, while the method as described by Yamada et al. (1995) is a good beginning, as with the other VA methods, development of the approach towards coastal management require more precise and detailed data to be available.

93. In terms of a VA framework, this method is logical and robust. The VA tools which are required are also simple and straight forward. This was the originators intention and they seem to have succeeded. However, application of this VA framework to settings other than the South Pacific would raise important questions. This would include a reevaluation of both the coastal sub-system classification and possibly the scores.

Caribbean Disaster Mitigation Project

94. The OAS, Caribbean Disaster Mitigation Project (CDMP), selected The Arbiter of Storms (TAOS) storm and surge model to create hazard maps (Watson, 1995). TAOS is a system which is a coupled model which takes data from GIS sources on land cover/land use, nearshore bathymetry and topography to deduce factors such as a digital elevation model and the frictional characteristics of the ground. When combined with meteorological inputs, a storm model is run and outputs include time series of surge height, wave height/direction and wind speed/direction suitable to be exported to a GIS. This GIS functionality makes TAOS a useful package for hazard management.

95. In terms of vulnerability assessment to sea-level rise and possible increased storminess, TAOS would be a useful VA tool to define extreme surge and wave characteristics. This could be accomplished with new model runs, or possibly simply using the results from the CDMP study.

RIKS and other decision-support methodologies

96. All the methodologies considered so far have been essentially low-level and bottom-up. They start with climate scenarios and in a step-wise manner they examine the implications of sea-level rise from

the climate scenario, through the physical consequences, the societal consequences, and ultimately adaptation and implications. An alternative approach is to develop a generic top-down model which can take site-specific georeferenced data as an input, analyze the impacts of different scenarios (such as sea-level rise) on the specific system and provide relevant output to support decisions. This type of model is usually termed a decision-support system (or DSS). The growth of computing technology and the related developments in GIS technology have allowed major growth in this area (see Costanza et al., 1990).

97. In the context of small islands, the Research Institute for Knowledge Systems (RIKS) has developed a DSS for small islands (Engelen et al., 1993; 1996). The DSS is very interesting as research tool and a means to structure questions about how a small island system works. Within the DSS model, the socio-economic system is explicitly defined and can interact with the physical effects of climate change, as well as changes in global trade patterns, and any other scenario you wish to develop. However, in terms of building capacity within the islands, this represents something of a "black-box" brought in from the developed world. Engelen et al (1993; 1996) stress the need not to believe the model -- it is a tool to assist decision-making, not the real world. Also the availability of data can be a problem.

98. Other Decision Support Systems have been reviewed by Klein and Nicholls (1997). Examples include the Adaptation Strategy Evaluator (ASE), developed by the US Environmental Protection Agency and the Coastal Zone Simulation Model (COSMO), developed for the World Coast Conference (Noordwijk, 1-5 November 1993) by the Dutch Coastal Zone Management Centre. At the present stage of development, these generic software packages have limited utility to site-specific application, although they do have important research and educational value. More detailed application assumes that we understand the behavior of the system that is being modeled. The physical impacts of sea-level rise are relatively easy to model if suitable data and scenarios are available, but the interaction between these impacts and an evolving socio-economic system is more complex, and an evaluation of response options is even more challenging. The selection of appropriate responses to sea-level rise is seen as a key weakness in our understanding of impact and adaptation assessment (Bijlsma et al., 1996).

99. Therefore, DSS approaches are not seen as appropriate for CPACC at this stage. However, the local capacity that will be developed will facilitate use of DSS approaches in the future, if that is desired.

Discussion of Vulnerability Assessment Methodologies

100. Table 3 summarizes the methods of vulnerability assessment considered here.

101. While the Common Methodology has a number of advantages, it also has numerous disadvantages. The UNEP Handbook Methodology supersedes this approach and it is unlikely to be applied again. The US Country Studies methodology is a rather muddled and confused approach which again suggests avoidance. However, the Workbook approach assists application in developing countries. The UNEP Handbook Methodology has a strong conceptual basis and a well-developed VA framework which considers all the impacts of sea-level rise and climate change and provides guidance on possible VA tools. However, it remains relatively untested. Further, it must be considered as one step in the development of vulnerability assessment methodologies due to generic problems such as limited data availability and the absence of appropriate models of important processes, particularly for the socio-economic aspects of the coastal system. The South Pacific Islands Methodology is appropriate for an area with limited quantitative data and has assisted efforts to understand the possible impacts and adaptations to sea-level rise in this region. However, the results are qualitative, or semi-quantitative at best. In the Caribbean, the availability of data may not be high,

but it is much greater than in the South Pacific. The Caribbean Disaster Mitigation Project is a good VA Tool and could be used within an appropriate VA Framework. The RIKS Decision Support Methodology provides an interesting educational and research tool to understand the response of small islands to sea-level rise and other changes. However, within CPACC's aim of capacity building, it seems an inappropriate approach.

Table 3. An assessment of the Different Methods for Vulnerability Assessment,

Methods	VA Framework or Tool?	Advantages	Disadvantages	Comments
Common Methodology	VA Framework	1. Logical prescribed structure 2. Lends itself to producing consistent results -- useful for global aggregation 3. Widely used	1. Inflexible, stressing susceptibility, not vulnerability assessment 2. VA tools not discussed 3. Adaptation options insufficiently developed. 4. See text for more.	Superseded by the UNEP Handbook VA Framework
US Country Studies Methodology	Muddled	1. Some VA tools described. 2. Workbook approach	1. Confuses VA Framework and Tools 2. Only addresses Land Loss impacts 3. Stresses susceptibility, not vulnerability assessment	Not recommended, except the Workbook approach
UNEP Handbook Methodology	VA Framework with guidance on VA Tools	1. Good conceptual basis. 2. All impacts considered. 3. Guidance on possible VA tools provided	1. Remains to be widely tested.	
South Pacific Islands Methodology	VA Framework with qualitative VA Tools	1. Useful in areas with limited data 2. Conceptualizes vulnerability into measurable elements	1. Results are qualitative to semi-quantitative	In the Caribbean, more data exists than in the South Pacific Islands.
Caribbean Disaster Mitigation Project	VA Tool	Not applicable	Not applicable	Useful within a VA Framework
RIKS Decision Support Methodology	Integrated Model	1. The complete coastal system is considered, and interactions can be specified as desired.	1. The approach can be become black-box. 2. The availability of appropriate data	Too complex for CPACC's aim of capacity building

109. In terms of the framework outlined in Figure 1, two of the VA frameworks encourage susceptibility assessment, rather than vulnerability assessment: (1) the IPCC Common Methodology, and (2) the US Country Studies Methodology. Thus, modeling tends to be based on a static view of the coastal zone. Three VA frameworks encourage a more dynamic perspective on the coastal zone, including resilient factors: (1) the UNEP Handbook Methodology, (2) the South Pacific Islands Methodology, and (3) the RIKS DSS Methodology. Within these approaches, even if a static analysis is undertaken this is an explicit decision rather than an implicit property of the VA Framework.

110. Of these three approaches, the UNEP Handbook Methodology appears to be most appropriate for vulnerability and adaptation assessment in the Caribbean. The South Pacific Islands Methodology is

qualitative, by definition. The RIKS DSS Methodology is too sophisticated and black-box given the mission of CPACC to strengthen capacity within the region. However, the UNEP Handbook Methodology is flexible and analysis can be conducted at the appropriate level of sophistication for the models and data available. Relevant experience from other approaches can be utilized within the UNEP Handbook Methodology, if appropriate. (Possibilities include 91) the TAOS model as a VA tool, (2) the qualitative techniques developed within the South Pacific Islands Methodology, and (3) the Work Book approach used in the US Country Studies Program). Applying the UNEP Handbook Methodology will give each study team a wide range of experience of assessing sea-level rise and other climate change impacts.

THE UNEP HANDBOOK GUIDELINES: IMPLICATION FOR THE CARIBBEAN

Introduction

111. While the UNEP Handbook Guidelines are the best approach for CPACC, their application to the Caribbean requires some careful consideration. This section outlines how the method might be used, with some specific recommendations as to its application.

112. An important point to note is that the philosophy of the analysis stresses understanding the sensitivity of different sectors to sea-level rise (and other climate change). A large amount of effort can be expended trying to determine the "right" climate change scenario to use in an impact analysis. However, there is no "right" scenario, as the most likely change in climate will evolve with our scientific understanding and is part of a range of possible changes. Therefore, it is more important to look at the impacts of a considerable range of climate change scenarios. Such results define a response surface that allows any climate change scenario within the range to be transformed into a potential impact. Therefore, such results lend themselves to repeated reinterpretation as climate change science improves.

113. The three countries which will be studied in Component 6 have quite different characteristics (summarized in Table 4) and this will influence how the UNEP Handbook Methodology might be applied. Grenada and Barbados are two small Caribbean islands that are quite similar in size. Tourism is important in both cases, providing significant pressure for development along the coast. Guyana is a quite different setting on the South American continent. It has a longer muddy coastline that is supplied with fine-grained sediment from the Amazon Delta, about 1,000 km away. Due to the muddy nature of the coast, tourism is not important, but most of the population and economic activity is still concentrated in the coastal zone, including extensive agricultural areas vulnerable to coastal flooding.

Table 4. Some characteristics of Guyana, Barbados and Grenada

	Coastal Length	Coastal characteristics	Present Coastal Problems	CZM Status	Previous impact assessments	Possible activities vulnerable to sea-level rise
Guyana	500 km	Deltaic coast	Coastal erosion, population growth, subsidence	Uncertain	Kahn and Sturm (1995)	Human settlements, agriculture, coastal wetlands and other ecosystems
Barbados	72 km	Small island	Coastal development, tourism pressure	Well developed	None	All activities, including tourism
Grenada	63 km	Small island	Coastal development, tourism pressure	Less developed	None	All activities, including tourism

118. As already discussed, previous studies suggest that both the Caribbean islands and deltaic coast of are highly vulnerable to sea-level rise. In the case of Guyana, this has been confirmed by previous studies of the impacts of sea-level rise (Kahn and Sturm, 1995; see also earlier discussion). Therefore, in Guyana there is a good foundation for a focussed vulnerability assessment that builds on the earlier work. In Grenada and Barbados, no previous assessment of the impacts of sea-level rise is available. However, Barbados has developed a detailed GIS-based inventory on coastal resources as part of its coastal zone management program. In Grenada coastal zone management is less developed and there

is less data on its coastal resources.

119. Therefore, the factual basis for the impact studies for sea-level rise is lowest in Grenada, intermediate in Barbados and highest in Guyana. Given the lack of any previous impact assessment studies, the CPACC studies of Grenada and Barbados should begin with a national overview and screening assessment, before moving to more detailed vulnerability assessment. In contrast, given the strong foundation in Guyana, a more detailed vulnerability assessment can be planned after a rapid screening assessment.

120. For the purposes of implementation, the UNEP Handbook Methodology can be usefully summarized into five main stages:

Stage 1. Problem definition and scope of the analysis (Steps 1, 2 and 3);
Stage 2. Scenarios for Coastal Vulnerability Assessment (Step 4);
Stage 3. Impact Assessment (Step 5);
Stage 4. Autonomous Adaptation (Step 6);
Stage 5. Planned Adaptation (Step 7).

Stage 1. Problem definition and scope of the analysis

121. A number of issues need to be considered in terms of defining the problem, selecting the method(s), and testing the method(s). These include:

- Level of analysis;
- Delineation of the study area;
- The likely magnitude of sea-level rise;
- The likely impacts of sea-level rise.

Level of analysis

122. Many vulnerability assessments have been hindered by the limited availability of data. Sometimes there has also been a mismatch between the available data, the level of effort, and the sophistication of the models utilized in vulnerability assessments. In some cases this has led to inappropriate expectations concerning the outcomes of the assessment studies. To help to structure the approach, to optimize the level of effort, and to make the likely outcome of studies more explicit, it is useful to consider three levels of increasingly complex assessment (Table 5):

- screening assessment (SA);
- vulnerability assessment (VA);
- planning assessment (PA).

Table 5. Three levels of assessment for coastal zones, showing the respective requirements and the factors to be considered (adapted from Klein and Nicholls, 1998; Nicholls, 1998).

Level of assessment	Requirements			
	Time (months)	Level of Detail	Prior Knowledge	Other Scenarios Considered (in addition to sea-level rise)
Screening Assessment	≤ 3	Low	Low (No previous SA or VA)	None
Vulnerability Assessment	6-12	Medium	Medium (Previous SA or VA)	Likely socio-economic changes and other climate change (if possible)
Planning Assessment	Ongoing	High	High	All realistic changes

128. Within a national study, analysis should start with SA, proceed to VA and ultimately attain PA. As its name implies, SA is a screening approach, which—by its quick nature—primarily focuses on the susceptibility of today's coastline to sea-level rise. Such analysis can be qualitative and use expert judgement, or semi-quantitative and use "rules of thumb" or other simple models. The results of SA can be used to plan how VA might be most effectively implemented, including selection of study areas and other scenarios to be considered. VA is a more comprehensive analysis providing broad concepts and ideas concerning impacts and possible adaptation. It includes explicit assessment of the biogeophysical effects and socio-economic impacts of sea-level rise and considers the potential for adaptation. PA can be viewed as the link between VA and detailed coastal zone planning and management. It is a response to more detailed and precise management questions and aims to produce management recommendations concerning possible adaptation measures. As an example, application of this approach to analyzing beach erosion due to sea-level rise has been discussed by Nicholls (1998) -- SA uses a "rule-of-thumb" Bruun Rule, VA uses the full Bruun Rule, and PA requires a complete sediment budget.

129. With our present understanding and knowledge base, most coastal vulnerability assessments will be of a basic nature and can only be expected to yield general results in terms of adaptation and day-to-day coastal zone management. As further experience is acquired, coastal databases improve and better analytical tools and techniques are developed, more comprehensive and integrated assessments of coastal zones will become feasible. Progressing from SA to VA (and ultimately to PA) provides a structured approach to steadily improve our understanding of the impacts and responses to sea-level rise. It also develops realistic expectations and maximizes the benefits of the limited resources available for VA studies. As already noted, VA can be repeated as more and more sophisticated questions are raised.

130. For the CPACC studies, it is recommended that the three participating countries begin with SA. Completion and evaluation of Table 6 using expert judgement (see below) would be an appropriate approach. The question being asked is what are the key impacts that a 1-meter rise in sea level will cause in each country. The result will be used to develop a plan for VA that can be applied within the remainder of the project.

Delineation of the study area

131. The definition of the coastal zone always presents difficulties, as there are no agreed limits to its extent. It is best that local judgement be used, based on an understanding of the key activities and sectors that might be affected by sea-level rise. A practical landward limit is the 1 in 1,000 year storm

surge elevation, after any rise in sea level (although this may not be easy to determine in most cases). This might be a useful limit in Guyana. On small islands, such as Grenada and Barbados, it is often reasonable to consider the entire island as within the coastal zone, as the socio-economic impacts will be felt across the island. The seaward limit can be defined based on the biogeophysical effects being considered. A practical limit on sandy coasts is at the minimum annual depth of closure (Nicholls et al., 1995). This can be determined using wave climate statistics (Nicholls et al., 1996; 1998)

Likely magnitude of sea-level rise (and other climate change)

132. The maximum likely magnitude of climate change is an important parameter for scoping any study. Warrick et al (1996) reported that the global rise in sea level would be up to 86 cm by 2100, if the cooling effects of aerosols are considered. Therefore, a 1-meter global rise by 2100 is taken as the maximum possible rise. In addition, local uplift and subsidence must be included with global changes to evaluate local (or relative) sea-level rise. In some urban areas rapid anthropogenic subsidence is occurring due to groundwater withdrawal (Nicholls, 1995b), with a pertinent example being Georgetown, Guyana. Kahn and Sturm (1995) estimate the subsidence at 1 meter/century if present rates of change continue. When added to the maximum possible global rises in sea level by 2100, Georgetown could see up to a 2-meter rise in sea level during the 21st Century. In contrast, in Barbados and Grenada such anthropogenic changes are unlikely, and the global scenarios of sea-level rise can be applied directly (to a first approximation).

133. Other aspects of climate change might also be important and issues such as changing storminess and rising sea temperature might be considered.

The likely impacts of climate change

134. As already noted, a relative rise in sea level, from whatever cause, will have a range of biogeophysical (i.e. physical and ecological) impacts and these impacts in turn will have direct and indirect socio-economic impacts on human activities in the coastal zone, such as tourism, human settlements, agriculture, freshwater supply and quality, fisheries, financial services and human health (Bijlsma et al., 1996; Klein and Nicholls, 1998). Ideally, impact assessment should consider all these impacts, but in practice few, if any, countries have achieved such an understanding, and the objectives of any impact assessment study should reflect the time and resources available. When scoping an impact assessment, it is important that at an early stage the available knowledge on likely impacts should be assessed to rank the relative importance of potential impacts as (1) not relevant, (2) low, (3) medium or (4) high, together with relevant comments, in a form such as Table 6.

Table 6. The screening assessment matrix for impacts of sea-level rise showing biophysical versus socio-economic impacts.

Biophysical Impact of Sea-Level Rise	Socio-Economic Impacts							
	Tourism	Human Settlements	Agriculture	Water Supply	Fisheries	Financial Services	Human Health	Others ?
Inundation								
Erosion								
Flooding								
Salinization								
Others?								

142. Sources of information for Table 6 could include previous studies, expert judgement, etc. The resulting matrix is useful to focus the limited resources of time and money at the major potential impacts. It is also illuminating if a ranking is not possible or problematic, as this would suggest that a broad, but general assessment is necessary, with a goal of achieving such a ranking for subsequent analysis.

Stage 2. Scenarios for Coastal Vulnerability Assessment

143. The UNEP Handbook Methodology gives complete freedom to select any scenarios that seem appropriate. For instance, a study could follow many earlier studies (see Nicholls, 1995a) and examine the impacts of sea-level rise on the present situation, i.e. with no other change. Such assessments have the advantage of being relatively simple and they generate useful relative results on impacts. However, the absolute magnitude of the impacts is certainly incorrect and the implications of sea-level rise interacting with other changes cannot be assessed.

144. If we consider a more realistic set of changes, then there is a wide range of possible climatic and non-climatic changes to be considered (Table 7). These can also be divided into environmental changes and socio-economic developments. Considering such a range of scenarios raises questions about the *relative importance* of sea-level rise, versus other climate change scenarios, and versus other plausible changes. The interaction of different scenarios can also be considered. Sea-level rise may not be the most important climate change. Rising sea temperatures might impact some coastal ecosystems (Maul, 1993), while changes in the tracks and intensity of hurricanes are a big concern (Gray, 1993). No credible scenarios for changes to hurricanes are available from climate models, but sensible changes might be investigated as part of a sensitivity analysis. Also note that the same change may have different causes -- for instance sediment budgets can be modified by climatic factors and changes in catchment management (a non-climatic factor) (Table 7).

145. It is important to note that there is often a time scale mismatch between environmental changes and socio-economic developments. While we project environmental changes for the next 100 years, the longest period that a detailed socio-economic scenario is credible is about 10 years. This does not mean that we should ignore socio-economic developments. Rather scenarios should be developed with simple methods such as trend analysis, or we should utilize widely-accepted sources, such as national governments or the World Bank (e.g., population forecasts).

Table 7. Examples of the four different types of scenarios that can be used in coastal vulnerability assessment (taken from Klein and Nicholls, 1997; 1998).

	Environmental Changes	Socio-Economic Developments
Climate-Induced	Sea level Sea-surface temperature Storminess Wave climate Sediment budget	Autonomous adaptation Planned adaptation
Non-Climate Induced	Vertical land movement Sediment budget	Population Land use Gross domestic product

149. As sea-level rise is the focus of these impact assessments, it is worth noting that relative sea-level rise scenarios have often been incorrectly calculated in previous vulnerability assessments. It is recommended that global sea-level rise scenarios of 0.2 meter (the present rate of rise), 0.5 meter and 1.0 meter by 2100 be evaluated (embracing the range of change reported by Warrick et al. (1996)). In Barbados and Grenada, these scenarios can be used directly as relative sea-level rise, while in Guyana, subsidence needs to be evaluated (i.e. vertical land movement in Table 7) and added to the global changes. If necessary subsidence scenarios can be used to express the range of uncertainty. In this case, the number of relative sea-level rise scenarios will exceed the global scenarios and they will have a greater range.

150. Other possible climate scenarios are sea-surface temperature (about 1^{o}C to 2^{o}C higher by 2100) and storminess (uncertain, so use a sensitivity analysis). One possible scenario for Barbados and Grenada would be a 20% decrease, no change and a 20% increase in the 100-year storm surge elevation. For changing wind speeds, the change in damage could be scaled from damage functions.

Stage 3. Methods for Impact Assessment

151. Impact Assessment can be divided into three stages:

(1) Acquisition and management of data

152. A range of data is essential for both biogeophysical and socio-economic impact assessment. The type of data required depends on the impacts being evaluated. Some of the data that is essential for impact assessment is listed in Table 8.

Table 8. Some of the data required for vulnerability assessment.

The best topographic data, including regular contours;
Evidence for subsidence/uplift, including the methods used to determine;
Bathymetric charts and maps, particularly for shallow water areas (<10-m depth);
Coastal geomorphology (i.e., hard unerodible cliffs, erodible cliffs, beaches, wetlands, etc.) to select appropriate impact models;
Wave data, or wave hindcasts to define the wave climate;
Tide gauge data to define tidal characteristics and flood elevations (Note that 50 years of data is required to confidently extract long-term sea-level trends (Douglas, 1991; Nicholls and Leatherman, 1996) so this is unlikely);
Estimates of flood return periods, from tide gauges and/or hindcasts;
Historical storm and flood damage from major storms, including physical changes and socio-economic costs;
Present status of coastal ecosystems, particularly coral reefs and wetlands. How much degradation and destruction has occurred, and what is the prognosis for the future without climate change?
Scientific research on ecosystem response to climate change, particularly examples in the Caribbean.
Present coastal problems, including (1) beach erosion, (2) cliff erosion, (3) coastal flooding by storm surge, (4) coastal flooding by run-off, (5) saltwater intrusion, (6) others? Information should be as quantitative as possible and put as much emphasis on the long-term rather than the short-term;
Any response to these problems, including both hard and soft engineering (seawalls, nourishment, etc.) and institutional changes (building setbacks, coastal zone management programs, etc.);
Human influence on sediment availability at the coast. List areas where dams have been built on rivers, coastal erosion has been stopped, and littoral drift has been impeded;
Coastal land use and historical changes in coastal land use;
Plans for major future infrastructure development such as ports, airports, etc. which will be close to present sea levels;
Development of coastal tourism, if appropriate and plans for future development;
Coastal population distribution and historical changes in coastal population distribution;
Forecasts of coastal population distribution.

172. A range of techniques and tools to acquire data are discussed by Klein and Nicholls (1997). Much of this data may already exist either in hard copy (on maps), or in soft copy (in GIS format). Other data will need to be developed for the study. For instance, data on coastal geomorphology may be quickly determined using oblique aerial videography (Leatherman et al., 1995), and then interpreted on to a map or into a GIS. Significant quantities of data will be collected and organized as part of Component 3 (Inventory of Coastal Resources and Use). Further Component 2 (Establishment of Databases and Information Systems) will facilitate use of any data. Therefore, there needs to be careful coordination between Components 2, 3 and 6.

(2) Assessment of biogeophysical effects

173. The main biogeophysical effects of sea-level rise are as follows:

- Increasing flood risk and storm damage
- Erosion
- Inundation
- Ecosystem (wetland and coral reef) loss
- Rising water tables
- Saltwater intrusion

174. Some suitable methods to assess these impacts are outlined by Nicholls et al (1995) and Klein and Nicholls (1997).

175. All these biogeophysical effects could cause significant changes within the Caribbean region. In previous vulnerability assessments around the world, most attention has focussed on erosion, inundation and wetland loss, with more limited assessment of increased flood risk. Rising water tables and saltwater intrusion have only been examined in detailed case studies. This relative effort reflects the increasing difficulty in modeling these different impacts. These difficulties are fundamental and it is recommended that quantitative analysis be focussed on the first four impacts.

176. Inundation and flood risk can be modeled by raising the appropriate water level by the sea-level rise and/or changing storminess scenario. Alternatively, the TAOS model might be used (Watson, 1995). Changes in storm damage, would need to consider the extent of erosion and increased exposure to wave action. Note: a 1 in 1 year flood elevation is often taken as the inundation contour -- i.e., nobody lives where they are flooded more than once per year.

177. Erosion of beaches can be modeled using the Bruun Rule (Nicholls et al., 1995; Nicholls, 1998). Erosion of erodible cliffs can be modeled using similar approaches (Bray and Hooke, 1997).

178. Ecosystem loss is more difficult to determine, because coral reefs and wetlands respond to changes such as sea-level rise by moving upwards and landwards. Hence, a dynamic equilibrium is feasible where gains balance losses. The first stage of such analysis is the present status and prognosis of coastal ecosystems. Given human destruction, some ecosystems may not survive to be adversely affected by sea-level rise. Taking those systems that are likely to be impacted, potential maximum rates of accretion should be examined in the literature. For wetlands, coastal setting needs to be considered -- small islands such as Grenada and Barbados are more sediment-starved than deltaic coasts such as Guyana, and wetlands in the latter case will be expected to accrete more rapidly. For coral reefs, the affects of rising sea temperature needs to be considered in addition to sea-level rise (Bijlsma et al., 1996). Using this analysis critical threshold of sea-level rise which will cause ecosystem loss can be identified.

179. If other biogeophysical impacts such as salinization are identified as being of significant concern when completing Table 6, as a first approach the qualitative index-based South Pacific Island approach (Yamada et al., 1995) could be used. More quantitative analysis could follow if so desired.

(3) Assessment of potential socio-economic impacts

180. There are a wide range of potential socio-economic impacts that could be produced by the biogeophysical impacts of sea-level rise. Three distinct categories of impact can be distinguished:

- (human) population
- marketed goods and services
- non-marketed goods and services

181. The resident population of the coastal zone (present or projected levels) can be affected by increased flooding, or ultimately, the need to move due to frequent flooding or land loss due to erosion. The number of people so effected can be counted for different scenarios. Hoozemans et al (1993) and Baarse (1995) applied the concept of people at risk (sum of the number of people in each hazard zone multiplied by the risk of flooding) and people to be moved (the number of people flooded more than once-per-year). These are good working definitions for impact assessment, although they can be redefined as appropriate.

182. Marketed goods and services such as land, infrastructure and agricultural and industrial productivity can be similarly analyzed. However, it is more complex than just counting people. In terms of loss, an inventory could be constructed, but the issue of discounting needs to be addressed and the assumptions made about the discount rate have a major impact on the results.

183. Non-marketed goods and services also need to be considered. Even though such services are (by definition) difficult to value, they have a value and their loss is a cost to society. One can simply inventory the non-market goods and services that might be lost, or try and value them using artificial methods (which is controversial).

Stage 4. Autonomous Adaptation

184. Autonomous adjustments are biogeophysical or socio-economic adaptive responses that will happen spontaneously without any decision being made by policy-makers. It has already been noted that if sea levels rise, coastal wetlands will respond by accreting vertically more rapidly and moving inland if there is available space. Therefore the actual losses of coastal wetlands are smaller than a simple “bath-tub” model would suggest. Taking a socio-economic example, if an area becomes flooded more frequently, then this may discourage further development of this area. Experience of human response to existing hazardous events such as storms and floods might give some indication of socio-economic autonomous adjustments.

185. When assessing the impacts and possible responses to sea-level rise, it is important to consider the potential for such autonomous adaptations to reduce the magnitude of impacts. In the case of the biogeophysical autonomous adjustments, these may have already been considered as part of the impact modeling. Klein and Nicholls (1997) reviewed the potential for autonomous adjustments to offset the impacts of sea-level rise. While numerous autonomous adjustments exist, in most cases they appeared to have limited effect in terms of reducing impacts. However, these conclusions need to be evaluated in detailed national case studies as there are limited empirical results.

Stage 5. Planned Adaptation

186. Planned Adaptation to sea-level rise is normally expressed as three possible technical options: (1) (planned) retreat (e.g., building setbacks), (2) accommodation (e.g., raise buildings on pilings above flood levels), or (3) protection (e.g., protect areas with seawalls, or nourish beaches) (IPCC CZMS, 1990; Bijlsma et al., 1996). In addition to adaptation being autonomous or planned, it can also be anticipatory (proactive), or reactive. In their analysis of the measures available to respond to sea-level rise, Klein and Nicholls (1997) concluded that most adaptation would need planning, and that planned retreat and accommodation would be most effective if implemented in a anticipatory manner, while protection can be both reactive or anticipatory.

187. The cost and feasibility of different responses to the impacts identified should be evaluated. For instance, the implications of setting new tourist developments back from the coast, as opposed to holding the beach in place with beach nourishment could be evaluated. Cambers (1994) has already noted the high cost of sand for beach nourishment in the Caribbean, but what are the costs of building setbacks? Innovative options should also be considered. For instance, in Guyana reducing the magnitude of anthropogenically-induced subsidence could be an important part of a response to sea-level rise.

188. To evaluate different policies, some criteria are required. Klein and Nicholls (1997) consider the range of available options and the methods available to evaluate the different response options. One attractive method which combines cost-effectiveness analysis with multi-criteria analysis is the decision matrix developed by Smith (1996a; 1996b) for the US Country Studies Program. It is based on a cost-effectiveness ratio which compares the cost of a measure to the benefits (as scored by expert judgement).

189. As discussed earlier, Klein et al (1998) note that the process of adaptation than the technical options and their evaluation discussed above. In addition, the *capacity* and *capability* to adapt needs to be considered. The process of adaptation to climate change comprises four stages, with a number of feedbacks:

- information and awareness raising (to show adaptation is necessary);
- planning (the adaptation);
- implementation (of the adaptation);
- evaluation (of the adaptation).

190. An assessment of the capacity for adaptation should be included as part of the VA. It could usefully be structured around the four stages of adaptation listed above. (It should be noted that the impact assessments is itself a major contribution to information and awareness raising).

Summary

191. Table 9 summarizes some of the key points of this section. While the study areas remain to be decided, the suggestions offered here seem to offer the most benefits, based on what is known.

Table 9. Possible approaches to implementation of the UNEP Handbook Guidelines

Country	Type of Study	Study Area	Global Sea-Level Rise Scenarios (m) and Other Environmental Issues	Suggested Study Area	Possible Adaptation Outcomes

Guyana	Rapid SA (Table 6) then build-on existing VA	1,000 year flood plain (after sea-level rise)	0.2, 0.5, 1.0 (by 2100) + Subsidence	Georgetown and environs	Recommendations on subsidence; long-term city planning
Barbados	SA (Table 6), then VA	Entire island	0.2, 0.5, 1.0 (by 2100) + Changing storminess	National Assessment	Retreat versus protection
Grenada	SA (Table 6), then VA	Entire island	0.2, 0.5, 1.0 (by 2100) + Changing storminess	National Assessment	Retreat versus protection

REQUIREMENTS FOR IMPLEMENTATION

196. The type of data, equipment, human resources and institutional arrangements necessary to apply the UNEP Handbook Methodology are outlined in Table 10. A range of data is required and an urgent task is good liaison with Components 2 and 3 as they will provide much of the necessary data. Equipment needs are not great, with good PCs and appropriate GIS software being the most important requirement. Other useful equipment include access to camcorders and video playback, and survey equipment to measure field data for analysis. Vulnerability assessment is a multi-displinary activity, and demands a multi-displinary team. It is suggested that each study comprise a three-person team with the following skills (1) environmental scientist/engineer, (2) socio-economist and (3) policy analyst. The team would require ready access to appropriate government officials dealing with coastal issues. To make sure that the study is relevant to government needs, a Steering Committee should be formed to guide the Project Team. Membership might include three in-country representatives (two government and one non-government) and CPACC representatives. There should be at least three meetings through the VA study in which the Steering Committee comment on the work.

CONCLUSION

197. This report has examined a range of issues, including the likely changes in sea level and other climate factors, their possible impacts with a focus on the Caribbean region and a discussion of a number of methods for vulnerability assessment. In an objective assessment of the methodologies considered, the UNEP Handbook Methodology (Klein and Nicholls, 1997; 1998) appears to be most appropriate Vulnerability Assessment Methodology for the Caribbean. Its application will facilitate adaptation to sea-level rise both within the three study countries, and in the wider region.

Table 10. Some of the requirements to implement the UNEP Handbook Methodology

	Requirement	Comment
Data	A wide range of environmental and socio-economic data, including trends and forecasts (see Table 8). Ideally data should be in GIS format	Need to liaise with Components 2 and 3.
Equipment	PCs and appropriate GIS software are essential. Access to camcorders and video playback and survey equipment	

	would be useful.	
Human Resources	A multi-disciplinary Project Team, comprising an environmental scientist/engineer, a socio-economist and a policy analyst	Probably a team of three people required, with access to government officials dealing with the coast
Institutional Arrangements	Direct links to the government	A Steering Committee comprising three in-country members and CPACC representatives would provide a good formal link with the VA work

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