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**PROFESSIONAL DEVELOPMENT PROGRAMME:
COASTAL INFRASTRUCTURE DESIGN, CONSTRUCTION AND
MAINTENANCE**

**A COURSE IN
COASTAL ZONE/ISLAND SYSTEMS MANAGEMENT**

CHAPTER 8

CLIMATE CHANGE

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1.0 GREENHOUSE EFFECT

1.1 Natural Greenhouse Effect

The balance between the inflow of solar radiation into the atmosphere and the re-radiation of heat determines the Earth's average surface temperature. The average amount of solar energy incident on the atmosphere is about 342 watts per square metre (W m^{-2}). Approximately 77 W m^{-2} is scattered or reflected directly back into space by molecules, microscopic airborne particles (referred to as aerosols), and clouds in the atmosphere, (the total effect is referred to as albedo), and another 30 W m^{-2} is reflected back by the earth itself. Of the remaining 235 W m^{-2} , $\sim 168 \text{ W m}^{-2}$ is absorbed by the earth's surface and the remainder by the atmosphere. To maintain its long-term thermal equilibrium, the earth must reradiate back to space, on average, the same amount of energy that is absorbed. It does so by re-radiating thermal "long-wave" radiation in the infra-red part of the electromagnetic spectrum.

According to the theory of black body radiation, the amount of thermal radiation emitted by a warm surface is dependent on its temperature and how "absorbing" it is. A perfect black body is a perfect absorber (i.e. no reflectance) and a perfect emitter. If the earth had a perfectly absorbing surface, it would re-emit thermal radiation (the 235 W m^{-2} that reaches the earth's surface) at a rather low temperature of about minus 19 degrees Celcius (-19°C). However, the mean global temperature at the surface of the earth is about 15°C . The difference in the theoretical temperature and the observed temperature can be explained by the natural greenhouse effect which effectively keeps the earth's surface about 34°C warmer than it would otherwise be. In fact, the present life forms depend on this natural greenhouse effect for their existence.

Most of the atmosphere consists of nitrogen and oxygen (99% of dry air), which are transparent to infra-red radiation. Therefore, a small amount of radiation leaving the earth's surface is transmitted relatively unimpeded back through the atmosphere. However, the bulk of the infra-red radiation is intercepted and absorbed by atmospheric gases such as water vapour, carbon dioxide, and other minor gases like nitrous oxide,

ozone and methane. These gases are referred to as greenhouse gases (GHGs). The GHGs in turn re-emit the infra-red radiation in all directions. The net result is that the atmospheric GHGs act as a partial blanket that traps some of the thermal radiation from the surface and makes the earth substantially warmer than it would normally be – giving rise to the natural greenhouse effect. (See Figures 1 and 2).

1.2 The Enhanced Greenhouse Effect

The Earth's average global temperature, therefore, is a function of the radiative balance of incoming solar energy and out-going infra-red radiation. Any changes in the average net radiative balance of radiation due to variations in the intensity of incoming solar radiation or out-going infra-red energy, is said to cause "radiative forcing" of the earth's atmosphere. An increase in the atmospheric concentrations of GHGs for example, and the consequent reduction in the efficiency of radiative cooling of the earth, will result in positive radiative forcing. (See Figure 3) This causes the enhanced greenhouse effect. This effect tends to further warm the lower atmosphere and surface, which is essentially the anthropogenic enhancement of a phenomenon that has operated in the earth's atmosphere for billions of years due to naturally occurring GHGs. The extent of the enhanced warming depends on the size of the increase in concentrations of GHGs and the radiative properties of the gases. Alternatively, increases in aerosols will have a negative radiative forcing such as the slight cooling of the earth's surface during 1992-3, caused in part by the eruption of Mount Pinatubo in mid-1991. However, these effects are short-lived. Nonetheless, any radiative forcing will tend to alter atmospheric and oceanic temperatures, weather patterns, and the entire hydrological cycle.

Natural climatic variations occur as a result of changes in the forcing of the climate system, for example as a result of aerosol due to volcanic eruptions. Climate variations can also occur without any external forcing as a result of complex interactions between components of the climate system such as the ocean and atmosphere. The El Nino Southern Oscillation (ENSO) is an example of such an internal variability. The output of

energy from the sun also changes by small amounts (~0.1%) over an 11 year cycle. Slow variations in the earth's orbit over timescales of tens to thousands of years, have led to changes in the seasonal and latitudinal distribution of solar energy. Such changes have played an important part in climate variations in the distant past, as during glacial cycles. There is therefore a certain degree of natural background "noise" or baseline conditions against which any anthropogenic signal has to be identified.

Increasing energy use since the Industrial Revolution has led to the rapid accumulation of GHGs – primarily carbon dioxide, methane, nitrous oxide - above their naturally occurring (historical) levels. (See Figure 4.) As emissions continue to increase as a result of continuing use of fossil fuels, it is expected that the risk of global warming above normal levels will occur as more heat becomes trapped in the atmosphere. However, the extent of such warming will depend on the relationship between GHG emissions and concentrations, which is determined by the global carbon cycle. Since 1750, atmospheric concentrations of carbon dioxide, methane and nitrous oxide have risen by about 30%, 100% and 15% respectively, and are continuing to rise. The total radiative forcing effect of a GHG depends on several factors including its concentration, global warming potential (GWP) and atmospheric lifetime. The GWP indicates the cumulative warming effect or radiative forcing caused by a unit mass of gas from the moment of release up to some time in the future. It is expressed as an index relative to carbon dioxide (which is given a GWP of 1). GWPs must take into account not only the direct radiative forcing effects of each gas but also the indirect effects such as the formation of new GHGs as a result of complex chemical reactions in the atmosphere.(See Figure 5).

The Atmospheric carbon dioxide is the key link in the global carbon cycle between human activities and the naturally occurring biological and physical processes. Analysis of historical carbon dioxide levels and temperature, estimated from Vostok ice core data, show a close correlation between the two for the past several thousand years. (See Figure 6). Carbon is exchanged among the oceans, the terrestrial biosphere, and the atmosphere, and less quickly with sediments and rocks, via the global carbon cycle (See Figure 7).

These complex physicochemical reactions occur at different rates in the different strata, any disruption in one part may cause interference in other parts of the cycle.

The global community has recognised that there is a problem and has responded by formulating the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol which aims at stabilising atmospheric GHG concentrations at a level that would prevent dangerous anthropogenic interference with the climate system within a timeframe that would allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner. The UNFCCC defines climate change as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.” (See Figures 8.).

2.0 PRESENT/CURRENT EVIDENCE

The Intergovernmental Panel on Climate Change (IPCC) established by the World Meteorological Organisation and the United Nations Environment Programme (UNEP), consists of scientists from around the globe and whose job is to assess the scientific evidence in respect of global warming and climate change. (See Figure 9). A broad consensus has emerged among the several thousand world's leading experts who have reviewed current information for the IPCC that there is a discernible human interference in the climate system. There is a concern that the changes in climate would intensify in the future because of the lag time in the global atmospheric/climate response system. What this means is that if all emissions were to stop as we speak, the earth's climate would be committed to the effects of past emissions, and so we are committed to some rise in temperature with the expected rise in sea level. However, in order to detect a human interference “signal” as explained above, it has been necessary to (a) detect whether a particular change in weather patterns is exceptional in a statistical sense (i.e. significantly different from baseline or background conditions, and (b) attribute such a

change to human influence. A lot of the scientific effort has been devoted to trying to separate the signal from the baseline “noise”. In any event, it is apparent that anthropogenic contributions to radiative forcing (as a result of past GHG emissions up to 1990) are quite significant compared to natural effects such as variations in solar output (refer to Figure on radiative forcing of GHGS) . The current evidence suggests that the twentieth century is probably warmer than any other century since 1400 (before which there were largely unreliable data). Within the 20th century, some areas have recorded the warmest decade-long spells that have occurred in the past millennium. Specifically, the earth’s average surface temperature has increased between 0.3 and 0.6⁰C over the past 100 years, and by about 0.2 to 0.3⁰C since 1950 (See Figure 10). The mean sea level has risen between 10 and 25 cm over the same period primarily due to the thermal expansion of the oceans (0.2 to 0.7 mm per year), retreat of glaciers (0.2 to 0.4 mm per year), and other temperature-related causes, including possible melting of the Antarctic and Greenland ice sheets.

Statistical analyses have indicated that the observed increasing trend in mean global temperature during the past century cannot be attributed entirely to natural variations. There have been wide regional climatic variations (such as the greater warming over middle latitude continental areas during winter and spring, but more cooling in the North Atlantic). Precipitation has increased over land areas in the high northern latitudes. The frequency of ENSO events has increased since the 1970s, and the sustained 1990-1995 oscillation was never observed before, on the basis of records going back 100 years. However, there is no clear link to human activities.

The methods used to detect human interference with the climate system have been largely based on numerical global climate models (or Global Circulation Models or GCMs). These models have been developed to seek to take into account not only the heat-trapping effects of GHGs, but also the negative radiative forcing provided by aerosols, as well as contributions from the ocean-atmosphere coupling over timescales of decades to

centuries. Accordingly, these models have been used to simulate the mean global climate and make comparisons with actual regional measurements. The projections made by such models correspond closely to the observed patterns of temperature changes to strongly suggest that these temperature changes cannot be caused solely by natural phenomenon. However, it must be borne in mind that, as with all models, there are inherent uncertainties, such as the inability to incorporate the variability of solar radiation and volcanic dust, and that the model outputs are mere projections as opposed to predictions. Nonetheless, comparisons of the model outputs with empirical measurements help to establish the validity of a particular model, and its usefulness in future projections.

3.0 LIKELY CHANGES IN THE FUTURE GLOBAL CLIMATE

In order to develop some idea of what the future climate might look like, based on the discussion above, the IPCC has developed various future scenarios. It is important here to understand that a scenario, much like a model projection, is not a prediction. A scenario is the cumulation of the various factors that are likely to exist in a particular future timeframe and based on past and present trends. Accordingly, it is more a probability estimation, but which can change based on developments such as scientific knowledge, changes in social attitudes and economic fortunes etc. Scenario development was therefore based on the radiative forcing of likely future emissions of GHGs, since this is the principal cause of global warming and climate change.

3.1 The IS92 Scenarios (without Intervention)

In 1992, the IPCC made a series of projections up to the year 2100 of emissions of the principal GHGs (carbon dioxide, methane and nitrous oxide) and aerosols that would most likely occur if no measures were taken to curb the emission of GHGs. (See Figure 11). The IS92 curves provide important baseline for thinking about climate change, and are based essentially on carbon dioxide emissions.

1. IS92a,b: This scenario assumes a “business as usual” approach for growth in GHG emissions (carbon dioxide). It uses moderate assumptions about global economic growth (2.3 – 2.9 %), population increase (11.3 billion people by 2100), and a mix of energy sources. IS92b assumes the same conditions as IS92a but with OECD countries committed to stabilize or reduce emissions.
2. IS92e is the highest emission scenario and is based on rapid economic growth (3.0 – 3.5 % per year), moderate population growth (11.3 billion people by 2100), high availability of fossil fuels, and the phasing out of nuclear fuels.
3. IS92c is a scenario in which emissions grow initially but fall in later years, a reduced economic growth (1.2 – 2 % per year), a limited increase in global population (6.4 billion by 2100), and severe constraints on fossil fuel use. The other scenarios are variations of the extreme (IS92c,e) and “business as usual” (IS92a) scenarios.

In the IS92a scenario, carbon levels in the atmosphere reach above 600 ppmv (more than twice that of pre-industrial times) while the most optimistic scenario (IS92c) projects atmospheric carbon dioxide barely beginning to stabilize below 500 ppmv. (See Figure 12). Projections from these scenarios indicate that the major radiative forcing in the future will be from carbon dioxide. Modeling also indicates that concentrations of GHGs with lifetimes shorter than carbon dioxide respond more quickly to changes in emissions (relative to carbon dioxide). For example, methane emissions affect atmospheric methane concentrations over a period of 9 to 15 years.

Increase in Mean Global Temperature

The modeling assumes three different levels of sensitivity of the global climate system to radiative forcing (high, medium, and low). Thus, a temperature rise of about 4.5⁰C by 2100 is projected for the highest emission scenario (IS92e) and high climate sensitivity

while the best case scenario (IS92a with low climate sensitivity) projects a temperature rise of about 1⁰C by 2100. The projections also take into account the cooling effects of aerosols. An important feature in the model projections is that in almost all cases, global temperatures will continue to rise beyond 2100 (toward some long term equilibrium state several hundred years into the future), due to the inertia and time lags in the climate system. (See Figure 15).

Global mean Sea Level Rise and Other Effects

After temperature increase, the rise in global mean sea level is the other major aggregate indicator of global warming. An increase in mean global sea level will be due mainly to the thermal expansion of sea water, and the melting of glaciers and ice sheets. The global mean sea level has already increased by 10 to 25 cm in the last century. (See Figures 13 and 14). The worst case scenario of a projected sea level rise of 110 cm by 2100 corresponds to the high emissions scenario (IS92e) coupled with a high sensitivity climate and ice melt level. By contrast, the most optimistic result is an increase in mean sea level of only 13 cm by 2100 for the best case scenario (IS92a) coupled with a low climate and ice melt sensitivity. All other combinations of assumptions give results that fall between these two extremes. The IS92f scenario assumes that world population grows to 17.6 billion by 2100 with economic growth continuing at 2.3-2.9% per annum.

3.2 Stabilisation Scenarios (With Intervention)

These scenarios are developed using a future stabilisation of atmospheric carbon dioxide levels of between 450 and 1000 ppmv (labeled accordingly as S450, S1000 etc.). The scenarios take into account the assumption of measures that may be taken to reduce GHG emissions.

Mean Global temperature Increase

The best case scenario (S450) coupled with a low climate sensitivity results in a global mean temperature rise of only about 0.5⁰C by 2100, which is a better result than the IS92a scenario of an average doubling of the atmospheric carbon dioxide level relative to pre industrial values (270 ppmv). Scenarios using the S450 and S650 assumptions coupled with a medium climate sensitivity result in a projection of a temperature rise in the range of 0.8 to 1.3⁰C by 2100 (which is better than the worst case emission scenario of IS92e). The point that these projections illustrate is that with significant effort, the stabilisation of atmospheric carbon dioxide is likely to result in a reduced severity of temperature rise, and sea level rise. (See Figure 12)

Global mean Sea Level Rise

The S450 and S650 scenarios coupled with moderate climate and ice melt sensitivity projects a sea level rise of between 25 to 30 cm by 2100 (which is better than the sea level rise expected in the IS92a moderate scenario of 50 cm).

Due to the very long time lags inherent in the climate and ocean systems, temperature and sea level will continue to rise for centuries after atmospheric carbon dioxide levels have stabilised.

4.0 IMPLICATIONS FOR SMALL ISLAND STATES

The characteristics of Small Island States make them particularly vulnerable to the impacts of global warming, climate change and sea level rise:

- Small (limited) physical size surrounded by a large expansion of ocean, which effectively reduces some adaptation options to climate change and sea level rise (such as retreat);
- Large Exclusive Economic Zones

- Limited natural resources, many of which are already stressed from unsustainable human activities;
- Proneness to natural disasters and extreme events and associated storm surge;
- Relative isolation from major markets;
- Extreme openness of their economies which are highly sensitive to external shocks (exhibit low economic resilience);
- Large populations with high growth rates and densities;
- Poorly developed infrastructure;
- Limited financial resources;
- Limited human resources and skills, which may severely limit the capacity to mitigate and adapt to the effects of climate change;

Almost without exception, small island states have been shown to be at great risk from projected impacts of climate change and sea level rise. The projected global rate of rise of 5mm per year is 2 to 4 times greater than the rate experienced in the past 100 years. Reliable instrumental records indicate that on average, Caribbean islands have experienced an increase in temperature exceeding 0.5⁰C since 1900. During the same period, there was a significant increase in rainfall variability, with mean annual total rainfall declining by ~ 250mm. The distinction between vulnerability, sensitivity and adaptability is given in Figure 16.

The IPCC in its Second Assessment Report (SAR) projected a global average temperature increase of the order of 1.0 to 3.5⁰C, and a consequential rise in global mean sea level of between 15-95 cm by the year 2100. Observational data show that temperatures have been increasing by 0.1⁰C per decade and sea levels by ~ 2mm/year in those regions of the world where small island states are found including the Caribbean. There is also evidence that the ENSO phenomenon will continue to have major influence on climate variability in these regions.

The most significant and immediate consequences for small island states are likely to be changes in precipitation (rainfall) regimes and soil moisture budgets, as well as short-term variations in regional and local sea levels and patterns of wave action. Vulnerability assessments recently undertaken in small island states reveal that climate change will impose diverse and significant impacts on them. In most small islands, including the high islands, the majority of the population, socio-economic activities such as agriculture, and infrastructure are located within a few hundred metres of the coast. Consequently, these sectors would be highly vulnerable to the impacts of climate change and sea level rise.

4.1 Scenarios of Future Climate Change and Variability in Small island States

As discussed before, coupled Atmosphere-Ocean Global Climate Models (A-O GCMs) offer the most credible tools for estimating the future response of climate to anthropogenic radiative forcing. A model validation exercise was undertaken for regions in which small island states are located, with the result that four GCMs (the HadCM2 model (UK), the ECHAM4 model (Germany), the CSIRO model (Australia) and the CCSR model (Japan)) have demonstrated reasonable capability in simulating broad features of present-day climate and its variability over these regions in terms of surface temperature, diurnal temperature range and rainfall.

Climate Change Projections for Small Island States

Surface air temperature

The projected area-averaged annual mean warming over the Atlantic Ocean and the Caribbean Sea as a consequence of increases in atmospheric concentration of GHGs is about 2.0⁰C for the decade of the 2050s and about 3.1⁰C for the decade of the 2080s. A marginal decrease in diurnal temperature range (between 0.3⁰ and 0.7⁰C) is also projected.

Extreme High Temperature and Precipitation events

The models suggest an increase in the probability of occurrence of more frequent droughts as well as floods in the Caribbean.

Tropical Storms

There is no consensus regarding the behaviour of tropical cyclones in a warmer world; however, recent studies indicate a possible increase of about 10 to 20% in intensity of tropical cyclones under enhanced carbon dioxide conditions.

5.0 KEY CONCERNS ARISING OUT OF MOST RECENT PROJECTIONS

5.1 Sea Level Rise

While the severity of the threat will vary regionally, sea level rise of the magnitude currently projected (5mm/yr, with a range of 2-9mm/yr) is expected to have great effects on the economic and social development of many small island states and low-lying coastal regions such as the low limestone islands of the Caribbean. A serious concern arising out of this projection is whether small islands and low lying coastal areas of developing countries such as Guyana and Belize, have adequate potential and capacity to adapt to sea level rise within their own national boundaries. As stated before, small island states are physically limited due to their small size and adaptation measures such as retreat, or raising of the land (which would require sand and other aggregate, perhaps already in scarce supply) appears to be of little practical value. In fact, one of the greatest risk is the loss of human capital, and associated economic losses as a result of “off-island” migration.

5.2 Storm Surge and Flood Risks

The change in mean sea level at a particular region will result in changes in the highest sea level as well as changes in storm-surge heights. If mean sea level rises, the present extreme levels will be attained more frequently. The increase in maximum heights will be

equal to changes in the mean sea level, and this may imply a significant increase in the area threatened with inundation. The passage of tropical cyclones with accompanying strong winds are also likely to exacerbate storm surge heights in a situation of increased sea level.

It has been estimated that global sea levels are expected to rise by about 38 cm between 1990 and 2080 based on global sea level rise scenarios produced by the Hadley Centre using the models HADCM2 and HADCM3. This projection implies that relative to a reference scenario without sea level rise, the number of people flooded by storm surge in any typical year will be more than 5 times higher by the 2080s, due to sea level rise. Consequently, many coastal areas of islands and low lying coastal states of the Caribbean are likely to experience more frequent flooding. Projections to the 2080s reveal that the number of people facing high flood risk from sea level rise in regions of Small Island states would be 200 times higher than in most parts of the world. Recent model runs for Cuba (HADCM2 and IS92a scenario) also project that approximately 98 coastal settlements with more than 50,000 persons would be inundated by rising sea levels.

5.3 Beach and Coastal Changes

The morphology, characteristics and classification of beaches and coastal areas are influenced by a variety of factors including island origin, geologic structure and composition (e.g. volcanic, coral etc.), age, elevation and size. Accordingly, there are many coastal types in the Caribbean. Coastal erosion is a problem in many of the Caribbean islands, and may be exacerbated by human-based activities such as sand mining. In many Small Island States, especially some of the Caribbean area, the beaches are maintained by sand produced from productive reefs (whose degradation is already causing accelerated coastal erosion as a result of the destruction of the natural defense to wave action).

5.4 Coral reefs, mangroves and seagrass beds.

Coral reefs are one of the most important resources of tropical islands. They function as a source of food, beach sand, as well as natural breakwaters along the coasts. They also provide habitats for many marine species and also generate income for small islands through tourism activities such as snorkeling and scuba diving. On many islands, coral reefs are facing severe threats from both climate and non-climate stressors. Due to their narrow temperature tolerances, some species of corals currently live at or near their thermal limits. Sea surface temperature projections suggest that the thermal tolerance of reef building corals will be exceeded within the next few decades. Further, the incidences of bleaching are expected to rise rapidly, with the rate of increase highest in the Caribbean relative to other regions. Perhaps the most serious concern with respect to coral reefs since the publication of the IPCC Second Assessment Report (SAR) and Regional Impacts Report, is the impact of increasing carbon dioxide concentrations in the oceans. Since the publication of the SAR, it is now suggested by the IPCC that the ability of reef plants and animals to make the limestone skeletons that build the reef is being reduced by rising atmospheric carbon dioxide concentrations. The higher carbon dioxide atmospheric concentration results in increased ocean surface water acidity, which causes a decrease in the concentration of calcium carbonate ions necessary for reef growth. In the long term (30-100 years), this situation could pose a threat to the sustainability of coral reefs worldwide. This has obvious implications for the islands of the Caribbean.

The effect of sea level rise on coral reef growth has been estimated to be negligible. The reasoning appear to suggest that healthy reef flats will be able to keep pace with the projected sea level rise. However, this prognosis is not so optimistic for the reefs of many Caribbean islands where the reef structures have been weakened by a variety of anthropogenic stresses.

5.5 Mangroves

Mangroves provide important functions as protection against storms, tides, cyclones and storm surges. Coastal fringe mangroves are especially important for shoreline protection. Many mangrove forests are already under stress from exploitation and development, which may result in reduced resilience to sea level rise. Studies have suggested that mangrove forests in some small islands will be lost as a result of elevated sea levels.

5.6 Seagrasses

Seagrass communities provide useful habitat for many marine fishes particularly in the shallow, inter-tidal environments of many islands. An increase in sea surface temperature will adversely affect seagrass communities as a result of physiological effects on growth rates. Higher sea levels may also result in a reduction of the amount of light reaching seagrass beds, which would reduce plant productivity.

6.0 ADAPTATION APPROACHES TO CLIMATE CHANGE IMPACTS IN COASTAL AREAS OF SMALL ISLAND STATES.

It is now widely accepted that strategies for adaptation tend to fall into three main categories:

1. Retreat;
2. Accommodation;
3. Protection

The traditional response to coastal erosion problems has been the construction of sea walls, breakwaters, groynes and bulkheads. It is questionable as to whether such approaches have been efficiently implemented. Other potential options available to small island states may include the enhancement and preservation of natural protection (replanting of mangroves and protection of coral reefs); beach nourishment and raising the height of the ground of coastal settlements. However, beach nourishment may not be an option to many islands as sand is already a scarce resource. Caribbean islands have

tend to adopt a “precautionary approach” such as the enforcement of building setbacks, land-use regulations, building codes and practices and insurance coverage.

An attractive response mechanism to the impacts of global climate change, given the clear vulnerability of small island states, is the employment of integrated coastal management (ICM) in planning for adaptation, and it may be regarded as an anticipatory and predictive tool so as to plan for and respond to medium and long term concerns such as sea level rise, as well as short term and present needs.

6.1 Cost-Benefit Analysis

Investment costs in coastal protection hard structures may be considerable. The question therefore naturally arises: would the major investments in coastal protection be justified. The simple answer is: it all depends. Investment costs, which may be uncertain in the future, and reflective of the nature of the understanding of climate change, have to be weighed against the investment benefits of protection, which are equally difficult to quantify. These benefits are two fold: Land loss is prevented and so the capacity to produce food, retain infrastructure for development etc. is preserved. These benefits can be valued objectively insofar as they accrue presently. On the other hand, however, there may be uncertain future benefits, as well as hard-to-value nonmarket benefits or damage avoided in terms of less human insecurity and suffering, as well as less loss of biodiversity due to the conservation of coastal ecosystems. The approach therefore appears to be the development of a comprehensive understanding of the various benefits in order to make a meaningful assessment of coastal protection investment.