Regional Assessment of the Vulnerability and Resilience of Pacific Islands to the Impacts of Global Climate Change and Accelerated Sea-Level Rise

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Contents

A summary for policy makers

Background

This report was initiated by the South Pacific Regional Environment Programme (SPREP) to assess the regional vulnerability and resilience of Pacific islands to the impacts of global climate change and accelerated sea-level rise. It reflects the continuing and growing concern of the small island developing states (SIDS) of the Pacific with respect to the regional and national manifestations of global climate change and accelerated sea-level rise. The regional synthesis presented here is intended to assist the SPREP Secretariat to continue its support of its members in international negotiations related to global climate change and accelerated sea-level rise.

The findings of the study are summarised below. The full report is available from SPREP.

Findings

There is now a consensus that there is a discernible human influence on global climate. The form these global changes will take in the Pacific is far less certain, but the most significant and more immediate consequences are likely to be related to changes in rainfall regimes and soil moisture budgets, prevailing winds (both speed and direction) and in regional and local sea levels and patterns of wave action.

A second finding is arguably of even greater and immediate importance. Pacific island countries are highly vulnerable to changes in both mean and extreme atmospheric and oceanic conditions. This applies to natural as well as socioeconomic systems. In some instances the vulnerability is partially offset by the intrinsic resilience of natural systems and by decisions to manage systems in a way which increases their ability to withstand the adverse impacts of variations in climatic and oceanic conditions. Notwithstanding such characteristics and interventions, Pacific island environments—both natural and human—are undeniably susceptible to extreme and anomalous persistent events occurring under present day conditions. Vulnerability and actual harm are enhanced by increased human pressure on natural systems. This sensitivity, and the consequences, leave little doubt that should the changes predicted in the Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report manifest themselves in the future, the repercussions will threaten the life-supporting capacity of natural systems and the sustainability of human habitation.

Climate change and sea-level rise are two of numerous environmental concerns for island nations and territories of the Pacific. These issues are accorded high government priority in all Pacific island countries, for it is generally recognised that they would exacerbate most other environmental problems and many social, cultural and economic issues currently facing these countries.

Vulnerability assessments have revealed that it is not only the low islands of the Pacific which are susceptible to the adverse effects of sea level rise. Human population, economic activity and infrastructural development are concentrated in the coastal areas of high islands. There are few effective opportunities for retreat in face of inundation consequent upon rising sea levels or increased frequency and magnitude of storm waves and surges. These characteristics mean that vulnerabilities are very high in such cases. Few land masses in the Pacific are tectonically stable—systematic changes in sea level may be significantly offset or exacerbated by local uplift or subsidence of the land.

Imperative for action

There are areas of uncertainty associated with the preceding findings. But many of the anticipated changes may well be irreversible by the time there is certainty of outcome. Moreover, the momentum of change in the combined atmosphere-ocean system is such that the modifications of atmospheric composition taking place as a result of current human activity are already committing our children and their children to living in a world substantially different to the one we know today. From the Pacific island perspective, dangerous anthropogenic interference is already occurring to the climate system.

Basic response strategies

There are two main categories of active response to climate change: mitigation and adaptation. The need for both has been recognised in the United

Nations Framework Convention for Climate Change (UNFCCC) as well as other agreements and strategies. Mitigation refers to those activities which seek to reduce the build up of greenhouse gas and other climate modifying constituents and thereby reduce the rate and magnitude of climate change. Many countries in the Pacific have done little to cause changes in atmospheric composition and hence in the global climate. Moreover, few are in a position, by themselves, to directly influence mitigation. But collectively Pacific island countries can have an influence on mitigation, as has been amply illustrated by the negotiations leading to the UNFCCC. Consistent with the Convention, Pacific island countries are also active in reporting on and implementing mitigation strategies. For all these reasons, adaptation rather than mitigation strategies were emphasised in the study.

Adaptation is used in the present context to refer to those activities which enable communities, now or in the future, to cope with changes resulting from global warming. It therefore includes activities which seek to offset the costs and increase the benefits that may accrue from climate change. Adaptive responses can be many and varied, reflecting differences in existing social, economic, cultural and environmental conditions and the likely stresses induced by climate change, both within and between countries.

International effort has tended to focus on gaining agreement to limit climate change. Significantly, even if an agreement to totally halt human-induced changes in atmospheric composition could be reached today, there would be residual effects far into the future. These would be due to lags in the response of the climate system to changes in atmospheric composition that resulted from human activity over the preceding decade or more. In the event that significant reductions in anthropogenic greenhouse gas emissions are not achieved for some time, adaptive action becomes even more necessary. Many adaptation strategies are effectively the same as those which constitute sound environmental management, wise resource use and appropriate responses to present-day climate variability. Often the strategies are found in policies and plans for sustainable development. Thus, adaptive responses may well be beneficial even if the climate does not change as anticipated.

Resource and environmental management strategies which are beneficial for reasons other than climate change, and which can be justified by current evaluation criteria and decision rules, may well be the measures to select first in developing responses to climate change. This approach is referred to as the ‘no regrets’ strategy.

Proposed policy responses for Pacific island countries

The fundamental motives of protecting environmental and human health and welfare should inspire all island countries in the Pacific to do everything in their power to limit climate change and to plan appropriate adaptations for changes that are anticipated to occur despite international attempts at mitigation. In addition, such planning and policy initiatives must be taken if parties to the UNFCCC are to meet their obligations.

It is important to realise that there is significant uncertainty surrounding our present information and understanding. For this reason, it is premature to be prescriptive regarding regional response strategies and priorities for addressing the impacts of climate change on Pacific island countries. Much remains to be accomplished in terms of both information gathering and methodology development before the procedures for assessing regional climate impacts and identifying optimal response options (be they mitigation, adaptation or simply no regrets) can be implemented in a comprehensive and rigorous manner for the entire region. Indeed, the study notes that meeting these prerequisites is a high priority in response formulation.

There are several regional responses which would facilitate adaptation to climate change. Priority is given to ‘no regrets’ policies and plans since, as also noted earlier, these form the basis of sound environmental and resource management regardless of climate and related changes. The following policy responses, some of which are already being coordinated by SPREP, may be worthy of further consideration:

- A Policy of Regional Cooperation and Coordination;
- A Policy of Owning the Issue of Climate Variability and Change;
- A Policy of Maximising the Benefits of Climate Change;
- A Policy to Base Plans and Actions on Factual Understanding of Climate Change;
- A Policy of Mainstreaming Climate Change Responses in National Planning;
- A Policy of Enhancing Capacities to Respond to the Consequences of Anticipated Changes in Climate; and
- A Policy of Enhancing Regional Security.

Priority policies

The policies outlined above are mutually supportive, rather than conflicting or competing. As such they could well be accorded equal and high priority with respect to implementation. However, securing the capacity to implement the policies could be accorded some overall priority. This would help ensure that the remaining policies are implemented in a favourable milieu and in a sustainable manner.

Proposed regional action strategies of high priority

The study confirmed the need for urgent action at the regional level in order to alleviate the adverse impacts of climate change on human, environmental and economic sectors of Pacific island countries. The strategies are developed in the context of the previously articulated policies. The priority ascribed to them is a reflection of the study's findings related to assessment of the vulnerability and resilience of Pacific island countries to climate and related changes.

- A Strategy for Capacity Building;
- A Strategy for Development and Application of Appropriate Assessment Methodologies and Information Sources;
- A Strategy to Identify, Assess and Implement Technologies Relevant to Adaptation;
- A Strategy to Identify, Assess and Implement Investment Instruments Relevant to Adaptation;
- A Strategy to Support Optimal Management Responses to Climate Change at the National Level; and
- A Strategy for Regional Support for Integrated Coastal Zone Management.

Implementation

In keeping with international understanding and priorities, Pacific island countries are committed, individually and collectively, to developing sustainably. Thus the intimate linkages between economic development, environmental, cultural and resource conservation and social progress are recognised. Development must involve achieving an equitable balance between the foregoing goals, rather than seeing them as distinct or differing in priority. For these reasons environmental management cannot be, and typically is not considered in isolation.

If policy development and the ensuing actions to address the anticipated impacts of climate change and accelerated sea-level rise are to be effective they must be mainstreamed in both development planning and disaster management, with core initiatives being identified and implemented within an integrated environmental management framework. This is a current and continuing challenge for Pacific island countries where limitations on resources (human, financial, technical and information) and institutional capacities mean responses that, on occasions, fall short of the optimum approach. The cost is further stress on systems already under pressure.

Further background to the study

The review is based, in part, on a synthesis of the findings of preparatory missions conducted under the auspices of SPREP. These involved the Pacific island countries and territories of Tonga, Kiribati, Tuvalu, Cook Islands, Guam, Palau, the Federated States of Micronesia, Samoa and Tokelau. Two similar studies were also undertaken in the Marshall Islands.

While each island country or territory in the Pacific faces its own specific mix of environmental problems which will be caused or exacerbated by changes in climate or sea level, or both, it is possible to identify features that are held in common. Despite their diversity, the island nations and territories of the Pacific do have many common environmental concerns, as was demonstrated so forcefully at the United Nations Conference on Environment and Development.

Current understanding of climate change and its implications for the Pacific

The recent findings of the Scientific Assessment Working Group of IPCC and other investigations reveal that continuing increases in greenhouse gas concentrations are tending to warm the surface and to produce other changes of climate. These changes are largely attributed to human activities, mostly fossil fuel use, land-use change and agriculture. The warming is being offset, in part, by tropospheric aerosols resulting from combustion of fossil fuels, biomass burning and other sources.

Analyses of meteorological and other data over large areas and over periods of decades or more have provided evidence for some important systematic changes in climate over the past century. Global mean surface temperature has increased by between about 0.3° and 0.6°C since the late 19th century. Recent years have been among the warmest since 1860, i.e. in the period of instrumental record, despite the cooling effect of the 1991 Mt. Pinatubo volcanic eruption. Assessments of the statistical significance of the observed global-mean temperature trend over the last century suggest a significant change and show that the observed warming trend is unlikely to be entirely natural in origin.

There are inadequate data to determine whether consistent global changes in climate variability or weather extremes have occurred over the 20th Century. On regional scales there is clear evidence of changes in some extremes and climate variability indicators. The 1990 to mid-1995 persistent warm phase of the El Niño–Southern Oscillation (ENSO) (which causes droughts and floods in many areas of the world) was unusual in the context of the last 120 years, as has been the dominance of the warm phase since the mid-1970s.

The climate is expected to continue to change in the future. For the mid-range IPCC scenario of greenhouse gas and aerosol precursor emissions, assuming the 'best estimate' value of climate sensitivity, models project an increase in global mean surface temperature relative to 1990 of about 2°C by 2100. This estimate is approximately one third lower than the 'best estimate' in 1990, due primarily to lower emission scenarios (particularly for CO_2 and the CFCs), the inclusion of the cooling effect of sulphate aerosols, and improvements in the treatment of the carbon cycle. Despite these reduced estimates of the magnitude of global warming, the Alliance of Small Island States (AOSIS) and others have noted that large reductions in greenhouse gas emissions are required to stabilise atmospheric concentrations at safe levels.

Moreover, future unexpected large and rapid climate system changes (as have occurred in the past) are difficult to predict. This implies that future climate changes may also involve 'surprises'.

Studies carried out under the auspices of the IPCC indicate that the biases in simulations of regional climate change and the inter-model variability in the simulated regional changes are still too large to yield a high level of confidence in simulated change scenarios.

The IPCC emphasises that regional temperature changes could differ substantially from the global mean value. Confidence is higher in the hemispheric-to-continental scale projections of coupled atmosphere-ocean climate models than in the regional projections, where confidence remains low. There is more confidence in temperature projections than hydrological changes. The cooling effect of aerosols is not a simple offset to the warming effect of greenhouse gases, but significantly affects some of the continental scale patterns of climate change, most noticeably in the summer hemisphere. The spatial and temporal distribution of aerosols greatly influence regional projections, which are therefore more uncertain.

Despite the serious constraints on the current use of global climate models for prediction of changes in regional climate, some benefits arise from studying the results of recent efforts. In general, temperatures in the Pacific exhibit minor sensitivity to an effective doubling of CO_2, though the sensitivity increases with latitude and in winter relative to summer. Changes in seasonal rainfall produce somewhat complex patterns, but mean annual rainfall is generally higher, except for mid latitude areas.

These results suggest that, for lower latitude areas of the Pacific, systematic increases in local temperatures will not be an important consequence of an enhanced greenhouse effect. However, recent calculations which include oceanic heat transfers more consistent with observations suggest that the Southern Hemisphere oceans would warm at twice the rate predicted by other models. Greater rates of warming in the tropical atmosphere than has been indicated in recent studies are also suggested by the recent finding that increasing water vapour resulting from higher temperatures is unlikely to form thicker and hence more reflective clouds. Instead it is likely to remain dispersed in the atmosphere, where it can act as a greenhouse gas, increasing the rate of warming, or increasing the amount of rainfall. Recent satellite studies suggest that clouds actually become thinner as warming increases. The findings are consistent with the predictions of many global climate models that the warming effect of increased water vapour would predominate over the cooling effect of increased cloud formation. Such results are consistent with recent studies of the geologic record which show that during the last ice age tropical temperatures varied more than previously thought.

A general warming is expected to lead to an increase in the occurrence of extremely hot days and a decrease in the occurrence of extremely cold days. Warmer temperatures will lead to a more vigorous hydrological cycle; this translates into prospects for more severe droughts and/or floods in some places and less severe droughts and/or floods in other places. Several models indicate an increase in precipitation intensity, suggesting a possibility for more extreme rainfall events.

Studies also show that it is necessary to consider climate elements other than temperature, including rainfall and wind and extreme events such as tropical cyclones. The naturally large interannual variability in these elements, and their poor characterisation by climate models, severely restrict the ability to make reliable estimates of changes in such variables as a result of greenhouse warming.

The IPCC notes that the behaviour of ENSO has been unusual since the mid-1970s and especially since 1989. Since the mid-1970s warm episodes (El Niño) have been relatively more frequent or persistent than the opposite phase (La Niña). The recent ENSO behaviour, and especially the consistent negative values of the Southern Oscillation Index since 1989, appears unusual in the context of the instrumental record that spans the past 120 years. However, evidence suggests that such unusual patterns have occurred prior to the period of instrumental record.

Several coupled ocean-atmosphere general circulation models are able to simulate ENSO-like sea surface temperature variability for present day climate, and also for climates associated with increased greenhouse gas concentrations. However, it is not at all clear whether global warming will affect the characteristics of ENSO and the climate patterns with which it is related.

The IPCC warns against overly simplistic conclusions that, since sea surface temperatures are likely to increase, so too will the occurrence of tropical cyclones. Although some models now represent tropical storms with some realism for present day climate, the state of the science does not allow predictions of future changes.

In the South Pacific the number of tropical cyclones appears to have increased and in the latter case this may be related to the increased frequency of El Niño events. But such conclusions must be qualified in light of the quality (especially the lack of consistency) of the long term cyclone data base. Knowledge is currently insufficient to say whether there will be any changes in the occurrence or geographical distribution of severe storms, e.g. tropical cyclones. The formation of tropical cyclones depends not only on sea surface temperatures, but also on a number of atmospheric factors including the vertical lapse rate of temperature and vertical wind shear. Although some models now represent tropical storms with a degree of realism for present day climate, the state of science does not allow conclusive assessment of future changes. Some research suggests that there are in fact no compelling reasons for expecting a major change in global tropical cyclone frequency, although substantial regional changes may occur. At present models are incapable of predicting the direction of such changes. But other researchers claim it is highly probable that the increasing temperature differences between the tropical atmosphere and oceans as a result of global warming would be accompanied by an increase in the maximum intensity of actual tropical cyclones. Meanwhile, another investigation indicates that there is unlikely to be more intense tropical cyclones than the worst that occur at present, though there is some propensity for changes in cyclone frequency in regions where sea surface temperatures are between 26° and 29°C at present. Another study found that for an enhanced greenhouse scenario the geographical distribution of tropical cyclones was unchanged but the number decreased, especially in the Southern Hemisphere.

The IPCC concludes that it is very much open as to whether the frequency, area of occurrence, time of occurrence, mean intensity or maximum intensity of tropical cyclones will change as a consequence of global warming.

Global sea level has risen by between 10 and 25 cm over the past 100 years and much of the rise may be attributed to the increase in global mean temperature. The 'best estimate' of the effect of global warming is an increase in sea level of about 50 cm from the present to 2100. This estimate is approximately 25 per cent lower than the 'best estimate' in 1990 due to the lower temperature projection, but also reflects improvements in the climate and ice melt models.

Sea level would continue to rise at a similar rate in future centuries beyond 2100, even if concentrations of greenhouse gases are stabilised by that time, and would continue to do so even beyond the time of stabilisation of global mean temperature. Regional sea level changes may differ from the global mean value owing to land movement and ocean current changes.

Additional information on common findings in the country studies

Based on the findings of country and more detailed studies, the following are the common themes, issues and findings relating to variations in, and changes to climate and/or sea level.

Physical changes to the environment

The relevant factors leading to physical changes to the coastal environment include not only sea-level rise, but also significant variations in the characteristics of storm surges, wind velocity, near shore currents and wave energy. Possible consequences depend on a range of factors—island size, elevation and shape; exposure to wind and waves; length of shoreline and its composition; vegetation cover and the nature of any adjacent reef and lagoon features.

For example, studies for Majuro Atoll (Marshall Islands) indicate that, even for a 25 cm increase in sea level, the shoreline would retreat by as much as 5 m. Nearly 10 per cent of the dry land area would be lost as a consequence of such a higher sea level. Flooding would impact a further 30 per cent of the land area. At one site, with a 25 cm increase in sea level, flooding frequencies would increase from the present one year in five to 10 times per year.

Flooding of land, or at least excessive levels of soil water or salt, may result from a rising water table which is in turn a natural consequence of higher sea levels. In lowland areas, groundwater can also lead to increased surface flooding or land can become swampy and springs more prevalent should rain storms be heavier or of longer duration. On steep uplands excessive soil loss can be expected with such changes, or with modification of surface land cover and use as a consequence of changes in the climate. The resulting sediment will likely have detrimental effects on lagoon and near shore ecosystems. Soil can be also be degraded through a loss of moisture due to decreased precipitation or enhanced evaporation, changes that are anticipated for some other areas of the Pacific.

Under storm conditions, strong winds are capable of carrying sea salt inland for considerable distance, with detrimental impacts on natural vegetation and crops, physical infrastructure and potable water supplies.

The effect of sea level on groundwater conditions can be increased further by dredging and quarry operations increasing the coupling of the ocean and groundwater. Similarly, projects such as channel development or causeway construction may modify lagoon circulation characteristics, and hence the factors controlling water level differences between lagoon and ocean.

A major issue is how coral reefs will respond to the projected rises in sea level. Their response may well be conditioned, in part, by higher ocean temperatures since above a certain temperature corals typically eject their symbiotic algae. This results in ‘bleaching’ and possible widespread death of corals. As this response is also associated with other excessive stresses on the ecosystem, a healthy reef ecosystem is more resilient to rising sea-surface temperatures. In the past, healthy reef systems have survived 1000 years or longer periods where sea level has risen by 20 mm y^{-1}. A ‘best guess’ of maximum vertical coral accretion under ideal conditions is 10 mm y^{-1}, but modal rates for shallow lagoonal reefs is 0.6 mm y^{-1}, for coral reef flats 3 mm y^{-1} and for coral thickets 7 mm y^{-1}. On the other hand a ‘best guess’ for sea-level rise is around 4 mm y^{-1}. Thus healthy reefs may be able to adapt to sea-level rise, the response being helped by fewer exposures at low tide and by enhanced water circulation. But such responses will be severely hampered by coral bleaching, sedimentation effects, physical reef damage, freshwater inputs, pH, sunlight, resource exploitation and other human-induced impacts.

Where reef fronts do not keep pace with sea-level rise there will be greater opportunity for storms and cyclones to damage exposed and degraded parts of lagoons, such as by burying corals and other animals in sediments and eroding shorelines. Particularly in the case of nursery areas for vertebrate and invertebrate species, destruction of these habitats could have a serious impact on the near shore environment and resources, and hence on the lifestyles of the people who depend on them.

Physical resources

Here emphasis is placed on the potential of climate change to impact adversely on water resources and materials availability. Considerable concern exists with respect to issues of water quality, quantity and security of supply.

Climatic factors are extremely important in determining the nature of small island surface and groundwater supplies. While one of the initial effects of sea-level rise may be a slight increase in groundwater resources—a consequence of the increased capacity of upper water-bearing units—in the longer term serious losses will likely occur. Two main causes are identified. Catastrophic flooding due to high storm tides may not have a permanent effect, but through saltwater intrusion may well make the groundwater resource unusable at a time when other water supplies are also disrupted. The second, and more insidious effect is a consequence of island area loss, either by frequent tidal inundation of low-lying areas or by erosional loss of shoreline. A 25 cm rise in sea level has been estimated to reduce the cross-sectional area of the fresh water lens on Laura (Marshall Islands) by some 10 per cent.

Demand for natural materials arises from four major activities—new construction, reclamation, protection and upgrading of infrastructure. Material can be removed from the lagoon, other land areas or from offshore. In the absence of other readily accessible sources, on many atoll and reef islands material is taken from coastal sand deposits or rubble banks created by cyclonic storms. Since these formations are integral to the continuing existence of the island system, their removal increases vulnerability to many of the likely manifestations of climate change. Dredging of lagoon sediments may also prove to be unsustainable under present conditions and increase vulnerability to future changes in climate and sea level by removing sediment from the natural system.

Living natural resources

Historically, living natural resources have been generally abundant throughout the Pacific. But this is changing rapidly as population increases and as modern and non-selective methods of exploitation replace more benign traditional practices. Organisms already under stress risk are likely to be further pressured by the consequences of climate change. For higher islands, living marine resources would be adversely affected by substantial increases in freshwater runoff and sediment input to lagoon and reef ecosystems. These would change salinity and light levels, as well as impair the physiology of many species. With the high degree of endism in terrestrial species in the Pacific native plants, animals and birds could be further threatened by land loss, inundation, flooding, drought and salinisation.

Extreme events

Natural hazards already have a disproportionate effect on the environment, resources and population of the Pacific islands. This is especially due to there being little excess natural or human capacity to absorb the additional stresses. Therefore island nations of the Pacific are particularly vulnerable to extreme events such as tropical cyclones, earthquakes, tsunami (seismic sea waves), storm surges and volcanic activity. Some 90 per cent of all indigenous and plantation trees on the Samoan island of Savai'i were defoliated during Cyclone Val, while 40 per cent of the indigenous and 47 per cent of plantation trees were snapped in half or uprooted.

The current inability to predict any of these extreme events, but their substantial influence on human safety and well being and on environmental sustainability, provides a special challenge to planning and management.

Agriculture, forestry and food security

Growth of some plants is expected to increase as a result of increased carbon dioxide concentration in the atmosphere, but this advantage may well be offset by increased heat and water stress, factors which are already prevalent in many countries by the end of the dry season. Prolonged droughts raise the likelihood of fires which destroy protective vegetation and agricultural crops, thus increasing the incidence of soil erosion and, in turn, reducing land productivity. On the other hand, excessive rainfall can threaten the viability of certain crops.

Saltwater intrusion into pulaka and taro pits has traditionally been a problem, especially during droughts, and hence could be exacerbated by global warming since higher sea levels and waves are likely to cause more salt mixing in the freshwater lens. Storm wave over-wash and salt spray would also damage crops, while increases in the groundwater level and the associated increased flooding of low-lying areas would reduce other opportunities for agriculture.

But there is evidence that people can respond quickly to climate related disasters. In Samoa after Cyclone Ofa (February, 1990) staple food crops were scarce and vegetables were not seen in normal quantities for ten months. By way of contrast, vegetables were soon available after Cyclone Val (December, 1991). In addition, the increased availability of taro and other 'storm resistant' crops show that farmers responded quickly to the first cyclone. Farmers have also changed their planting schedules to avoid cyclone damage to crops. Adaptation of temperate forestry concepts to the higher temperature tropics has required the use of new tree planting and husbandry methods in order to protect seedlings and workers from the sun and from storm damage. These experiences will assist in identifying and responding to the additional changes required should global warming occur.

Very little has been done to model the complex circulation patterns in the Pacific at large, and locally. Fish is a major source of protein for many Pacific islanders. Fish take is closely related to ocean currents, zones of upwelling, temperature and to tidal patterns. For many countries storm conditions bring fishing activities to a halt, or severely reduce catches. This again compromises food security given fish is often a major food source and cannot be stored for long time periods. Should the frequency of such weather conditions increase as a consequence of global warming this will place added burden on populations already facing protein deficiency and other food shortages. Access to imported foods can similarly be restricted by severe weather conditions which limit air and sea transport.

Human health

The vulnerability of Pacific island people to health problems is a concern as is the inadequacy of facilities for treatment. While increases in thermal discomfort and heat stress may not be as great as those based on earlier estimates of global warming, higher water tables in some circumstances are likely to cause deterioration in human health. For example, longer periods of standing water could lead to an increase in mosquitoes which in the Pacific are vectors for dengue fever, malaria and elephantiasis. The degree of contamination of surface, ground and lagoon water by human and domestic waste will also increase as the water table rises.

Higher temperatures would influence the ability to store food and medication while climate change in general has implications for healing of injuries and skin and other infections. The demand for mental health services may also be affected due to increased mental stress associated with the real and perceived personal consequences of climate change.

Many of the dispensaries and related health care facilities in the more remote areas of the Pacific are housed in buildings which are highly vulnerable to hurricane force winds. This, and possible damage to other structures such as radio transmission equipment, would greatly impair the ability to arrange for, and provide, emergency care during adverse weather conditions. There is also the possibility that underground reticulated systems (power, telephones), which provide for the basic needs of all people, will be adversely affected by rising and salt-contaminated groundwater.

Commerce, transport and communications

In most countries there is a scarcity of raw materials and even the existing tenuous methods of supply are highly vulnerable to disruption by natural events. Many island nations have sea and air services run by single operators with limited or no reserve capacity. In-country inter island communications often make use of vulnerable high-frequency radio. Several countries are now totally reliant on satellite-based systems for international telecommunications. But to reduce the risk of damage to the antenna the usual procedure is to take it out of service and protect it when tropical cyclone or other potentially damaging conditions are forecast. This may well be the time when there is the greatest need to send messages overseas.

Underground utility reticulation could be affected as water levels rise, especially if the water is saline. In many island countries these underground aquifers are the only source for the fresh water necessary to sustain human habitation.

Tourism is considered by most countries to be at least a partial remedy to depressed economies, but both operations and patronage can be impeded by adverse weather and climate conditions brought about by climate change.

Waste management

The disposal of solid waste and waste water is having a serious detrimental environmental impact in most countries, thereby reducing the resilience of these systems to accommodate change. Land, land-based marine disposal and marine disposal are all implicated. The problem is exacerbated by a lack of planning and inadequate management of waste materials, including enforcement of existing regulations. Changed coastal current patterns could have the undesirable effect of preventing the anticipated dispersal of sewage from ocean outfalls. As water levels increase, in-ground waste disposal facilities such as septic tanks and latrines could be affected adversely. The lack of appropriate waste management and planning can lead to increased methane production, thus contributing further to global warming.

Physical infrastructure

Sea walls, breakwaters, groynes, wharves, slipways and causeways are all threatened by rising sea level and increased storm waves, as are coastal tourism facilities, port infrastructure, roads and other structures built at or near sea level.

Often infrastructure development in coastal areas involves clearance of mangroves, rendering shorelines more vulnerable to erosion and causing loss of important habitat for many marine organisms. This will in turn increase vulnerability to any further environmental changes.

Studies have highlighted difficulties associated with inadequate information resources to support assessments of the risk to infrastructure and humans that are undertaken using more advanced techniques such as those found in geographic information systems. While a contour interval no greater than 0.5 m is desirable, in many instances the interval is 10 or even 30 m. Land use maps are often outdated and scales inadequate for locating individual communities and buildings.

Moves away from traditional forms of housing has increased vulnerability to thermal stress and, in some countries, increased the use of air conditioning. Imported materials used in buildings are often difficult to replace after a storm or other damage causing events, and are prone to causing additional damage and personal injury relative to more harmless local materials.

A wider view of climate change in the Pacific

Identifying and responding to the implications of climate change and sea-level rise requires improved regional coordination and integration of national and local concerns, needs and capacities. This suggests an acceleration of recent initiatives to heighten the influence of small island developing states in negotiations of international agreements and a strengthening of national level capacity. It also implies a balance between top down and bottom up policy formulation and implementation of response strategies. Importantly, in addition to the coordination roles of regional and international organisations, local people must be mobilised to regard climate change and its consequences as their problem. They must assume a role in deciding upon and implementing remedies. This approach requires participation of non-governmental organisations (NGOs), especially religious and village organisations.

There is also a need for increased awareness at the political level, and at the upper levels of the religious and social hierarchies. Such an awareness must be built on a firm foundation of understanding, resulting from additional scientific data and other information being made available in a way which is commensurate with requirements at both national and regional levels.

The spatial and temporal scales of climate change and sea-level rise, and the processes involved, are unfamiliar to all but a minority of well-educated Pacific islanders. There is also the 'competition' with more immediate problems—changes occurring over decades or perhaps centuries can be worried about in the future. Change is also of less practical concern to those living in a naturally highly dynamic (variable) environment, leading to a feeling of powerlessness to modify nature. In addition, there is a prevalent attitude that the ability to cope with the devastating effects of tropical cyclones and other natural hazards is evidence of an aptitude to handle any future environmental threats. While this might have been the case in the past, many of today's natural systems have been degraded by human activity and are therefore more vulnerable to stress, be it natural or human-induced. Moreover, changes in construction materials, methods and styles have all reduced the ability to make rapid and locally sourced repairs to homes and other buildings.

Over and above these personal attitudes is the perception that global warming and rising sea levels may bring tangible benefits to the Pacific. For this reason, some argue that the changes should not be impeded—rather, the approach should be one of adapting to the detrimental consequences and maximising any benefits. The latter include the increased productivity of tropical food crops being grown in areas where the climate is distinctively sub-tropical and improved navigation due to increased water depth over hazards to shipping. As noted by the IPCC, the potential negative impacts are likely to far outweigh any benefits.

The present study has highlighted the importance of climate change, accelerated sea-level rise and associated issues to Pacific island countries and territories. Their vulnerability to such changes has been recognised in a series of country studies and recently confirmed by the IPCC in its recently completed Second Assessment.

The vulnerability is in some instances partially offset by the intrinsic resilience of many natural systems. But this in turn is under threat, from increasing human pressures and from the instabilities likely under a changed climate.

Many institutions and organisations—national, regional and international—are addressing the policy, planning and management issues that arise during consideration of the implications of climate change and accelerated sea-level rise. But their efforts are hampered by limited capacities, nationally and regionally, to identify, evaluate and implement appropriate response options.

Despite these shortcomings, and because of the seriousness and urgency of the problem, a number of appropriate policy responses may be identified. The most important and urgent is to address the capacity constraints. Within the framework provided by these policies a number of more detailed response strategies have been proposed. They all provide support at the regional level for responses that must ultimately be developed and implemented at the local and national levels.

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1. Introduction

1.1 Background

Regional and national manifestations of global climate change and accelerated sea-level rise are a continuing and growing concern of the Small Island Developing States (SIDS) of the Pacific. This is evident from the technical reports prepared by the South Pacific Regional Environment Programme (SPREP) and other regional intergovernmental organisations, and from the communiques issued by the South Pacific Forum and other political bodies. For example, in 1993 the Twenty-Fourth South Pacific Forum 'reaffirmed that global warming and sea-level rise were among the most serious threats to the Pacific region and to the survival of some island states' (South Pacific Forum, 1993).

Through SPREP and other organisations, such as the Alliance of Small Island States (AOSIS), these concerns have been communicated at international fora including the United Nations Conference on Environment and Development (UNCED) and the Global Conference on the Sustainable Development of Small Island Developing States.

As a further reflection of these concerns, and to assist SPREP to continue its support of Pacific SIDS in international negotiations related to global climate change and accelerated sea-level rise, the present study provides an assessment of the regional vulnerability and resilience of Pacific islands to the impacts of global climate change and accelerated sea-level rise.

1.2 Terms of reference

Under the agreed Terms of Reference, the study is to result in a report on the regional vulnerability, and resilience, of Pacific islands to the impacts of global climate change and accelerated sea-level rise. The review should be based upon a synthesis of national studies conducted under the preparatory missions phase to Tonga, Kiribati, Tuvalu, Cook Islands, Guam, Palau, the Federated States of Micronesia, Western Samoa and Tokelau, and also on two similar studies in the Marshall Islands.

In particular, the study is to focus on the following critical issues:

- the issue of climate change, including scientific, environmental management, legal, geopolitical and historical perspectives;
- institutional linkages, both regional and international, between relevant countries and organisations;
- methodologies and findings used in assessing vulnerability of Pacific islands to climate change and sea-level rise;
- strategies and priorities for response options based on an analysis of the findings above;
- the relationship between the climate of the region and the human, environmental and economic sectors of Pacific islands; and
- the requirement, or otherwise, for urgent action to alleviate the negative impacts of climate change on the human, environmental and economic sectors of Pacific islands.

If relevant, examples of observed environmental changes due to changes in the climate or sea-level are to be used for demonstration purposes.

The study should result in two reports: a main substantive report and a brief report for use by policy makers, political leaders and the public.

2. The related issues of global climate change and accelerated sea level rise

2.1 Scientific perspectives

The following account draws heavily on the recent findings of the Scientific Assessment Working Group of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 1995a). Where possible, these conclusions are given greater regional relevance by referring to other recent studies which provide more detail on the possible nature and consequences of climate change in the South Pacific.

In the first instance the following discussion of climate change science and related topics will have a global perspective. This will be followed by a discussion that focuses on the Pacific region.

2.1.1 Global climate change

Considerable progress has been made in the understanding of climate change science since the IPCC Scientific Assessment Working Group issued its first report in 1990. New data and analyses have become available. The IPCC has concluded that continuing increases in greenhouse gas concentrations tend to warm the Earth's surface and produce other changes of climate. Since pre-industrial times (i.e. about 1750) atmospheric concentrations of greenhouse gases have grown significantly–carbon dioxide (CO_2) by about 30%, methane (CH_4) by about 145% and nitrous oxide (N_2O) by about 15%, as of 1992. These trends can be attributed largely to human activities, mostly fossil fuel use, land use change and agriculture. Many greenhouse gases remain in the atmosphere for a long time (for CO_2 and N_2O, many decades to centuries). Hence they have the potential to affect climate on long time scales.

The IPCC has demonstrated that, if carbon dioxide emissions were to be maintained at near current levels, they would lead to a nearly constant rate of increase in atmospheric concentrations for at least two centuries, reaching about twice the pre-industrial concentration by the end of the 21st century. Stabilisation of atmospheric CO_2 concentrations near that level could be achieved only if global anthropogenic CO_2 emissions drop to 1990 rates by approximately 40 years from now, and drop substantially below 1990 levels subsequently. Any eventual stabilised concentration is governed more by the accumulated anthropogenic CO_2 emissions from now until the time of stabilisation, than by the way those emissions change over the period. This means that, for a given stabilised concentration value, higher emissions in early decades require lower emissions later on.

Stabilisation of CH_4 and N_2O concentrations at today's levels would involve reductions in anthropogenic emissions of 8% and more than 50%, respectively.

The IPCC shows that the direct and combined effect of chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) is substantially less than that of CO_2 and their net effect is reduced still further because they cause stratospheric ozone depletion which gives rise to a potential cooling. Growth in the concentration of CFCs, but not HCFCs, has slowed to about zero. The concentrations of both CFCs and HCFCs, and their consequent ozone depletion, are expected to decrease substantially by the year 2050 through implementation of the Montreal Protocol and its Adjustments and Amendments.

At present some long-lived greenhouse gases (particularly HFCs [a CFC substitute], PFCs and SF6) make little potential contribution to atmospheric warming, but their projected growth could make them more significant during the 21st century.

There is evidence that, as a result of human activity, tropospheric ozone concentrations in the Northern Hemisphere have increased since pre-industrial times and may also contribute to atmospheric warming. Recent observations have shown that the upward trend has either slowed significantly or stopped (IPCC, 1995a).

According to the IPCC, tropospheric aerosols (microscopic airborne particles) resulting from fossil fuel combustion, biomass burning and other sources, have the potential to cause a modest cooling of the atmosphere both directly and indirectly. While the potential for cooling is focused in particular regions and subcontinental areas, it can affect climate patterns from a continental to a hemispheric scale. Locally, the aerosol forcing can be large enough to more than offset the positive forcing due to greenhouse gases. In contrast to the long-lived greenhouse gases, anthropogenic aerosols are very short lived in the atmosphere. Hence their potential effect on climate adjusts rapidly to increases or decreases in emissions.

At any one location, year to year variations in weather can be large. Nevertheless, analyses of meteorological and other data over large areas and over periods of decades or more have provided evidence for some important systematic changes in climate over the past century. Global mean surface temperature has increased by between about 0.3° and 0.6° C since the late 19th century—the additional data available since 1990 and subsequent re-analyses have not significantly changed this range of estimated increase (IPCC, 1995a).

Recent years have been among the warmest since 1860, i.e., in the period of instrumental record, despite the cooling effect of the 1991 Mt. Pinatubo volcanic eruption. Night-time land temperatures have generally increased more than daytime temperatures. Regional changes are also evident. For example, the recent warming has been greatest over the mid-latitude continents in winter and spring, with a few areas of cooling, such as the North Atlantic ocean. Precipitation has increased over land in high latitudes of the Northern Hemisphere, especially during the cold season.

There are inadequate data to determine whether consistent global changes in climate variability or weather extremes have occurred over the 20th Century (IPCC, 1995a). On regional scales there is clear evidence of changes in some extremes and of climate variability indicators. Some of these changes have been toward greater variability; others have been toward lower variability. The 1990 to mid-1995 persistent warm phase of the El Niño Southern Oscillation (which causes droughts and floods in many areas) was unusual in the context of the last 120 years.

The IPCC is of the opinion that the balance of evidence suggests a discernible human influence on global climate. However, any human induced effect on climate is superimposed on the background 'noise' of natural climate variability, which results both from internal fluctuations and from external causes such as solar variability and volcanic eruptions. Detection and attribution studies attempt to distinguish between anthropogenic and natural influences. 'Detection of change' is the process of demonstrating that an observed change in climate is highly unusual in a statistical sense, but does not provide a reason for the change. 'Attribution' is the process of establishing cause and effect relations, including the testing of competing hypotheses.

Progress has been achieved in distinguishing between natural and anthropogenic influences on climate. By including the effects of sulphate aerosols in addition to greenhouse gases, more realistic estimates of human-induced climate change have been achieved. Additionally, new simulations, with coupled atmosphere-ocean models, have provided important information about natural internal climate variability over time scales of decades to centuries. A further major area of progress has come from the shift of focus from studies of global mean changes to comparisons of modelled and observed spatial and temporal patterns of climate change (IPCC, 1995a).

The IPCC considers that the most important results related to the issues of detection and attribution are:

- the limited available evidence from proxy climate indicators suggests that the 20th century global mean temperature is at least as warm as any other century since at least 1400 AD. Data prior to 1400 are too sparse to allow the reliable estimation of global mean temperature;

- assessments of the statistical significance of the observed global mean temperature trend over the last century suggest a significant change and show that the observed warming trend is unlikely to be entirely natural in origin;

- more convincing recent evidence for the attribution of a human effect on climate is emerging from pattern-based studies. In these the modelled climate response to combined forcing by greenhouse gases and anthropogenic sulphate aerosols is compared with observed geographical, seasonal and vertical patterns of atmospheric temperature change. These studies show that such pattern correspondences increase with time, as one would expect as an anthropogenic signal increases in strength. Furthermore, the probability is very low that these correspondences could occur by chance as a result of natural internal variability only. The vertical patterns of change are also inconsistent with those expected for solar and volcanic forcing; and

- our ability to quantify the human influence on global climate is currently limited because the expected signal is still emerging from the noise of natural variability, and because there are uncertainties in key factors. These include the magnitude and patterns of long-term natural variability and the time evolving influences by, and in response to, changes in concentrations of greenhouse gases and aerosols, and land surface changes. Nevertheless, the balance of evidence suggests that there is a discernible human influence on global climate.

According to the IPCC the climate is expected to continue to change in the future. The increasing realism of simulations of current and past climate by coupled atmosphere-ocean climate models has increased confidence in their use for projection of future climate change. Important uncertainties remain, but these have been taken into account in the full range of projections of global mean temperature and sea level change.

For the mid-range IPCC scenario of greenhouse gas and aerosol precursor emissions, assuming the 'best estimate' value of climate sensitivity, models project an increase in global mean surface temperature relative to 1990 of about 2°C by 2100. This estimate is approximately one-third lower than the 'best estimate' in 1990. This is due primarily to lower emission scenarios (particularly for CO_2 and the CFCs), the inclusion of the cooling effect of sulphate aerosols, and improvements in the treatment of the carbon cycle. Combining the lowest IPCC emission scenario with a 'low' value of climate sensitivity leads to a projected increase of about 1°C by 2100. The corresponding projection for the highest IPCC scenario combined with a 'high' value of climate sensitivity gives a warming of about 3.5°C. In all cases the average rate of warming would probably be greater than any seen in the last 10,000 years, but the actual annual to decadal changes would include considerable natural variability (IPCC, 1995a).

Because of the thermal inertia of the oceans, only 50–90% of the eventual equilibrium temperature change would have been realised by 2100 and temperature would continue to increase beyond 2100, even if concentrations of greenhouse gases were stabilised by that time.

The IPCC also notes that future unexpected, large and rapid climate system changes (as have occurred in the past) are, by their nature, difficult to predict. This implies that future climate changes may also involve 'surprises'. In particular these arise from the non-linear nature of the climate system. When rapidly forced, non-linear systems behave unexpectedly.

However, Crowley (1993) has noted that geologic records do not support one of the major predictions of greenhouse models—that tropical sea surface temperatures will increase. He recognises that full acceptance of the above findings requires more measurements and more systematic compilations of existing geologic data. Only then will the uncertainties associated with his conclusions be reduced to acceptable levels.

2.1.2 Changes in global

The dynamic processes of the atmosphere and ocean account for a large portion of the interannual and interdecadal variability in sea-level. These fluctuations reflect changes in temperature and salinity, currents and coupled atmospheric-oceanic forcing such as that associated with the El Niño – Southern Oscillation (ENSO) phenomenon. These large variations in sea-level limit the ability to determine reliable sea-level trends and accelerations (Sturges and Hong, 1994). But as ocean modelling becomes more detailed and surface and deep ocean observations become more routine this situation will improve.

As documented by the IPCC, global sea-level has risen by about 18 cm over the past 100 years, with a range of uncertainty between 10 and 25 cm. As geodynamic models, measurements of vertical land movements and the length of observational record improve, this uncertainty will lessen.

Much of the observed rise is attributed to the increase in global mean temperature. Average sea-level is also expected to rise in the future, as a result of thermal expansion of the oceans and melting of glaciers and ice sheets. For the mid-range IPCC scenario, and assuming the 'best estimate' values of climate sensitivity and of ice melt sensitivity to warming, models project an increase in sea-level of about 50 cm from the present to 2100. This estimate is approximately 25% lower than the 'best estimate' in 1990 due to the lower temperature projection, but also reflecting improvements in the climate and ice melt models. Combining the lowest emission scenario with the 'low' climate and ice melt sensitivities gives a projected sea-level rise of about 15 cm from the present to 2100. The corresponding projection for the highest emission scenario, combined with 'high' climate and ice melt sensitivities, gives a sea-level rise of about 95 cm from the present to 2100.

As anticipated by the IPCC, sea-level would continue to rise at a similar rate in future centuries beyond 2100, even if concentrations of greenhouse gases were stabilised by that time, and would continue to do so even beyond the time of stabilisation of global mean temperature. They also point out that regional sea-level changes may differ from the global mean value owing to land movement and ocean current changes.

2.1.3 Climate changes in the Pacific region

Studies carried out under the auspices of IPCC indicate that the biases in simulations of regional climate change and the inter-model variability in the simulated regional changes are still too large to yield a high level of confidence in simulated change scenarios.

The IPCC emphasises that regional temperature changes could differ substantially from the global mean value. Confidence is higher in the hemispheric to continental scale projections of coupled atmosphere ocean climate models than in the regional projections, where confidence remains low. There is more confidence in temperature projections than hydrological changes. The cooling effect of aerosols is not a simple offset to the warming effect of greenhouse gases, but significantly affects some of the continental scale patterns of climate change, most noticeably in the summer hemisphere. The spatial and temporal distributions of aerosols greatly influence regional projections, which are therefore more uncertain.

Pittock (1993) notes that, since impacts of climate change manifest themselves at a local or regional level, they will not be correctly anticipated by considering only globally averaged changes in the atmosphere or marine climates. For some variables, it may be that globally averaged changes will be the opposite of those occurring in a specific location or region. Intraregional differences in historic climate variations are highlighted for temperature and precipitation by Salinger et al. (1995) for temperature and rainfall and by Hay et al. (1993) for rainfall alone. Five main South Pacific precipitation regions showing distinctive trends could be identified.

With respect to mean air temperature, areas to the southwest of the South Pacific Convergence Zone have displayed steady climate warming, while those to the northeast cooled during the 1970s and warmed in the 1980s. Salinger et al. (1993) show that warming in the southwest Pacific over the past five decades can be attributed to increases in both mean maximum and mean minimum temperature while for Northern Hemisphere land areas warming has occurred mainly through increases in the minimum temperature.

Pittock (1993) identified several climate change related issues that are special to the South Pacific region. He includes:

- tropical cyclones, which cannot be adequately simulated in global climate models as they are sub-grid scale;

- the El Niño – Southern Oscillation phenomenon is a major source of atmospheric and oceanic variability in the South Pacific, but it is not well modelled by the current generation of global climate models;

- variations in the Intertropical and South Pacific Convergence Zones have a major influence on the seasonal and interannual patterns of rainfall in the region but many global models are incapable of reproducing these variations under present conditions let alone those associated with elevated levels of greenhouse gases;

- in addition to temporal variations in global mean sea-level, relative sea-level will vary locally due to tectonic movements, changes in ocean currents, and regional variations in sea water density due to salinity and temperature changes;

- impacts on coastal zones will depend critically on any local changes in ocean currents and wave climatologies;

- regional and local variations in sea surface temperatures have large potential effects on fisheries and on coral reef ecosystems;

- the sensitivity to changes in carbon dioxide and stratospheric ozone concentrations for natural and managed ecosystems, both terrestrial and marine, of importance to the South Pacific, will vary locally and regionally; and

- changes in the magnitude and frequency of extreme or threshold events produce significant impacts. Since such changes are a composite effect of the above factors they too will be specific to a given region or locality.

While awaiting the implementation of global climate models with appropriately increased spatial resolution, Pittock (1991) argues that high resolution, limited area models offer a useful interim approach especially when they are driven by, or nested within, global models. Various statistical approaches can also be used to interpolate to spatial scales finer than those of the current grid spacings in global climate models. Thus even now, the capability exists to prepare climate change and sea-level rise scenarios with an appropriate regional focus and spatial resolution, and tailored to the needs and priorities of the countries concerned.

Pittock et al. (1996a) summarises recent progress in the development of climate change scenarios for the South West Pacific and identifies where even more useful information will be available in the near future. Global climate models used in global warming studies simulate many of the major features of the Southern Hemisphere circulation, including the subtropical high pressure belt and the circumpolar trough. But in general the older models are less reliable in simulating features of regional climatic significance. Pittock et al. (1996a) review recent progress with limited area models.

Currently the boundary conditions of such models are supplied by a global climate model, but the results of the limited area model are not passed back. Two-way nesting, where results are passed in both directions, may improve the quality of simulations, especially in tropical latitudes where weather patterns are slower-moving, and quasi-stationary systems may evolve within the nested model domain independently of the boundary forcing.

Whetton et al. (1996a) and Pittock et al. (1996b) highlight the uncertainty in characterising the present day climate in oceanic regions, let alone making predictions about changes as a consequence of global warming. Pittock et al. illustrate the point using annual rainfall. They compare the differences between two observed data sets for the South Pacific and the annual rainfall as simulated in a control run of the CSIRO Mark 2 GCM. Considerable differences are noted, both between the observed fields as well as between these and the modelled distribution. Whetton et al. (1996b) have also noted, for the Southern Hemisphere, large and apparently systematic differences between rainfall simulated in experiments using coupled and mixed layer models.

Despite the serious constraints on the current use of global climate models for prediction of changes in regional climate, some benefits arise from studying the results of recent efforts. Zillman et al. (1992) present the changes in temperature and rainfall for the Pacific region. These are based on the work of McAvaney et al. (1992). They determined the seasonal climate response to an effective doubling of CO_2 in an equilibrium simulation using the Australian Bureau of Meteorology Research Centre's (BMRC) atmospheric general circulation model coupled with a mixed layer ocean model. The ocean hemisphere exhibits minor sensitivity to an effective doubling of CO_2 relative to adjacent continental areas, the sensitivity generally increasing with latitude and in winter relative to summer. One notable response in the Pacific region is a cooling of up to 1.5°C over northern Australia in the southern summer, with a general increase in rainfall over the Timor Sea. While changes in seasonal rainfall produce somewhat complex patterns, the annual pattern is much simpler—mean annual rainfall is generally slightly higher for the Pacific, except for mid-latitude areas.

Increased confidence may be placed on such predictions produced by a global climate model if these are in agreement with those of other models. But this confirmation can never be absolute as the various models have much in common. Nevertheless, it is educational to undertake such comparative analyses. For 14 representative locations over the Pacific region Zillman et al. (1993) compared the above BMRC model results with those for comparable experiments using four other models (Canadian Climate Centre, Geophysical Fluid Dynamics Laboratory, UK Meteorological Office and CSIRO). For the South Pacific the BMRC estimates of increase in seasonal temperature are consistently lower than those of the other models, typically by at least one degree. For precipitation, the BMRC model is also somewhat more conservative, at least for the South Pacific locations that are analysed. In this case there is no general consensus amongst the models as to whether precipitation will increase or decrease at a given location.

On the other hand, as will be noted later, there is more consistency in model simulations of heavy rainfall intensity.

While much can be learnt from determining the atmosphere's equilibrium response to an instantaneous doubling of greenhouse gas concentrations in the atmosphere, it is believed that there is more realism in simulations where the concentration of the gases is increased gradually to obtain time dependent (transient) patterns of climate change. At the time of effective CO_2 doubling transient models typically have global surface temperature increases which are about 60% of those produced in the equilibrium simulation. This is partly due to the fact that the transient models take into account the thermal inertia of the deep ocean and are therefore not in equilibrium at the time of effective CO_2 doubling (Houghton et al., 1992). Moreover, the larger temperature increases identified in the equilibrium models for higher latitudes are greatly reduced, especially over the oceans.

These results suggest that, for lower latitude areas of the Pacific, systematic increases in local temperatures will not be an important consequence of an enhanced greenhouse effect. Rather, it is necessary to consider other climate elements, such as rainfall and wind, and extreme events, such as tropical cyclones. The naturally large interannual variability in these elements, and their poor characterisation by climate models, severely restrict the ability to make reliable estimates of changes in such variables as a result of greenhouse warming.

However, there is recent evidence to suggest that the large-scale vertical mixing in the southern high latitude oceans in the coupled models is excessive (England, 1995). Recently McDougall et al. (1996) included a new parametrisation of oceanic eddies in coupled atmospheric-oceanic models and found that the Southern Hemisphere oceans would warm at twice the rate predicted, using models with more conventional parameterisations. The new parametrisation is justified on the basis that it yields deep ocean salinities and temperatures that are significantly closer to observations. In addition, the depth to which surface-induced tracers penetrate in the Southern Ocean is predicted with greater realism. The depth was overestimated by previous ocean models with consequential reductions in the rates of atmospheric and ocean-surface warming.

Rind (1995) also anticipates greater rates of warming in the tropical atmosphere than has been indicated in recent studies. A major factor bringing about this change in expected heating rates is the finding that increasing water vapour resulting from higher temperatures is unlikely to form thicker and hence more reflective clouds. Instead it is likely to remain dispersed in the atmosphere, where it can act as a greenhouse gas, increasing the rate of warming, or increasing the amount of rainfall. Recent satellite studies suggest that clouds actually become thinner as warming increases. The findings are consistent with the predictions of many global climate models that the warming effect of increased water vapour would predominate over the cooling effect of increased cloud formation. Such results are consistent with recent studies of the geologic record which show that during the last ice age tropical temperatures varied more than previously thought.

Whetton et al. (1996a; 1996b) have questioned whether the possible underestimates of the sensitivity of the Southern Hemisphere to global warming could account for large and apparently systematic differences between changes in rainfall with global warming, as simulated by global climate models using, on the one hand, a fully coupled dynamic ocean model and, on the other, a simple mixed layer ocean formulation. For example, all five mixed-layer models agreed on a simulated rainfall increase in summer in the tropics and subtropics of the Australian sector. The coupled experiments were consistent in simulating a weak rainfall decrease.

Whetton et al. (1996b) also noted the lack of data with which to validate the simulation of ocean circulation in coupled models. They express concern that the large uptake of heat by the Southern Ocean may be exaggerated, therefore leading to excessive suppression of surface warming in the high latitude Southern Hemisphere. Such an error would have the potential to significantly affect simulated climate change in the Southern Hemisphere.

Pittock (1993) expresses a concern that planning and other decisions are being based on inappropriate, poorly-based and possibly outdated scenarios. He encourages the use of the latest generation of scenarios based on the findings of recent experiments with global climate models combined with outputs from limited area models. Pittock (1996) also describes the challenges presented to climate modellers by Article 2 of the United Nations Framework Convention for Climate Change (UNFCCC), and particularly how they might define the level of greenhouse gases which would lead to a 'dangerous anthropogenic interference with the climate system'.

2.1.4 Oceanic changes in the Pacific region

The IPCC has recently confirmed that, for oceans, the most pervasive impacts of mean atmospheric temperature increases will be on water circulation, water levels, wave climate and, possibly, extreme events.

As the IPCC also notes, regional changes in oceanic conditions may differ from the anticipated global changes. For local and regional changes in sea-level this is due, in particular, to vertical land movement and ocean current changes.

Pittock et al. (1996a) presented an illustration of the differential magnitude of sea-level rise for the southwest Pacific and adjacent oceans. The values take into account thermal expansion only, and do not include the effect of melting of land-based glaciers or changes in the mass balance of the Greenland and Antarctic ice sheets. Vertical land movement is also ignored as are the effects of global warming prior to 1973, the start date for the model run. The results relate to a doubling of CO_2 in the IS92a scenario of IPCC (about 2102). They show that regional variations in sea-level rise can be in the order of ±50%.

Changes in circulation and vertical mixing will also influence nutrient availability and primary production. Fresh water influx to the oceans as a result of melting ice, glaciers and river runoff, can lead to a weakening of the global thermohaline circulation, which controls the distribution of heat and carbon dioxide across and within the ocean, with presently unpredictable instabilities in the climate system.

As recently summarised by the IPCC, GCMs predict a decrease in the latitudinal gradient of temperature and consequently of pressure and wind at the ocean scale. With increasing greenhouse gases in the atmosphere, the meridional (north-south) gradients of sea surface temperature will be reduced by a strong warming in the high latitudes. This, in turn, will lead to a decrease in the trade wind intensity the strength of the upper ocean currents, Land and to a reduction in the area and the intensity of upwelling. One area that is anticipated to experience such a decrease in upwelling is the equatorial eastern tropical Pacific.

Coastal areas are not only vulnerable to a rise in sea-level on longer time scales, but also to temporary sea-level fluctuations which occur as a result of severe storms. In combination, strong surface winds and low atmospheric pressure can lead to storm surges which flood low-lying coastal areas. High tides exacerbate the problem. Wind-generated waves can penetrate further inland. High rainfall can also compound the situation to produce extensive and prolonged surface flooding.

Pittock et al. (1996a) describe methods by which these effects can be determined for coastal areas and present the results of several case studies. But they also note that, for the southwest Pacific, impacts on particular coasts will require detailed calculations for each locality to account for the local topography and bathymetry, and possible changes in beach alignment and transport of sand and coral debris.

2.1.5 Changes in the ENSO regime

The ENSO phenomenon is the primary mode of climate variability on the 2–5 year time scale. Release of latent heat associated with El Niño episodes affects global temperature (Graham, 1995) and associated changes in oceanic upwelling influence atmospheric CO_2 levels (Keeling et al., 1989).

The IPCC notes that the behaviour of the ENSO has been unusual since the mid-1970s and especially since 1989. Since the mid-1970s warm episodes (El Niño) have been relatively more frequent or persistent that the opposite phase (La Niña). The recent ENSO behaviour, and especially the consistent negative values of the Southern Oscillation Index (Hay et al., 1993) since 1989, appears unusual in the context of the instrumental record that spans the past 120 years. Latif et al. (1995) conclude that the anomalous 1990s are not the result of global warming, though this conclusion is not in agreement with the findings of Trenberth and Hoar (1996). However, Allan and D'Arrigo (1996) present evidence to suggest that such unusual patterns have occurred prior to the period of instrumental record. Solow (1995) found no significant trend in the frequency of El Niño events over the period 1525 to 1987.

Recent variations in precipitation over the tropical Pacific Ocean and surrounding land areas are related to this ENSO behaviour. It has also affected the pattern and magnitude of surface temperatures.

Graham (1995) used satellite data, a coarse Tropical Pacific Ocean data set and numerical modelling based on observed sea surface temperatures to demonstrate that tropical Pacific precipitation had increased in conjunction with the change to increased frequency of El Niño in the mid 1970s. Salinger et al. (1995) analysed trends in precipitation observed at tropical Pacific atolls and islands. They found that central and eastern equatorial Pacific rainfall increased during the mid-1970s while that in the southwest Pacific decreased. These findings are consistent with linkages between spatial distribution in tropical Pacific rainfall anomalies and ENSO events (Hay et al., 1993).

In tropical areas since 1979, warm season sea surface temperature anomalies of 1°C or more have been associated with coral bleaching events (Hayes, 1994). Bleaching events were more prevalent in 1983, 1987 and 1991, in association with El Niño warm events, and scarce in 1992 as a result of the cooling following the eruption of Mt. Pinatubo. Glynn (1993) suggests that the scale of bleaching since 1979 has not been observed previously.

Several coupled ocean-atmosphere general circulation models are able to simulate ENSO-like sea surface temperature variability for present day climate, and also for climates associated with increased greenhouse gas concentrations (e.g. Meehl et al., 1993; Knutson and Manabe, 1994; Tett, 1995; Pittock et al., 1996a). Some modes of climate variability characteristic of ENSO are also being simulated in more specialised coupled models that have higher resolution in the tropical Pacific Ocean (Philander et al., 1992; Tokioka et al., 1995; Pittock et al., 1996a).

Pittock et al. (1996a) conclude that evidence from both the observed record and model simulations suggests no significant changes to the amplitude or frequency of ENSO-induced sea surface or atmospheric temperature anomalies as a consequence of global warming.

2.1.6 Regional changes in extreme events, including tropical cyclones

There is encouraging consistency in model simulations of heavy rainfall intensity. A general increase is indicated (Fowler and Hennessy, 1995). Results indicate that heavy rainfall events with a return period of at least a year will occur 2–4 times more often. In the UKMO and CSIRO9 General Circulation Models (GCMs) there is an approximate 50% increase in the frequency of rainfall exceeding the 1xCO_2 90th percentile in the southwest Pacific (Pittock et al., 1996a).

The IPCC (1995a) assessment is that a general warming is expected to lead to an increase in the occurrence of extremely hot days and a decrease in the occurrence of extremely cold days. Warmer temperatures will lead to a more vigorous hydrological cycle; this translates into prospects for more severe droughts and/or floods in some places and less severe droughts and/or floods in other places. Several models indicate an increase in precipitation intensity, suggesting a possibility for more extreme rainfall events.

On the other hand, there is currently insufficient knowledge to say whether there will be any changes in the occurrence or geographical distribution of severe storms, e.g. tropical cyclones (IPCC, 1995a). The formation of tropical cyclones depends not only on sea surface temperatures, but also on a number of atmospheric factors including the vertical lapse rate of temperature and vertical wind shear (Gray, 1979).

In the southwest and southeast Pacific the number of tropical cyclones appears to have increased (Thompson et al., 1992). In the latter case this may be related to the increased frequency of El Niño events (Philander, 1990), but such conclusions must be qualified in light of the quality (especially the lack of consistency) of the long-term cyclone data base (Raper, 1993, Maunder, 1995).

In their review, Lighthill et al. (1995) conclude that the state of science does not allow conclusive assessment of future changes in tropical cyclone frequency or intensity. They suggest that there are in fact no compelling reasons for expecting a major change in global tropical cyclone frequency. However, they suggest that substantial regional changes may occur, as indicated by the extra-polation of empirical relationships. At present global climate models are incapable of predicting the direction of such changes.

But this dismissal of the possibility that global climate models can provide useful information about the sensitivity of tropical cyclone climate to increased greenhouse gases is challenged by Broccoli et al., 1995. They note that the climate modelling approach has much better potential for future improvement than do the empirical approaches which Lighthill et al. offered as alternatives.

The conclusions of Lighthill et al. are also questioned by Emanuel (1995). He claims that basic physics, coupled with the historic record of tropical cyclone intensities, suggests that it is highly probable that there will be greater thermodynamic disequilibrium between the tropical atmosphere and oceans as a result of global warming. He concludes that this increased disequilibrium would be accompanied by an increase in the limiting intensity of actual tropical cyclones.

All tropical cyclones have features which are smaller than the few hundred kilometres typical of a climate model. This is one of the reasons why tropical cyclones are not reliably simulated in coarse resolution global climate models and why the impact of climate change on tropical cyclones has generally been assessed by the use of various indirect techniques (Pittock et al., 1996).

Pittock et al. have reviewed such methods. One is to determine the variation between tropical cyclone frequency and intensity, with sea surface temperature under current conditions, and to then estimate the frequency and intensity given the higher ocean temperatures associated with global warming. Nicholls (1989) found little evidence of any such underlying relationship for tropical cyclone frequencies. While Basher and Zheng (1992) demonstrated that, in the Coral Sea region, seasons with relatively high tropical cyclone frequency were preceded by significant positive anomalies in sea surface temperature, areas to the east showed only weak or no relationships. By way of contrast, the spatial distribution of tropical cyclone frequency over the western North Pacific can be explained by sea surface temperatures for specific months and can be used to predict annual cyclone frequencies for the South China Sea (Chan, 1994). In summary, Whetton et al. (1996b) concluded that existing analyses of historical data do not show a clear relationship between sea surface temperature and tropical cyclone formation, above a minimum threshold of about 27°C.

Evans (1993) showed that intensity was largely independent of sea surface temperature except for intense storms in the North Atlantic. Similarly in the assessment given above, Whetton et al. (1996b) consider this a valid conclusion based on historic data.

Investigations by Holland (1995) also indicate that it is unlikely that there will be more intense tropical cyclones than the worst that occur at present, though there is some propensity for changes in cyclone frequency in regions where sea surface temperatures are between 26° and 29°C at present. Moreover, Bengtsson et al. (1994) found that for an enhanced greenhouse scenario the geographical distribution of tropical cyclones was unchanged but the number decreased, especially in the Southern Hemisphere. The warmer surface waters associated with global warming were counteracted by generally weaker surface winds (reducing evaporation) and by changes in vertical stability.

Another of the approaches considered by Pittock et al. assumes that present-day tropical cyclone frequencies and intensities may be related by theoretical arguments to large-scale fields such as temperature and wind. For example, Gray (1975) has shown that a composite parameter based on such fields as low-level vorticity, mid-tropospheric relative humidity and sea surface temperature could be used to predict realistic tropical cyclone frequencies. But investigations by Ryan et al. (1992), using a general circulation model, have shown that changes in the parameter as a consequence of global warming are predominantly in response to changes in sea surface temperature. Since this contradicts the findings of Nicholls (1989) and others, Pittock et al. conclude that composite parameters, such as those used by Ryan et al., and in another form by Henderson-Sellers et al. (1995), may need modification for use in studies of how tropical cyclones respond to global warming.

Some finer-resolution global climate models can now represent tropical storms with some realism for present day climate (e.g. Haarsma et al. 1993, Bengtsson et al., 1995). Walsh and McGregor (1995) have shown that a limited area model with a horizontal resolution of 125 km is also capable of generating tropical cyclone-like vortices. But when using their model in a preliminary assessment of global warming on tropical cyclone characteristics, Bengtsson et al. (1994) found that the numbers of tropical cyclones in the Southern Hemisphere was reduced by more than a factor of two. As Pittock et al. (1996) comment, this unusually sensitive response makes it unwise to use such unsubstantiated results, especially when the climate response of the Southern Hemisphere oceans may be inadequately represented due to overestimation of the uptake of heat (England, 1995; McDougall et al., 1996).

The IPCC concludes that it is very much open to debate as to whether the frequency, area of occurrence, time of occurrence, mean intensity or maximum intensity of tropical cyclones will change as a consequence of global warming. A similar conclusion is reached by Pittock et al. (1996a; 1996b). As Lighthill et al. (1994) determined, any changes in global average tropical cyclone characteristics as a result of climate change will likely be overshadowed by interannual variability and any regional changes are even less certain.

2.1.7 Decreasing the current regional uncertainties

Pittock et al. (1996a) identify a number of critical tasks to be carried out if the current uncertainty in characterising atmospheric and oceanic climate is to be reduced:

- improving the performance of global climate models in the region, particularly to ensure that coupled models include a realistic ocean circulation and capture the behaviour of major permanent circulation features;
- developing the capability to run nested models at fine resolution over the region, down to scales relevant to the topography of particular islands;
- capturing the behaviour of ENSO and of tropical cyclones in computer simulations; and
- taking account of regional variations in mean sea-level, and possible changes in wave climates and extreme events, including ENSO and tropical cyclones, in highly location-specific studies of coastal impacts.

2.2 The issues from environmental and disaster management and sustainable development perspectives

This section will explore some of the broader issues arising from climate and its related changes. The discussion will be in the context of environmental and disaster management and sustainable development.

In keeping with international understanding and priorities, Pacific island countries are committed, individually and collectively, to developing sustainably. Thus the intimate linkages between economic development, environmental, cultural and resource conservation and social progress are recognised. Development must involve achieving an equitable balance between the foregoing goals, rather than seeing them as distinct, or differing in priority. For these reasons environmental management cannot be, and typically is not, considered in isolation.

Along with the preparation of National Development Plans, most Pacific island countries have also prepared National Environmental Management Strategies (NEMS) or the equivalent. Such strategies are a statement of a country's environmental principles and also a detailed plan for realising a country's long-term environmental goals. They outline the priority environmental action programmes needed to achieve those goals. Each country has developed its own strategies, unique to its own economic, physical, cultural, legal, institutional and social situations. The strategies clearly link environmental conservation and protection with the economic development of that country. Typically a task force, comprising senior representatives from government departments, NGOs and the private sector, coordinates the strategies, thereby helping to ensure that an integrated approach is taken, not only to environmental management but also to environmentally sound and sustainable development.

Each NEMS is based on existing knowledge of a country's environment as well as an understanding of the linkages between environmental quality and existing and planned development. This information is usually compiled in a national State of the Environment Report. The Report also identifies for the given country the major environmental issues for key sectors, such as forestry, fisheries, tourism and agriculture.

In general, a NEMS has four major environmental objectives, namely to:

- integrate environmental considerations in economic development;
- improve environmental awareness and education;
- manage and protect natural ecosystems and resources; and
- improve waste management and pollution prevention and control.

For most Pacific island countries environmental management and development planning are closely linked with disaster management. A conceptual model of this relationship has been formulated by Kay et al. (1993) and is presented here as Figure 1. Both natural and human-induced disasters are included in disaster management, and encompass not only short-lived extreme events such as a tropical cyclone or fire, but also the more insidious phenomena such as drought. The environmental consequences of these incidents must be considered alongside the human and economic costs (ADB, 1992).

Based on an analysis of 20 years of records of disasters declared by U.S. Ambassadors to countries in the region, Dilley (1995) concluded that the majority of disasters in the South Pacific are caused by extreme hydro-meteorological events. Dilley and Heyman (1995) linked drought disasters in Fiji to the occurrence of ENSO warm events. They encouraged the use of an ability to predict disaster-causing conditions, given linkages with ENSO, in order to prepare for and mitigate the effects of such disasters.

Bruce (1994) has noted that there are three categories of change that affect human and economic losses due to natural disasters. These are:

Figure 1: Conceptual model showing how environmental management, development planning and disaster management combine to provide an optimal management model (from Kay et al., 1993).

- increasing economic development, especially along coastlines, in flood plains and other hazard-prone areas;

- changes in land surfaces and cover; and

- variability and change in frequency and severity of natural hazards.

The strong interactions between and within these three categories emphasises the need for integrated approaches to development planning, environmental protection and disaster management. These responses would include vigorous efforts to ensure that infrastructure is built to be safe in extreme events, land use planning and zoning to keep unsafe development out of high-risk zones and good warning and preparedness systems that can greatly reduce loss of life and limit property damage.

If policy development and the ensuing actions to address the anticipated impacts of climate change and accelerated sea-level rise are to be effective they must be mainstreamed in both development planning and disaster management, with core initiatives being identified and implemented within an integrated environmental management framework. This is a current and continuing challenge for Pacific island countries where limitations on resources (human, financial, technical and information) and institutional capacities mean that responses frequently fall short of the optimum approach. The cost is further stress on systems already under pressure. The present report is one of many attempts to break this crippling cycle.

3. Context of the current assessment

3.1 Historical context

This background summary is restricted to providing an historic overview of programmes and activities assessing the potential impacts of climate and related environmental changes on Pacific island countries. Broader historic perspectives on global and regional environmental changes and their implications for the sustainable development of Pacific island countries may be found in Hay (1994) and in Hay and Humphries (1994).

In early 1987, Task Teams on Implications of Climate Change were established for the six regions covered by the United Nations Environment Programme (UNEP) Regional Seas Programme. The Task Team for the South Pacific was jointly sponsored by UNEP, the Association of South Pacific Environmental Institutions (ASPEI) and the Secretariat of the South Pacific Regional Environment Programme (SPREP), with ASPEI coordinating the work of the Task Team. The Task Team was mandated to prepare regional overviews and site specific case studies on the possible impact of predicted climate changes on the ecological systems, as well as on the socio-economic structures and activities in the South Pacific region. Another task was to identify areas or systems which appeared to be most vulnerable to the changes in climate.

In 1988 the first results of the Task Team were presented to the Second Intergovernmental Meeting on the SPREP Action Plan. Since that time the SPREP Secretariat has increasingly become the climate change clearing house and coordinating unit for the South Pacific region, relaying information from international bodies and metropolitan counties to Pacific island governments and seeking to ensure the Pacific island perspective is included in international discussions and developments. The Intergovernmental Meeting on the SPREP Action Plan also recommended that SPREP organise an intergovernmental meeting on climatic change and sea-level rise in the South Pacific, with the meeting to be sponsored by the South Pacific Commission, UNEP and ASPEI. The meeting was held in the Marshall Islands in 1989. The objectives of the meeting were:

- to consider the potential impact of expected climatic change and sea-level rise on ecosystems as well as socio-economic structures and activities of Pacific islands;

- to review the possible policy options and management measures for the mitigation of the negative effects of climatic change and sea-level rise; and

- to develop a programme of further studies and assistance to the governments of the region which would enhance their response capabilities to the expected impact of climatic change and sea-level rise (South Pacific Commission, 1989).

The meeting examined the results obtained by the Task Team (ASPEI, 1988; Pernetta and Hughes, 1989; Pernetta and Hughes, 1990), reviewed the possible response options to expected climatic changes, developed a programme of further studies and assistance to the South Pacific region and requested the SPREP Secretariat to continue in its role as clearing house and coordinating unit for the South Pacific region on climate change and sea-level rise. In response UNEP, SPREP and ASPEI developed a regional programme with the long-term objective of avoiding or mitigating the potential impact of expected climatic changes on Pacific island countries and territories. The short-term objectives were:

- to improve understanding of the potential impact of expected climatic changes on the Pacific island countries and territories;

- to assist Pacific island countries and territories in determining the possible response options and measures to avoid or mitigate the impact of these changes; and

- to assist Pacific island countries and territories in implementing measures which may avoid or mitigate the impact of climatic changes.

There were nine (national and regional) follow-up activities recommended by the conference, including preparation of in-depth studies on the potential impact of expected climatic change on the national environment and the socio-economic structure and activities for six countries in the region (Federated States of Micronesia, Cook Islands, Kiribati, Marshall Islands, Tokelau and Western Samoa), direct involvement from Pacific island states in the work of the Intergovernmental Panel on Climatic Change (IPCC) and expansion of public awareness campaigns and educational activities on all levels of subjects relevant to the expected impacts of climatic change.

A popularised booklet summarising the results of the Task Team work (Hulm, 1989) was also produced. Hay (1992) summarises the accomplishments, status and planned future activities of the Task Team.

In 1988, the World Meteorological Organisation (WMO) and UNEP jointly formed the Intergovernmental Panel on Climate Change (IPCC). It in turn formed three Working Groups—WG I to assess the available scientific information on climate change; WG II to assess the environmental and socio-economic impacts; and WG III to formulate response strategies (IPCC, 1990a; IPCC, 1990b; IPCC, 1990c). SPREP has coordinated Pacific island representation at plenary and working group meetings of IPCC.

Among the conclusions, the IPCC found that expansion of economic activities, urbanisation, increased resource use and population growth are continuously increasing the vulnerability of the coastal zone. But this vulnerability is now being increased still further by the threats of climate change and accelerated sea-level rise. The potential significance of the resulting impacts forces policy-makers to also consider long term planning for climate change and sea-level rise. Efficiency and effectiveness mean that such planning should be integrated with existing short term economic and social plans in the form of an integrated coastal zone management programme.

In recognition of the need to identify strategies for adaptation to sea-level rise, possible response options were enumerated in IPCC (1990c) following workshops in Miami, U.S.A. and in Perth, Australia. A starting point for identifying response options and integrating them in coastal zone management programmes is an assessment of a country's vulnerability to accelerated sea-level rise. Following the above workshops and subsequent meetings the IPCC developed a common methodology for this purpose (IPCC, 1991).

The conclusions of the three IPCC working groups were discussed in the Second World Climate Conference (November, 1990) which indicated further plans of international action related to global climate change. As significant advances were made in climate change research in the intervening period a supplement to the 1990 report was released in 1992 (IPCC, 1992a; IPCC, 1992b). IPCC (1992c) reviewed the status of 25 case studies assessing vulnerability to sea-level rise, including Kiribati (Tarawa Atoll), the Marshall Islands and Tonga (Tongatapu). The findings were fed into the 1992 Supplement to the IPCC First Assessment Report and into the negotiations for the UN Framework Convention on Climate Change (UNFCCC) and preparations for the United Nations Conference on Environment and Development (UNCED) to be held in Brazil in 1992.

In December 1990, the UN General Assembly agreed to establish an intergovernmental negotiating process to respond to the threat of global climate change. The activity would be supported by UNEP and WMO. An Intergovernmental Negotiating Committee (INC) for a Framework Convention on Climate Change was formed. SPREP sought assistance from the Centre for International Environmental Law (CIEL) to advise and work closely with South Pacific island governments to develop their inputs into this convention. This development led to the formation of the Alliance of Small Island States (AOSIS), which includes a majority of the Pacific island countries which have the same principles and objectives.

The Second Intergovernmental Meeting on Climate Change and Sea-level Rise in the South Pacific was held in Noumea, New Caledonia in 1992. The objectives of the second meeting were to:

- Review and examine the results of (i) the UNEP-sponsored case studies, (ii) in-country studies, (iii) case studies of IPCC Coastal Zone Management, (iv) other relevant international or national climate change programmes;

- Review the results of the three IPCC working groups;

- Further review policy options and management measures to avoid or mitigate climate change;

- Raise awareness and understanding of Pacific island country governments on implications of climate impacts for the region; and

- Review the objectives and contents of the SPREP programme on climate change.

Both a meeting report (Kaluwin et al., 1992) and a volume containing the technical papers (Hay and Kaluwin, 1993) were published. The meeting took place in several contexts. There had been major advances in climate change science and development of response strategies, due in part to work undertaken by the IPCC. Significant progress had also been made in the implementation of country case studies on the expected impact of climate change and, by the IPCC Subgroup on Coastal Management, on vulnerability to sea-level rise. In addition, the ongoing negotiations regarding UNCED and the related UN Framework Convention on Climate Change (UNFCCC), meant there was a need to take both retrospective and prospective analyses of climate change and related issues in the South Pacific. These would assist in identifying the priority items for inclusion in the UNCED, including its formal outcomes such as the UNFCCC.

The meeting prepared a draft work programme for climate change and sea-level rise. This and the other meeting outcomes were used to guide discussions on climate change and sea-level rise at the 5th Intergovernmental Meeting of SPREP, held in Western Samoa in 1992. At that meeting the SPREP work programme on global change (including climate change and sea-level rise) was discussed and approved. In developing the work programme it was recognised that many other organisations, regional and international, interact with Pacific island governments on the climate change issue. These include the South Pacific Applied Geosciences Commission (SOPAC), the International Oceanographic Commission and the Commonwealth Science Council. SPREP's role, as mandated by the Intergovernmental Meeting on Climate Change, was to act as a clearing house/coordinating unit for the South Pacific region on climate change, in order to avoid duplication.

Following the Intergovernmental Meeting on Climate Change SPREP concentrated on developing and finalising a project document with the UNEP Ocean and Coastal Areas Programme for a regional programme on climate change. It included further country assessments of the potential impacts of climate change on selected Pacific island nations, information and public awareness workshops and seminars in several countries and coordination of a sea-level rise vulnerability case study using the common methodology developed by the Coastal Zone Management Subgroup of the IPCC Response Strategies Working Group. The study was based on Majuro Atoll, Marshall Islands (Crawford et al., 1992; Holthus et al., 1992). Other case studies were also undertaken for Kiribati, supported by the Commonwealth Science Council (Lewis, 1988; McLean, 1989).

The in-country missions were the main initial focus of the SPREP work programme. The main purpose of the series of preparatory missions was to prepare, in close consultation with national counterparts identified by the respective Governments, a proposal for a programme of assistance to undertake an in-depth study of the potential impact of expected climatic changes (including sea-level rise) on the natural environment and the socio-economic structures and activities. This was also to include the identification of response options which might be suitable and available to avoid or mitigate the expected negative impact of climatic changes.

On the basis of the activities undertaken during the mission, as well as information collected prior to their mission, the experts prepared a report containing:

- a general overview of the climatological, oceanographic, geological, biological and socio-economic factors which may be relevant to, or affected by, the potential impacts of expected climatic change;
- a preliminary identification of the most vulnerable components and sites of the natural environment, as well as the socio-economic structures and activities which might be most critically affected by expected climatic change;
- an overview of current environmental management problems in the country and an assessment of how such problems might be exacerbated by climatic change; and
- a detailed proposal for a joint programme of assistance. This would provide in-depth evaluation of potential impacts of expected climatic change on the natural environment and the socio-economic structures and activities of the country concerned. The programme would include identification of policy or management options suitable to avoid or mitigate the impact of climatic change. The proposal should identify the work plan, timetable and financial requirements of in-depth evaluation as well as the possible institutional arrangements for carrying out the evaluation.

The results of these studies provide the main information base for the present regional assessment of vulnerability and resilience of Pacific islands to climate change and accelerated sea-level rise.

Two Australian Government projects, namely the South Pacific Sea-level Rise Monitoring Programme and Climate Monitoring and Impacts in the South-West Pacific have also worked closely with SPREP during the development and implementation of their programmes.

Preparations for a Second Assessment Report of the IPCC began in early 1993. In order to provide a parallel with the workings of the UNFCCC, the IPCC combined WG II and WG III into a new WG II which would assess available technical, environmental, social and economic information regarding impacts of climate change and response options to adapt to and/or mitigate climate change. A newly established WG III would, in consultation with WG I and WG II, deal with cross-cutting issues such as emission scenarios and international economic aspects.

In 1993 the IPCC Eastern Hemisphere Workshop, Vulnerability Assessment to Sea-Level Rise and Coastal Zone Management, was held in Japan (McLean and Mimura, 1993). It reflected the central roles of the IPCC to clarify the possible impacts of future changes in mean sea-level and climate induced by global warming and to help ensure that sea-level rise and other coastal impacts are addressed within the framework of integrated coastal zone management. A priority was considered to be the development of relevant response strategies to the future changes. The workshop summarised the current state of knowledge, experience and methodologies with respect to coastal impacts, including vulnerability assessments. A report on a preliminary assessment of the vulnerability of Kiribati to accelerated sea-level rise was presented (Abete, 1993). Kaluwin also reviewed the appropriateness of the IPCC common methodology for vulnerability assessment from the perspective of Pacific island countries (Kaluwin, 1993).

The findings of the 1993 workshop provided material for the International Conference on Coastal Zone Management (IPCC, 1994) and subsequently the Second Assessment Report of the IPCC (IPCC, 1995b). The former conference considered the results of 46 vulnerability studies including those for Kiribati, Marshall Islands, Moorea and Tonga.

In 1994 Porter completed a study of the vulnerability of Fiji to current climate variability and future climate change (Porter, 1994). She also identified possible response strategies. The same year Henderson-Sellers presented a paper on adaptation to climate change in Oceania (Henderson-Sellers, 1996). She argued that, although adaptation is clearly feasible and potentially beneficial, it has been largely neglected in decisions and strategies related to climate change. She put forward the case for a positive approach to adaptation in Oceania, including incorporating climate change risk assessment into development planning.

The United States of America has been assisting the Federated States of Micronesia, Marshall Islands, Kiribati, Western Samoa and Fiji through its Climate Change Country Study Initiative. They undertake emissions inventories, vulnerability and adaptation response studies, and mitigation strategies. Preliminary results were reported at the Workshop on Climate Change Implications and Adaptation Strategies for the Indo-Pacific Island Nations (CCCSIP, 1995). One of the motivations for this workshop was to address the problems of 'potential' conflict between traditional land tenure systems and newly emerging governments with responsibility for shoreline development and the protection of lives, property and ecosystems.

3.2 Regional geopolitical context

The oceanic basin containing the Pacific island countries is distinctive, given that the combination of geographical, biological, sociological, cultural and economic characteristics is found nowhere else in the world. The region is characterised by small land masses dispersed over the largest ocean in the world, by a large range of ecosystems and high species diversity and endism, by a high degree of economic and cultural dependence on the natural environment and resources, by vulnerability to a wide range of natural disasters, and by a diversity of cultures, languages, traditional practices and customs which is central to the close and special relationship of Pacific people with their environments (Asian Development Bank, 1992).

In socio-economic terms Pacific island countries are in general characterised by small land areas, large EEZs, small populations, and in some cases by relatively high population densities and growth rates. For many countries the population statistics would be even higher were it not for emigration, either for temporary employment or permanently.

In this study frequent reference is made to 'Pacific island countries'. By common usage, this term is taken to include both states and territories comprised mainly of one or more small islands and located within the Pacific Basin. Hess (1990) defines 'small islands' as those with a land area less than approximately 10,000 km^2 and a population of approximately 500,000 or fewer.

Many of these island countries cooperate politically and in other ways through one or more of the regional organisations described in the following section. For example, the South Pacific Regional Environment Programme (SPREP) has a membership of 22 Pacific island countries and territories (American Samoa, Cook Islands, Federated States of Micronesia, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Nauru, New Caledonia, Niue, Northern Marianas Islands, Palau, Papua New Guinea, Pitcairn, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu, Wallis and Futuna and Western Samoa) and four developed countries—Australia, New Zealand, France and the United States of America. Despite its name, SPREP includes countries and territories north of the equator for the region extends as far as 20°N in the western Pacific. But it is limited to the equator in the east, and therefore excludes Hawaii and other islands such as Johnston Atoll and Midway.

Less than 6 million people (about one-tenth of 1% of the world's population) reside in SPREP's 22 developing island member countries. On the other hand, their EEZs occupy more than 30 million km^2 of the Pacific Ocean or one-sixth of the globe's surface. But their land area is less than 2% of the total. If Papua New Guinea, the largest of the developing SPREP member countries, is excluded, the land area of the remaining 21 island countries is only 89,000 km^2, or barely 0.003% of their total area of EEZ (Asian Development Bank, 1992).

Pacific island countries work with other small island nations in responding to the challenges associated with global warming. During the negotiations for the UNFCCC these countries sought to ensure that their concerns were heard and acted upon by the rest of the world. During the Second World Climate Conference in 1990, the Alliance of Small Island States (AOSIS) was formed at the ministerial level, with the assistance of the Caribbean Community and Common Market, SPREP and the International Environmental Law Centre (IECL). AOSIS now has over 35 members for the Atlantic, Indian and Pacific Oceans and the African, Caribbean and Mediterranean Seas. Through the meetings of the Intergovernmental Negotiating Committee for the UNFCCC, AOSIS achieved rapid recognition and demonstrated its potential to influence the climate change negotiations. This role has continued into the Conference of the Parties to the UNFCCC.

During and subsequent to the negotiating sessions for the UNFCCC, AOSIS has advocated adoption of six fundamental principles:

- immediate and significant cuts by developed countries in the emission of carbon dioxide and other greenhouse gases;
- a preventive approach based on the precautionary principle;
- new and equitable funding mechanisms, which recognise AOSIS as a special geopolitical grouping;
- the transfer of appropriate environmentally sound technologies on an equitable basis;
- recognition of the 'polluter pays' principle in relation to climate change; and
- binding obligations regarding energy conservation and efficiency and on the development of renewable energy resources.

AOSIS maintains an office in New York to advise its member countries regarding issues of common concern, to provide a clearing house for member countries' views on major issues and to coordinate negotiating positions. Through AOSIS many Pacific island countries are able to enhance their interactions with small island nations in other regions of the world.

The following section will summarise some of the other regional organisations that bring together small island countries of the Pacific. Additional information may be found in Asian Development Bank (1992).

3.3 Institutional context

There are several other regional bodies and institutions which facilitate and/or undertake scientific and technical studies related to climate and associated environmental changes and are engaged in the application of the resulting information. Their activities are overseen, in the sense of facilitating communication and cooperation, by the South Pacific Organisations Committee (SPOC). They also have close links with international organisations such as UNDP, UNEP and UNESCO. The United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), based in Bangkok, Thailand, has a Pacific Operations Centre in Port Vila.

The South Pacific Regional Environment Programme (SPREP) is the institution with the principal mandate for environmental matters within the Pacific islands region. The professional staff have a wide range of expertise, with this being augmented by environment and conservation officials on short-term secondment from SPREP member countries. A comprehensive action plan, approved by these governments, defines a broad range of activities related to environmental protection, resource conservation and to economic and social development.

The South Pacific Forum cooperates with SPREP in coordinating environmental technical assistance for the region and addresses environmental matters with geopolitical implications.

The South Pacific Applied Geosciences Commission (SOPAC) is a regional organisation which investigates mineral and other non-living resource potential and builds inventories of geophysical data which assist with resource assessment, coastal management and hazard evaluation. SOPAC's Environmental Geoscience programme is concerned with coastal and offshore areas, focusing on the physical preservation of the coast; the Mineral and Energy Resources programme addresses the sustainable development of resources, particularly on access to sand and aggregate resources for infrastructure development. Training to improve national technical skills and capacities is an ongoing activity of SOPAC.

The South Pacific Commission (SPC) has programmes related to integrated rural development, assessment and management of coastal fisheries and community education. The Pacific Islands Development Programme (PIDP), based at the East-West Centre in Hawaii, helps Pacific island countries to meet their special development needs through cooperative research, education and training designed to enhance the quality of life, based on the available resources of each island nation and through the 'Pacific Way'.

The University of the South Pacific is a regional university serving 12 Pacific island states through three campuses, a network of centres and a satellite-based distance learning programme. Tertiary level education and training on aspects of global change are also conducted at a regional level by the University of Papua New Guinea (UPNG) and by the French University of the Pacific (FUP).

The Forum Fisheries Agency (FFA) has a mandate for technical assistance covering fish and other living marine resources.

Regional non-governmental organisations in the Pacific are playing an increasing role in issues related to environment and development, including those associated with global warming. The South Pacific Action Committee on the Human Environment and Ecology (SPACHEE) has as its main objective improvement of environmental information sharing. Through its resource centre SPACHEE disseminates a wide range of materials. The Foundation of the Peoples of the South Pacific, International (FSPI) has environment and sustainable development as one of its four programmes. Greenpeace works at a variety of levels and in diverse ways to promote sound management of environment and resources. It has a very active climate change campaign at the international level, often advocating positions which relate to the concerns of small island and developing countries. The World Wide Fund for Nature (WWF) is increasingly active in the Pacific region, promoting and implementing projects demonstrating sustainable management and conservation of natural resources. ORSTOM Institut Français de Recherche Scientifique pour le Développement en Coopération (ORSTOM) is a research institute with several programmes, many of which have environmental application. Most of these are concerned with marine environments and resources. ORSTOM has facilities in both New Caledonia and French Polynesia.

Further information on these and other regional organisations may be found in Asian Development Bank (1992).

3.4 Context provided by legal and related instruments

As noted in the preceding section, for responses to climate change and sea-level rise to be effective they must take place in a supportive atmosphere, which includes institutional capacities and constructive legislation—both international and domestic.

Along with growing international awareness of the potential impacts of global climate change, came pressing calls for a global treaty to address the issue of climate change. The identified need was for a global response to a global problem since it could not be solved by individual states, nor by small groupings of them. An Intergovernmental Negotiating Committee was established in 1990 under the auspices of the United Nations. The Committee was instructed to draft a convention on climate change, and between 1991 and early 1992 almost all countries of the world were involved in the negotiations and the drafting process. The resulting UN Framework Convention on Climate Change (UNFCCC) was opened for signature at the UN Conference on Environment and Development (Brazil, 1992) and signed by 155 countries.

The Convention entered into force in March 1994, for by then it had been ratified by 50 countries. Now over 120 countries have ratified the UNFCCC. It is now binding in international law, at least for those countries which have both signed and ratified the Convention.

For the Pacific, Parties to the UNFCCC include the following developing island states: Cook Islands, Fiji, Federated States of Micronesia, Kiribati, Marshall Island, Nauru, Papua New Guinea, Solomon Islands, Tuvalu, Vanuatu and Western Samoa. The only other island states eligible to be Parties are Tonga and Palau. Territories such as Tokelau, American Samoa and French Polynesia participate in the UNFCCC through their parent country.

The Convention provides a framework within which countries can cooperate to implement policies and measures which will achieve the 'stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system' (Article 2). Article 3 of the Convention establishes a series of principles which are of critical importance to developing countries, especially in the context of the present study. These principles are that:

- developed countries should take the lead in combating climate change and its adverse effects;
- full consideration should be given to the specific needs and special circumstances of developing countries, especially those that are particularly vulnerable to the adverse effects of climate change and/or those that would bear a disproportionate or abnormal burden;
- precautionary measures should be taken to anticipate, prevent or minimise the causes of climate change and mitigate its adverse effects; thus lack of scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures should ensure global benefits at the lowest possible cost; and
- parties have a right to, and should, promote sustainable development, with the policies and measures to protect the climate system against human-induced climate change being appropriate to the specific conditions of each country. They should also be integrated with national development programmes given that economic development is essential when adopting measures to address climate change.

In order to meet their obligations under the UNFCCC countries must undertake inventories of their greenhouse gas emissions and sinks and submit the results to the Conference of the Parties to the Convention in the form of 'national communications'. They must also carry out national programmes to mitigate climate change and adapt to its impacts. In addition, countries commit themselves to promoting education programmes and public awareness about climate change and its likely effects. Finally, all parties to the Convention are bound to strengthen scientific and technical research and systematic observation related to the climate system, promoting the development and diffusion of relevant technologies.

On top of the above joint commitments, developed countries have agreed to accept some additional obligations. These include adopting policies and measures to limit their greenhouse gas emissions—implicitly to their 1990 emissions level by the year 2000—and to protect and enhance their greenhouse gas sinks and reservoirs. Developed countries have also agreed to provide developing countries with new and additional financial and technical resources and to support their efforts to fulfil their commitments under the Convention.

The first Conference of the Parties to the UNFCCC, held in Germany in March/April of 1995, adopted the 'Berlin Mandate'. This recognised that the present implicit commitment of developed countries to return greenhouse gas emissions to 1990 levels by the year 2000 were inadequate. Parties agreed to the strengthening of developed country commitments beyond 2000 by setting quantified objectives for limiting and reducing emissions within specified time frames, with agreement to be reached by 1997. A current pilot phase, where there is no credit for reduced emissions where one country invests in energy efficient projects in other countries, is likely to end in 1999. There was a renewed commitment to national reporting and a strengthening of financial instruments for assisting developing country parties to the UNFCCC. The approach of New Zealand to use nett emissions reduction was not opposed, but neither was it endorsed.

The agreements reached in Berlin must be seen in the context of a proposed protocol brought to the meeting by the Alliance of Small Island States (AOSIS). The main features of the proposed protocol are:

- an additional commitment that developed countries reduce CO_2 emissions to 20% below 1990 levels by 2005;
- no additional commitments for developing countries;
- a comprehensive approach to other greenhouse gases in a phased manner; and
- a coordination mechanism for cooperation on economic, administrative and other implementation measures.

At the Conference of the Parties, AOSIS pointed out that it would take an 80% reduction to achieve a real stabilisation of greenhouse gases in the atmosphere. Only then would the drowning of the island states represented by AOSIS be avoided. The proposed measure would also prevent more intense storms and freshwater becoming salty, and allow coral reefs to survive.

The Rio Declaration on Environment and Development, and Agenda 21, both outcomes of the 1992 UN Conference on Environment and Development (UNCED), are not formal legal agreements—and hence are not binding on any state. However, they do represent a consensus reached by 179 States at the Conference, and as such make some contribution to international common environmental law. They therefore have some potential influence on all states. Importantly this would include those Pacific island countries which are not party to the UNFCCC, and even more so if they had signed the Declaration and endorsed Agenda 21.

The Rio Declaration contains 27 principles to guide future development in a way which protects the integrity of the global environment and the development system. In the context of the present study some of the more pertinent principles incorporate the following important messages:

- peace, development and environmental protection are interdependent and indivisible;
- people are entitled to a healthy and productive life in harmony with nature;
- development today must not undermine the development and environment needs of present and future generations;
- nations shall use the precautionary approach to protect the environment—where there are threats of serious or irreversible damage, scientific uncertainty shall not be used to postpone cost effective measures to prevent environmental degradation;
- the polluter should, in principle, bear the cost of pollution;
- nations shall cooperate to conserve, protect and restore the health and integrity of the Earth's ecosystem—developed countries acknowledge the responsibility they bear in the international pursuit of sustainable development in view of the pressure their societies place on the global environment and of the technologies and financial resources they command;
- sustainable development requires better scientific understanding of the problems—nations should share knowledge and innovative technologies to achieve the goal of sustainability; and
- nations shall warn one another of natural disasters or activities that may have harmful transboundary effects.

Agenda 21, the programme of action agreed to by 179 States at UNCED, provides a reference point for environment and development policies for the next century, defines the major areas for action required to realise the goal of sustainable development and calls for a series of partnerships involving governments, international organisations, business, regional, state, provincial and local governments and non-governmental and citizen's groups.

With respect to protecting the atmosphere and related systems, Agenda 21 calls on governments to develop more precise ways to predict levels of atmospheric pollutants (including greenhouse gas concentrations) that cause dangerous interference with the climate system and the environment as a whole. Since energy consumption is a major source of such emissions, Agenda 21 also recognises the need to help people to learn how to develop and use more energy efficient and less polluting forms of energy, to modernise existing power and transportation systems to gain energy efficiency and to develop new and renewable energy sources such as solar, wind and biomass. The use of environmental impact assessment to foster sustainable industrial development and the development—and transfer to developing countries—of safer, cleaner and more efficient technologies is also encouraged. Governments should also create or strengthen international and regional agreements, such as the 1979 Convention on Long-range Transboundary Air Pollution, in order to reduce transfers of pollutants that harm such things as the environment and human health.

Agenda 21 acknowledges that global warming caused by climate change is likely to cause sea-levels to rise, with even a small increase having the potential to cause significant damage to small islands and low-lying coasts. At that time it was agreed that small island developing states could be totally inundated as sea-level rise, and that most tropical islands were already experiencing the more immediate impacts of the increasing frequency of cyclones, storms and hurricanes associated with climate change. It was noted that tropical islands support many unique species of plant and animal life and that they have rich and diverse indigenous cultures with knowledge of the sound management of island ecosystems and resources.

For such reasons, one recommendation is to undertake precautionary measures to diminish the risks and effects, particularly on small islands and low-lying and coastal areas. Since development options for small island nations are restricted by their small size and limited resources, they need to assess their carrying capacity and prepare sustainable development plans that emphasise multiple use of land and marine areas and their resources, integrate environmental and development planning, maintain biological and cultural diversity and conserve critical habitats and ecosystems. Other countries and international organisations were urged to assist small island developing states to plan and implement sustainable development.

4. Institutional activities and linkages

4.1 Introduction

As a follow-on from the preceding broad discussion of institutional activities, this section will review institutional involvement in assessments of the vulnerability and resilience of Pacific island countries to the impacts of climate change, including accelerated sea-level rise. Relevant programmes and activities of both regional and international organisations will be summarised, and the linkages between them will be explored, as appropriate.

Few references to the literature are included in this section. Relevant publications have already been referenced in the preceding sections or will be identified in the following section. That section describes specific methodologies and the findings of vulnerability and resilience assessments conducted for Pacific island countries.

4.2 South Pacific Regional Environment Programme

Many of the relevant initiatives taken by SPREP have been described in the previous section. The SPREP climate change programme includes building the region's capacity to plan and adapt to climate change and sea-level rise and assisting countries with international negotiations related to these issues. As part of its many other programmes SPREP provides further assistance to Pacific island countries which are faced with the impacts of climate change and accelerated sea-level rise. These programmes include coastal management and planning (with its various capacity building activities), population and sustainable development, environmental assessment, environmental education and information and institutional strengthening. The latter includes coordinating activities related to a number of international conventions and providing advice on environmental legislation.

4.3 Forum Secretariat

The principal role of the Forum Secretariat is to provide a context for more geopolitically oriented discussions and decisions amongst the independent and self-governing countries of the Pacific. These discussions are supported by the more technical work of the other regional organisations and by staff of the Secretariat itself. But, in addition to addressing international political topics of regional concern, the Forum does deal with such matters as energy, economic development, trade and investment. All these and many other elements of the Forum's work programme have linkages with the impacts of, and responses to, climate change and sea-level rise.

4.4 South Pacific Applied Geosciences Commission

The following material summarises SOPAC's policy position on sea-level rise predictions (SOPAC, 1993) and some of its relevant activities in applied geoscientific research. SOPAC acknowledges that, while a global rise of sea-level, from whatever cause, would obviously be a problem for many Pacific island countries, there are current problems needing more immediate attention. One of SOPAC's key tasks is to study these problems and thereby help provide a sound technical basis for their solution. Addressing these immediate problems will also place Pacific island countries in a better position to cope with a global rise of sea-level.

Sea-level changes are one of a number of influences acting on the coastal zone. The coral islands of the Pacific were formed as a result of natural changes of sea-level, and the same natural fluctuations that formed the islands a relatively short time ago could also cause their modification in the future.

SOPAC shares the concerns of Pacific island countries that arise from the profound impact of sea-level rise on low-lying coastal areas in light of predictions being made by the IPCC. But it points out that IPCC puts considerable qualifications on estimates. There is great difficulty in accounting for present, let alone future, rates of sea-level change. Historical rates of local sea-level change in the Pacific are variable and dependent at least as much on local and regional geological and oceanographic factors as on global effects. Tide gauge records from the Pacific show no net rise over the last 80 years, but do show short term fluctuations up to 50 cm. These natural fluctuations are of the same order of magnitude as predicted sea-level rise over the next century. SOPAC notes that detailed studies of coastal erosion problems it has conducted show that the causes are either natural fluctuations of normal processes or human-induced effects from beach mining or building coastal structures.

In 1987 SOPAC convened the workshop 'Coastal Processes in the South Pacific Island Nations' in Papua New Guinea (SOPAC, 1991). In addition to several keynote papers on topics that included coral reef ecology, sea-level changes and sediment budgets, the workshop addressed the evidence for coastal changes and their effects and predicted trends, the effects of cyclones and floods on coastal morphology, sediment budget studies, hazard mapping and technology. The proceedings reflect the importance of coastal and nearshore environments to Pacific island countries, their natural dynamism and the ability of present-day human activity to have considerable impact. The range of tools and techniques for defining the processes and assessing the effects is well illustrated. Specific papers presented at the workshop will be discussed later in the present report.

Early in 1995 SPREP and SOPAC convened jointly the Second Coastal Protection Meeting (SOPAC/SPREP, 1995). The forum recommended further assessment of coastal protection systems now being used in the region.

4.5 The South Pacific Commission

The South Pacific Commission (SPC) was one of the four founding institutions of SPREP. Some of the SPREP initiatives summarised above were undertaken while the SPREP Secretariat was a part of SPC. But SPC has undertaken relevant activities in addition to those associated with SPREP. The pertinent work programmes include agriculture, marine resources, rural development and technology and community education and training.

4.6 University of the South Pacific

The University of the South Pacific has been very active in a range of studies which relate to vulnerability of Pacific island countries to climate change and sea-level rise. Some of the investigations have been undertaken in collaboration with SPREP or other organisations; others have been the sole initiative of staff within the University. Taken together, the various studies contribute to a comprehensive understanding of both geologic (e.g. tectonic) and historic (e.g. human-related) processes resulting in changes in the coastal environment and of the consequences of these changes for environmental quality, resource use and human health and safety. The main approach has been to gather information concerning recent environmental changes and to use the results as examples to illustrate future likely impacts that might occur as a consequence of global warming. A variety of conventional and innovative methods are used in the investigations. The latter includes interviewing elderly inhabitants of coastal settlements throughout the South Pacific in order to obtain information about recent changes in sea-level and other indicators of environmental quality and variability.

The University has also been the host of SPACHEE (see preceding section) and organiser of many conferences and other meetings related directly or indirectly to climate change and its associated causes and effects.

4.7 Intergovernmental Panel on Climate Change

The critical role played by IPCC in reviewing the relevant scientific evidence, assessing impacts and response strategies and investigating emission and international economic scenarios, has already been clearly demonstrated. Through SPREP, AOSIS and their direct participation, Pacific island countries have had numerous opportunities to influence and benefit from the activities of IPCC. Due to activity generated by the two scientific assessments the IPCC has accelerated the processes leading to enhanced understanding and provided a forum for minority concerns and views to be heard. But the process is based on reaching a consensus and as such some individuals, countries and organisations have felt marginalised by the process, or consider that their contrary views have been ignored entirely.

One considerable difficulty facing IPCC is that, as a global initiative, it does not have the capacity to make detailed regional predictions and assessments. This is in a very real sense aggravated by the current inability to develop regional, let alone national-scale scenarios for future climatic and sea-level conditions. The present report has already highlighted this fact and also noted that the Pacific Basin may be to some extent decoupled from global responses such as sea-level rise. Concerns have also been expressed as to the applicability of some methodologies developed by the IPCC to Pacific island countries.

The preceding observations should not foster any doubt as to the overall value of the IPCC activities and outcomes to Pacific island countries. The IPCC products provide an excellent foundation upon which to base the development of regionally and nationally applicable methodologies, as well as the assessments of impacts and the identification and selection of responses.

4.8 United Nations Environment Programme

UNEP continues to support climate change assessment studies in the Pacific, since the South Pacific region is one of its regional seas areas. Indeed, UNEP was one of SPREP's four co-founders. Support now comes primarily through UNEP's Oceans and Coastal Areas Programme Activity Centre. Implementation of UNEP's relevant programmes and activities is now handled largely by SPREP.

4.9 Commonwealth Secretariat

The Commonwealth Secretariat Expert Group on Climate Change and Sea-level Rise has supported two sea-level rise assessments in the Pacific. A rapid reconnaissance mission was undertaken in Tonga and Tuvalu in 1988. A more comprehensive assessment was undertaken for Kiribati the following year.

4.10 Economic and Social Commission for Asia and the Pacific

The Economic and Social Commission for Asia and the Pacific (ESCAP) has taken several initiatives related to climate change in the wider Asia-Pacific region. In response to the decisions made at UNCED and at the Global Conference on the Sustainable Development of Small Island Developing States (Barbados, 1994) ESCAP programmes are giving increasing attention to the island nations of the Pacific. ESCAP has undertaken a recent assessment of the state of the environment of the Asia-Pacific region, including highlighting the environmental degradation and resource depletion occurring in coastal areas as a result of increasing population pressure and growth in industry, agriculture, fishing, mariculture and other activities (ESCAP, 1995a).

ESCAP has also prepared 'Guidelines for Coastal Environmental Management'. These are tailored to the needs and requirements of developing countries of the Asia-Pacific region. ESCAP has also produced 'Guidelines for the Environmental Management of Tourism Development in Coastal Areas'.

At the recent Meeting of Senior Officials in preparation for the Ministerial Conference on Environment and Development in Asia and the Pacific, ESCAP tabled a paper which provided an overview of the issues on climate change and sea-level rise which concern the Asian and Pacific region (ESCAP, 1995b). Emphasis was given to the socio-economic impacts and response strategies related to climate change and the potential rise in sea-level. The paper presented initiatives which could be pursued by countries of the region—individually and collectively—to address the issues that are of concern to the region.

4.11 Australia

In addition to work conducted nationally or at the state level, including the above-mentioned evaluations and subsequent revisions of the IPCC Common Methodology, Australia has undertaken several investigations of relevance to the present study. It has funded and implemented both the South Pacific Sea-Level Rise Monitoring Programme (Lennon, 1993), the project on Climate Monitoring and Impacts in the South West Pacific and a vulnerability assessment case study for Kiribati. Australian scientists have also been the key players in the Commonwealth Climate Impact Assessment and Management Programme.

A case study on vulnerability assessment for Australia's Cocos (Keeling) Islands in the eastern Indian Ocean has applicability to the mid-ocean atolls of the Pacific.

4.12 France

Little specific information was available on activities conducted by France in or for countries and territories of the South Pacific. The French Ministry of Research and Technology assembles and coordinates the monitoring and research tasks of the Institutions and Laboratories engaged in the World Climate Research Programme and in the International Geosphere-Biosphere Programme. The Ministry for the Environment coordinates Evolution of the Climate and the Atmosphere. This is a programme which conducts studies on the contribution of human activities to the greenhouse effect and on the climatic changes and sea-level rise likely to follow from the resulting radiative forcing The studies also cover the ecological and socio-economic impacts of these changes and the national, regional and global actions needed to avoid, mitigate or adapt to the negative effects of such changes.

Most of the available information of relevance to the present study relates to activities of ORSTOM

(Organisation de la Recherche Scientifique des Territoires Outre-Mer) in Noumea and Tahiti. Motivation for much of the research comes from the common understanding that irregularities in the Earth's climate are mainly due to interactions between tropical oceans and the global atmosphere, and particularly to the tropical Western Pacific El Niño Southern Oscillation (ENSO) phenomenon. The purpose of the research, conducted mainly in the context of the international TOGA (tropical ocean and global atmosphere) programme and its COARE (coupled ocean-atmosphere response experiment) sub-programme in the western Pacific, is to observe, study, understand, model and ultimately forecast these climatic variations.

For example, studies are being made of the variations in planktonic biomass as a consequence of water mass changes associated with interannual variations in the equatorial current system and the close coupling between the ocean and the atmosphere. The data set gathered since 1984 includes both El Niño and La Niña events. It shows a common response of chemical and biological parameters to variations in water mass composition along the 165°E meridian between 10°N and 20°S.

The observed variations in planktonic production impact in turn on the structure of the pelagic ecosystem. System efficiency—measured with respect to fish production and the amount of matter (mainly carbon) being transferred to the deeper layers of the ocean—are two major consequences of the changes in ecosystem structure.

ORSTOM has also hosted several scientific meetings of relevance to climate change studies in the Pacific. For example, in 1995 international scientists gathered to assess the results of their investigations into the carbon cycle of the equatorial Pacific. This body of ocean is thought to play a major role in two aspects of the global carbon cycle: through the flux of CO_2 to the atmosphere and through the export of organic carbon to the deep ocean. New data obtained recently as part of the Joint Global Oceans Flux Study (JGOFS) compares the distributions and fluxes of selected parameters for 140°W and 155–165°E. The variables studied include winds, ocean temperatures, ocean currents, CO_2 flux, carbon fluxes and the food web. The results show that the boundary between the central and western equatorial Pacific occurs almost as a step function at about the international dateline. Primary, new and export production are all normally lower west of the dateline. The gradient of CO_2 across the air-sea interface is smaller and the food web has relatively fewer plant of nutrients in the west. These chemical and biological differences are largely the result of differences in physical forcing. The central equatorial Pacific is dominated by local winds that favour upwelling. The nutrient content of the upwelled water, however, depends on remote westerly winds in the western Pacific. In the western equatorial Pacific winds are weaker and more variable. A low salinity surface layer lies over an isothermal barrier layer that blocks the vertical transport of nutrients.

Under the auspices of the IPCC Coastal Zone Management Subgroup a study of the vulnerability of Moorea to accelerated sea-level rise has been undertaken. Moorea is a 70 km long mountainous and coralline island in French Polynesia. Its limited dry, flat land is mostly dedicated to residential and other buildings, with 2400 homes. The principal economic activities include agriculture and tourism. Moorea experiences significant floods and erosion during cyclones. These have a current frequency of about four every 10 years.

4.13 SPREP/Japan Cooperation Projects

The Environment Agency of the Government of Japan, through the Overseas Environmental Cooperation Centre in that country, is collaborating with SPREP in assessments of coastal vulnerability and resilience to sea-level rise and climate change. Also involved are coastal experts from Ibaraki University in Japan and members of the SPREP Climate Change Task Team. It is under this project that the concerns about the inapplicability of aspects of the IPCC Common Methodology for Vulnerability Assessment have been formalised, modifications developed and the revised assessment methodologies tested in a series of case studies.

Studies have been undertaken in both Samoa and Fiji. The Fijian studies are continuing, with the assessments now also being extended to include Tuvalu. This will allow the revised methodology to be applied and evaluated in the context of the vulnerability and resilience of coral atolls.

Japanese experts have also participated in a bilateral assessment project for the island of Tongatapu in Tonga. The objectives of the study were to assess the vulnerability of Tonga using the IPCC Common Methodology, to identify problems specific and important to small Pacific islands and to provide a basis for further Tongan-based studies of response strategies and comprehensive coastal zone management. The case study for Tongatapu also contributed to the work programme and findings of the IPCC Coastal Zone Management Subgroup.

4.14 United States of America

The United States of America has been assisting the Federated States of Micronesia, Marshall Islands, Kiribati, Western Samoa and Fiji through its Climate Change Country Study Initiative. These countries are undertaking emissions inventory, vulnerability and adaptation response studies, and mitigation strategies. Preliminary results were reported at the Workshop on Climate Change Implications and Adaptation Strategies for the Indo-Pacific Island Nations (CCCSIP, 1995). One of the motivations for this workshop was to address the problems of 'potential' conflict between traditional land tenure systems and newly emerging governments with responsibility for shoreline development and protecting lives, property and ecosystems.

5. Vulnerability and resilience assessments: methodologies and findings

5.1 Introduction

This section describes the need for, and nature of, assessments of the vulnerability and resilience of Pacific island countries to climate change and accelerated sea-level rise. It then goes on to review the assessment methodologies that have been and are being used globally and in the Pacific. The section also provides an indication of the relative strengths and weaknesses of the methodologies along with an introduction to the supporting technologies and techniques. This review is presented in something of an historical context to demonstrate the evolution that has taken place in the methods used. The final and main part of this section presents a regional synthesis of the results of various country-based assessments that have been conducted in the region since 1987.

The findings related to both methodologies and vulnerabilities will be used to guide the discussion on response option strategies and priorities which is presented in the later section of the current report.

5.2 Review and assessment of methodologies

5.2.1 The UNEP/SPREP/ASPEI methodologies

The first assessments of the vulnerability of Pacific island countries, and the region as a whole, to climate change and to anticipated higher sea-levels were undertaken by the UNEP/SPREP/ASPEI Task Team on Implications of Climate Change for the South Pacific (ASPEI, 1988; Pernetta and Hughes, 1989; Pernetta and Hughes, 1990; Hughes and McGregor, 1990). The task team undertook its assessments assuming that low latitude temperatures would rise by 2°C by 2100, with an approximate warming rate of 0.3°C/decade. It was also anticipated that areas of the South Pacific receiving the bulk of their rainfall during the southeast season would continue to do so, perhaps with a slight increase in rainfall amounts. On the other hand, areas with a dominant southeast dry season would be likely to experience a prolongation of that dry period. Areas already experiencing pronounced dry seasons would be likely to be affected by desertification by the year 2100. The studies assumed that northwest rainfall amounts would decrease slightly. Frequencies of cyclonic storms in Vanuatu, the Solomon Islands and in parts of Papua New Guinea were expected to increase. A northwards shift in the tropical convergence zone was anticipated to result in changes in ocean currents, zones of upwelling and in surface wind patterns. The latter would have an impact via waves on coastal beach platforms, resulting in increased shoreline retreat and erosion in some areas.

The case studies assumed a sea-level rise of 1 m by around 2050, with the increase continuing beyond that date. The value of 1 m was considered conservative, given that at the time estimates ranged as high as 4.5 m by 2100.

In a pioneering paper for the region, McGregor (1988) used an ensemble of methods—results of general circulation models; relationships between atmospheric circulation and climate; comparison of rainfall anomalies for ensembles of warm and cold years—to assess likely changes in the magnitude and distribution of rainfall in Papua New Guinea and the impact of temperature increases on human comfort. He argued that as Papua New Guinea possessed a range of tropical sub-climates generally representative of those found elsewhere in the tropical southwest Pacific, his results would be applicable to other areas in the southwest Pacific.

In his assessment of the effects of increased temperature, McGregor (1988) used the Relative Strain Index (RSI) as an index of human comfort. The index is the ratio of the amount of sweat evaporation needed for comfort to the amount of evaporation possible. Discomfort is experienced when the ratio exceeds 0.3. McGregor undertook the study for a number of coastal centres throughout Papua New Guinea. He based his calculations on an assumed 2°C temperature increase and a 7% vapour pressure increase over current conditions. He also used the observed mean annual environmental lapse rate to determine at what altitude in Papua New Guinea temperature regimes would be similar to those presently experienced at coastal locations.

The thermal comfort analyses based on the RSI were extended to the western tropical Pacific in McGregor (1990). The same changes in temperature and vapour pressure were assumed.

Pernetta (1988) developed a relative index of susceptibility to climate change and sea-level rise. The index was based on an approximate equal weighting for altitude, island numbers, total land area and island type. It was applied to Pacific island countries, allowing them to be grouped into four susceptibility categories.

In a case study for the Pogera Valley in Papua New Guinea, Hughes and Sullivan (1988) observed the lower and upper limits of both subsistence and cash cropping. They found that zones of agricultural productivity were sharply delimited, both above and below. While not all controlling factors were related to the general climatic regime, the linkages were such that it was feasible to estimate the effects of a possible increase in temperature on those elevations at which agriculture would be possible in Papua New Guinea. This involved using accepted relationships between temperature and altitude. The study was able to identify areas in the highlands where people could move upslope through a vertical distance and still maintain the temperatures where agriculture was currently practised.

Nunn (1988) used student researchers and collaborated with government officials to assess the loss of land, overall and in certain use categories, as a consequence of assumed increases in sea-level. Studies were undertaken for parts of the Cook Islands, Fiji, Kiribati, Tonga and Western Samoa. Contours were interpolated on large scale maps of the study areas, for values of 20 cm (a medium sea-level scenario for 2025), 50 cm (high scenario for 2025), 1.5 m (medium scenario for 2100) and 3.5 m (high scenario for 2100). The researchers estimated the area between each contour and chart datum in order to estimate the area of land lost with a given higher sea-level. Each area was also apportioned on the basis of land use in order to enable a quantitative impact to be expressed in terms of economic impact. Problems experienced during the study were the general lack of availability of maps of suitable scale and with appropriate contour intervals. No maps in rural areas had suitable scales. In many cases the chart datum was not specified. In such cases it was assumed to be mean high water. On only a few maps was it possible to estimate the placement of the 0.2 and 0.5 m contours. In urban areas the presence of sea walls commonly rendered these contours coincident with chart datum. Nunn (1988) contains a detailed description of the methods used in the study.

The above study was followed by a further investigation into recent environmental changes, with the results being used as examples to illustrate future likely impacts that might occur as a consequence of global warming (Nunn, 1990). The study was designed to demonstrate changes in sea-level since 1900, to record and analyse important environmental changes associated with recent sea-level changes and to summarise likely future impacts of global warming on coastal areas in the South Pacific. The basic data for the study were obtained by students who questioned elderly inhabitants of coastal settlements in the Cook Islands, Fiji, Kiribati, the Solomon Islands, Tonga, Tuvalu, Vanuatu and Western Samoa in order to obtain information about recent changes in sea-level and other indicators of environmental quality and variability.

The actual questionnaire was never shown to those interviewed. Rather, responses were recorded after the interview had been concluded. The first part of the questionnaire was intended to gather background data on the settlement, and the second part, information on such topics as changes in drinking water access and quality, ease of fishing off the village front, changes in frequency of fish in normal diets, perceived changes in tropical cyclone frequency, temperature and rainfall and changes in the tidal regime and sea-level. The third part of the interview encouraged elderly interviewees to indicate the approximate location of low tide in their youth. The researchers were then required to measure the horizontal and vertical distances between the old and present low tide marks.

Nunn acknowledged the imprecision of the information obtained through such procedures. He argues that discussion of the results on the basis of national and regional averages will minimise the effects of any errors while still providing a generalised picture of recent shoreline changes in the Pacific.

Bualia and Sullivan (1988) used existing topographic maps with a scale of 1:100,000 and a contour interval of 40 m to assess the overall effect of a 1 m rise in global sea-level on the coastal areas of Papua New Guinea. For limited areas larger scale maps or additional contour information were available. LANDSAT imagery, aerial photographs and local knowledge were also used where possible. A 1 m contour line was interpolated between the present shoreline and the near-shore 40 m contour. In general, on rocky cliffed or sloping (erosional) shorelines the 1 m level was interpolated approximately 1⁄40 of the distance inland. For coastal areas where a narrow coastal plain (either erosional or depositional) existed between the shoreline and any near-coastal hillslope zone, the 1 m contour was interpolated 1/20 the distance inland of the 40 m contour.

Coastlines were classified into three broad categories according to the degree of inundation indicated in the analysis: negligible, where there was no discernible land area likely to be inundated; moderate, where the total land area likely to be inundated was discernible but comprised either discrete land areas each of less than 1 km^2, or a coastal strip of any length but less than 500 m wide; and severe where contiguous land areas in excess of 1 km^2, or strips of coastline more than 500 m wide were affected.

Pernetta and Osborne (1988) developed a 'simplistic' model of possible changes in mangrove communities as a consequence of an increase in sea-level. Three alternative scenarios are presented for situations where a realistic rise in sea-level (<2 m) will lead to a compression of the mangrove zones (pure mangrove, *Nypa* and mangrove, mangrove and forest) against an inland, biophysical boundary. The first scenario assumes that each zone is merely moved further landwards, and that the most landward zones disappear. It is acknowledged that this was an unlikely scenario. The second scenario assumes that the reduced width of the coastal plain is divided amongst the various associations in proportion to their present extent at the given site. The third scenario assumes that differential compression of the seaward zones occur, coincident with the proportions in a presently uncompressed profile. It is argued that if shorelines stabilised with sea-level at 1 m above present this last scenario would be the most probable.

O'Collins (1988) used a variety of methods in a sociological investigation of the decisions confronting atoll dwellers facing the threat of, and experiencing, relocation as a consequence of sea-level rise. The case study was based on the inhabitants of the Carteret Islands who were involved in relocation under the Atolls Resettlement Scheme. They moved from their atoll to mainland Bougainville Island in the North Solomons Province of Papua New Guinea as a consequence of food shortages associated with land loss and population growth. Methods used in the investigation included studying patrol reports prepared by Australian administrative officers between 1950 and 1975, North Solomons Government reports and minutes of meetings and field reports from agriculture and social work students. Interviews were also conducted with island leaders, settlers and government and non-government officials, Finally the author made several site visits to the Atolls Resettlement Scheme.

Two simple models of the changes likely to occur to atolls and low islands should sea-level continue to rise, or rise and then stabilise, were developed by Sullivan and Pernetta (1989). They differentiated between a situation where coral growth keeps pace with sea-level rise and one where it does not. The distinctive impacts associated with the two models were expressed in descriptive form.

Buddemeier and Oberdorfer (1988) used basic hydrologic principles combined with a general knowledge of the directions of climate change. They sought to establish how vulnerable the ground water resources of small islands are to climate change and sea-level rise. They acknowledged the variety of scenarios that could result because of local factors influencing island groundwater resources and uncertainties in the exact patterns and magnitudes of climate change. However, empirical data showing a moderate correlation between freshwater lens size and the ratio of rainfall to island width was used to support methods based on the assumption that rainfall and island size play significant roles in recharge of the groundwater.

The traditional conceptual model of island groundwater occurrence was the Ghyben-Herzberg Lens, usually treated mathematically in resource assessments by use of the Dupuit assumption of horizontal flow. Such a model may work well for islands that are relatively symmetrical and homogeneous on a field scale. It may thus apply to some large volcanic islands and possibly to raised coral islands. An alternative conceptual model which is more applicable to low atoll islands takes into account the heterogeneity of the geological materials and the tidal signal response observed in island wells. The contrasting permeabilities commonly observed in boreholes on reefs and islands induces a pattern of oscillating water movement that is inconsistent with the horizontal flow assumptions generally associated with the simpler model. Thus past fresh groundwater assessments based solely on the height of the water table above sea-level and the Ghyben-Herzberg relationship for density differences have often grossly overestimated the amount of water resource available. This is a result of failing to recognise the extent of the transition zone of mixed fresh and saline water associated with the downward mixing of freshwater into the saline water below the lens, a consequence of the vertical mixing in a heterogeneous system. A deeper transition (mixing) zone reduces the potable water inventory.

In an assessment of the effects of sea-level rise on tropical riverine lowlands, Chappell (1988) notes that the extent to which tidal and fluvial flooding is increased by a given rise in sea-level is influenced by factors such as floodplain slope downstream and laterally away from the river, by the form of the river levees and by the extent to which floodplain sedimentation can keep pace with rising tidal and flood levels. While the problem may be addressed using computer models, based on hydrological and geomorphological processes and on channel hydraulics, Chappell argued that in 1988 the levels of understanding and available information precluded development of reliable models. Rather, he advocated examination of the actual behaviour of riverine lowlands under various conditions of sea-level changes during the part of the Holocene period when sea-level was rising rapidly. Present riverine lowlands evolved during this period, and their behaviour during the rising phase of sea-level is recorded in shallow sub-surface deposits. He investigated two river systems to illustrate the way in which response to sea-level rise varies with tidal behaviour and with sediment input.

Spennemann et al. (1989) studied the potential impacts of projected changes in climate and sea-level for Tongatapu in Tonga. Based on the findings of the NRC Committee on Engineering Implications of Changes in Relative Mean sea-level, they assumed three sea-level rise scenarios for 2085 (approximately 100 years into the future at the time), namely 0.5 m, 1.0 m and 1.5 m. The study reconstructed the placement of new shorelines in Nuku'alofa township area for the three assumed sea-levels and assessed the impact of inundation on human habitation, sanitation, natural resources and archaeological heritage. Two types of inundation were recognised: 'direct inundation' caused by a rise in relative sea-level; and 'indirect inundation' due to related rise in the groundwater table in inland areas. The latter inundation is not prevented by coastal protection walls, though they may help alleviate the effects of tidal movements. A third cause of (temporary) inundation of land up to 0.5 m above MSL was also recognised, namely extensive sheet flooding after torrential rainfall.

The investigation used the results of a detailed spot levelling of Nuku'alofa township. Contours for 0.65, 1.15 and 1.65 m above present mean sea-level (MSL) were interpolated on 1:5000 maps. The mean high water at spring tides is 0.6 m above MSL in Nuku'alofa Harbour while the lagoonal mean sea-level at spring tides is about 0.25 m above MSL. The level of the groundwater lens in Nuku'alofa was equated with MSL. Areas affected by inundation for the 3 sea-level rise scenarios were determined using the above information.

The impacts of tropical cyclones were also considered. While the 'normal' cyclone paths run west of Tonga, ENSO leads to the Tongan group being affected more frequently. Spennemann assumed that the cyclone patterns under ENSO could be used as a 'rough approximation' of conditions with global warming. This would increase the frequency of cyclones and gale force winds for Tongatapu.

The findings of an investigation of the likely impacts of sea-level rise of a 170 km long, low-lying stretch of coastline in Gulf Province, Papua New Guinea were presented by Bualia (1989). He estimated the amounts of land that would be lost by inundation due to a 1 m rise in sea-level, along with the likely impacts. The spatial extent of permanent inundation, coastal erosion, non-tidal flooding and salt water intrusion were all estimated using topographic data, interrelationships observed under present conditions and an assumed 1 m rise in sea-level.

Hackett (1989) advocated that standardised plant ecophysiological datasets, mapped at an appropriate scale for fuelwood, forest, weed species and crops, be used for predicting plant performance for different global warming scenarios. He demonstrated how the data might be used in such studies. Studies would be expedited if undertaken within a geographic information system.

Jacobs (1990) used published results from a variety of sources to define future environmental conditions, especially related to increases in CO_2 in the South Pacific region. He examined the effects of the identified changes on the physiology of crops and suggested strategies which address the need for cultivars of food crops which are adapted to the changed environmental conditions. In a related study, Singh et al. (1990) evaluated the effects of projected climate change on the productivity and sustainability of agricultural systems. Two general circulation models were interfaced with crop models for maize and rice in a series of studies for Nadi and Laucala Bay, Fiji. The latter models simulate crop production under varying environmental and management conditions. Temperature, radiation and rainfall data for the two locations were estimated for a doubling of CO_2 using the general circulation models. The authors noted some of the limitations of such an approach and the resulting uncertainties in the analysis.

In his study of socio-economic change in Fiji agriculture, Overton (1990) began by examining the broad context of environmental and agricultural change. He discussed evidence of both landscape modification and high intensity of settlement in pre-European Fiji, and rapid and profound economic transformation in the past century. He then went on to examine the present processes of economic change, noting aspects of inertia and reaction as well as novelty. Against this background he assessed how the impacts of future changes in environmental conditions will interface with projections of present processes.

Nurse (1990) examined the possible effects of climate change on human health in the Pacific island countries. His qualitative analysis is based on the available literature.

In summary, much of the above work, and other studies conducted during the 1980s, were influenced by the assumptions of a 1 m rise in sea-level by 2050, assumptions of accelerated increases beyond that date, by predictions of increased frequency and intensity of tropical cyclones, by uncertainty as to the ability of coral reef systems to keep pace with rising sea-level and by 'the cataclysmic events forecast by the prophets of doom' (Connell and Roy, 1990). In contrast, very few studies were influenced by the more cautious and optimistic views as typified by McLean (1989).

In a period as short as five years there were fundamental changes in assumptions and attitudes regarding the impact of climate change on small islands of the Pacific. Despite the lack of a more circumspect view, such as that subsequently provided by the IPCC assessments, the contributions of the various individuals working under the auspices of the UNEP/SPREP/ASPEI were substantial, as the preceding summaries indicate. They also laid an excellent foundation for the subsequent and more detailed country studies undertaken by SPREP with the assistance of UNEP and with the benefit of enhanced understanding provided by the IPCC assessments.

5.2.2 SPREP/UNEP Country Studies (Preparatory Missions)

In recent years the SPREP, with the assistance of the UNEP and regional experts, has undertaken studies of the potential impact of expected climate change on the national environment and socio-economic structure and activities. Ten countries in the region have been studied. The first study was for the Republic of Kiribati (Sullivan and Gibson, 1991). This served as something of a model for the subsequent investigations, by recognising that changes in climate and sea-level are only two, and in many cases not the most urgent, of a number of environmental problems facing small island nations in the Pacific. Thus the approach adopted in the Kiribati study, and followed to a large extent in subsequent assessments, was to focus on existing and anticipated environmental problems which are likely to be exacerbated by a change in climate or an increase in sea-level. In their assessment of the vulnerability of Kiribati to climate change and sea-level rise Sullivan and Gibson used a scenario of 2°C and 40 cm for the respective temperature and sea-level increases by 2020. This was one of the earliest times that the results of IPCC assessments and scenarios were incorporated explicitly in vulnerability studies in the South Pacific. They also considered that the increase in tropical cyclone intensity and, possibly, frequency, with an increase in sea surface temperature would only impact on Kiribati through increased storm surges and marginal climatic instability. Impacts on coral reefs were assessed using the models presented in Sullivan and Pernetta (1989).

The subsequent studies, listed in order of publication, were for Tuvalu (Aalbersberg and Hay, 1992), Cook Islands (Sem and Underhill, 1992), Marshall Islands (Connell and Maata, 1992), Tonga (Nunn and Wadell, 1992), Western Samoa (Chase and Veitayaki, 1992), Tokelau (McLean and d'Aubert, 1993), Federated States of Micronesia (Hay and McGregor, 1993), Palau (Sem and Underhill, 1993) and Guam (Prasad and Manner, 1994).

These studies were not full vulnerability assessments. Rather they were field and desktop based scoping exercises designed to lay the foundation for more comprehensive assessments at a later date—and called 'preparatory missions'. None of the studies used the IPCC's Common Methodology for Vulnerability Assessment. While some of the resulting reports do not even specify the changes in climate and sea-level that are assumed in the preliminary studies, those that do tend to favour the projections provided by the IPCC (1990a, 1992a), viz. a temperature increase of 0.3°C per decade and a rise in sea-level of 6 cm per decade.

5.2.3 The IPCC Common Methodology for vulnerability assessment

The Coastal Zone Management Subgroup of IPCC Working Group II developed the 'Seven Steps to the Assessment of the Vulnerability of Coastal Areas to Sea Level Rise—A Common Methodology' (IPCC, 1991). It was published after a detailed process of review, comments and revisions. The Common Methodology is a guideline for assessing vulnerability to accelerated sea-level rise. In such an assessment three levels of boundary conditions and scenarios are incorporated in the methodology:

- impacts on socio-economic development;
- impacts on the natural coastal systems; and
- the implications of possible response strategies for adaptation.

The Common Methodology includes consideration of the present (reference) situation, and increases in sea-level of 0.3 and 1.0 m by 2100. These scenarios represent the low and high estimates of the IPCC 'Business-as-Usual' scenario (IPCC, 1990a, 1992a). Where appropriate, modifications are made for subsidence, uplift and storm surges and for circumstances peculiar to the area under study. In its present form the Common Methodology focuses on the effects of accelerated sea-level rise and existing storm patterns. It is anticipated that more attention will, in the future, be given to the vulnerability of coastal areas with respect to other anticipated consequences of global warming, such as rainfall distribution and soil moisture and, possibly, changing storm patterns and intensities.

The Common Methodology has been described in detail in its original form in IPCC (1991) and in its revised form in IPCC (1992c). For this reason its specific procedures will not be presented in this report. Rather, a brief summary will suffice.

The Common Methodology comprises seven steps:

- Delineation of case study area and specification of boundary conditions for climate change and accelerated sea-level rise for the period of the assessment;

- Inventory of study area characteristics, including both natural and socio-economic systems;

- Identification of the relevant development factors;

- Assessment of physical changes and natural system responses;

- Formulation of response strategies and assessment of their costs and effects;

- Assessment of the vulnerability profile and interpretation of results; and

- Identification of the needs and actions to develop a long term coastal zone management plan.

In the Pacific, the Common Methodology has been applied in the following vulnerability assessments:

- Tonga (Tongatapu) [Fifita et al. (1992); Fifita et al., (1993)]

- Kiribati [Abete (1993)]

- Marshall Islands (Majuro Atoll) [Crawford et al. (1992); Holthus et al. (1993)]

- French Polynesia (Moorea) [IPCC (1992c; 1994)]

The strength and weaknesses of the Common Methodology were discussed in 1992 at an IPCC workshop (IPCC, 1992c). The relatively detailed instructions were seen as a positive attribute by many of those who had conducted assessments. But in certain cases it was thought that some data requirements were either not as crucial to the analysis as were others, or were not needed at all. Also it was observed that some hard-to-value coastal resources were not included, despite often being considered of great importance. Examples include cultural heritage and aesthetic values.

These reactions highlight an important feature of the Common Methodology. It was the intention of IPCC that the documentation on the Common Methodology serve as guidelines for a generic tool, thereby providing sufficient detail for those initiating an assessment. It was never intended that the Common Methodology restrict assessments from reflecting the importance of the coastal resources and assets under review.

Initially it had been assumed that assessments conducted following the Common Methodology could be completed relatively quickly, but experience has shown this not to be the case. This is particularly so when data required for the assessment do not exist. Even if the data do exist, considerable time is often spent endeavouring to access and process the information. Excessive costs can also be incurred at this stage of the assessment. This highlights the need for coordination in the collection and management of data, since the information required by the Common Methodology is also critical to the implementation of effective integrated coastal zone management. There is also likely to be much benefit in completing, as an initial step, even the most basic assessment requiring minimal data.

The IPCC has documented three broad categories of response—retreat, accommodation and protection. Under interpretation of vulnerability in the Common Methodology only two 'extreme' options are evaluated. These are 'no measures' and 'protect'. While these choices may have some commonality with the formal retreat and protect options of IPCC, it is unclear if the retreat is planned or forced. Retreat may give the impression of an unplanned and undesirable option, while in many cases planned retreat will be the lowest cost response to accelerated sea-level rise. Moreover, building setbacks were sometimes described as accommodation when they should be considered as a planned retreat option. In IPCC (1992c) there is a suggestion that the lack of clarity and concordance be addressed by introducing a two-tier division of responses—'do nothing' and 'do something' could be introduced to specifically allow for 'planned retreat' and other positive responses.

Experience with the Common Methodology led to the judgment that it tended to favour protection, due in the main to its reliance on a cost-benefit approach. Many evaluators of the Common Methodology have also commented on the absence of a specific economic valuation method in the procedures. In response IPCC noted that while cost-benefit analysis is a standard method for decision making, it is inappropriate to prescribe a valuation method. The analytical approaches used in the Common Methodology can be refined when there is improved understanding of the value, and valuing, of coastal resources. The Common Methodology also assesses vulnerability for those elements that cannot be given a market value. IPCC stressed the need for these elements to be given greater attention in the assessment.

In its present form the Common Methodology does not allow for the complex, nonlinear interactions between stresses, resources and response options. An exception is the vulnerability assessment for ecosystems where responses are assumed to be influenced by the rate of accelerated sea-level rise. Those developing the Common Methodology considered that the incorporation of more complicated interactions into the assessment procedures was impracticable. These might best be left to be undertaken in more comprehensive studies in support of coastal planning and management.

Criticism has also been levelled at the Common Methodology due to its use of different time frames for accelerated sea-level rise (100 years), for specification of relevant development factors (30 years) and for response measures (0 years, i.e. instantaneous). In defence of the approach, IPCC notes that sea-level is allowed to rise over 100 years in order to reflect the gradual but often irreversible nature of the process due to the large lags that are involved. The 30 year time frame for development is an acknowledgement that economic forecasts beyond that time would carry little if any credibility. IPCC claims that a good first-order approximation of adaptation costs may be obtained by assuming an instantaneous rise of mean sea-level for the design of protection measures. This assumption avoids the need to specify how the measures will be introduced over time and the need to discount costs.

These and other limitations of the Common Methodology are also addressed in IPCC (1994).

Kaluwin (1993) has highlighted concerns about the applicability of the Common Methodology in the South Pacific and in comparable areas elsewhere. Similar reservations have been expressed by Morvell (1993) and by Kay and Waterman (1993) as a consequence of testing the procedures in Australian case studies and by Woodroffe and McLean, (1992; 1993) based on studies conducted for both Cocos (Keeling) Islands and Kiribati.

At issue is:

- the biophysical framework for the assessment,
- the cost-benefit orientation of analyses of response options, and,
- variations in how governments and communities perceive climate change and sea-level rise as important relative to other regional planning and environmental issues.

If a low priority is accorded, the climate change and related response strategies could be biased towards reactive policies implemented only after erosional or storm events have caused damage. Morvell notes that such a point is a key factor to be considered in the development of methodologies with common features encompassing governmental arrangements as well as biophysical conditions. He went on to conclude that the case studies referred to above show that what is needed are methodologies sharing common features rather than a single Common Methodology.

Some of the circumstances in Pacific island countries which tend to limit the applicability of the Common Methodology have been described by Kaluwin (1993). He lists them as:

- subsistence economy;
- close ties of indigenous people to their land through customary land tenure;
- importance of extended family structures;
- gift giving and remittances as a mechanism for extended family economic resilience;
- comparative lack of urban land use planning or building codes;
- in rural areas the importance of proximity to roads;
- strength of religious beliefs;
- ineffective linkages between national (parliamentary) and village (customary) decision making;
- political commitments; and
- limitations due to a lack of appropriate human, technical and information resources.

As will be discussed in the following sub-section, SPREP has assisted in the adaptation of the Common Methodology to more suit the conditions prevailing in most Pacific island countries.

5.2.4 The SPREP/Japan Stress-Response Methodology

In response to the difficulties experienced in applying the Common Methodology to Pacific island countries, as outlined above, members of the SPREP/Japan Integrated Coastal Zone Management Programme for Western Samoa and Fiji built on and expanded the Common Methodology into a broader assessment and decision-making support framework appropriate to the South Pacific and even more widely applicable. The Stress-Response Methodology for the Assessment of Vulnerability and Resilience to Sea-Level Rise and Climate Change is described by Kay and Hay (1993) and elaborated by Kay et al. (1993), Nunn et al. (1993; 1994a; 1994b) and Yamada et al. (1995). These publications also describe the application of the methodology to case study areas in both Fiji and Western Samoa. The methodology is currently also being applied in vulnerability and resilience assessments in Tuvalu.

Since the Stress-Response Methodology is also well documented it too will not be described here in detail. The framework of the Methodology is illustrated in Figure 2. The assessment is conducted in terms of both external and internal stresses on biophysical and socio-economic systems. In addition to climate and sea-level changes, the external stresses typically evaluated include waves, tropical cyclones, fluctuations in global economic markets and foreign tourist activities. Internal system stresses, such as those resulting from population growth, natural resource depletion, pollution and cultural changes are implicitly considered in the decision support framework. The approach is similar in concept to the interacting systems approach for the decisions to mitigate potential climate change impacts on Caribbean islands. This approach was recently explored through computer modelling (Engelen et al., 1993a; 1993b).

The Methodology thus views a coastal zone as a set of separate, but interacting, coastal systems (e.g. natural, institutional, economic, cultural, infrastructural). This facilitates a flexible, non-prescriptive method of analysing the diverse coastal systems of the Pacific region, recognising the distinctive attributes described above (Kaluwin, 1993). The vulnerabilities and resilience of the coastal zone are analysed separately in the Stress-Response Methodology. This is an artificial separation undertaken in order to clarify the range of management responses available to reduce further climate change and sea-level rise impacts.

Figure 2: Framework of the Stress-Response Methodology for Assessing the Vulnerability and Resilience of Coastal Systems (from Kay and Hay, 1993).

As a result, impact reduction responses are divided into measures for vulnerability reduction and resilience enhancement. The term 'vulnerability' is used in the Methodology to describe the attributes of a coastal system which will react adversely to the occurrence of external or internal stress. Such attribute responses will generally produce a negative outcome. The term 'resilience' is used in the opposite sense to vulnerability—resilient attributes of a coastal system will typically reduce the impact of internal and external stresses. Resilient system attributes can be intrinsic characteristics which allow adaptation to stress, or be conscious adjustment decisions and actions taken by people in order to reduce adverse impacts.

Qualitative scores are assigned to the vulnerable and resilient components of each coastal system, collectively for both internal and external stresses. Separate scores are assigned for present-day and for the assumed future conditions. The net impact on each coastal system as a result of external and internal stresses is the net difference between the system's vulnerability and resilience scores. This net system impact for either present-day or future conditions is interpreted to be a measure of the system's ability to cope sustainably with stress. Accordingly, a net value is termed the 'sustainable capacity index'. The concept of sustainability was introduced to highlight the long-term viability of coastal systems, as shown by the difference between the vulnerability and resilience scores.

The future conditions include the additional stresses associated with climate change and sea-level rise, cumulative consequences of ongoing internal and external stresses, and assumed intrinsic changes to the coastal systems. Thus the assessment framework considers a realistic evolving and dynamic coastal zone.

Future condition vulnerability and resilience scores are assigned for two alternate management intervention scenarios. The 'no incremental management' scenario assumes no action will be taken by decision-makers and managers to reduce the impact of stresses in addition to those exerted on the present coastal system. In contrast, the 'optimal management response' scenario assumes a suite of management interventions will be undertaken in order to optimise the reduction of stress-induced impacts on coastal systems. These may include national coastal management and disaster management policies and plans, and education and training of community-level decision makers.

A number of shortcomings in the Stress-Response Methodology are currently being examined. These include:

- the subjectivity in assigning the vulnerability and resilience scores to individual coastal system components;
- the penalties of working with only six levels of coastal system components as opposed to aggregating the scores for sub-system elements;
- the failure to acknowledge explicitly the non-linear interactions between system components; and
- the ongoing difficulty of quantifying intrinsic values and valuing elements of subsistence societies.

5.2.5 IPCC guidelines for assessing climate change impacts and adaptation responses

Experience gained during the First Assessment conducted by IPCC demonstrated the need for a more credible approach to the development of a global picture of the potential effects of climate change. The Assessment revealed difficulties in comparing impacts in different regions and economic sectors when different assessment methods had been used. Thus IPCC recognised the need for a compatible set of methods in order to provide comparable regional and sectoral impact assessments.

The result was a study framework which allows comparable assessments to be made of impacts in different regions, geographical areas, economic sectors and countries (Carter et al., 1994). The general framework has seven steps:

- definition of the problem;
- selection of the method;
- testing the method;
- selection of scenarios;
- assessment of biophysical and socio-economic impacts;
- assessment of autonomous adjustments; and
- evaluation of adaptation strategies.

The steps and related information are described in detail in Carter et al., 1994 and will not be presented here. The report also discusses organisation of research and communication of results.

Carter et al. (1994) make a basic distinction between system responses to climate change that are automatic and built in (termed 'autonomous adjustments') and responses that require deliberate policy decisions and implementation. The latter are described as adaptation strategies. While there are overlaps between these two types of adaptation, Carter et al. made the distinction because of the different treatment each receives in assessment studies.

(A) Internal adaptation responses – autonomous adjustments

As Carter et al. note, most ecological, economic and social systems will undergo some natural or spontaneous adjustments in the face of changing climate. These 'autonomous adjustments' are likely to occur in response to both gradual changes in average climate as well as to more drastic shifts in climate. It is usually unclear what specific forms these adjustments will take and what costs they will incur. But to obtain credible estimates of impacts, and hence develop appropriate response strategies, there is a need to account for these autonomous adjustments in the assessment process.

Carter et al. identified three groupings of autonomous adjustments, based on the degree of spontaneity:

- Inbuilt (or physiological) adjustments—these are the unconscious or automatic reactions of an exposure unit to a climatic perturbation. Some are easy to identify (e.g. the automatic response of a plant to water stress is to reduce transpiration by closing its stomata) and can be accounted for in models that describe the system. Others are more difficult to detect (e.g. the ability of long-lived organisms such as trees to acclimatise to a slowly changing climate). Identification might involve dedicated controlled experiments to determine the nature of the adjustment mechanisms and provide the information for modelling the response.

- Routine adjustments—everyday, conscious responses to variations in climate that are part of the routine operations of a system. For example, as the climate changes the growing season for crops may well change too. Crop performance might be improved by shifting the sowing date. In some crop growth models the sowing date is in fact determined by climate (e.g. the start of the rainy season) so it is selected automatically to reflect the changing conditions. In such cases the model is performing internally an adjustment that a farmer might make instinctively or routinely.

- Tactical adjustments—a level of response over and above the adjustments made routinely in the face of climatic variability. Such adjustments might become necessary following a sequence of anomalous climatic events which indicate a shift in the climate. For example, a run of low rainfall years might convince a farmer to switch to an existing, more drought resistant cultivar despite its lower yield capacity under favourable conditions. Adjustments of this type require a behavioural change but can still be accommodated internally within the system.

(B) Exogenous responses – adaptation

Burton et al. (1993) and Carter et al. (1994) identify six generic types of deliberate behavioural adaptation strategy for coping with the negative effects of climate:

- Prevention of loss—anticipatory actions to reduce susceptibility of an exposure unit to the impacts of climate (e.g. controlled coastal zone retreat to protect wetland ecosystems from sea-level rise and its related impacts).

- Tolerating loss—adverse impacts are accepted in the short term because they can be absorbed by the exposure unit without long-term damage (e.g. a crop mix designed to ensure a guaranteed minimum return under the most adverse conditions and to minimise the maximum loss).

- Spreading or sharing loss—actions which distribute the burden of impact over a larger region or population beyond those directly affected by the climate event (e.g. international disaster relief).

- Changing use or activity—a switch of activity or resource use from one that is no longer viable following a climatic perturbation to another that is, so as to preserve a community in a region (e.g. by employment in public relief works).

- Changing location—preservation of an activity or grouping is considered more important than location, and migration occurs to areas that are more suitable under the changed climate (e.g. the relocation of an atoll community due to loss of land).

- Restoration—reconstruction of a system to its original condition following damage or modification due to climate (this is not strictly an adaptation to climate as the system remains susceptible to subsequent comparable climatic events (e.g. rejuvenation of a silted water supply after flood damage).

IPCC (1990c; 1995b) identified three main categories of response to accelerated sea-level rise: retreat, accommodate and protect. These are illustrated in Figure 3. They essentially combine elements of the classification described above.

In addition there is a range of strategies that may be used to capture the positive consequences of climate change.

Strategies for adaptation may be grouped in four categories (Stakiv, 1993), as follows:

- long-range strategies—generally pertinent to issues involving changes in the average climate (e.g. institutional changes for water allocation);
- tactical strategies—concerned with mid-term considerations of climate variability
- contingency strategies—relate to short-term extremes associated with climatic variability (e.g. emergency drought management); and
- analytical strategies—embracing climatic events at all scales (e.g. data management).

Carter et al. (1994) note that there are numerous alternative ways to classify adaptive measures, but following their suggestions the actions should include management measures that reflect:

- structural/institutional measures;
- legal/legislative measures;
- institutional/administrative/organisational/ governance measures;
- regulatory measures;
- education/training/public awareness;
- financial incentives/subsidies/taxes/tariffs/user fees/market mechanisms;
- research and development; and
- technological changes and transfer.

Development of an adaptation strategy

Until recently there were no generally accepted procedures for formulating national and regional policies for adaptation to climate change (Carter et al., 1994). The situation has changed as a result of initiatives by the IPCC to develop guidelines to

Figure 3: The main categories of response to accelerated sea-level rise (from IPCC, 1992c).

enable estimations of impacts and adaptations. These guidelines allow comparable assessments to be made for different regions/geographical areas, sectors and countries. The resulting 'IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations' (Carter et al., 1994) are intended to assist parties to the UNFCCC to meet, in part, commitments under Article 4 of the Convention.

The Guidelines for Development of an Adaptation Strategy (Carter et al., 1994) draw on the formal evaluation procedures used by many developed countries when formulating national policies and plans. The framework for developing adaptation strategies comprises seven steps:

- define objectives;
- specify important climatic impacts;
- identify adaptation options;
- examine constraints;
- quantify measures and formulate alternative strategies;
- weight objectives and evaluate trade-offs; and
- recommend adaptation measures.

Since the above steps for identifying and evaluating available response options for decision-making are detailed in Carter et al. (1994) they will not be repeated here. The objectives should be quantifiable and testable using quantitative measures, rather than general goals such as avoidance, reduction or elimination of any adverse impacts or such as the promotion of sustainable development. Four basic categories of objective or impact might be considered: national economic development; environmental quality; local economic development; and other social and strategic effects such as health and safety, food security and energy requirements.

The second step, specifying the climatic impacts of importance, would normally involve some of the methods reviewed earlier in this report. Identification of adaptation options involves the compilation of a detailed list of possible adaptive responses that might be employed to cope with, or take advantage of, the effects of climate change. This list can be compiled by field survey and by interviews with relevant experts. The process should include consideration of all practices currently and previously used, possible alternative strategies that have not yet been used, and newly created or invented strategies. The material on coastal protection in the South Pacific in SOPAC/SPREP (1993) provide an example of the information that might be drawn upon at this stage of the procedure. It should be recognised that in some cases existing policies and practices may actually increase the impacts of present-day climatic variability. These cases of maladaption should be identified at an early stage of assessment. Consideration should also be given to the likely impact of technological change on adaptation measures.

Constraints may encourage, restrict or totally prohibit certain adaptation options. Each management option must also be assessed in terms of its ability to fulfil each of the stated objectives. If appropriate data and analytical tools exist it may be possible to use simulation models to test the effectiveness of different measures under given climate scenarios. Historical and documentary evidence, survey material or expert judgment are other sources of information which may facilitate the assessment. Adaptation measures can be ranked according to their relative responsiveness to individual objectives as a way of assessing their robustness, effectiveness and resilience.

A further task is to assess the relative performance of each management strategy across all objectives because of a recognition that some objectives may conflict with another. The ultimate aim is to identify strategies which maximise the level of achievement of some objectives while maintaining at least baseline levels of progress towards the other objectives. At this stage it should also be possible to quantify achievable rates of adaptation and their incremental costs.

The penultimate step in the analysis is to identify a mix of strategies which collectively maximise progress towards the integrated objectives. Each objective must be weighted according to preassigned preferences. Comparisons may then be made between the effectiveness of different strategies in meeting these objectives. A key requirement is that all the potential adaptation strategies are compared against the same set of objectives and criteria. Only in this way can decision makers and the public see the relative range of benefits and costs for each strategy, as well as the distribution of remaining impacts among the various sectors and population. Only with such information can rational trade-offs be made among objectives and between adaptation strategies.

Finally, the results of the evaluation process should be compiled in a form that provides policy advisers and decision-makers with information on the best available adaptation responses. This information should include indications of the assumptions and uncertainties inherent in the evaluation procedure and the rationale used to narrow the choices.

Carter et al. (1994) also discuss some of the practical considerations involved in conducting an adaptation strategy assessment such as is described above. The factors include institutional and data requirements, analytical tools, costs, policy exercises and sensitisation seminars.

Where anticipated climatic events are expected to cause damage these need to be specified in detail so that the most appropriate adaptation options can be identified. Where beneficial climatic events are predicted these too should be examined, both in their own right and because they may help to compensate for other negative effects.

Identification of critical levels of vulnerability and critical levels of climate change is likely to be the important in the determination of what constitutes 'dangerous' levels of climate change—a term used in Article 2 of the UNFCCC (Carter et al., 1994). Swart and Vellinga (1994) have proposed a six step approach to determine the critical levels of greenhouse gas concentrations in so far as risks to natural and human systems are concerned.

5.2.6 Other methods and associated techniques

Empirical field observations are critical to the assessment of the valusability of terrestrial and marine areas to the consequences of climate change, including accelerated sea-level rise. For example, field investigations are the principal method used by SOPAC to produce new information that will assist its member countries, and others, with coastal zone and EEZ resource assessment and management. The objective is to enhance understanding of all physical coastal processes and the way in which they interact with human activities.

In the early 1980s beach profile monitoring programmes were established by SOPAC, in conjunction with the respective governments, on Betio and Bairiki, South Tarawa Atoll, Kiribati, and on the lagoon side of Fangafale, Funafuti Atoll, Tuvalu (Howorth, 1991). The profiles have been resurveyed in order to show which sections of the coastline are undergoing systematic changes. Harper (1989) reports on the evaluation of the beach profile data for Betio and Bairiki while Howorth and Woodward (1994) describe the re-establishment and surveying of 19 of the original 22 profiles established along the lagoon side of Fangafale, Tuvalu. The methods and results of field studies of coastal erosion in Kiribati, Tuvalu and the Cook Islands are summarised in SOPAC (1996a). In 1993 12 beach profiles were established at two localities in Samoa (formerly) (Howorth and Woodward, 1993).

Rearic (1991) reports on field mapping in Tuvalu in order to identify areas of coastal erosion.

Beach profiles and aerial photographs in combination with more extensive field reconnaissances have also yielded useful information on the response of coastal areas to tropical cyclones. For example, Danitofea and Baines (1991) used beach profile data, aerial photographs and hazard assessment methods to investigate the implications for economic development as a consequence of a tropical cyclone affecting the north Guadalcanal coast in the Solomon Islands. Howorth and Greene (1991) report the effects of three cyclones on the Port Vila – Mele Bay area of Vanuatu while Cowan and Utanga (1991) describe field assessments of the consequences of Cyclone Sally for Rarotonga, Cook Islands.

Field studies that make use of anecdotal data (e.g. Nunn, 1990) have also been shown to supplement more conventional sources of information on historic changes in sea-level such as those documented by Wyrtki, 1990.

IPCC (1992c) describes the use of aerial video mapping and remote sensing for making inventories of coastal areas. Other methodologies that aid the assessment of vulnerability to climate change and sea-level rise include hazard assessment and mapping (e.g. Harper and Owens, 1991). IPCC (1992c) also describes a computer model developed to aid the undertaking of vulnerability analyses and to support the generation of vulnerability profiles. Examples of its use in studies for the Netherlands are provided.

Gillie (1993) describes the use of aerial photographs spanning several decades to assess shoreline changes for Betio Islet, Kiribati. The results of these analyses were compared with those from beach profiles to assess mutual consistency. Shorten et al. (1996) report on the use of meteorological data, aerial photographs and field measurements to assess the effect of climate and sea-level changes on the coastline of North Tarawa in Kiribati. Solomon (1994) used aerial photographs, literature reviews and ground surveys to enhance understanding of the processes which influence coastal and nearshore sedimentary systems and thereby provide information which would improve decision-making regarding sand mining and other uses of the coast. Lemaire et al. (1991) used SPOT imagery to establish a map of sea bottom characteristics and compare this to a map based on a conventional bathymetric study. Application of the methodology to two SPOT images also enabled the technique to be used to assess the damage produced by a tropical cyclone that occurred in the intervening period. Seismic reflection profiling and side scan sonar can also be used to produce detailed maps of nearshore areas (Berne et al., 1991). Harper (1991) has described a range of equipment and techniques that can be used for nearshore and coastal surveys. Hopely and Catt (1991) have demonstrated the application of large-scale colour infrared and true colour aerial photography to coral reef studies.

Numerical and computer-based modelling is now fundamental to the specification of boundary conditions for anticipated climatic and sea-level conditions some time into the future (e.g. Carter et al., 1994; Pittock, 1993). Estimates of the influence of factors such as tectonic uplift, glacial rebound and subsidence (whether natural or human induced) may also be aided by the use of computer models (e.g. Peltier and Tushingham, 1991). Nunn et al. (1994a; 1994b) undertake calculations to determine the composite effects of sea-level rise and storm wave conditions on the port infrastructure of Suva and Lautoka Harbours, Fiji and Apia Harbour, Western Samoa. Calculations are undertaken for sea-level increments up to 1 m and for storms with a return period of 50 years.

The application of geographical information systems (GIS) to vulnerability assessments has been demonstrated for Western Samoa by Chase and Veitayaki (1992), using the unpublished results of Crawley. He mapped the coastal areas around Apia that would be inundated for sea-levels higher than present by 1, 1.5 and 2 m. No allowance was made for sedimentation, erosion or human intervention. Similar studies have been undertaken by Nunn et al. (1994a; 1994b) for Viti Levu, Fiji and Upolu and Savai'i, Western Samoa. In GIS-based analyses, land use and infrastructure information provided layers in addition to the elevation data. This made it possible to estimate such values as the crop areas and buildings at risk from given increments in sea-level.

5.3 Findings

The focus of the findings presented here is the tropical and sub-tropical Pacific i.e. that part of the Pacific equatorward of the areas dominated by the mid-latitude westerlies. Despite the current lack of information and certainty which exists for this scale of analysis, particularly for this part of the globe, the evident vulnerability of Pacific island countries to the suite of anticipated consequences of climate change makes such a study imperative. The intrinsic resilience of some of the natural systems can do little to offset the overwhelming adverse effects that are projected to occur.

The intent of this section is to synthesise the results of a series of studies of the vulnerability of climate change and sea-level rise of individual Pacific island countries, to identify the common issues and finally to suggest some appropriate follow-up actions. Given the large and inseparable interannual variability in climate and sea-level that occurs in the equatorial Pacific, the assessment is concerned as much with present-day variability as with change. This approach is also justified by the belief that a priority for Pacific island countries is to implement policies and plans that address present day variability—they will form many of the most appropriate responses to possible future changes in climate and sea-level. Especially in the context of the tropical Pacific, large seasonal and interannual variations dominate both the atmospheric and marine climate signals, making it both difficult to recognise systematic changes and somewhat redundant to plan for them given the significant consequences of the more immediate and possibly more substantial variations.

Assessments such as those summarised earlier in this report suggest that for lower latitude areas of the Pacific, systematic increases in local temperatures may not be the most important consequence of an enhanced greenhouse effect. Rather, it is also necessary to consider other climate elements, such as rainfall and wind, and extreme events such as tropical cyclones. But the naturally large interannual variability in these latter elements, and their poor regional let alone local characterisation by climate models, again severely restrict the ability to make reliable estimates of changes in such variables as a result of global warming.

For these reasons, Basher et al. (1990) argued against considering individual climate elements. They proposed and pursued a more holistic approach based on systematic and coherent changes in circulation features and phenomena, such as El Niño – Southern Oscillation (ENSO) events, and in the frequency and intensity of extreme events, such as tropical cyclones and storm surges. The complex interactions between these features and natural and managed systems similarly requires an integrated approach. Moreover, the current dominance and anticipated significant impacts of these features also justifies a high level of attention being paid to them, now as well as into the future.

The present assessment relies principally on the country studies undertaken by or in cooperation with SPREP. The principal materials considered here are those for the Republic of Kiribati (Sullivan and Gibson, 1991; McLean, 1989), Tuvalu (Aalbersberg and Hay, 1992), Cook Islands (Sem and Underhill, 1992), Marshall Islands (Connell and Maata, 1992; Holthus et al., 1992), Tonga (Nunn and Wadell, 1992; Fifita et al., 1993), Samoa (Chase and Veitayaki, 1992; Kay et al., 1993; Nunn et al., 1994b), Tokelau (McLean and d'Aubert, 1993), Federated States of Micronesia (Hay and McGregor, 1993), Palau (Sem and Underhill, 1993), Guam (Prasad and Manner, 1994) and Fiji (Nunn et al., 1993; Nunn et al., 1994a; Porter, 1994). Details of the methods used and the boundary conditions assumed in the above studies may be found in the preceding section of this report.

Additional background information on the islands of the Pacific may be obtained from several sources. For example, Nunn (1994) is an account of the geology and geomorphology of oceanic islands, including those in the Pacific. The book includes a chapter which addresses the influence of climate on island environments. SOPAC (1996b) provides information on the coasts of Pacific island countries. Hay (1993c) provides numerous examples of the interactions between Pacific islands and the weather and climate of the region. Nunn and Mimura (1996) provide an account of the climate change-related problems facing selected Pacific island nations, with a focus on high islands. Hay et al. (1996) provide a regional synthesis of the implications of climate change and sea-level rise for small island nations of the South Pacific.

The remainder of the present section synthesises the regionally relevant findings of the preceding country studies. This is undertaken with respect to the environmental, cultural and socio-economic problems which will be caused or exacerbated by changes in climate and/or increases in sea-level. The conclusion includes broader considerations that will influence strategies and priorities for response options.

5.4 Common findings in the country studies

While each island country or territory in the Pacific faces its own specific mix of environmental problems which will be caused or exacerbated by changes in climate or sea-level, or both, it is possible to identify features that are held in common. Despite their diversity, the island nations and territories of the Pacific do have many common environmental concerns, as was demonstrated so forcefully at the U.N. Conference on Environment and Development (SPREP, 1992; Asian Development Bank, 1992).

Based on the findings of the country studies listed above, the following are the common themes, issues and findings relating to variations in, and changes to climate and/or sea-level.

5.4.1 Physical changes to the environment

The relevant factors leading to physical changes to the coastal environment include not only sea-level rise, but also significant variations in the characteristics of storm surges, wind velocity, nearshore currents and wave energy. Possible consequences depend on a range of factors—island size, elevation and shape; exposure to wind and waves; length of shoreline and its composition; vegetation cover and the nature of any adjacent reef and lagoon features.

Calculations of shoreline retreat for an assumed rise in sea-level, while straightforward, are dependent upon coastal lowlands being mapped with an appropriate contour interval. Holthus et al. (1992) estimated shoreline retreat for four study areas at Majuro Atoll (Marshall Islands). Even for a 25 cm increase in sea-level, the shoreline would retreat by as much as 5 m. For the four sites combined, nearly 10% of the dry land area would be lost as a consequence of such a higher sea-level. Additional flooding would result from wave runup and overtopping of berms, reefs or artificial protective structures as a consequence of the effects of tropical cyclones, storm surges and strong winds being superimposed on a higher sea-level. Overtopping means that larger waves than present would be able to cross reefs, resulting in increased scour and sediment movement in lagoons and along shorelines. The case study for Majuro found that flooding would have an impact on a further 30% of the land area. At one site, with a 25 cm increase in sea-level, flooding frequencies would increase from the present 1 year in five to 10 times per year.

Similar studies for other Pacific island countries typically lack relevance due to assumptions of excessive sea-level rise (e.g. 1.5 m) or to the large contour interval on existing topographic maps forcing assessments to be unreasonably crude. For example, calculations had to be based on contour intervals of 100 ft. for Viti Levu in Fiji (Nunn et al., 1994a) and 10 m and 50 ft. for Upolu and Savai'i in Western Samoa (Nunn et al., 1994b).

Tropical cyclones can either add to island size by depositing lagoon sediment or ocean rubble onto land, or decrease it by eroding coastal landforms. For example, in 1972 Hurricane Bebe deposited a bank of boulders 19 km long and up to 4 m high, on the ocean side of Funafuti Atoll, Tuvalu. This increased the island size by about 20% (Baines and McLean, 1976). Had a second hurricane occurred before sediment was replenished offshore it is likely that the large waves would have been erosive as there would be little additional material to deposit and wave energy would not be dissipated by such sediment transport. Thus the frequency of tropical cyclones, a variable that might change with global warming, can determine whether such an extreme event will add to, or reduce, an island's land mass.

Many Pacific islands have long coastlines per unit area of land, making even small changes in the coastline of considerable significance. This is particularly so given the cultural importance of land to most island societies. The shorelines of the true atoll motu (sand islands) are especially dynamic, even in the absence of climate change. For example, since 1945 the west and northwest coasts of Betio, the western islet of South Tarawa, Kiribati, has undergone a maximum of 75–100 m of accretion while the southwest corner has receded by 40–50 m (Howorth and Radke, 1991). More recent studies, summarised in SOPAC (1996a), cover coastal sedimentation, sand transport, coastal erosion and stability and coastal management in Tuvalu, Kiribati and the Cook islands.

Investigations of coastal erosion adjacent to the Tungaru Central Hospital, South Tarawa, show that the distance from the backshore beach scarp to the emergency access road now ranges from 0–8 m, and less than 9 m to the nearest hospital ward. Damage to the road foundation has already begun and partial loss is imminent. Between 1969 and 1992 the rate of coastal recession was approximately 0.2 to 0.4 m annually. Between 1992 and 1995 the backshore scarp retreated at an increased annual rate of about 1.2 m, and at one site it was up to 2.5 m per year. Most of this erosion may have occurred in a single extreme event in December, 1992, though the accelerated rates could also be related to unusual and persistent ENSO conditions in 1991–1995. There is also evidence to suggest cyclic variations in sand volume on the beach, associated with ENSO-driven changes in prevailing winds. Regardless, the preceding information highlights the sensitivity of coastal environments and indicates that rapid change could occur should global warming bring about systematic changes in atmospheric and nearshore circulation patterns. It is highly likely that atoll shorelines would become even more dynamic.

Islands with more resistant shoreline materials and higher elevations are less vulnerable to sea-level rise and storm waves. As in the case of some islands, such as some in Tonga and Vanuatu, vulnerability to sea-level rise may be lessened still further or even totally offset by tectonic uplift. Nunn (1990) used surrogate data to study sea-level changes over recent decades in coastal settlements from the Solomon to the Cook Islands. He found that many islands in Vanuatu, and Niuatopatapu in Tonga, are rising so fast—uplift rates up to 5 mm/year have been determined by Taylor et al. (1980)—that the effect of the regionally rising sea-level (Wyrtki (1990) gives a figure of 1 mm/year) is being reversed. Kirch (1978) reports that Niuatopatapu has increased in area by 60% since initial settlement some 3000 years ago. Shorelines have emerged by some 12 m since the 1930s, while for the tectonically stable islands of Tonga lateral shoreline inundation has been at the rate of around 10 cm/year (Nunn, 1990), similar to that occurring in 48 tectonically-stable coastal settlements from the Solomon Islands to the Cook Islands.

Flooding of land, or at least excessive levels of soil water or salt, may result from a rising water table which is in turn a natural consequence of higher sea-levels. In lowland areas, groundwater can also lead to increased surface flooding or land can become swampy and springs more prevalent should rain storms be heavier or of longer duration. On steep uplands excessive soil loss can be expected with such changes, or with modification of surface land cover and use as a consequence of changes in the climate. The resulting sediment will likely have detrimental effects on lagoon and nearshore ecosystems (Holthus, 1991). Soil can be also be degraded through a loss of moisture due to decreased precipitation or enhanced evaporation, changes that are anticipated for some other areas of the Pacific.

Under storm conditions, strong winds are capable of carrying sea salt inland for considerable distance, with detrimental impacts on natural vegetation and crops, physical infrastructure and potable water supplies.

The effect of sea-level on groundwater conditions can be increased further by dredging and quarry operations increasing the coupling of the ocean and groundwater. Similarly, projects such as channel development or causeway construction may modify lagoon circulation characteristics, and hence the factors controlling water level differences between lagoon and ocean (Buddemeier, 1991).

A major issue is how coral reefs will respond to the projected rises in sea-level. Their response may well be conditioned, in part, by higher ocean temperatures since above a certain temperature corals typically eject their symbiotic algae (zooxanthellae). This results in 'bleaching' and possible widespread death of corals. As this response is also associated with other excessive stresses on the ecosystem, a healthy reef ecosystem is more resilient to rising sea-surface temperatures. In the past healthy reef systems have survived 1000 years or longer periods where sea-level has risen by 20 mm y^{-1} (Edwards, 1995). At the other extreme a reef system suffering 50% mortality resulting from high ocean temperatures was found to be eroding vertically at 6 mm y^{-1}. A 'best guess' of maximum vertical coral accretion under ideal conditions is 10 mm y^{-1}, but modal rates for shallow lagoonal reefs suggests 0.6 mm y^{-1}, for coral reef flats 3 mm y^{-1} and for coral thickets 7 mm y^{-1}. On the other hand a 'best guess' for sea-level rise is around 4 mm y^{-1}. Thus healthy reefs may be able to adapt to sea-level rise, the response being helped by fewer exposures at low tide and by enhanced water circulation. But such responses will be severely hampered by coral bleaching, sedimentation effects, physical reef damage, freshwater inputs, pH, sunlight, resource exploitation and other human-induced impacts (Edwards, 1995). Wilkinson and Buddemeier (1994) also stress that human pressures pose a far greater immediate threat to coral reefs than does climate change. It may only threaten reefs in the distant future. The sea-level rise that is predicted will, however, devastate the habitability of low islands and coastal plains that are protected by coral reefs, necessitating urgent assistance to threatened human societies.

Nunn and Wadell (1992) note that when Pacific reefs reached close to present sea-level some 3000–4000 years ago, they became dominated by species involved in lateral reef extension. These replaced the species which dominated during the preceding sea-level rise when reefs were growing vertically. Should sea-levels rise again due to global warming, any consequential change to a species composition favouring vertical growth would likely be hampered for reef ecosystems under additional stress due to increased water temperatures.

Where reef fronts do not keep pace with sea-level rise there will be greater opportunity for storms and cyclones to damage exposed and degraded parts of lagoons, such as by burying corals and other animals in sediments and eroding shorelines. Particularly in the case of nursery areas for vertebrate and invertebrate species, destruction of these habitats could have a serious impact on the nearshore environment and resources, and hence on the lifestyles of the people who depend on them.

Creation of a storm rampart on the outer reef platform can also restrict circulation between the ocean and the lagoon. But in the absence of such extreme events, the enhanced movement of water across the reef flat may help rehabilitate lagoons by decreasing the effects of pollution, runoff and siltation.

5.4.2 Physical resources

Here emphasis is placed on the potential of climate change to impact adversely on water resources and materials availability. Considerable concern exists with respect to issues of water quality, quantity and security of supply.

Climatic factors are extremely important in determining the nature of small island surface and ground water supplies. The amount, frequency and intensity of rainfall, the evaporative regime and the permeability of surface and subsurface materials modify the water resources. The quantity and quality of the groundwater is further influenced by sea-level and related factors. While one of the initial effects of sea-level rise may be a slight increase in groundwater resources—a consequence of the increased capacity of upper water-bearing units—in the longer term serious losses will likely occur. Two main causes are identified (Buddemeier, 1991). Catastrophic flooding due to high storm tides may not have a permanent effect, but through saltwater intrusion may well make the groundwater resource unusable at a time when other water supplies are also disrupted. The second, and more insidious effect is a consequence of island area loss, either by frequent tidal inundation of low-lying areas or by erosional loss of shoreline. Holthus et al. (1992) estimated that for a 25 cm rise in sea-level the cross-sectional area of the fresh water lens on Laura (Marshall Islands) would decrease by some 10%.

The groundwater resource is already under extreme pressure in many islands. For example, on Fongafale in Tuvalu the compacting of land by road and airfield construction and increased land coverage by construction has reduced rainfall infiltration into a freshwater lens already fragile due to the narrowness of the land mass and the demands of a relatively large and growing population. As a result, there is no longer significant fresh groundwater on the islet. Throughout the Pacific rain-fed supplies of potable water are dependent on reliable precipitation, a situation that cannot be guaranteed under present conditions, let alone if climate changes. A similar situation exists for water supplies for the limited irrigation that occurs in Pacific island countries. Since interannual variability in rainfall is strongly linked to the El Niño – Southern Oscillation (ENSO) phenomenon (Hay et al., 1993), uncertainties regarding the response of ENSO to global warming (IPCC, 1995a) give little basis for planning.

Demand for natural materials arises from four major activities—new construction, reclamation, protection and upgrading of infrastructure. Material can be removed from the lagoon, other land areas or from offshore. In all cases there are significant adverse effects on the environment, though impacts vary somewhat between source areas (Aalbersberg and Hay, 1992). Because of the absence of other readily accessible sources on many atoll and reef islands, material is taken from coastal sand deposits or rubble banks created by cyclonic storms. Since these formations are integral to the continuing existence of the island system their removal increases vulnerability to many of the likely manifestations of climate change.

Dredging of lagoon sediments may also prove to be unsustainable under present conditions and increase vulnerability to future changes in climate and sea-level by removing sediment from the natural system. For example, dredging represents the biggest threat to benthic marine communities around the main Palauan islands of Koror and Babeldaob. In addition it threatens such historical or cultural resources as burial sites, sacred platforms, fishing grounds and underwater war relics. Adverse environmental effects are not mitigated by the use of sediment screens or siltation curtains (Birkeland et al., 1990).

5.4.3 Living natural resources

Historically, living natural resources have been generally abundant throughout the Pacific. But this is changing rapidly as population increases and as modern and non-selective methods of exploitation replace more benign traditional practices. The modern cash economy is also a major contributing factor to diminishing resources, as is the shift of focus from community welfare to individual benefit. Thus organisms already under stress risk are likely to be further pressured by the consequences of climate change. For higher islands, living marine resources would be adversely affected by substantial increases in freshwater runoff and sediment input to lagoon and reef ecosystems. These would change salinity and light levels, and would impair the physiology of many species. Some 90% of all indigenous and plantation trees on the Samoan island of Savai'i were defoliated during Cyclone Val, while 40% of the indigenous and 47% of plantation trees were snapped in half or uprooted.

With the high degree of endism in terrestrial species in the Pacific native plants, animals and birds could be further threatened by land loss, inundation, flooding, drought and salinisation.

5.4.4 Extreme events

Natural hazards already have a disproportionate effect on the environment, resources and population of the Pacific islands. This is especially due to there being little excess natural or human capacity to absorb the additional stresses. Therefore island nations of the Pacific are particularly vulnerable to extreme events such as tropical cyclones, earthquakes, tsunami (seismic sea waves), storm surges and volcanic activity. None of these events is predictable within a planning time frame. The IPCC (1995a) warns against overly simplistic conclusions that, since sea surface temperatures are likely to increase, so too will the occurrence of tropical cyclones. Although some models now represent tropical storms with some realism for present-day climate, the state of the science does not allow predictions of future changes.

Neither do extreme events occur uniformly in time or in space. For example, the length of time between each of the last five major cyclones to affect Tokelau has decreased, viz. 1914–1966–1987–1990–1991, taking the experience beyond that of traditional knowledge and practices (McLean and d'Aubert, 1993). Tonga has experienced earthquakes of magnitude 7.5 or greater on nine occasions this century while on the island of Niuafo'ou 10 volcanic eruptions have occurred since 1853 (Nunn and Wadell, 1992).

The current inability to predict any of these extreme events, but their substantial influence on human safety and well-being and on environmental sustainability, provides a special challenge to planning and management, as the concluding section will highlight.

5.4.5 Agriculture, forestry and food security

Perspectives on the impact of climate change on agriculture in Pacific islands have been offered by Aalbersberg et al. 1993. Growth of some plants is expected to increase as a result of increased carbon dioxide concentration in the atmosphere (Jacobs, 1990), but this advantage may well be offset by increased heat and water stress, factors which are already prevalent in many countries by the end of the dry season. Prolonged droughts raise the likelihood of fires which destroy protective vegetation and agricultural crops, thus increasing the incidence of soil erosion and, in turn, reducing land productivity. On the other hand, excessive rainfall can threaten the viability of certain crops.

Salt water intrusion into pulaka and taro pits has traditionally been a problem, especially during droughts, and hence could be exacerbated by global warming since higher sea-levels and waves are likely to cause more salt mixing in the freshwater lens. Storm wave overwash and salt spray would also damage crops, while increases in the groundwater level and the associated increased flooding of low-lying areas would reduce other opportunities for agriculture.

The observations of Chase and Veitayaki (1992) provide some compensation to the above mentioned concerns. They describe the aftermath of Cyclone Ofa in Western Samoa (February, 1990) when staple food crops were scarce and vegetables were not seen in normal quantities for 10 months. By way of contrast, vegetables were soon available after Cyclone Val (December, 1991). In addition, the increased availability of taro and other storm resistant crops show that farmers responded quickly to the first cyclone. Farmers have also changed their planting schedules to avoid cyclone damage to crops.

Chase and Veitayaki (1992) also describe how the adaptation of temperate forestry concepts to the higher temperature tropics has required the use of new tree planting and husbandry methods in order to protect seedlings and workers from the sun and from storm damage. These experiences will assist in identifying and responding to the additional changes required should global warming occur.

Very little has been done to model the complex circulation patterns in the Pacific at large, and locally. Fish is a major source of protein for many Pacific islanders. Fish take is closely related to ocean currents, zones of upwelling, temperature and tidal patterns. For many countries storm conditions bring fishing activities to a halt, or severely reduce catches. This again compromises food security as fish is often a major food source and cannot be stored for long periods. Should the frequency of such weather conditions increase as a consequence of global warming this will place an added burden on populations already facing protein deficiency and shortages of other food. Access to imported foods can similarly be restricted by severe weather conditions which limit air and sea transport.

Primo (1996) has reported on the anticipated effects of climate change on commercial pelagic and artisanal coastal fisheries in the Federated States of Micronesia. She notes that accelerated sea-level rise and erosion runoff from possible increased precipitation due to climate change will affect mangrove ecosystems which are the nurseries for many ocean species. Pelagic fisheries are vulnerable to climate change because changes in sea surface temperature and ocean circulation patterns will inevitably affect the migratory patterns of fish.

Primo also points out that population growth (intensified by the influx of outer island migrants, who do not have a stake in the traditional systems of marine resource management) has resulted in increased demand and non-sustainable catches. Outside technical advisers specialising in coastal and marine resource management have proposed preservation strategies such as temporary closure of vulnerable areas. Such proposals do not take into account community perceptions of reef ownership and fishing rights, nor traditional solutions to depletion of resources. Any practical adaptation scheme must consider the needs and culture of the local Micronesian populations. Moreover, increasing future income from commercial fishing is one of the highest development priorities in the Federated States of Micronesia.

Edwards (1996) provides an assessment of the effects of climate change on the overall security of the South West Pacific. He argues that climate change could create new threats to the region and exacerbate those that already exist. Lower economic growth rates, worsening trade deficits, increasing dependence on foreign aid, the breakdown of traditional land management systems and the forced migration of people from their homes are all implicated. Under such unfavourable conditions, political, economic and social tensions could lead to intergroup rivalry, low intensity military conflicts and political instability.

5.4.6 Human health

The vulnerability of Pacific island people to health problems is a concern as is the inadequacy of facilities for treatment. While increases in thermal discomfort and heat stress may not be as great as those based on earlier estimates of global warming, higher water tables in some circumstances are likely to cause deterioration in human health. For example, longer periods of standing water could lead to an increase in mosquitoes which in the Pacific are vectors for dengue fever, malaria and elephantiasis. The degree of contamination of surface, ground and lagoon water by human and domestic waste will also increase as the water table rises.

Aalbersberg and Hay (1992) provide further elaboration of the possible implications for human health with changed environmental conditions and the availability of food and fresh water. Higher temperatures would influence the ability to store food and medication while climate change in general has implications for healing of injuries and skin and other infections. The demand for mental health services may also be affected due to increased mental stress associated with the real and perceived personal consequences of climate change. They go on to question whether the reported appearance of melanoma in the indigenous population of Tuvalu is related to improved diagnostic and reporting procedures, to environmental factors such as ozone depletion or to other as yet unrecognised causes.

Many of the dispensaries and related health care facilities in the more remote areas of the Pacific are housed in buildings which are highly vulnerable to hurricane force winds. This, and possible damage to other structures such as radio transmission equipment, would greatly impair the ability to arrange for, and provide, emergency care during adverse weather conditions. There is also the possibility that underground reticulated systems (power, telephones), which provide for the basic needs of all people, will be adversely affected by rising and salt-contaminated ground water.

5.4.7 Commerce, transport and communications

In most countries there is a scarcity of raw materials and even the existing tenuous methods of supply are highly vulnerable to disruption by natural events. Many island nations have sea and air services run by single operators with limited or no reserve capacity. In-country inter-island communications often make use of vulnerable high-frequency radio. Several countries are now totally reliant on satellite-based systems for international telecommunications. But to reduce the risk of damage to the antenna the usual procedure is to take it out of service and protect it when tropical cyclones or other potentially damaging conditions are forecast. This may well be the time when there is the greatest need to send messages overseas. The maintenance of transportation and communication systems is critical for human welfare.

Underground utility reticulation could be affected as water levels rise, especially if the water is saline. In Western Samoa the telephone company has begun replacing the old pressurised cables with grease-filled cables which will function under water (including sea water) for decades.

Tourism is considered by most countries to be at least a partial remedy to depressed economies, but both operations and patronage can be impeded by adverse weather and climate conditions brought about by climate change.

5.4.8 Waste management

The disposal of solid waste and wastewater is having a serious detrimental environmental impact in most countries, thereby reducing the resilience of these systems to accommodate change. Land disposal, land-based marine disposal and marine disposal are all implicated. The problem is exacerbated by a lack of planning and inadequate management of waste materials, including enforcement of existing regulations. Changed coastal current patterns could have the undesirable effect of preventing the anticipated dispersal of sewage from ocean outfalls. As water levels rise, in-ground waste disposal facilities such as septic tanks and latrines could be affected adversely. The lack of appropriate waste management and planning can lead to increased methane production, thus contributing further to global warming.

5.4.9 Physical infrastructure

Sea walls, breakwaters, groynes, wharves, slipways and causeways are all threatened by rising sea-level and increased storm waves, as are coastal tourism facilities, port infrastructure, roads and other structures built at or near sea-level. Such increasing risk is, for example, one motivation for upgrading a secondary inland road that essentially parallels the main road that encircles Rarotonga in the Cook Islands.

Often infrastructure development in coastal areas involves clearance of mangroves, rendering shorelines more vulnerable to erosion and causing loss of important habitat for many marine organisms. This will in turn increase vulnerability to any further environmental changes.

Aalbersberg and Hay (1992) note that preparation of a national draft building code for Tuvalu was begun in response to the high risk of injury and damage that cyclones pose to the people and facilities of Tuvalu. In the draft no provision was made to meet the diverse impacts (e.g. rising water table and flooding) of climate change and sea-level rise on building design and construction practices. Given that an incentive for preparing the code was to mitigate the damage of cyclones, a design speed at Funafuti of 45 m s^{-1} left little margin beyond the maximum observed gust of 38 m s^{-1}.

Nunn et al. (1994a) report on an assessment of the impact of sea-level rise on port facilities in Fiji. A similar study has been completed for Apia Harbour in Western Samoa (Nunn et al., 1994b). For Suva Harbour, Fiji, the wharves themselves would be overtopped if, for example, the sea-level rose by slightly more than 0.5 m and the harbour experienced winds and waves associated with a 50 year return period cyclone (Table 1, p. 47). But before this there would be flooding of the hinterland and the decreased clearance between the wharf superstructure and water level would increase the uplift force and might lead to critical stress on the structure. At Lautoka Port, Fiji, the wharf would not be overtopped in a similar scenario (Table 1), though use of an adjacent breakwater might be restricted by waves overtopping that structure. The port facilities at Apia have a similar vulnerability to those in Suva (Table 1), including both overtopping and flooding of the hinterland.

The results of Nunn et al. (1994a, 1994b) may be used to confirm the propensity for infrastructure to be located in areas vulnerable to climate change and sea-level rise. But the studies also highlight the difficulties associated with inadequate information resources to support analyses undertaken using more advanced techniques such as those found in geographic information systems. While a contour interval no greater than 0.5 m is desirable, Upolu Island in Western Samoa is mapped with a contour interval of 10 m, forcing the 0 to 10 m zone to be classed as 'coastal lowland'. The landuse map for Viti Levu was compiled between 1960 and 1972. Substantial changes have occurred since then. Map scales for Viti Levu were inadequate for locating individual community buildings.

Nevertheless, some results indicative of infrastructure vulnerability are provided (Table 2). For example, while only 6% of the land area is 'coastal lowland' on Upolu Island, some 70% of the churches and 60% of the schools are located in this zone. This led Nunn et al. to conclude that between 60 and 70% of household infrastructure may also be located on 'lowland'. Similar values were found for Savai'i Island (Table 2). A preliminary estimate for Viti Levu suggests that more than 70% of the population lives at less than approximately 30 m above sea-level.

Moves away from traditional forms of housing has increased vulnerability to thermal stress and, in some countries, increased the use of air conditioning. For example, in Pohnpei the dominant form of modern construction is solid, concrete structures, built at ground level. Such buildings are designed to be cooled by air conditioning and often have little provision for natural ventilation. As island nations develop or revise their building codes, they should encourage more climatically suitable forms of commercial, industrial and residential construction, for example by maximising natural ventilation for cooling. Energy demands could also be reduced by limiting solar heat gain and encouraging the use of solar energy for water heating and, in remote centres, for lighting and domestic appliances.

Table 1

Heights of existing structures, water levels, storm surge sea-level and incident waves for port facilities in Fiji and Samoa

(Heights in metres above chart datum for an assumed 0.5 m sea-level rise and a storm with 50 year return period)

From Nunn et al., 1994a, 1994b

Site	**Incremental Heights**				**Structure Height**
	Mean High Water Spring	Storm Surge	Wave Set Up	Sea Level	
Kings Wharf, Suva, Fiji	1.6	2.4	3.0	3.5	3.7
Queens Wharf, Lautoka, Fiji	1.9	2.8	2.8	3.3	5.2
Apia Wharf, Samoa	1.0	1.8	2.4	2.9	3.0

Table 2

Spatial clustering of selected infrastructure

Data from Nunn et al., 1994a, 1994b

Island	**Category**	**All Island**	**Coastal Lowland***	**% In Coastal Lowland***
Upolu, Samoa	Area (km^2)	1,132	72	6
	Roads (km)	706	158	22
	Churches (no.)	302	211	70
	Schools	126	77	61
Savai'i, Samoa	Area (km^2)	1,704	124	7
	Roads (km)	890	147	17
	Churches (no.)	144	105	73
	Schools	52	31	60
Viti Levu, Fiji	Area (km^2)	10,830	1,280	11
	Roads (km)	2,360	840	36

* *Operationally defined as below 10 m for Upolu Island, below approximately 17 m for Savai'i Island and below approximately 30 m for Viti Levu.*

6. Policies, strategies and priorities for response options

6.1 Introduction

The preceding sections of this report have highlighted two major findings which are the result of intense, collective investigations over the past decade. As a result of international studies there is now a consensus that there is a discernible human influence on global climate. The form these global changes will take in the Pacific is far less certain, but the most significant and more immediate consequences are likely to be related to changes in rainfall regimes and soil moisture budgets, prevailing winds (both speed and direction) and in regional and local sea levels.

The second finding, while not as new, is arguably of even greater and more immediate importance. Pacific island countries are highly vulnerable to changes in both mean and extreme atmospheric and oceanic conditions. This applies to natural as well as socio-economic systems. In some instances the vulnerability is partially offset by the intrinsic resilience of natural systems and by decisions to manage systems in a way which increases their ability to withstand the adverse impacts of variations in climatic and oceanic conditions. Notwithstanding such characteristics and interventions, Pacific island environments—both natural and human—are undeniably susceptible to extreme and anomalous persistent events occurring under present-day conditions. Vulnerability and actual harm are enhanced by increased human pressure on natural systems. This sensitivity, and the consequences, leave little doubt that should the changes predicted in the IPCC second assessment report manifest themselves in the future, the repercussions will threaten the life-supporting capacity of natural systems and the sustainability of human habitation.

Despite the fact that there remain areas of uncertainty which surround the preceding conclusions, planning and action must take place now. Many of the anticipated changes may well be irreversible by the time there is certainty of outcome. Moreover, the momentum of change in the combined ocean atmosphere system is such that the modifications of atmospheric composition taking place as a result of current human activity are already committing our children and their children to living in a world substantially different to the one we know today (Warrick, 1993; Wiggley, 1995; Pittock et al., 1996a). From the Pacific island perspective, dangerous anthropogenic interference is already occurring to the climate system.

The remainder of this section reviews response options and identifies those which might deserve priority.

6.2 Basic strategies for response options

There are two main categories of active response to climate change: mitigation (sometimes called 'limitation') and adaptation (IPCC, 1990c). The need for both has been recognised in the UNFCCC as well as other agreements and strategies. Campbell (1993) has placed both mitigation and adaptation in the context of the Pacific island countries. Mitigation refers to those activities which seek to reduce the build-up of greenhouse gas and other climate modifying constituents and thereby reduce the rate and magnitude of climate change.

As noted by Campbell, studies of climate change impacts, such as those reviewed in the preceding section, are important for the development of mitigation responses for several reasons:

- identification of the full range of climate change effects which collectively would cause serious difficulties for humanity unless avoided;
- identification of specific effects of climate change that are anticipated to be so serious that there is an imperative to avoid their occurrence even if all people or nations are unlikely to be affected; and
- the uncertainty concerning the likely impacts resulting from predicted climate changes raises serious questions about the levels of risk people are prepared to accept on behalf of future generations.

Many countries in the Pacific have done little to cause changes in atmospheric composition and hence in the climate. Moreover, few are in a position, by themselves, to directly influence mitigation. But collectively Pacific island countries can have an influence on mitigation, as has been amply illustrated by the negotiations leading to the UNFCCC (Hecht and Tirpak, 1995).

Adaptation is used in the present context to refer to those activities which enable communities, now or in the future, to cope with changes resulting from global warming (Campbell, 1993). It therefore includes activities which seek to offset the costs and increase the benefits that may accrue from climate change. Adaptive responses can be many and varied, reflecting differences in existing social, economic, cultural and environmental conditions and the likely stresses induced by climate change, both within and between countries.

International effort has tended to focus on gaining agreement to limit climate change (Campbell, 1993; Henderson-Sellers, 1996). Successful negotiation and implementation of mitigation strategies requires global cooperation. In addition, the greater the success of mitigation, the less the need for adaptation. But even if the agreement to totally halt human-induced changes in atmospheric composition could be reached today, there will be residual future effects due to lags in the response of the climate system to changes in atmospheric composition that resulted from human activity of yesterday and the preceding decade or more (Pittock and Enting, 1993). In the event that anthropogenic changes in greenhouse gas composition are not achieved for some time, adaptive action becomes even more necessary. As noted by Campbell (1993), a further compelling reason for exploring the options for adapting to climate change is that such assessments also inform the mitigation process. Where the costs of adaptation can be shown to be very high, in environmental, economic or social terms, the need for mitigation will be reinforced. Finally, many adaptation strategies are effectively the same as those which constitute sound environmental management, wise resource use and appropriate responses to present-day climate variability—natural hazards, more subtle adverse effects and opportunities. Often the strategies are found in policies and plans for sustainable development. Thus, adaptive responses may well be beneficial even if the climate does not change as anticipated.

Resource and environmental management strategies which are beneficial for reasons other than climate change, and which can be justified by current evaluation criteria and decision rules, may well be the measures to select first in developing responses to climate change. This approach is referred to as the 'no regrets' strategy (Carter et al., 1994).

The remainder of this section will focus on adaptive responses to anticipated changes in climate. This is not an expedient reaction to the imbalance alluded to by Campbell (1993) and Henderson-Sellers (1996). Rather, it is recognition that mitigation responses are being addressed in other fora, notably the negotiations taking place under the UNFCCC. Support for the process by which Pacific island countries might implement further strategies to limit greenhouse gas emissions can be found in Hay (1995) and SPREP (1995). Moreover, the action strategies proposed in the final section of this report will not be totally silent on the matter of mitigation.

6.3 Policy responses for Pacific island countries

The following are suggested options for policy responses to climate change. The intent is that these may be worthy of further consideration.

It is clearly premature to be prescriptive regarding regional response strategies and priorities for addressing the impacts of climate change on Pacific island countries. As a whole, the Pacific region lacks the comprehensive information which would form the basis for developing a set of possible response strategies and subsequently assigning priorities. The small number of relevant case studies of vulnerability assessment, complemented by field and other detailed studies, do provide some guidance. So too do the more general scoping studies undertaken by SPREP in ten of its member countries. For a small number of other countries (e.g. Porter, 1994, for Fiji) other relevant information does exist. But much remains to be accomplished in terms of both information gathering and methodology development before the procedures for assessing regional climate impacts and identifying optimal response options (be they mitigation, adaptation or simply 'no regrets') can be implemented in a comprehensive and rigorous manner for the entire region. Indeed, addressing these prerequisites must form one of the substantive recommendations to come out of this study.

The fundamental motives of protecting environmental and human health and welfare should inspire all island countries in the Pacific to do everything in their power to limit climate change and to plan appropriate adaptations for changes that are anticipated to occur despite international attempts at mitigation. In addition, such planning and policy initiatives must be taken if Parties to the UNFCCC are to meet their obligations to:

- 'formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change... and measures to facilitate adequate adaptation to climate change' (Article 4 1 (b)); and to

- ‘cooperate in preparing for adaptation to the impacts of climate change; develop and elaborate appropriate and integrated plans for coastal zone management, water resources and agriculture, and for the protection and rehabilitation of areas...’ (Article 4 1 (e)).

The remainder of this section will identify a range of regional responses which would facilitate adaptation to climate change. As noted previously, identification of mitigation strategies is outside the scope of the present study, though in practical terms the two categories of strategy should not be treated in isolation. Priority will be given to ‘no regrets’ policies and plans for, as also noted earlier, these form the basis of sound environmental and resource management regardless of climate and related changes. The section will conclude with additional comments on prioritising adaptation strategies.

6.3.1 A policy of regional cooperation and coordination

Regional cooperation allows responses to problems of mutual concern which no single state or institution can undertake effectively in isolation. Regional cooperation helps offset a weak knowledge base, any lack of understanding, poor capacity to access, share and act on information and a limited appreciation of the range of responses available for consideration. Regional cooperation also involves meaningful and equitable collaborative approaches involving partners outside the region. This facilitates maintenance of a critical global perspective.

Coordination of activities is necessary if redundancies in effort are to be avoided. But the priority must be implementation rather than coordination and administration. Regional initiatives should not conflict with efforts to strengthen the capacity to implement policies and plans at national and community levels. As a ‘bottom up’ strategy, the latter is more consistent with traditional approaches in the Pacific. These can be integrated with benefits that flow from international and regional initiatives.

6.3.2 A policy of owning the issue of climate variability and change

To date the consensus view in the Pacific has been to view climate change as an imposition, forced on the region by external sources. This has resulted in an unfortunate distinction being made between responses that address possible future changes in climate and those which are concerned with the detrimental consequences of variations in the current climate. It is evident from the information presented in this report that, in terms of response options, much can be gained from considering the strong linkages between these two perspectives.

Since the Pacific region experiences some of the greatest interannual variations in climatic and oceanic conditions many of its natural systems are well adapted to the stresses that result. These natural adaptive responses are critical to the well-being of the region and form an important body of knowledge on how to manage related systems, both in the Pacific and elsewhere. Furthermore, the variability provides historic analogues of the biophysical, social and economic consequences of climatic change. The experience thus acquired can be usefully incorporated in developing and assessing future response options. This contribution to understanding can benefit not only the peoples of the Pacific, but also those outside the region. It will help address the perception of ‘powerlessness’ that has developed in the general population of many Pacific island countries—a perception that is linked, in part, to the view that the problem, and hence the solutions, originate from outside the region.

Either by way of the historic analogues or due to the sensitivity of Pacific island countries to climate change, the search for appropriate responses provides opportunities to learn. On the one hand, the sensitivity of small island systems increases the need for immediate action to limit adverse consequences. On the other, the very factors which heighten the sensitivity of many small islands today may well provide lessons regarding the future well-being of systems in extra-tropical and continental areas.

Human activity is having an increasing impact on many of the natural systems in the Pacific region. One consequence is a reduction in the natural resilience of these systems. A logical response is thus to reduce or remove those human impacts which inhibit the responses of natural systems to climatic and oceanic variations. Any decision to take such action is largely, if not entirely, the prerogative of the peoples of the Pacific—another element of ownership.

Past exposure to climatic and oceanic variations have led to the development of both intrinsic resilience by natural systems and traditional knowledge and practices by the indigenous peoples. These and other attributes should be used as a foundation for responses which see the problem as being as much internal as external. It is counter-productive for the inhabitants of Pacific island countries to view themselves as ‘innocent victims’. They should take charge of their destiny. One way is to ensure that all local capacities and resources, both natural and human-derived, are used in an optimal way to address the adverse consequences of climate and oceanic variability and change.

6.3.3 A policy of maximising the benefits of climate change

Such a policy in no way implies that atmospheric pollution which leads to global warming should be condoned due to the positive consequences. It goes hand in hand with a policy to minimise the costs of climate change, through both mitigation and adaptation.

The consensus view globally, and for the Pacific region, is that positive outcomes are few and are more than offset by the costs. But the acknowledged inevitability of climate change, despite uncertainty as to its nature, means that some benefits will be likely to accrue to regions and nations. It would be wise to exploit any opportunity to at least partially offset the enormous costs that are liable to result from climate change. Indeed, the incremental resources made available might well be used to directly support activities to mitigate and adapt to climate change. Such resource transfers could take place regionally, internationally and nationally.

6.3.4 A policy to base plans and actions on factual understanding of climate change

In some instances, both views on, and the consequent responses to, climate change have been influenced by misinformation, either deliberate or inadvertent. At times, political agendas have been either determined by, or exploited, misunderstandings as to the certainty and seriousness of climate change. Any short term gains achieved in this way will be eroded once the credibility of the information and actions are called into question. Uncertainty should not be manipulated in ways which raise people's fears, cause emotional stress and force reluctant responses.

The risks the Pacific region faces as a result of possible changes in climate and oceanic conditions have been highlighted earlier in this report. They should leave no doubt as to the overall seriousness of the situation and the need for determined action. Uncertainties should be acknowledged, but accommodated by way of the precautionary principle. There is no justification for more covert approaches.

It is important to note that in specific cases it is equally clear that current inadequacies concerning methodologies and or information provide little basis for assessing impacts and developing response options. In such cases the policy being proposed would give priority to addressing these shortcomings in methodology and information, thereby improving the basis for identifying and implementing appropriate responses.

6.3.5 A policy of mainstreaming climate change responses in national planning

The present report has already made much of the need to harmonise the policies and activities which impact on environmental quality, economic development, social progress and cultural values. This goal will be achieved most readily through the adoption of sustainable management policies and practices. One task is to ensure the economic mainstreaming of climate change response strategies by having them become integral components of such modalities as national development and disaster management plans and national environmental management strategies.

6.3.6 A policy of enhancing capacities to respond to the consequences of anticipated changes in climate

In the Pacific region, a severe impediment to the successful implementation of responses to climate change is the lack of capacity to achieve the desired goals. Shortcomings may be identified in terms of human resources (e.g. lack of individuals with appropriate training and in relevant employment; absence of well informed politicians and public), institutional structures (e.g. need for improved linkages between the public and private sectors); governance arrangements (e.g. sectoral as opposed to cross-sectoral systems); legislation (e.g. sector and media-based legislation rather than integrated legislation); technologies (e.g. failure to retain, develop or transfer environmentally sound and sustainable technologies); infrastructure (e.g. inability to maintain coastal protection systems); intellectual property (e.g. lack of ability to develop genetic resources); and financial (absence of relevant insurance mechanisms).

Agenda 21 has identified strategies by which such shortcomings might be addressed, as have the follow-up initiatives such as the Global Conference on the Sustainable Development of Small Island Developing States.

Within the overall policy, a priority must be that of developing an endogenous and sustainable capacity. Only then can the other policies be implemented in ways that are appropriate to the immediate and long-term needs of the region.

6.3.7 A policy of enhancing regional security

No longer is national or regional security measured in terms of military strength. Other factors, including vulnerability to natural disasters, are now carrying equal if not greater weight. Water shortages, soil degradation, food shortages, air pollution and habitat destruction are all capable of fomenting social, economic and political unrest. It is not a great step to include climate change amongst these factors, either as a direct or contributing cause.

Efforts to limit climate change, and or to adapt to its adverse consequences with minimum disruption, can make desirable contributions to national and well as regional security.

6.4 Priority policies

The policies outlined above are mutually supportive rather than conflicting or competing. As such they could well be accorded equally high priority with respect to implementation. However, securing the capacity to implement these other policies could be accorded some overall priority. This would help ensure that the remaining policies are implemented in a favourable milieu and in a sustainable manner.

As the next section of this report will illustrate, it is a far greater challenge to assign priorities to individual strategies through which the broader policies are achieved.

7. Proposed regional action strategies of high priority

This section addresses requirements identified in the study for urgent action at the regional level to alleviate the negative impacts of climate change on human, environmental and economic sectors of Pacific island countries.

The strategies are developed in the context of the previously articulated policies. The priority ascribed to them is a reflection of the earlier findings related to assessment of the vulnerability and resilience of Pacific island countries to climate and related changes.

7.1 A strategy for capacity building

Capacity building has been accorded a high priority at the policy level. Human resources development will be accorded paramount priority here. In terms of awareness-raising, the recently completed Second Assessment by the IPCC represents an excellent opportunity to undertake comprehensive programmes for awareness-raising in the Pacific. Immediate target groups should be national politicians, senior government officials, community leaders, media professionals and practitioners in the formal and non-formal education sectors. Through these groups, awareness will be enhanced in the public at large and the necessary official processes will take place in a more understanding environment.

Technical capacities need to be enhanced in the following areas: preparing and reporting on national inventories of greenhouse gas sources and sinks and on options for limiting anthropogenic emissions and enhancing sinks of greenhouse gases; undertaking and reporting on national assessments of vulnerability to future climate change and accelerated sea-level rise and on associated adaptation options; management systems for information relevant to climate change assessment and response studies (including GIS, natural resource and environmental accounting systems and decision support systems) and development and maintenance of environmentally sound and sustainable technologies and infrastructure which will reduce vulnerabilities to climate change and sea-level rise.

A high priority must be assigned to developing the ability to provide nationally relevant forecasts of atmospheric and marine conditions—from seasonal to long term. This may well require establishment of a Regional Climate Analysis and Prediction Centre, possibly by extending the current capacity of the Regional Weather Forecasting Centre at Nadi, Fiji. Coincident with such a development would be the need to strengthen research institutions and programmes so they can support this and related initiatives.

Much of this capacity building could take place within the framework of the UNFCCC, to benefit parties to the convention. Excellent progress has already been made through CC:TRAIN, a joint initiative of the UN Institute for Training and Research (UNITAR) and the Secretariat for the UNFCCC. Implementation of CC:TRAIN for Pacific island countries will be through, in part, the Pacific Islands Climate Change Assistance Programme (PICCAP), an initiative that holds much potential.

However, not all Pacific island countries are parties to the UNFCCC. Moreover, some territories of parties to the convention are less actively involved in UNFCCC oriented initiatives. This could be seen to inhibit a comprehensive regional assessment of, and response to, the problems raised by a possible change in climate. For example, some territories may not have the capacity to participate in a regional assessment of the impacts of climate change and accelerated sea-level rise even though their countries as a whole have substantial involvement at the international level.

Despite its major physical role in influencing global changes in the atmosphere and oceans, changes and responses in the Pacific Basin are not presented in great detail in assessments such as those conducted by the IPCC. This is understandable when one considers the data and population paucity of the region. But the situation is of little comfort to individuals, communities and countries in the Pacific which are forced to take the general findings of such assessments and extrapolate them to the region and to specific countries or territories. A thorough understanding of the response of Pacific atmospheric and oceanic systems to systematic changes in atmospheric composition is critical to meaningful policy development, planning and implementation of responses. Similarly, current assessments of impacts and identification of appropriate response strategies are equally broad and hence of limited value in specific contexts. Despite the best efforts of current regional and country assessments, the absence of regionally specific climate change scenarios makes such work somewhat academic and of decreased utility. As at the global level, increased understanding and enhanced ability to implement appropriate responses would be hastened by ensuring that all island countries and territories in the Pacific have the scientific, technical, human and financial resources to contribute meaningfully to regional assessments of the impacts of climate change and of the various response options.

This enhanced capacity would also give more authority to the collective of Pacific island countries and territories during international negotiations related to climate change. Such an outcome would build, and contribute further, to the success of SPREP and AOSIS in international negotiations related to climate change.

7.2 A strategy for development and application of appropriate assessment methodologies and information sources

The IPCC has prepared technical guidelines for assessing climate change impacts and adaptations. These methods need to be systematically applied to Pacific island countries to develop both national and regional assessments of impacts and to then prepare adaptation strategies. Initial studies have identified numerous difficulties in applying the IPCC methodologies. In response, more fitting methods have been developed. But these too have shortcomings and the multiplicity of approaches currently being used within the region is far from ideal. It also inhibits preparation of the important global assessments based on individual country studies.

There is thus great urgency to develop and evaluate a methodological framework which is both internationally accepted and applicable to the distinctive conditions existing in Pacific island countries. Once a common approach has been agreed upon, a combination of regional cooperation and national commitment should be activated to ensure that impact assessments are undertaken in all countries and that the indicated adaptation strategies are implemented.

7.3 A strategy to identify, assess and implement technologies relevant to adaptation

As noted above, Pacific island countries should consider employing a variety of environmentally sound technologies which will facilitate adaptation to climate change. These include both indigenous technologies in current or former use and those in existence or under development in other countries, in the region and further afield.

The strategy would incorporate such steps as identifying candidate technologies, assessing their appropriateness, establishing the procedures for technology transfer and use, and ensuring adequate ongoing support for maintenance and upgrading.

7.4 A strategy to identify, assess and implement investment instruments relevant to adaptation

Adaptive responses often involve large up-front costs, with long-term payback periods. Moreover, responses which simply maintain the status quo may also carry large costs. The associated risks are often spread through such instruments as insurance. Governments and bi-lateral and multi-lateral donors can no longer be expected to underwrite the risks associated with climate change. The private sector should be encouraged to see climate change as both an opportunity and a cost of conducting business in the region. But 'surprises' associated with climate change may jeopardise instruments such as loans and insurance.

The distinctiveness of the Pacific region necessitates a suite of investment instruments that reflect the needs, opportunities and risks which prevail in that part of the globe. Such findings would have benefit to other regions where small island nations and territories can be found. There might be merit if adoption of the more appropriate instruments was formalised through negotiated provisions in regional and international agreements related to climate change.

7.5 A strategy to support optimal management responses to climate change at the national level

Such a strategy involves assistance to countries and territories to integrate environmental management, disaster management and development planning policies and actions. This will have to be reflected in institutional arrangements, systems of governance, financial support, infrastructure and technical resources. The response must be extended to coastal, marine as well as terrestrial environments, be cross-sectoral and be able to draw on nationally relevant predictions of future climate, both mean and extreme.

An example would be establishment of mechanisms that would support development of rational and sustainable responses to anticipated systematic changes in wind and wave patterns. This may lead to a need to protect selected coastal areas in parts of a given country or territory as a consequence of increased vulnerability to extreme events, such as a storm surge and of additional infrastructure in the coastal margins due to economic growth and social development.

Other examples would include institutional strengthening and restructuring, formulation of insurance packages reflecting an increased threat to coastal systems and revision of trade agreements in light of changed cropping patterns and consumer demand.

7.6 A strategy for regional support for integrated coastal zone management

Parties to the UNFCCC are required to develop and elaborate appropriate and integrated plans for coastal management—by 1997 for developing countries. This places an enormous burden on the Pacific island countries which are parties to the Convention. In order to both spread this burden and ensure that optimal strategies are implemented in all countries (i.e. not only parties to the convention) there is an urgent need for regional support for integrated coastal zone management. This could be achieved within the framework of the National Environmental Management Strategies and national plans.

Regional organisations such as SPREP and SOPAC should collaborate to provide:

- guidelines for appropriate integrated coastal management planning and integrated implementation;
- methodological and technical support systems; and
- performance assessments and ongoing improvement in the quality of advice and technical support.

8. Conclusions

This study has highlighted the importance of climate change, accelerated sea-level rise and associated issues to Pacific island countries and territories. Their vulnerability to such changes has been recognised in a series of country studies and recently confirmed by the IPCC in its recently completed Second Assessment.

The vulnerability is in some instances partially offset by the intrinsic resilience of many natural systems. But this in turn is under threat, from increasing human pressures and from the instabilities likely under a changed climate.

Many institutions and organisations—national, regional and international—are addressing the policy, planning and management issues that arise during consideration of the implications of climate change and accelerated sea-level rise. But their efforts are hampered by limited capacities, nationally and regionally, to identify, evaluate and implement appropriate response options.

Despite these shortcomings, and because of the seriousness and urgency of the problem, a number of appropriate policy responses may be identified. The most important and urgent is to address the capacity constraints. Within the framework provided by these policies a number of more detailed response strategies have been proposed. They all provide support at the regional level for responses that must ultimately be developed and implemented at the local and national levels.

9. Analysis and synthesis of the findings

Climate change and sea-level rise are two of numerous environmental concerns for island nations and territories of the Pacific. These issues are accorded high government priority in all countries, for it is generally recognised that they would exacerbate most other environmental problems and many social, cultural and economic issues currently facing these countries.

Vulnerability assessment has revealed that not only the low islands of the Pacific are susceptible to the adverse effects of sea-level rise. The concentration of human population, economic activity and infrastructural development in the coastal areas of high islands, and the few effective opportunities for retreat in the face of inundation from rising sea levels or increased frequency and magnitude of storm waves and surges, mean that vulnerabilities are very high in such cases. But few land masses in the Pacific are tectonically stable—systematic changes in sea-level may be significantly offset or exacerbated by local uplift or subsidence of the land.

In the Pacific economic development is the primary goal of national governments and of the donor countries and international agencies active in the region. Today, most countries acknowledge that development should be sustainable in terms of social, economic, resource and environmental factors. But the terms under which this can be achieved are unclear and elusive. Moreover, economic development is often seen as a pre-condition to achieving other development objectives. The challenge, therefore, is to seek a balanced and integrated approach to development planning. This would ensure that economic development, environmental quality and social progress are all given full recognition, with response to climate change and its repercussions also being an integral part of the resulting strategies.

At the official operational level, environmental issues are often given low priority. Such problems are considered to be caused by industrialised countries and hence exist elsewhere, or are being imposed locally on 'innocent victims'. This is compounded by feelings of powerlessness—of being inhabitants of 'poor', 'small', 'remote', and 'dependent' nations. In those countries where local environmental problems are more formally acknowledged, a common official response is to establish a new and separate unit which is responsible for environmental management, rather than integrate the responsibilities and responses within existing structures and programmes. Few countries have developed policies and plans related to climate change and sea-level rise. The serious implications of climate change for Pacific island countries should engender a sense of ownership of the problem—specifically the solutions as opposed to the causes.

The spatial and temporal scales of climate change and sea-level rise, and the processes involved, are also unfamiliar to all but a minority of well-educated Pacific islanders. For the individual, global environmental change (including climate change and sea-level rise) is something caused by others and hence their responsibility. Some inhabitants link climate change and nuclear testing.

There is also the 'competition' with more immediate problems—changes occurring over decades or perhaps centuries can be worried about in the future. The complex processes linking changes in the chemical composition of the atmosphere with increased temperatures and higher sea levels offer ample chance for confusion—most often between ozone depletion and global warming. Totally foreign language, concepts and analogies (a 'greenhouse' being the prime example!) compound the problem. So too does the widely acknowledged scientific uncertainty associated with global warming and sea-level rise, especially when this is exploited by those who seek to modify opinions and hence gain support for their own political and other agendas.

Change is also of less practical concern to those living in a naturally highly dynamic (variable) environment, leading to a feeling of powerlessness to modify nature. In addition, there is a prevalent attitude that the ability to cope with the devastating effects of tropical cyclones and other natural hazards is evidence of an aptitude to handle any future environmental threats. While this might have been the case in the past, many of today's natural systems have been degraded by human activity and are therefore more vulnerable to stress, be it natural or human-induced. Moreover, changes in construction materials, methods and styles have all reduced the ability to make rapid and locally sourced repairs to homes and other buildings.

Pacific islanders generally share a religious-based fatalism or optimism—of either being protected by God or being punished by Him. Many adherents show no concern about sea-level rise, drawing comfort from the promise that there will never be another Great Flood. McLean and d'Aubert (1993) report the eloquent comment of a village elder in Tokelau—'When there are no more rainbows I will prepare for sea-level rise'. Other Pacific islanders see the direct and indirect consequences of environmental degradation of the environment as 'God's will'—a punishment for improper and excessive behaviour.

Over and above these personal attitudes is the perception that global warming and rising sea levels may bring tangible benefits to the Pacific. For this reason, some argue that the changes should not be impeded—rather, the approach should be one of adapting to the detrimental consequences and maximising any benefits. The latter include the increased productivity of tropical food crops being grown in areas where the climate is distinctively sub-tropical and improved navigation due to increased water depth over hazards to shipping. As noted by the IPCC, the potential negative impacts are likely to outweigh any benefits.

Attitudes to the Pacific have also resulted in a 'scientific neocolonialism'—scientific and other information is collected in Pacific island countries and adjacent ocean areas, but is seldom controlled by or interpreted by local people (Hay, 1993). In addition, with the increasing privatisation of government services and the imposition of increased charges on resource and service users, information is becoming less accessible, just at a time when there is an expanding need and demand. However, there are some encouraging signs that the situation is improving:

- growing numbers of Pacific islanders are acquiring the expertise to act as specialist consultants;
- SPREP has a growing role as a clearing house for much needed information and as a coordinator to reduce duplication; and
- local acquisition and interpretation of data are being made integral parts of research and other international programmes. Examples of the latter are the US Department of Energy's Atmospheric Radiation Monitoring project and the Australian National Tidal Facility's sea level monitoring project.

But in many instances there is still a heavy reliance, even by politicians, government officials and other senior level decision-makers, on news media reports for basic information related to climate change and sea-level rise. Furthermore, in the absence of reliable regional and national scale information, uncritical and imprudent use is commonly made of generalised scientific appraisals, impact assessments and response options that are applicable only at the global scale.

The country studies conducted by SPREP revealed that in most instances many resource materials on environmental and related themes were not readily accessible, either to the consultants or to politicians, government officials and community leaders. Bibliographic services, cataloguing, consolidation of holdings and storage of materials were often less than adequate. These findings are consistent with those of Stewart (1993), who identified several impediments to the official dissemination and use of information on climate and sea level variability that was provided to Pacific island countries by regional and international organisations.

The 'neocolonialism' is also being manifest in other ways, not the least undesirable being the unwarranted duplication of effort by donor countries and agencies. For example, in the last few years five different countries have installed tide gauges in Tonga in response to the concern about rising sea levels. There is no coordination between the researchers, the data are analysed overseas and the Tongan government has limited access to the results (Nunn and Wadell, 1992). Additionally, the work plans of many regional and national environmental programmes are influenced unduly by the priorities of external funding bodies. But these shortcomings have also been addressed, with increasing vigour, over the past few years. As noted previously, SPREP and other regional organisations are making increasing effort to reduce duplication, enhance cooperation and ensure that national priorities are reflected in bilateral, regional and international initiatives.

A fourth attribute of this 'neocolonialism' is the involvement of government officials and other Pacific islanders in international meetings concerned with global change issues. In such fora these participants typically play a reactive role, if they have an active role at all—they work to a predetermined agenda developed with little consultation with, or appreciation of, the real concerns of those from the small island nations of the Pacific. It is encouraging to note a reversal of the preceding situation as a result of the efforts of such organisations as the Alliance of Small Island States (AOSIS) and of the Governments of Vanuatu and Samoa working in the Bureau for the UN Framework Convention for Climate Change. They have all been effective in influencing outcomes prior to plenary sessions.

But even in fora designed to address the regional and more local issues facing small island nations, and where the voices of the inhabitants should be heard, the larger metropolitan countries are having an undue influence on agendas and on outcomes.

In the Pacific attitudes as to what is acceptable or unacceptable also vary, and must be understood when deciding regional policies and developing education, awareness and other programmes.

In summary, identifying and responding to the implications of climate change and sea-level rise requires improved regional coordination and integration of national and local concerns, needs and capacities. This suggests an acceleration of recent initiatives to heighten the influence of small island developing states in negotiations of international agreements and a strengthening of national level capacity. It also implies a balance between top down and bottom up policy formulation and implementation of response strategies. Importantly, in addition to the coordination roles of regional and international organisations, local people must be mobilised to regard climate change and its consequences as their problem. They must assume a role in deciding upon and implementing remedies. This approach requires participation of nongovernmental organisations, especially religious and village organisations.

There is also a need for increased awareness at the political level, and at the upper levels of the religious and social hierarchies. Such an awareness must be built on a firm foundation of understanding, resulting from additional scientific data and other information being made available in a way which is commensurate with requirements at both national and regional levels.

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