CLIMATE CHANGE

MEETING THE CHALLENGE

Report by a Commonwealth Group of Experts

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Commonwealth Secretariat
Marlborough House
Pall Mall, London SW1Y 5HX

September 1989

Foreword by Commonwealth Secretary-General

Environmental issues have achieved remarkable prominence in the last few years. As a member of the World Commission for Environment and Development I naturally welcome this attention and hope that the concept of 'sustainable development' which the Commission promulgated in its report, Our Common Future, is now much more firmly established in policy making.

One of the factors which has brought environment to the centre of public debate is the succession of major disasters, some of which had underlying man-made, as well as natural, causes. Among these disasters was the inundation of the Maldives; another was catastrophic flooding in Bangladesh. Both were discussed in Vancouver by Commonwealth Heads of Government in 1987, and it was that discussion which led to the formation of this Expert Group.

Among the various threats to the world's environment, that of climate change induced by increased concentrations of 'greenhouse gases' is the most pervasive and truly global in its implications. If the earth is to warm by even the more modest of the various projections, there could be far reaching, long term implications for natural ecological systems, farming, the design of major energy and water projects and for low lying areas that could be affected by rising sea level. The inundation of the Maldives by extraordinarily high storm surges may or may not be one of the early products of these changes. It symbolises, however, the vulnerability of many low lying island states such as Bangladesh and Guyana where people live at, or even below, sea level.

It was on this set of inter-connected issues—the impact of climate change on sea level and their interaction with the problem of flooding—that I was asked to convene an Expert Group. I was fortunate in the calibre of people who were willing to put their combined experience together, to serve the Commonwealth in this way. Dr. Holdgate, the

Director-General of the International Union for Conservation of Nature and Natural Resources (IUCN) and formerly Chief Scientist in the UK Department of the Environment was an ideal choice as Chairman. Those who were there will remember his masterly summary of proceedings at the 1989 London Conference for the Saving of the Ozone Layer and he has been in an excellent position to provide leadership in the important and fast moving subject of climate change.

This group breaks new ground in several ways. First, the membership was predominantly from developing countries. The development perspective—the concern of the poor—is kept well in the foreground. The report makes it plain that the world's poor could be the main victims of climate change but that this must not be allowed to occur; it concludes that a global strategy for controlling global emissions must permit rapid economic growth in developing countries. Second, the report is practical and businesslike in suggesting how some planned adaptation to climate change can take place. It sounds an alarm, but is not alarmist. It sketches out how a vulnerable small island state or those responsible for farming in drought-prone regions can prepare for, and mitigate, the worst consequences of climate change. And it provides a detailed guide to the kind of data collection effort which is needed for governments to monitor and analyse the changes taking place, so as to help individuals adjust to known facts.

Within the next few years, a major international initiative will be needed to establish global responsibilities for preventing unmanageable rates of increase of global temperature. This will require both technical preparation of the highest order and a great deal of political will. This report has contributed substantially to the former and helps to create a basis for the latter through a clearly formulated Commonwealth Plan of Action.

It gives me great pleasure to present this report to Commonwealth Governments and to make it available to the international community.

Shridath S. Ramphal

September 1989

Letter of Presentation

Marlborough House
London

31 July 1989

H.E. Mr S. S. Ramphal
Commonwealth Secretary-General
Marlborough House
Pall Mall
London SW1

Dear Secretary-General

In accordance with the wishes of Commonwealth Heads of Government when they met at Vancouver in October 1987, you appointed us as a group of independent experts, with diverse backgrounds, to examine and report on climate change, sea level rise and flooding. We now present our Report, which we have signed in our personal capacities and not as representatives of the governments, organisations or countries to which we belong.

There has been growing concern in recent years about environmental issues. Among these, the problems that may be posed by changing climate are potentially very serious and of truly global significance.

We have proposed a Plan of Action for Commonwealth governments. We also recognise that the problem of climate change has been receiving attention in the wider international community and we hope that the Report will help to take these discussions forward.

We should like to express our thanks for the support and encouragement you provided and the great interest you showed in our work. We would like to express our appreciation to you for your confidence and trust in appointing us to undertake this task. Our thanks are due to your staff for their ready administrative and technical support in helping us to fulfil our mandate, particularly the Economic Affairs Division under its Head, Dr Persaud, who did so much to make our task agreeable as well as easy. Among them, our debt to Dr Cable, the Secretary of the Group, is particularly great. On him has fallen the main burden of preparation and coordination and he deserves credit for a significant portion of such merit as our report possesses.

Finally, we would like to record our indebtedness to the consultants who contributed so much to our work, and in particular Dr Richard Warrick, Dr Jill Jäger and Mr James Lewis.

Please accept, Secretary-General, the expression of our highest consideration.

Martin W. Holdgate

Jim Bruce

R F (Bobby) Camacho

Nitin Desai

Fasih Uddin Mahtab

Ophelia Mascarenhas

W John Maunder

Hussain Shihab

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Executive Summary and Action Plan for the Commonwealth

1. The world is worried about the weather. That worry has increased in recent years, partly because of extreme events which have affected many countries, including a number of members of the Commonwealth. There was flooding in Bangladesh in 1987 and again, on a massive scale, in 1988 when cyclones and tidal waves brought additional death and destruction. The Maldive Islands were inundated in 1987. Hurricane Gilbert devastated Jamaica in the following year. Many African countries have experienced severe drought. India has been assailed by both drought and monsoon flooding. Mid-western Canada had a serious drought in 1988. A severe cyclone hit New Zealand. Severe flash flooding caused damage in northern Australia. Britain was damaged by the worst gales since 1703. These events illustrate vividly how the climate profoundly affects our lives and economic activities.

2. Such disasters are disturbing enough in their own right, but political and public concern has been intensified by the increasing belief among scientists that the underlying pattern of global climate is being altered by humanity to humanity's detriment. Five of the warmest years on record have occurred in the decade of the 1980s. Global mean temperatures are increasing, and many people believe that there is a link between these changes and the extreme events that have affected so many countries. Human activities are undoubtedly altering the chemical composition of the atmosphere, and there is a widely held view among scientists, elaborated later in this report, that this is likely to be a cause of the temperature increases we have experienced.

3. Moreover, there are good reasons for regarding these changes in climate as just one consequence of human pressures on the global environment. The analysis in *Our Common Future*, the report of the World Commission on Environment and Development, leads to the conclusion that the present patterns of human activity which we call 'development'—the transformation of the earth to serve perceived

human needs—are not sustainable and threaten a breakdown in the environmental systems essential for the support of human and other life. This unsustainable environmental pressure is in turn linked to the incessant expansion of humanity's consumption of natural resources, and the rapid growth of human population. Climate change, caused by 'greenhouse gas pollution' is bound to make sustainable development more difficult, exacerbate problems of poverty and increase pressure on water, soil, and food production systems.

4. The implications for Commonwealth countries are perhaps more profound than for many other nations. Since the Commonwealth includes a disproportionate number of small, low-income states, any change which increases their vulnerability and aggravates problems of poverty is to be regarded with the greatest concern. Recognition of the potential seriousness of the problem spurred Heads of Government in Vancouver to propose the establishment of our Expert Group.

5. Since then, concern over climate change and sea level rise has absorbed a growing amount of international attention at the highest level and there has been increasing popular anxiety. The work of the Intergovernmental Panel on Climate Change (IPCC), established in November 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP), and discussions in other fora, will help to clarify both the scientific facts and the policy implications in the next few years. However, the scale of public concern is such that evaluation of the policy options needs to start now. The Expert Group seeks to contribute to that evaluation by providing a balanced summary of the scientific evidence, of the possible socio-economic impacts, and of the policy implications of climate change and sea level rise, in the particular context of the Commonwealth with its varied membership including countries from virtually every major climatic region in the world.

6. The scientific study of global warming and climate change has progressed in recent years from tentative hypothesis and speculation to somewhat firmer consensus. It is now accepted, from extensive observation, that the world's mean surface temperature has risen over the past century by around 0.5°C, and the sea level has risen by around 10-15 cm. While it cannot be proved that the observed global warming has been caused by the build up of greenhouse gases—predominantly carbon dioxide originating from the burning of fossil fuel—the observed temperature rise is consistent with this belief. Measurements show that greenhouse gas emissions and concentrations in the atmosphere have increased considerably in recent decades, in parallel with the rapid expansion of the world economy. These emissions are bound to continue to rise for many years, and, at some date between 2015 and

2050, their effect on global radiation balance is likely to be equivalent to that expected from a doubling of pre-industrial concentrations of carbon dioxide. The lags in the system (especially due to heat storage in the ocean) mean that, even when concentrations stabilise, the earth will continue to warm and the seas to rise, for some decades.

7. There is a range of estimates of future warming—based on different modelling assumptions regarding the warming process and different projections of future emission levels. But there is a scientific consensus that global warming of the order of 1 to 2°C will occur by 2030 and some estimates predict much bigger temperature increases. Moreover, the increase in global mean temperature to which the world would be committed if greenhouse gas concentration were stabilised at the equivalent of a doubling of pre-industrial CO_2 would be 1.5 to 4.5°C. It should be stressed that these figures are somewhat conservative, and assume, *inter alia,* an effective control over emissions of other greenhouse gases such as chlorofluorocarbons, as is now provided for under the Montreal Protocol. Moreover, while a few °C may seem a small increase to the layman, a change of such magnitude over 50 years is in fact unprecedented in recorded human history. Since the coldest point of the last Ice Age, world mean temperature has only increased by some 4 to 5°C. By 2030 the earth is likely to be warmer than at any time in the past 120,000 years.

8. While there is a reasonable agreement about global average increases, there is much less agreement about what these could mean for the climate of particular regions, let alone individual countries. The current state of science simply does not enable predictions of future temperature and precipitation to be made at that scale with any confidence. Some countries will, however, experience changes significantly greater than the global average. While it should be stressed that these are speculative suppositions, there are reasons for expecting greatest warming in winter in high latitudes (especially Canada, Scandinavia and the USSR); and some of the models suggest that, in general, wet areas could become wetter and dry areas drier. Extreme events could become more common. There seem good reasons for believing that tropical storms could increase in intensity.

9. One of the consequences of global warming would be the expansion of the oceans and some melting of icecaps and glaciers. Scientists have produced different estimates of how much sea level would rise, but a 'best guess' is in a range of 17 to 26 cms by 2030 followed—even if global warming were then to cease—by some continued increases thereafter. These changes would be superimposed on the global mean sea level rise of 10 to 15 cm that has occurred over the past century. The national consequences of such global rises will depend on the topog-

raphy of particular areas and the extent to which they are undergoing land subsidence or elevation; on human activities that affect the durability of natural or artificial defences; and on the variability of sea level round the mean—in tides, seasonal variations and exceptional storm surges due to tropical cyclones and other storms.

10. Predicting the social and economic impact of climate change and sea level rise involves imposing another set of imponderables on a picture already characterised by uncertainty, particularly as regards the effects of climatic change at the regional and country level. Nonetheless, at a joint UNEP/WMO/ICSU Conference held in Villach, Austria, October 1985, scientists from 29 industrialised and developing countries agreed that:

> "Many important economic and social decisions are being made today on long-term projects . . . such as irrigation and hydro-power; drought relief; agricultural land use; structural designs and coastal engineering projects; and energy planning—all based on the assumption that past climatic data . . . are a reliable guide to the future. This is no longer a good assumption since the increasing greenhouse gases are expected to cause a significant warming of the global climate in the next century".

11. There will be a need to adjust to climate change and sea level rise, and a rapid change will be more difficult to adapt to than a slow one. It is the fact that projected climate change is so rapid in historic terms that causes such concern and threatens a costly process of adjustment. Greater climate variability and more extreme events also have costs. Many future problems will arise because of the uneven distribution of these costs. In general, poor countries, and poorer groups within countries, have less capacity to adjust. Poor countries are also, in general, more vulnerable since their economies are more dependent on agriculture and natural resources. Thus the action required to correct underlying problems of poverty and achieve sustainable development would become even more difficult. Although some countries or districts might gain a more benign climate (for example because of warmer, wetter conditions in the northern higher latitudes) and have the resources to exploit the opportunities presented, we do not believe that such local benefits would come near to offsetting the losses of other regions. The overall impact of climate change is likely to be strongly negative because of the costs of adjustment to the unprecedently rapid warming likely to be experienced.

12. The story is complex at the level of sectors, as of countries. One major set of impacts is that on natural ecosystems: forests, wetlands, savannah and—in relation to sea level—mangroves and coral. A

particular concern about the rate of anticipated climate change is that it may well exceed the capacity of some natural ecosystems to adjust. Forest tree species, for example, can probably disperse at most by two kilometres a year which is less than the speed at which the natural frontiers of different forest types—temperate and boreal for example—would move with global warming. The ecological adjustments would therefore lag behind climate change. Because the species would move more slowly than the conditions favourable to them, extinctions would probably increase, compounding the present serious problem of loss of the world's biological diversity. The problem would be aggravated by the probability that the world's limited network of nature reserves and protected areas would no longer be in the right place to safeguard the ecosystems or species for which they were established.

13. Like ecosystems, agriculture is generally highly sensitive to climate and carbon dioxide concentrations in the atmosphere. Yields could be affected positively by increased concentrations of CO_2, but higher temperatures (and the inevitably associated higher evaporation), changed precipitation, extremes of temperature and rainfall and the impact of climate change on the growth of weeds and pests would all have a major influence, so that the overall pattern for a particular area is difficult to predict. The effects of climate change on production will depend on how farmers respond through changed farm management practices, as a result of changing relative prices, and according to the actions taken by governments. If the climate changes are progressive, and not marked by an increased frequency of extreme events, it should be possible for most farming systems to adapt because of the short cycle between crops. But there are long maturing tree crops and the lead time for developing new strains averages 10 to 15 years, so adjustment to climate change could be highly problematic in some instances. And marginal farming, where environmental stress is already severe, could have particular difficulty in coping with new demands. For these reasons it will be necessary to initiate long term research and planning to ensure that agriculture, particularly rain-fed farming in developing countries, is helped to adjust to climate change.

14. One particular set of impacts that could be of concern to policy makers is where climate change undermines the assumptions underlying long term infrastructure projects. One sector requiring particular attention is water supply, with particular implications for drinking water, irrigated agriculture and hydro-power generation. A warmer world will, in general, be a wetter world; but a warmer world will also experience greater evaporation of water from the soil, reservoirs and lakes, with effects on the availability of economically usable supplies. The water supply situation is already regarded as serious in many countries and the climatically induced change in water distribution and

availability in these countries could be critical. Pressure on ground water resources, which are already over-exploited in many countries, is likely to intensify. Energy is another sector where long term planning is required, particularly in respect of hydropower where climate change could affect both demand and—through changes in precipitation—supply. Construction standards generally will need in future to take account of climate change.

15. Most economic and social sectors would be affected directly or indirectly by climate change, but among those that are most climate sensitive and face the need for a long term perspective is tourism, on which a good many Commonwealth countries depend. The Maldives for example could face the loss of its international airport and severe pressure on water supplies, while Caribbean and Pacific islands face potentially increased storm hazards. Human health could be affected by even quite small changes in average mean temperature and there is the prospect of some major diseases flourishing in warmer conditions and of more resistant strains of infection emerging.

16. Case studies carried out for the Expert Group show how sea level rise could have far reaching social and economic effects on low lying coastal areas, as in Guyana, Bangladesh, the Maldives, Kiribati, Tuvalu and other Commonwealth countries. Rising sea level threatens fragile ecosystems—mangroves, coral reefs, marshes—that protect coastal areas at present. It could add another element of instability into the rapidly changing, and hazardous, environment of deltas like that of the Ganges in Bangladesh; they face the prospect not only of flooding from the sea and greater risk of storm surges but deeper flooding on inland flood-plains. A one metre sea level rise would flood 15 per cent of Bangladesh, directly affecting ten million people. The small island atolls rarely exceed 2 to 3 metres in height and face greater risk of inundation, erosion of barrier reefs and defences, and contraction of fresh water lenses. Low lying coastal areas such as that of Guyana—where 90 per cent of the population live—are already at or below mean sea level and could face both flooding and disruption of traditional drainage systems. There are potential implications in each of these low lying countries for agriculture; fresh water supply threatened by salination; the siting of towns, factories, power plants and airports; and hazardous waste disposal. Given the long term nature of many investment decisions, planning of coastal infrastructure has to begin to incorporate likely sea level rise.

17. Low lying countries face a series of options in adjusting to rising sea level and it is important that these options are carefully examined in the broader context of coastal zone management. Major sea defences are one option but these are likely to be very expensive and, in any

event, impractical on small coral islands and in shifting deltas. Case studies we have carried out suggest a variety of ways in which, through diversification of food supplies, improved water collection, re-design of dwellings, more careful husbanding of natural defences and effective disaster preparedness strategies, it would be possible for many inhabited low lying islands to adapt, albeit with external assistance. For vulnerable deltas, as in Bangladesh, controlled flooding to increase siltation is one possibility to be seriously considered.

18. We are in no doubt that climate change will have far reaching and substantial consequences. Broadly, three approaches to policy can be adopted. One is for governments to do nothing. While this is understandable given the uncertainty we believe this is the wrong approach and could prove the most costly in the long term. A second is to try to prevent global warming by controlling emissions. We have suggestions to make for strong policy action on a concerted basis in that area but would emphasise that it is already too late to prevent significant warming. A third is planned adaptation.

19. In Chapter 4 we set out the actions we believe that the Commonwealth should take in the light of this serious situation. Our recommendations are grouped within three broad themes. First, we are clear that action must be taken to reduce the burden of uncertainty which hampers the formulation of policy in many areas. This means an increasing investment in sound scientific studies of many kinds, in the development of more reliable climate models, and in the maintenance of monitoring so that these models have sound data upon which to work. It is also essential to inform the public of the conclusions of these studies and monitoring, so that they understand the argument for the changes in lifestyle and circumstances which they may be asked to accept. The second area of action is needed in the sphere of adaptation. Some of the worst consequences of climate change and sea level rise can be avoided by adjustment in patterns of development, in the location of particular agricultural, industrial and development activities, and in consumer preferences for particular types of products. There is a need for governments to evaluate how best to bring about such adaptation within their own national circumstances. The third area of action must be to reduce emissions of greenhouse gases and bring their atmospheric concentrations towards stability. This demands both the application of existing knowledge, for example in energy conservation and the elimination of greenhouse gases like chlorofluorocarbons, and the development of new technologies.

20. In framing our recommendations under these headings we have been conscious of two factors of fundamental importance. The first is that developing countries face particular problems in relation to

climate change. They have an immediate, and immense, task in reducing poverty which climate change could make more difficult. To realise this goal they will need to achieve rapid rates of growth—albeit in a sustainable manner. They cannot, in these circumstances, be expected to curb that growth in order to help alleviate a global problem which they have, in any event, done little to create. The burden of measures to reduce emissions will therefore fall overwhelmingly on the developed world. A second point is that climate change is only one of several major manifestations of environmental stress and cannot be tackled in isolation from others. Our recommendations lay particular emphasis on actions that are prudent in any event, whatever view is taken over the likelihood of impacts of climate change.

21. Our full recommendations appear at the end of Chapter 4. In the paragraphs now following we are grouping the most important of these in a Commonwealth Action Plan, which we commend to Heads of Government as an achievable formula for the near future.

ACTION PLAN FOR THE COMMONWEALTH

1. *Co-operation in Research and Evaluation*

It is essential to reduce the uncertainty about how particular Commonwealth countries, or groups of countries, will be affected by climate change and sea level rise. All members of the Commonwealth should exchange scientific knowledge, co-operate in research and evaluation—including evaluation of socio-economic aspects—and participate actively in the work of the Inter-Governmental Panel on Climate Change, the World Climate Programme, and other international initiatives that promise to enhance our knowledge of the world climate system, our ability to predict its behaviour and our capacity to determine appropriate responses.

2. *Co-operation in Monitoring*

It is important for all countries to understand their own climate and to be able to monitor it effectively. Such monitoring, leading to better data, will also contribute to a deeper understanding of the greenhouse effect. Models of the world climate depend on the quality and global extent of the data fed into them. The test of the validity of models lies in comparison between what they predict and what actually happens. For both, a series of routine measurements of the climate at a network of points over the earth's surface is essential. With this in view, governments should ensure that any historic archives of weather records they have are maintained, should continue measurements at locations where there is already a good series of data, and should support one another in initiating new series where they will contribute most usefully to the wider global coverage of data. Many small countries in particular will need assistance to establish and operate the detailed programme of climate monitoring and climatic hazard warning that we have recommended.

3. *Co-operation in Public Information and Awareness*

Public information, education and training are essential, to help people understand the need for adjustment to climate changes and to prepare for it. Co-operation between governments would facilitate the dissemination of balanced information. The new Commonwealth of Learning initiative could be a valuable means to this end.

4. *Assisting Adaptation*

Suffering, cost and hazard are likely to result from inability to adjust to climate change. These negative effects will be felt most acutely by the poorest countries which have limited capacity for adjustment and are most dependent on natural systems. All members of the Commonwealth should review the sensitivity of their national and local development policies to likely climate and sea level changes, and so avoid unwise public and private investment. Technical assistance should be available, where necessary, to facilitate these reviews. Commonwealth activity can especially be focused on:

* assisting small island, and other low lying, states to prepare realistic strategies for coping with sea level rise and flooding, in the overall context of coastal zone management;
* assisting countries to develop effective disaster preparedness, including early warning systems, especially as climate change could well increase the intensity of tropical storms;
* studying the 'coping mechanisms' of marginal farmers in rainfed agricultural regions with a view to promoting relevant research and training.

5. *Co-operation in Reducing the Rate of Increase in Greenhouses Gases*

It is essential to slow down the increases in atmospheric concentrations of greenhouse gases and eventually to bring them to stability. This will demand national strategies, especially for:

* energy efficiency and conservation (the most cost-effective and immediately achievable area of action);
* greater use of, and research on, renewable energy sources, especially hydro-power, biomass, wind and solar power;
* phasing out of chlorofluorocarbons;

* sustainable use of forests, promotion of agroforestry and social forestry, and extensive afforestation;
* promotion of fuel substitution towards low CO_2 emitting fuels, notably natural gas, where this is economically feasible.

All of these actions are desirable on broader grounds regardless of the view that is taken of the uncertainty governing climate change, and determined action could reduce CO_2 emissions from developed countries substantially (by at least 20 per cent by 2005 according to the 1988 Toronto Conference).

Commonwealth countries should help one another in this work through the exchange of national analyses and expertise, and with financial assistance to permit developing countries to curb the greenhouse effect without penalty to their growth and development.

6. *Co-operation in the Development of New Technology for Greenhouse Gas Control*

New technology is needed:

* to manufacture and apply substitutes for chlorofluorocarbons that are neither strong greenhouse gases nor hazardous to the ozone layer;
* to increase the range of cost-effective small-scale renewable energy systems suitable for use in village communities of the developing world;
* to enhance energy efficiency in industry, power generation, homes and offices and transport.

The Commonwealth countries should assist in the transfer of such technology to the developing country members on a bilateral and multilateral basis.

7. *Co-operation in International Action*

The Commonwealth is the source of only a minor proportion of the global emission of greenhouse gases. To solve the problems now confronting the world community, action is therefore needed on a wider international scale. Some Commonwealth governments have already taken a leading role in strengthening international co-operation in this area. Commonwealth members should intensify their efforts and also work together to enhance the effectiveness of international agreements on the environment, especially the Vienna Convention on the Protection of the Ozone Layer and the Montreal Protocol, and to develop the proposed Framework Convention on Climate and its subsequent Protocols.

8. *Machinery for Co-operation and Assistance*

There are many ways in which this co-operation can be achieved. But two central components will be organisation and finance. We specifically suggest:

* Environment Ministers of the Commonwealth should hold periodic consultations to exchange views and experiences;
* delegations from Commonwealth countries to international meetings concerned with the impact of human activities on world climate and sea level should also endeavour to work in harmony;
* a Standing Commonwealth Expert Group should be established to assist governments to evaluate developments in the whole area of climate change and sea level rise through periodic reports;
* the Secretariat should be strengthened in this area to provide effective support to member governments on environmental issues in general as well as to liaise specifically with the Expert Group;
* additional assistance to developing country members of the Commonwealth to carry out the action in the Expert Group Report and highlighted in the Plan, above, should be accepted as a priority within the technical assistance programmes of the Commonwealth.

Chapter 1

Introduction: Origins of the Inquiry

On 19 October 1987, His Excellency Mr Maumoon Abdul Gayoom, President of the Republic of the Maldives, addressed the United Nations General Assembly on the issues of environment and development. In that address he spoke of the implications of predicted global warming and sea level rise, especially for coastal and island nations, and drew attention to the vulnerability of his own country, little of which rises more than two metres above sea level.

1.2 President Gayoom had raised these concerns with Commonwealth Heads of Government, meeting in Vancouver shortly before he spoke to the General Assembly. The Heads of Government:

a) expressed great interest in the memorandum submitted by the Government of the Maldives on Sea Level Rise and its Predicted Impacts on Low-Lying Areas of the World;

b) noted the study which the Government of the Maldives had already put in hand;

c) asked the Secretary-General to consider (following the expression of concern of President Ershad of Bangladesh) the problems posed for member countries by the apparently growing incidence of natural disasters, especially floods;

d) asked him to convene a group of experts to examine the implications for Commonwealth countries of rises in sea level and other natural disasters resulting from possible climate change;

e) called for this study to cover the problem of flooding.

1.3 Our Expert Group was duly constituted by the Secretary-General. A list of members is given at Annex 1. It was assigned the terms of reference set out in Annex 2. The members of the group were selected not only to provide a suitable blend of professional expertise and practical experience, but to give representation to the Commonwealth countries especially concerned. As a consequence, experts from the developing world predominated in the membership of the Group.

The Context of the Group's Work

1.4 Our Group met first in May 1988. Between that date and our third and final meeting in July 1989 the issues with which we were concerned assumed an unexpected and unprecedented prominence in the debates of the world's leaders and in the mass media. Her Majesty the Queen referred to them, and defined the Commonwealth's role, in her 1989 Commonwealth Day Message, which had an environmental theme:

> "The threat to the environment takes many forms, of which some are so far-reaching that it is difficult to grasp them. We hear, for example, of the possibility of radical changes in our climate leading, among other things, to a rise in the sea level, with all that that would mean for small islands and low-lying regions. The Commonwealth has a particular part to play in facing up to such issues as these. A concern for the resources we share in common means partnership not only across the oceans but also between generations. A recognition of what our predecessors have bequeathed to us increases our responsibility to transmit these gifts unspoilt to the future inhabitants of our planet".

1.5 Because environmental concerns are so far-reaching, the subject of our inquiry has not only been the subject of a number of parallel scientific evaluations, conferences and debates but has been accompanied by the discussion of many other environmental themes. The United Nations General Assembly has endorsed the proposal to convene a World Conference on Environment and Development in June 1992, and preparations are already beginning. The report of the World Commission on Environment and Development, published in 1987, and the United Nations Environmental Perspective to the Year 2000 and beyond, have given impetus to these discussions. It is now widely accepted that environmental resources constitute a large part of the world's 'natural capital' on which development to meet human needs depends. Any development which dissipates that capital and jeopardises the functioning of the planetary life-support system is neither sound nor durable. As a consequence, governments have come to accept that 'the environment' can no longer be treated as the concern of just one among many ministries or departments of State (and that one commonly a comparative newcomer), but has to be regarded as a truly unifying and comprehensive theme taken into account in the determination of national land use, industry, energy and investment policies in general.

1.6 Our Report has to be read in this wider context. But its theme is none-the-less crucial. Decisions about the use of our environment, from the level of international and national strategy down to the day-to-day decisions of the individual, depend on assumptions about climate and weather. People have commonly assumed that the climate of the next decade will—despite the inevitable fluctuations and occasional memorable extremes—be on average the same as that of the past ten years. The massive investment in many countries in sea defences, ports, coastal settlements and resorts certainly appears to be based on the assumption that the sea will remain within its historic bounds. What we are saying in this Report is that those assumptions are invalid.

1.7 Our Report needs to be viewed against another trend in attitude. Over the past 20 years much writing about the world environment has been of the variety castigated as 'gloom and doom'. There is sound scientific foundation for many stories of environmental degradation and consequent disaster and loss. It is a fact that soil, forests, water resources and the biological richness of the earth are being squandered by mismanagement in ways that make it less and less likely that rapidly rising human populations, many in great poverty and with major unmet material needs, *will* come into balance with nature in 'a world that is more secure, more prosperous, and more sustainable both economically and environmentally' (to quote the Global Possible Conference of 1984). But the world community shows clear signs of determination to grapple with these problems rather than bemoan them. International co-operation is increasing, as the essential indivisibility of the world environment is recognised. There are increasing demands for incorporation of environmental concerns and considerations into development planning and policies, a point recognised by the Governing Council of the United Nations Environment Programme at its Fifteenth Session in May 1989. The members of the Commonwealth are among the leaders of this international quest for a durable solution to the present problems of the world environment, and this report has to be viewed as one of many inputs to that continuing process.

The Interpretation of the Group's Mandate

1.8 At its first meeting, the Group considered the interpretation of its mandate. It emphasised that, with so much turning on the soundness of its conclusions, these had to be based on a thorough review of the substantial volume of scientific evidence and assessment concerning recent and likely future changes in climate, and the underlying causes, especially those involving human agency. On the other hand, the Group had neither the time nor the expertise to engage in new and original investigations. Review, not research, was its business.

1.9 Such reviews were not an end in themselves. They were designed to lead on to an examination of what the most plausible of projected climate changes would mean for the environment, human societies and economies of the Commonwealth countries. Although the Group was requested to focus especially on islands and other low-lying areas, and to look especially keenly at the impacts of sea level rise, it was agreed that it could not be unduly exclusive. The environment is a system of wide-ranging interactions, and casual connections need to be traced widely. Similarly, while the Commonwealth was the central area of concern, it does not exist in isolation and will be affected by what happens to other countries. A wide survey of the world situation was therefore appropriate.

1.10 The Group agreed that its task was to evaluate probabilities. Certainty is unattainable at present. A balance has to be struck. The Group needed to be as clear as possible in its conclusions, but must not mislead Heads of State and Government by over-assertive statements that could lead to unnecessary alarm and to misplaced investments.

1.11 Particular stress was placed on the third and fourth terms of reference, concerning the measures the countries likely to be affected could take and the scope for complementary action at international level. The Group recognised that it was expected to produce a practical Report emphasising the actions that could be taken, the likelihood of their success, and the policies that should be considered to facilitate these actions and successes. Such policies needed to be developed both nationally and internationally. This was inevitable, for man-induced climate change is the most global of all today's environmental problems. All countries share in its cause, and all will experience its effects, though causes and effects are not evenly distributed.

1.12 The Group commenced its work with a review of the scientific evidence, summarised by three consultants[1]. The conclusions of this survey appear in Chapter 2. The initial analyses led the group to commission certain additional studies, and thanks to the generous support of the Australian Government, the following have been carried out:

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1. Warrick R. A., Jones P. D. and Russell J. E., (1988), *The Greenhouse Effect, Climatic Change and Sea Level: An Overview*, University of East Anglia, Norwich, UK; Lewis J., (1988). *Sea Level Rise: The Implications of Sea Level Rise for Island and Low-Lying Countries*, Datum International, Marshfield, Wiltshire, UK; Jäger J., (1988). *Developing Policies for Responding to Climatic Change*, Beijer Institute, Stockholm, Sweden.

a) Separate case studies of the possible socio-economic impact of sea level rise in *Bangladesh, Guyana, Maldives* and a group of low-lying *Pacific* atolls in Tonga, Kiribati and Tuvalu[1]. The case studies set out to define areas of vulnerability to flooding or saline intrusion; identify the implications for current patterns of agriculture, residence and other economic activities and for any future plans that are based on the assumption of unchanged sea level; sketch out strategies for adaptation which seem feasible in the particular circumstances (relocation, sea defences, more ambitious systems of disaster management); attempt rough estimates of the economic costs likely to be incurred; summarise the implications of possible sea level rise for coastal and estuary management; treating the above as being in the nature of a pre-feasibility study. The main conclusions of these studies and their policy implications are incorporated in the text of the report, while some, at least, of the studies are likely to be published separately;

b) a survey of the literature and of current research into how farming communities in Africa have adapted to climate change in recent years; in particular how cropping and livestock patterns can be modified to deal with growing aridity. A consultant was engaged to visit the main centres in Africa to assemble this data[2];

c) A review by IUCN, the World Conservation Union, of the ecological implications of climate change and sea level rise[3]. This examined the main habitat types likely to be affected and the way in which species and ecosystems would be likely to redistribute themselves, noting consequences for the earth's biological diversity and the adequacy of national parks and protected areas. It focused especially on coastal habitats and ecosystems such as coral reefs, mangroves and coastal marshes, and suggested parameters which the countries concerned should examine as a basis for environmental impact analysis.

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1. Mahtab F. U., (1989), *Effect of Climate Change and Sea Level Rise on Bangladesh;* Camacho R. F., (1988). *The Implications of Sea Level Rise For The Coastlands of Guyana;* Lewis J., (1989). *Sea Level Rise: Tonga and Tuvalu,* Datum International; Edwards A. J., (1989). *The Implications of Sea Level Rise For The Republic of Maldives,* Centre for Tropical Coastal Management Studies, University of Newcastle upon Tyne; McLean R., *Implications of The Projected Rise in Sea Level For Kiribati,* Dept. of Geography and Oceanography, University College, Australian Defence Force Academy.

2. Mascarenhas O., (1989), *Response To Climate Change in Eastern and Southern Africa,* University of Dar es Salaam.

3. IUCN (1989). *The Impact of Climate Change and Sea Level Rise on Ecosystems,* Gland, Switzerland.

1.13 As noted above, neither the environment nor the world community stood still while the Group completed its work. There were disastrous floods in Bangladesh in September 1988, which led to increasing emphasis on this aspect of the problem. The summer of the same year brought severe drought to much of the cornlands of North America, leading to public alarm about the threat such phenomena would pose, if they became more frequent, to the security of the world's food supply. Many international studies were carried forward, supporting the increasing tempo of policy debate. Some of the more important of these have been taken close note of by the Group in its work.

International Analysis and Debate

1.14 Almost innumerable scientific conferences have been convened in the past 18 months to address some aspect of the world's environmental problems. In addition several programmes of international cooperative scientific research of real importance are in progress. They are reviewed in more detail in Annex 3.

1.15 *The World Climate Programme,* and within it the World Climate Impact Programme, is operated by the World Meteorological Organisation jointly with the United Nations Environment Programme, the International Oceanic Commission of UNESCO and the International Council of Scientific Unions. Initiated in 1979 as a result of the First World Climate Conference, it seeks to provide an institutional framework for research and data collection, specifically to improve understanding of the world's climate system, and to assess its likely impacts. The current phase of the Programme will culminate in the Second World Climate Conference to be held in 1990.

1.16 *The International Geosphere-Biosphere Programme* of the International Council of Scientific Unions was established in 1986 to 'describe and understand the interactive physical, chemical and biological processes that regulate the total Earth system . . . the changes that are occurring in this system, and the manner in which they are influenced by human actions'. This programme builds upon and integrates other work by ICSU, especially through its Scientific Committee on Problems of the Environment (SCOPE).

1.17 *The Inter-Governmental Panel on Climate Change* (IPCC) was established in 1988, by WMO and UNEP, with three specific tasks:

i) to assess the scientific information related to the various aspects of the climate change issue;

ii) to evaluate the environmental and socio-economic impacts of climate change;

iii) to formulate realistic response strategies for the management of the greenhouse issue.

The immediate task of the IPCC is a first assessment report to the 1990 Second World Climate Conference and an evaluation of the results of the World Climate Programme. Longer term objectives include the stimulation of scientific work in the developing world on the climate issue.

1.18 Arising from this scientific work, and also prompting it, have been a series of important recent meetings that have served to focus attention on the policy implications. Of these, the Group has taken particular note of:

a) the Villach Conference in October 1985, which reached a consensus that the accumulation of carbon dioxide and other greenhouse gases in the atmosphere will lead to a rise in global mean temperature of between 1.5°C and 4.5°C. The conclusions are discussed more fully in Chapter 2;

b) a second Villach Conference in September 1987, followed by a meeting in Bellagio, Italy, in November of that year, which considered how climate change resulting from greenhouse gas accumulation could affect different regions of the earth in the next century, and what policy steps might be taken in the near future to limit or adapt to change. The Bellagio meeting also considered the institutional arrangements needed to implement such policies;

c) a Conference at Toronto in June 1988, which included the Prime Ministers of Canada and Norway, among other political leaders, and which produced a consensus 'call for action' including:

    i) general acceptance and ratification of the Montreal Protocol on Substances that Deplete the Ozone Layer;

    ii) adoption of energy policies to reduce carbon dioxide emissions by 20 per cent of 1988 levels by the year 2005 and by 50 per cent as soon as practicable;

    iii) adoption of a target of 10 per cent improvement in energy efficiency by 2005;

    iv) development of a comprehensive global convention on the protection of the atmosphere, backed by a World Atmosphere Fund (financed in part by a tax on fossil fuel consumption in industrialised countries);

v) measures to promote intergovernmental co-operation and public awareness.

The work of the Commonwealth Expert Group was reported to this conference by the former Deputy Secretary General, Sir Peter Marshall.

d) The 43rd Session of the United Nations General Assembly in 1988 which adopted a resolution introduced by Malta on 'The protection of global climate for present and future generations of mankind', with special emphasis on the role of the IPCC;

e) Conferences in London and Helsinki in February and March 1989, which agreed on the strengthening of the Montreal Protocol and the acceleration of its implementation, with the aim of the earliest practicable elimination of chlorofluorocarbons and other substances which deplete the ozone layer;

f) a Conference in the Hague in March 1989, involving 24 governments, many represented at Head of Government level, which issued a declaration on the atmosphere and climate change and called for a strengthening of international law, and assistance to countries so as to ensure that their development is not inhibited by the need to set higher environmental standards;

g) the Fifteenth Session of the Governing Council of the United Nations Environment Programme in May 1989, attended by representatives of over 100 governments, many of them of Ministerial rank, which endorsed the work of the IPCC and called for the preparation of a new International Convention on the Protection of the Atmosphere;

h) the World Meteorological Organisation's Executive Council meeting in June 1989, which established a special fund for climate and atmospheric environment studies to assist developing countries to measure and analyse their climate and climate changes, and to improve global observation networks of climate and greenhouse gases. In addition the Executive Council called for WMO to continue to support IPCC, to work with UNEP towards a global framework convention on climate change, to establish a world-wide climate change detection project, and to organise the Second World Climate Conference (12-21 November 1990) in two inter-locking segments of a technical and policy (Ministerial) nature. This Conference will provide the major opportunity for intensive consideration of an assessment report of the Intergovernmental Panel on Climate Change;

i) a Conference on Global Warming and Climate Change held in New Delhi in February 1989 organised by the Tata Energy Research Institute, the Woods Hole Research Centre, UNEP and the World Resources Institute. This was one of the few meetings to have focused in detail, and with particular emphasis, on the concerns of developing countries. Since the concerns of that meeting were in many respects close to those of our Expert Group, we have summarised its main conclusions in Box 1.1.

The Commonwealth Dimension

1.19 Commonwealth countries were active in all the major conferences and programmes described above, and initiated or hosted several of the main meetings. Scientists from the Commonwealth are active in the IPCC and other major professional bodies. There are, in addition, distinctive Commonwealth scientific and technical networks, such as the occasional meetings of Commonwealth Meteorological Officers. There is no reason to doubt that there will continue to be a vigorous and informed Commonwealth contribution to the global debate about science and policy.

1.20 On the other hand, there are particular Commonwealth concerns that may not receive sufficiently detailed attention in the wider fora. The problems of climate change and sea level rise will manifest themselves in multifarious ways that alter the lives of individuals and of small communities in a fashion that depends closely on precise local circumstances. The Commonwealth has a large number of small states with low incomes that may face particular difficulties in forecasting, evaluating and adjusting to those changes. But the Commonwealth also brings together a distinctive membership that includes countries with major scientific and technical institutions, and there are well-established traditions and frameworks for professional and economic co-operation. It may well be that by analysis of these issues on a Commonwealth basis, needs will be assessed more precisely, and practical co-operation more exactly targeted, than in the complexities of the wider world. If so, the Commonwealth may not only aid itself by its united efforts, but guide the world by its example. This Report is written and offered in that hope.

Box 1.1: Major Conclusions of the New Delhi Conference on Global Warming and Climate Change: Perspectives from Developing Countries

1. Keys to the Future

a) Act now—it is already too late to prevent significant damage;
b) Give priority to efficiency in the use of fossil fuels;
c) Accelerate the development of technology that is not based on fossil fuels;
d) Phase out CFCs as quickly as possible;
e) Halt deforestation;
f) Stabilise human populations.

2. Responsibilities of Nations

a) Developed countries must make the first and largest response;
b) But there must be an equal partnership with the developing world in the formulation of plans for sustainable growth.

3. Specific Actions by Developed Countries

a) Increase energy efficiency, using fees and taxes to deter greenhouse gas emissions;
b) Do not allow the oil industry to make gasoline cheap;
c) Use revenues gained to finance research and development, technology transfer to the developing world, and reafforestation (including reafforestation in the developing countries).

4. Specific Actions in Developing Countries

a) Develop the national information base for government and public;
b) Adjust energy policies and investment priorities;
c) Favour renewable energy sources, biomass, natural gas, and a transfer from coal and fuelwood to oil in the short term;
d) Halt deforestation and encourage reafforestation;
e) Enhance research and training.

Source: Woods Hole (1989)

Chapter 2

The Scientific Evidence

Introduction

2.1 The volume of literature on the possibility of climate change and sea level rise resulting from human activities is now immense and is growing rapidly. Much is highly speculative, especially those accounts that are designed to popularise scientific findings. Within the scientific literature itself more confidence can be attached to work based on atmospheric chemistry and physics, and on climate systems and processes, than on attempts to apply these to the climate of particular countries or regions or to the impact of climate change on natural systems and human societies. But the level of concern and the sense of urgency in international and national decision-taking circles are such that it is imperative to develop the best practical overall assessments now, as a basis for policies that will not wait.

2.2 While the Expert Group was neither qualified nor required to review the original scientific literature, its first task was naturally to examine enough of the secondary literature to satisfy itself that it was confronting a genuine phenomenon we need to take seriously. It was helped in this respect by studies commissioned by the Secretariat, referred to in Chapter 1, the sequence of reports published by ICSU under the International Geosphere-Biosphere Programme (IGBP) and by WMO under the World Climate Programme, and by certain case studies and reviews in the wider literature.

2.3 It has long been realised that the atmosphere acts in a similar way to the glass walls and roof of a greenhouse in trapping heat from the sun: the effect was described by John Tyndall in 1861. The possibility that increasing concentrations of carbon dioxide due to the burning of fossil fuel could lead to global warming was raised by Arrhenius in 1896, and he calculated that a doubling of carbon dioxide could raise average temperatures by 5°C. Another scientist, G. S. Callendar, attributed an apparent rise in surface temperatures from the 1880s to the 1930s to industrial pollution by carbon dioxide. Interest in the subject waned when the earlier temperature rise was not sustained. But it has returned with unprecedented strength now that evidence has accumulated of the rise in atmospheric concentrations of carbon dioxide and other greenhouse gases and because there are now clear indications of an actual rise in global mean temperature.

The Reality of Climate Change

2.4 Various estimates of the changes in the global mean surface temperature from year to year are now available, derived from the many millions of meteorological observations made on land and sea. They indicate that, since the late 19th century, the global mean temperature has shown irregular inter-annual and decadal fluctuations, but has risen overall by about 0.5°C (Jones *et al,* 1988). This warming is compatible with what might be expected to have resulted from the increase in atmospheric concentrations of carbon dioxide and other greenhouse gases (0.4 to 1.1°C), but proof of cause and effect is lacking and other explanations are possible. The warming has not been uniform over the globe (and indeed some countries have become cooler).

2.5 Sea level has also been rising. The best estimate is that the global mean sea level has risen by 10 to 15 cm over the past century, although the tide gauge records on which this conclusion is based are notoriously 'noisy' and regionally biased (Warrick, Jones and Russell, 1988)[1]. One-third to one-half of this past rise could be accounted for by the shrinking of mountain glaciers (Meier, 1984), while ocean expansion due to warming could account for 2 to 5cm (Wigley and Raper, 1987); any remainder could have been caused by polar ice sheet melting (for which, however, there is no convincing evidence). Again, the observed change in global mean sea level cannot be proved to result from a 'greenhouse effect', but it is not incompatible with the expected effects of the increased concentration of atmospheric CO_2 and other greenhouse gases.

The Causes of a Greenhouse Effect

2.6 There is no scientific doubt that the atmospheric concentrations of a number of 'greenhouse gases' capable of causing global warming have increased. Such gases are transparent to short-wave radiation from the sun, but retain long-wave radiation that would, in their

1. Some authors suggest that a figure of only half to one third of this value may be nearer reality (Pirazzoli, 1988), while others estimate a larger factor.

absence, pass from the Earth into space, thus warming the Earth's surface and lower atmosphere. These gases (excluding water vapour, also a greenhouse gas) are (data from Bolin *et al*, 1986, and Warrick *et al*, 1988):

a) carbon dioxide (CO_2), whose atmospheric concentration has increased from an estimated 275 parts per million by volume (ppmv) in 'pre-industrial' times (mid-eighteenth century) to 315 ppmv in 1958, and to about 350 ppmv in 1988.

b) methane (CH_4) which has increased annually by about 15 parts per billion by volume (ppbv) (equivalent to a growth rate of 1.0 per cent averaged over the ten years between 1975 and 1985), and has now reached over double the pre-industrial concentration of 700 ppbv;

c) nitrous oxide (N_2O) which has been increasing at about 0.25 per cent per year to reach about 310 ppbv by 1988, as against 280 ppbv in preindustrial times.

d) chlorofluorocarbons (CFCs), which increased rapidly (5 to 7 per cent per annum) throughout the 1970s.

In addition, tropospheric ozone, which is being produced near the earth's surface in industrialised areas as a result of chemical reactions involving hydrocarbons (largely from motor vehicle emissions) and nitrogen oxides, is also a greenhouse gas, but its contribution to the greenhouse effect is hard to estimate due in part to its high spatial and temporal variability.

2.7 The increasing concentration of greenhouse gases is the result of human activities related to energy use, agriculture and industrial expansion, especially the first. Some 65 to 90 per cent of the increase of carbon emissions in the atmosphere today is believed to come from the burning of 'fossil fuels' (coal, oil, gas), (Bolin *et al*, 1986; Warrick *et al*, 1988). The remainder presumably comes from the biosphere, and especially from the clearance of tropical forests, which appears to have accelerated in the late 1980s (Houghton and Woodwell, 1989). Emissions of methane probably come from fermentation processes in agriculture (especially wet rice paddy and livestock), from the burning of plant material, and from the extraction and combustion of fossil fuels. Nitrous oxide emissions are also linked to fossil fuel combustion and the burning of plant material, as well as to fertilizer use and the clearance of land for agriculture. Hence, the growth of human populations and the associated processes of agricultural expansion and development are intimately linked to the increased emission of these gases (Table 2.1).

Table 2.1: Greenhouse Gases and Their Man-Made Sources

	Carbon dioxide (CO_2)	Methane (CH_4)	Nitrous oxide (N_2O)	Chlorofluoro-carbons (CFCs)	Tropo-spheric Ozone
% contribution to "greenhouse effect" over period 1950-1985	56	14	7	23	*a.*
Concentration of greenhouse gases – pre-industrial *b.*	275ppmv	700ppbv	280ppbv	zero	15ppbv
Concentration in 1988 *b.*	350ppmv	1700ppbv	310ppbv	0.26ppbv (CFC-11) 0.44ppbv (CFC-12)	335ppbv
Annual growth of concentrations in 1980s	0.5%	0.5%	0.25%	5 to 5.5%	1%
Sources of greenhouse gases	Fossil fuel burning Deforestation/land use changes	Rice paddy cultivation Rearing of ruminants (e.g. cows) Biomass burning Fossil fuel extraction and burning	Fertilizers Fossil fuel and biomass burning Land conversion for agriculture	Manufactured for: solvents; aerosol spray propellants; foam packaging	Product of sunshine and pollutants: carbon monoxide; methane; other hydrocarbons; nitrogen oxides

Source: for percentage contribution, Wigley (1987); for growth, Mintzer (1987); for concentrations, Ramanathan et al (1985), UNEP/Beijer (1989).

Notes: *a.* contributions of ozone not estimated, perhaps around 8 per cent of total.
b. ppmv is parts per million; ppbv is part per billion.

2.8 Although apparently large, the additions by human agency to the carbon flux of the atmosphere of some 7 billion tonnes of carbon annually are small by comparison with more than 200 billion tonnes exchanged each year between the atmosphere, living organisms, and the ocean. Similarly, the modifications of the global nitrogen cycle by human activity add only slight increments to the total flows of this element. The fact that such proportionately small alterations can none the less have widespread environmental effects is testimony to the intricacy—and delicate balance—of the whole system, and is itself a reason for great care.

2.9 By contrast, chlorofluorocarbons are synthetic products of industry, used especially as solvents, refrigerator fluids, aerosol propellants and agents to expand (or 'blow') insulating plastic foams. They began to be manufactured in the 1930s, and production of various formulations increased rapidly until the 1970s, when they began to be incriminated as a cause of depletion of the ozone in the upper atmosphere that screens the earth against damaging ultra-violet radiation from the sun. This concern led to the 1987 Montreal Protocol to the Vienna Convention on the Protection of the Ozone Layer and subsequent international agreement to limit production of CFCs and to eliminate their manufacture and use as soon as practicable (Ridley and Holdgate, 1989).

2.10 It is generally accepted within the scientific community that the continuing increase in greenhouse gas concentrations will result in substantial global warming. There is, however, uncertainty over the magnitude and timing of the warming, the regional patterns of climate change, the seasonal differences, the effects on climate variability and extreme events and the extent of changes in the global sea level.

2.11 Predictions of climate change depend on the validity of climate models and the accuracy with which the trends in greenhouse gas emissions and atmospheric concentrations are simulated. One of the objectives of the World Climate Research Programme and the ICSU International Geosphere-Biosphere Programme is to improve the accuracy of such models. Many of those used so far have grossly simplified the complex atmospheric system and, especially, have been unable to deal adequately with the crucial processes at the interface between atmosphere and ocean (eg Clark, 1982). Because of the resolution of the global climate models, cloud processes are not adequately represented. Despite the uncertainties, however, the best models available today are consistent with one another in indicating a warming of *global* mean temperature.

2.12 It is also important to model accurately the global carbon cycle. This is necessary in order to predict future CO_2 concentrations, as well as to suggest ways of effectively preventing further increases. About half the carbon dioxide emitted today is taken up by the oceans, which provide the main 'sink' for CO_2, for example in the shape of limestone sediments. Carbon cycle modellers have difficulty, however, in balancing their 'carbon budgets', and some components of the carbon cycle are not well understood. For example, it is not clear how far plant growth might be stimulated by higher atmospheric CO_2 concentrations and increase the global sink for CO_2.

Future Trends in Greenhouse Gas Concentrations

2.13 Future atmospheric concentrations of greenhouse gases will depend on world energy demands, and the ways in which they are met, on the effectiveness of a wide range of pollution controls, and on trends in agriculture and in the use (or dis-use) of CFCs. Current (1988) emissions of carbon dioxide from fossil fuel combustion are equivalent to about 5.6 billion tonnes of carbon per year. If future energy demand led to a continued increase in atmospheric CO_2 concentrations at a growth rate of 0.5 per cent per annum, a doubling of the pre-industrial CO_2 concentration would occur by about the year 2080 (for all greenhouse gases considered together, the doubling occurs much sooner).

2.14 Almost all analyses of likely energy scenarios involve continuing increases in CO_2 emissions. This holds even if energy conservation, increased industrial efficiency, and non-fossil sources (nuclear, solar, wind, wave, hydro- and geo-thermal) are expanded at the highest practicable rate. In part this is because, even if the developed nations are able to adopt sophisticated strategies, it is assumed that the development imperative in other regions will lead to an increasing combustion of fossil fuels. The developing nations are beginning to catch up with the developed world in this respect: in 1980 the former accounted for only 13 per cent of global CO_2 emissions from fossil fuels but between 1973 and 1980 their energy consumption grew at 6.2 per cent per year while that of the Western industrial countries grew at only 0.5 per cent per annum (in contrast to the annual increase in the latter of 4.8 per cent per year in 1960-73)—(Table 2.2). On this basis, the developing world could overtake the present (western) developed nations in only 27 years (Warrick *et al,* 1988), though other projections suggest that such a cross-over would occur much later (see Chapter 4).

2.15 Similarly, growth in methane and nitrous oxide emissions is almost inevitable if agriculture expands to feed the increasing human population and fossil fuel use continues to increase. Current projections are of a further doubling of the global population from the present 5.5 billion to around 10 billion before the number of human beings levels off in the latter part of the next century. Even if stability is reached below this figure, it is clear that intensification of agriculture on the land able to sustain it is more likely than its substantial extension onto new sites, and this intensification is most likely to bring about an expansion in greenhouse gas emissions more or less in proportion to the scale of agricultural activities.

Table 2.2: Sources of CO_2 Emissions from Fossil Fuels

	1950 (%)	1980 (%)
N. America	44.7	26.7
W. Europe	23.4	16.5
USSR/E. Europe	18.0	24.2
Japan/Australia	2.8	5.8
China/Communist Asia	1.4	8.5
Developing	5.7	12.2
Others	3.9	6.0
	100%	100%
Total	1.62bn tonnes	5.17bn tonnes

Source: UNEP/Beijer (1989).

2.16 There are mounting pressures today to eliminate chlorofluorocarbons because of concern over the likely impact of ozone depletion on human health and the functioning of biological systems. Substitutes are already available for many of the functions of CFCs, albeit at higher costs. Some of these proposed alternatives, however, are environmentally unsatisfactory because they are just as potent greenhouse gases as CFCs—a factor which should be taken into consideration before they are approved. Even if there is swift action to introduce truly satisfactory substitutes, atmospheric concentrations of CFCs will nevertheless continue to increase (although at a diminishing rate) for a number of decades, because these substances persist for a long time in the atmosphere. Moreover, even if a reduction is secured in the industrialised nations, and other chemicals are substituted, in the developing countries, where refrigerants are likely to be of growing importance, it will be difficult to maintain the tempo of development yet secure the elimination of CFCs unless significant assistance is available for the transfer of the new technology. We return to this question in Chapter 4.

2.17 It is clear that projections depend entirely on assumptions about the seriousness of the commitment of the world community to limit climate change and about the political and economic practicability of the necessary actions. However, a cautious judgement is needed, and we conclude that future growth in the atmospheric concentrations of all greenhouse gases is extremely likely for at least the next six decades, even if the rate of increase slows as a result of preventive action. In Figure 2.1 we present an envelope of feasible projections. As can be seen, these suggest a doubling of CO_2 equivalent concentration from pre-industrial times by the year 2030, when all greenhouse gases are considered together. There is already a commitment to global warming, with attendant consequences for the environment and human society, and further warming must be regarded as probable. As Table 2.3 shows, carbon dioxide, especially from energy generation is the dominant contributor to this global warming. This in turn constrains our options for limiting the greenhouse effect to which we return in Chapter 4.

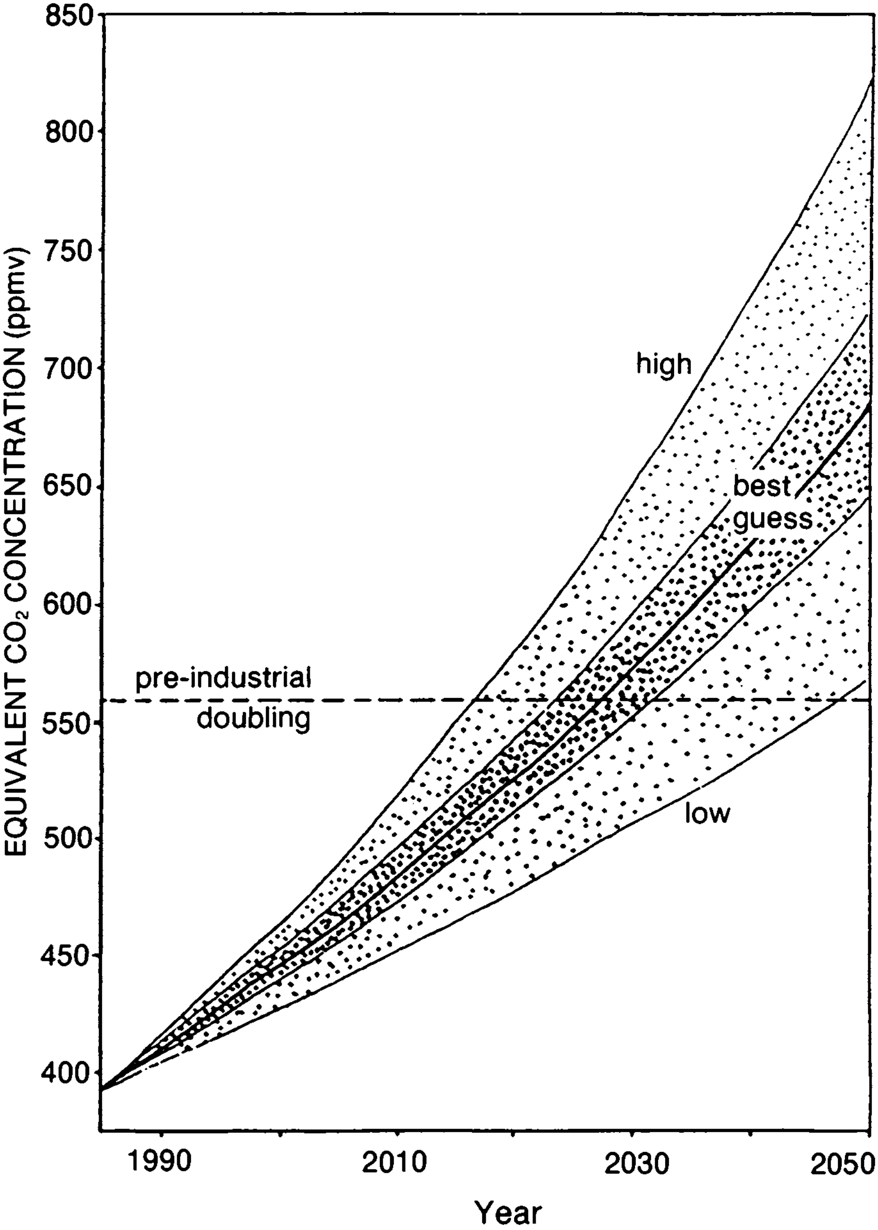
The Likely Magnitude of Global Temperature Change

2.18 Given the best estimates of future greenhouse gas concentrations and the climate sensitivity to such changes, it is most likely that, by the year 2030, the global mean temperature will be 1 to 2°C warmer than today. Given the full range of scientific uncertainties, the warming could be as little as about 0.5°C, or as large as 2.5°C. (See Fig. 2.2).

2.19 These estimates take account of substantial lags in the climate system due to the slow absorption of heat by the oceans. The most likely 'equilibrium' warming—that is, neglecting the lags—to which we would be committed by the projected greenhouse gas concentrations in 2030 lies between about 1.5°C and 3.0°C warmer than today. The implication is that today's generation is creating risks from which tomorrow's generation will suffer—and that corrective action today will not avert the risks to which we are already exposed as a result of past actions.

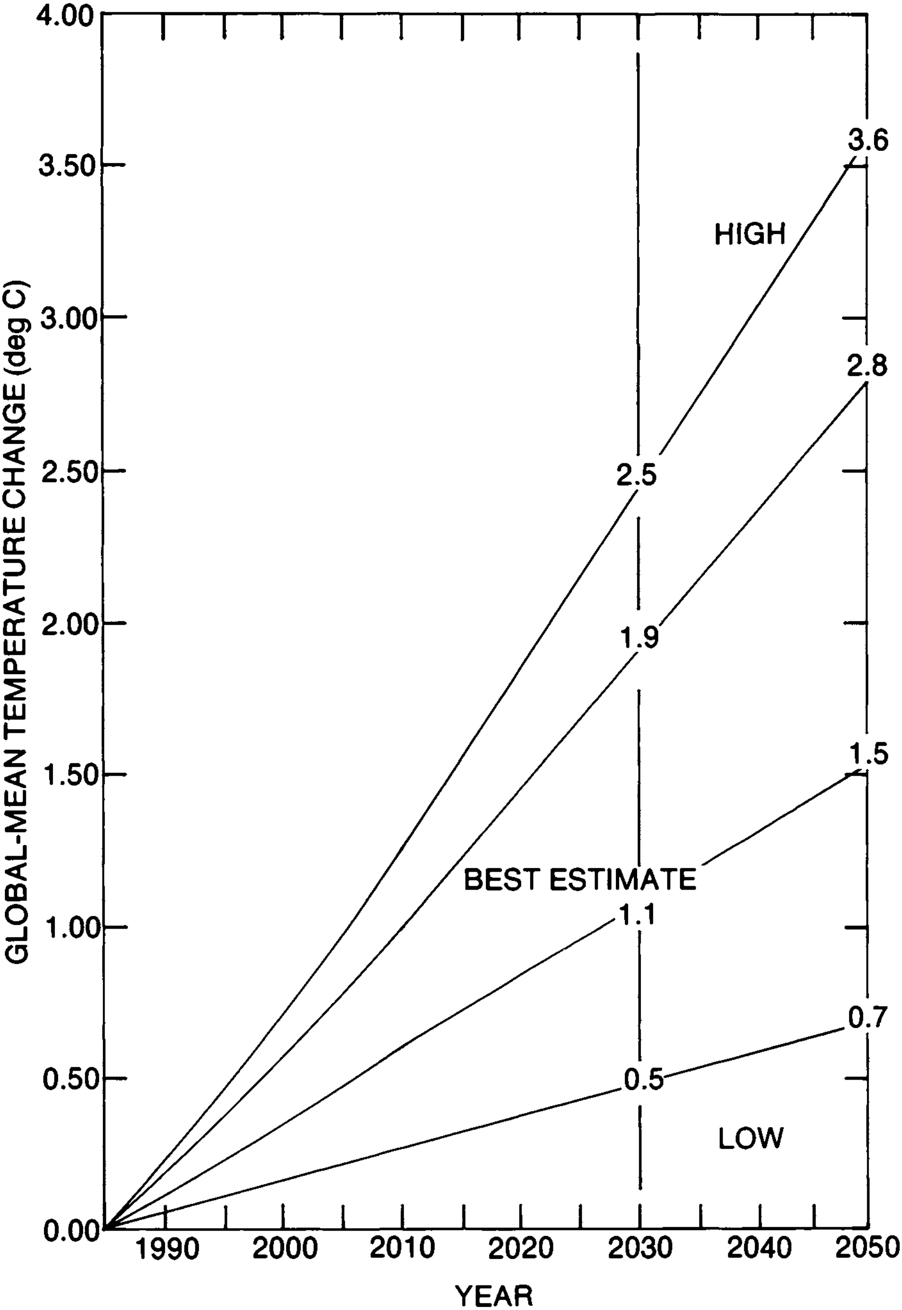
2.20 Two diagrams (Figures 2.3 and 2.4) summarise and demonstrate the seriousness of the problem. Figure 2.3 shows the projections of global temperature change at the upper and lower bounds of probability. It is evident that even the lower curve (which the actual trends of temperature seem more or less to follow) takes the world above the band of warmest climate experienced in the past 10,000 years. In fact, the likelihood is that by 2030 the earth will be warmer than at any time in the past 120,000 years.

Figure 2.1: GREENHOUSE GAS PROJECTIONS, 1985-2050



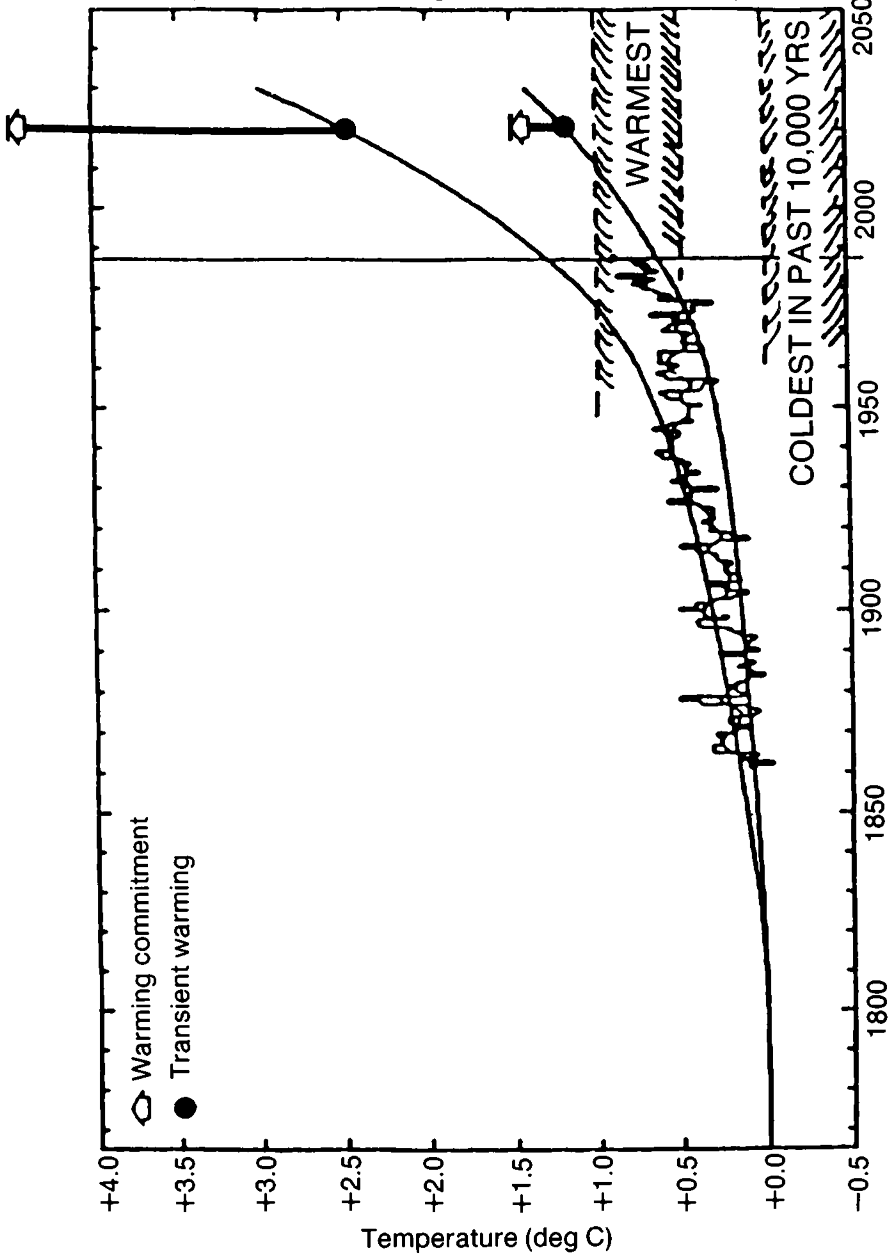
Source: T. Wigley (1989).

Figure 2.2: PROJECTED TEMPERATURE RISE, 1985-2050



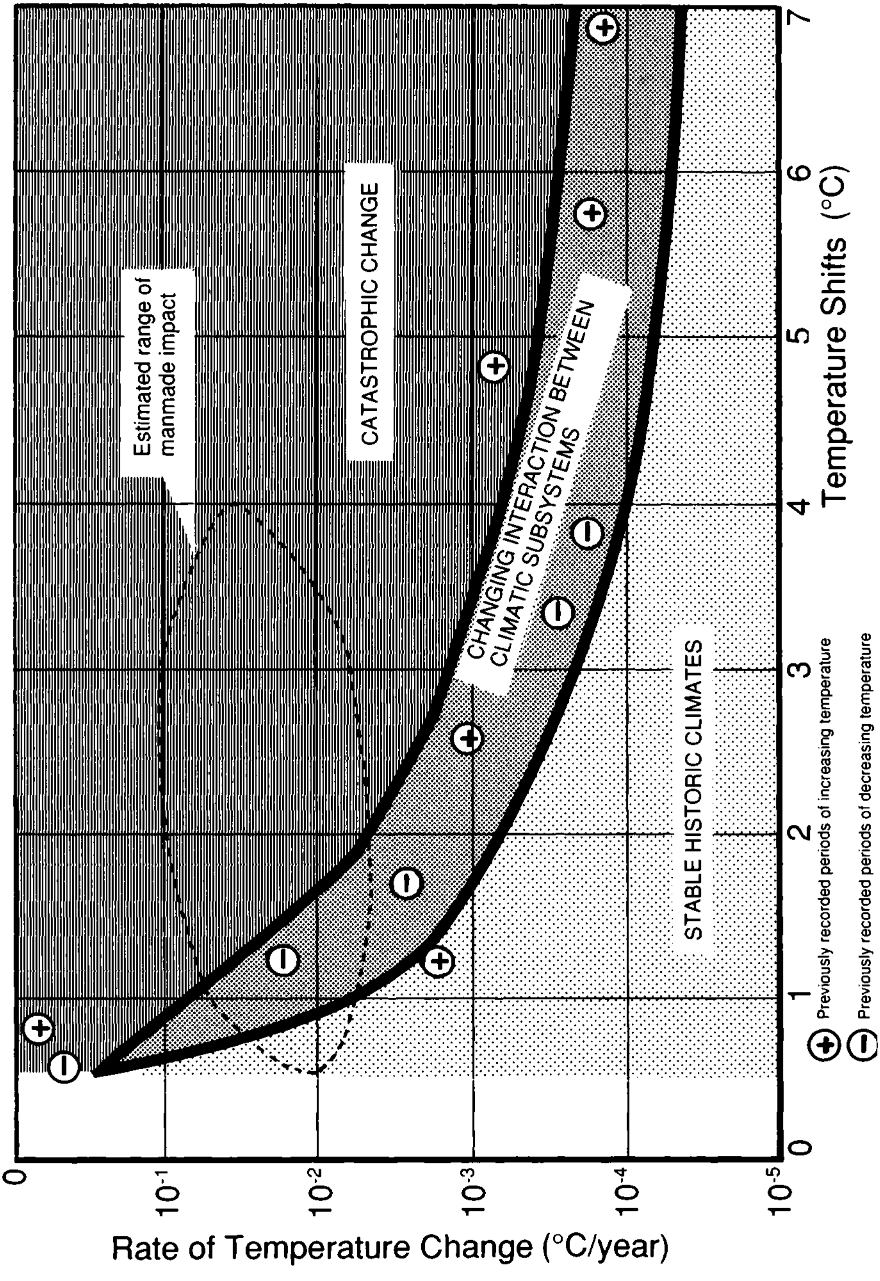
Source: T. Wigley (1989).

Figure 2.3: GLOBAL MEAN TEMPERATURE CHANGES
(Past 130 Years Compared with Next 40 Years)



Source: Based on T. Wigley (1989).

Figure 2.4: HISTORIC EXPERIENCE OF TEMPERATURE CHANGE



Source: Sassin et al (1988).

Table 2.3: Estimates of Contributions to Global Warming over 1980-2030 by Sector and Gas

	Carbon dioxide	Methane	Ozone	Nitrous oxide	CFCs	% by Sector
Energy–Direct	35	3	–	4	–	42
–Indirect		1	6	–		7
Deforestation	10	4	–	–	–	14
Agriculture	3	8	–	2	–	13
Industry	2	–	2	–	20	24
% by Gas	50	16	8	6	20	100

Source: UNEP/Beijer Institute (1989).

Note: Values based on current trends (if Montreal Protocol is implemented, CFC contribution would fall by half). All values subject to large margin of uncertainty.

2.21 Figure 2.4 is even more striking. It relates the magnitude of global temperature changes deduced from various analyses of past environments to the rates at which these changes have occurred. Changes of the order of several degrees Celsius have generally occurred over 1,000 to 10,000 years. Changes of over 0.5°C to 1.0°C per century have been seen only on a localised, regional, basis. As a best estimate, we now face changes of 1.0°C to 2.0°C in a time period of about 40 years and this lies outside the envelope of past experience at a global level. We have meagre historic evidence for predicting how ecosystems and human cultures will react.

The Likely Regional Variations in Effect

2.22 At present, it is not possible to predict how climate will change within specific regions of the world. The climate models are still unable to simulate reliably the regional details of climate and are likely to remain so for five years at the very least. But there are reasons to expect that some parts of the world will experience climate changes significantly greater than the global average. The greatest warming is likely to occur in winter in high latitude (60-90°), especially in the northern hemisphere, and the least warming in the tropical latitudes in summer. Climate models agree that global average precipitation should increase, with higher precipitation tending to occur in high latitudes in winter (Table 2.4). Some models suggest greater aridity in existing dry tropical areas and drier conditions in mid-continental locations. Further disaggregation would be highly speculative.

2.23 If the regional zonation of effect summarised in Table 2.4 is even crudely right, however, Canada would be the Commonwealth country experiencing greatest warming, with perhaps 2°C–6°C higher winter temperatures by 2030. Winter precipitation in the higher latitudes could be enhanced (there is already some evidence of an increase in this zone of the northern hemisphere over the past three decades). The key question is what proportion of this would fall as snow and what as rain and how early in the spring snow melt and run-off could occur and soil drying begin. There would be likely substantial ecological adjustments, discussed in Chapter 3. Reduction in pack ice would facilitate shipping and offshore energy exploitation in the Arctic.

Table 2.4: Regional Scenarios for Climate Change

Region	Temperature change (as a multiple of global average increase)		Precipitation change
	Summer	Winter	
High latitudes (60-90 deg)	0.5x to 0.7x	2.0x to 2.4x	Enhanced in winter
Mid latitudes (30-60 deg)	0.8x to 1.0x	1.2x to 1.4x	Possibly reduced in summer
Low latitudes (0-30 deg)	0.9x to 0.7x	0.9x to 0.7x	Enhanced in places with heavy rainfall today

Source: WCIP, 1988.

2.24 Most of the Commonwealth lies in low latitudes (0°–30°) where the warming in winter and summer is likely to be less than the global average. Some models suggest that precipitation may be enhanced by 5 to 20 per cent in the areas where rainfall is already heavy, but with some reduction in rainfall in today's semi-arid regions, aggravating the problems evident in places like the Sahel since the 1970s. Evaporation losses would increase in proportion to temperature, accentuating the contrasts.

2.25 If such changes were to occur, they would inevitably alter the productivity of agriculture in tropical regions that are already highly sensitive to the impacts of climate and are often marginal for agriculture. Africa, in particular, experienced a 15 per cent decline in *per capita* food production between 1970 and 1985 and conditions here could well become worse. Where water availability is reduced, fuelwood productivity would generally also decline. Even small climate changes are known to have serious potential impact on crops grown near their margins of tolerance and, on a detailed scale, considerable changes in the distribution of profitable cash cropping could occur.

2.26 These possible ecological and socio-economic implications for

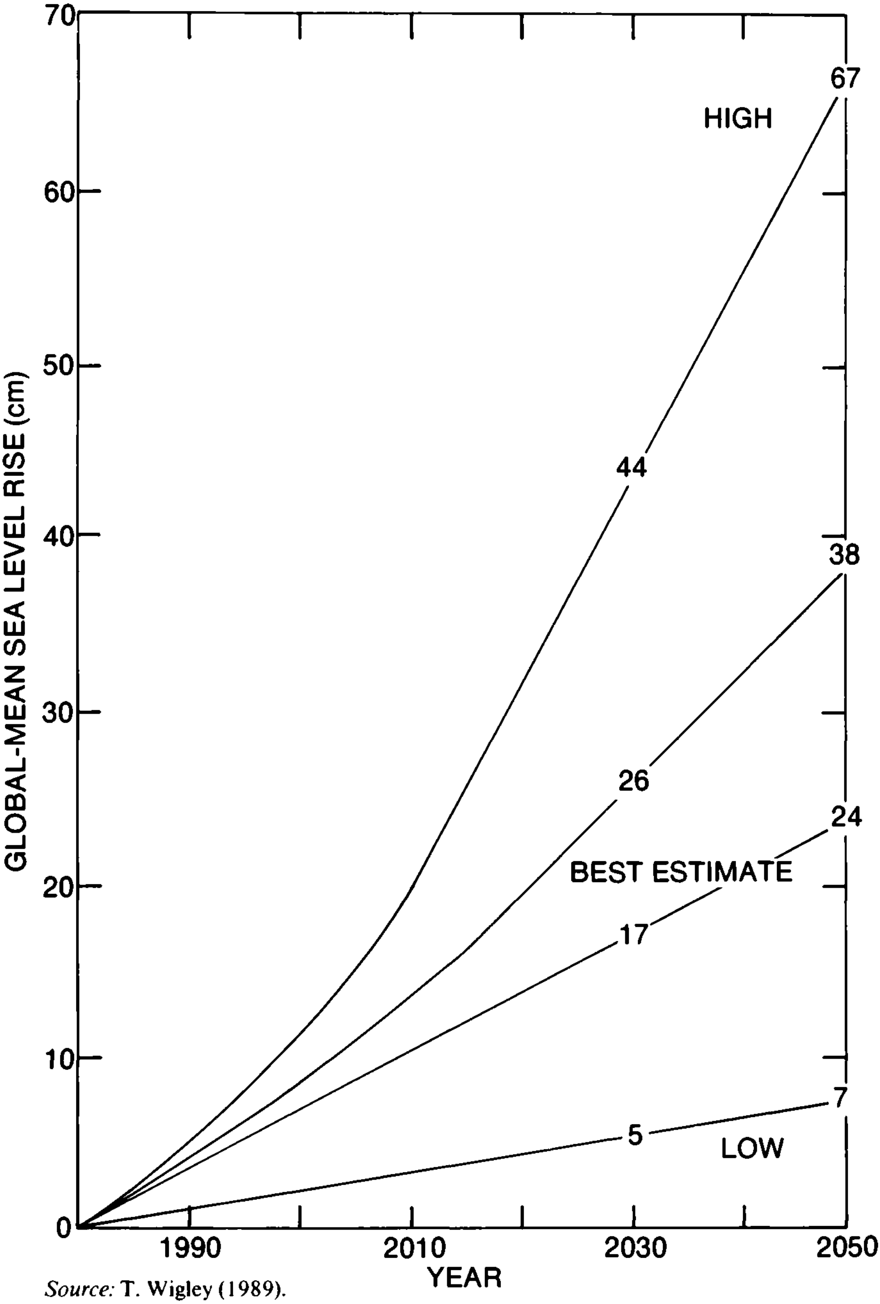
Commonwealth countries are discussed in more detail in Chapter 3. But one overall conclusion needs stating here: it cannot be assumed that the potential benefits that some countries will derive from climate change will balance the costs others will experience. All countries will be faced with the need to adapt to rapid change, with attendant costs; in many cases the resulting disruptions and tensions are likely to be considerable.

2.27 It is also likely that changes in climate will change the frequency of extreme climatic events such as severe tropical storms, floods, droughts or extremes of heat. Some changes in climatic extremes could be relatively large. With an average one degree increase in temperature in the UK, for instance, the extremely hot, dry year of 1976 would no longer be considered a rare event. Warmer conditions in the North American grain growing regions would most likely result in a higher frequency of crippling droughts, like that which occurred in 1988. Some analysts suggest an increase in the intensity of severe tropical storms—which are directly related to sea temperature—as a consequence of global and regional warming. One study suggests that a mean August ocean warming of 2.3°C to 4.8°C could increase the maximum intensity of tropical cyclones by up to 60 per cent, though not necessarily the number or the mean intensity of cyclones (Emmanuel, 1987). It is in this changed frequency of such short-term, climatic, extremes that the social impacts of long-term climate change are most likely to be manifested, just as it is in the succession of environmental disasters experienced in the 1980s that has brought home the extent of environmental stress more generally.

Sea Level Changes

2.28 There is a general consensus that global warming will be accompanied by a rise in global mean sea level. The 'best' estimate is that this will lie between about 17 and 26 cm by 2030, corresponding to the 1 to 2°C warming over the same period. Given the full range of uncertainties, the rise could be as little as about 5 cm or as large as about 45 cm (but these extremes are unlikely)—See Fig. 2.5. The main factors changing the ocean water volume are likely to be the melting of mountain glaciers and the expansion of the warming seas (Table 2.5). Changes in Antarctic ice sheets, where about 90 per cent of the Earth's land ice is located, are unlikely to contribute to sea level rise on this time-scale and in fact may have a small negative influence due to increased precipitation and ice accumulation. Greenland ice sheets are likely to make a small positive contribution to the rise. Because of the

Figure 2.5: PROJECTION OF SEA LEVEL RISE



Source: T. Wigley (1989).

slow process of heat transfer from atmosphere to ocean, and of the very long response times of polar ice, even if global warming stopped abruptly in 2030, global sea level would continue to rise for many decades, and possibly for hundreds or even many hundreds of years (Warrick *et al*, 1988).

Table 2.5: Sea Level Rise (centimetres), 1985–2030

Source	low	best guess	high
Thermal Expansion	4	9 to 14	18
Alpine Glaciers	2	8 to 12	19
Greenland	1	2 to 3	4
Antarctica	−2	−2 to −3	3
Total	5	17 to 26	44

Source: Warrick *et al.*

Note: Increases will continue past 2030.

2.29 Sea level is changing for reasons other than climate change on many of the world's coasts. In Scandinavia, for example, the land is still slowly rising following the disappearance of ice sheets some 10,000 years ago and relative sea level is declining, in some areas at a rate of 100 cm/century. Some coastal areas are sinking; in south-east England, the relative sea level is rising by about 25 cm per century—twice the global average. A number of islands have been built up by coral growth on the foundations of extinct volcanoes which are slowly subsiding. The pumping out of ground water is leading to the subsidence of some coastal areas. The Nile and Mississippi deltas are displaying rapid marine encroachment because of human interference with the sediment flow of those rivers. All these regional and local factors must be taken into account when estimating future sea level and judging the risk to particular areas.

2.30 Sea level rise brings several kinds of risk. The most obvious is a rapid loss of land to the sea. There is nothing new in this: the coasts of Europe, for example, display many areas of forest peat below present sea level, and history records the disappearance of various important towns, such as the English port of Dunwich, as a consequence of erosion and marine encroachment. Numerous Pacific islands have disappeared altogether over the past 10,000 years as a result of rising sea level caused by the melting of the northern hemisphere ice sheets (Lewis, 1988a). What is new is the prospect of a rapid acceleration of the process and its extension to new areas, including parts of the developing world which lack the resources to construct massive defensive works like those of the Netherlands. What is also new is that, unlike in earlier epochs, much of the low-lying land is settled and large investments have been made there. Many small island states would lose a significant part of their land area if there was a sea level rise of 1 metre (Lewis, 1988). The entire 1,190 small islands making up the Republic of the Maldives barely rise two metres above sea level (Gayoom, 1987).

2.31 At the regional scale, it is the coastal effect of sea level changes that can be forecast with least (albeit still with considerable) uncertainty. Half of humanity (and over half the citizens of the Commonwealth) inhabits coastal regions and it is here, too, that the pressures of population growth are most acute. Twenty-six Commonwealth Member States are island countries, and 21 of these are small island developing countries (Lewis, 1988a) so that almost half the Commonwealth countries are particularly vulnerable to the impact of sea level rise.

2.32 Rising sea level increases the vulnerability of coastal areas to flooding from storm surges. In the Bay of Bengal, where hundreds of thousands of lives are at risk, the impacts of severe storm surges on India and Bangladesh are already large and could be exacerbated by rising sea level. The incidence of sea flooding in low-lying areas is in large part a function of the narrowing difference between storm surge heights and the height of sea defences on the one hand, and the incidence and magnitude of storms on the other (the prediction of which requires regional details of climate changes). If sea levels rise and storms increase there can be a dramatic increase in the probability of inundation. Analyses in the Netherlands indicate that a 0.5 metre rise in sea level would bring a tenfold increase in the risk of storm surges overstepping sea defences (Goemans 1986, as reported in Warrick *et al*, 1988). Some regions are unprotected and particularly vulnerable. The low-lying delta of Bangladesh fronts the Bay of Bengal for a distance of 650 km, and little of this coastline has any protection works: 250,000 people were killed by a very high sea surge driven by a tropical cyclone in 1970. If the intensity of tropical storms increases, the risks can only increase.

2.33 Rising sea level also increases the intrusion of salt water into surface and ground water systems. The results can include loss of agricultural capacity and the need to replace, modify or expand domestic water supply systems. Damage from saline intrusion into fresh water wells has already been noted in southern Kiribati and in Tuvalu (Lewis, 1988).

2.34 Many low-lying tropical coasts are protected by coral reefs and mangroves. Both are under pressure in many areas from human activities including pollution, sedimentation as a result of bad land-use and construction processes, dynamite fishing and coral block quarrying, and the excessive cutting of mangrove for poles and fuelwood. A rising sea level poses two threats. It would tend to narrow the band of mangrove able to exist at the margin between the sea and human occupation (which would be unlikely to withdraw inland faster than it must) and it might outstrip the growth capacity of some coral reefs (see Chapter 3). In either case, the vulnerability of the coast to erosion and flooding would increase.

Conclusions

2.35 We have argued that there are good grounds for accepting the scientific consensus that rises in global mean temperature and sea level are likely. Beyond this, the speculative nature of the regional details of climate change summarised in this section is unsatisfactory. It is of crucial importance that governments support the research that is needed to permit more precise predictions of the probable implications of change for regions and individual countries. Governments obviously vary greatly in their ability to support such activities, unaided, but we believe that as a minimum, individual countries should have, or should be helped to acquire, some capacity to assess their own climate and sea level, and changes in them, even if not all countries can contribute to the basic science. Without such science, and effective monitoring, much money may be wasted in inappropriate responses—and much human anxiety risked by erroneous conclusions. We develop these thoughts further in Chapter 4.

Chapter 3

The Ecological, Economic and Social Impacts of Climate Change and Sea Level Rise

Introduction

3.1 Most economic and social decisions today assume that the climate in the future is going to be same as the climate now. It is clear from the analysis in Chapter 2 that this assumption is no longer valid. Decisions on water supplies, coastal defences, forestry policy, energy supply, farming strategies and many other components of the national economy must be based on, or at least take account of, the probable differences in tomorrow's climate. Forestry planning, for example, must involve the use of species that have a good probability not only of survival but of productivity as well under the expected circumstances of the future. Most tree and shrub crops like coffee or tea have shorter growth periods than this, but still require planning years ahead—they can, moreover, be highly sensitive to climate. Energy planning, likewise, has long lead times and needs to take account of alterations in consumption. Water reservoir and distribution systems have to be planned over long periods. Tourism is climate sensitive in general; in particular, beaches are vulnerable to sea level changes; and some national parks may no longer be viable in future. Management policy in respect of all these must be reappraised against the background of likely climate change. The present chapter looks in detail at possible ecological consequences and the implications for particular sectors of the economy.

3.2 There is bound to be uncertainty. As Chapter 2 showed, we are not able to predict detailed patterns of change at national or even regional level. It is, however, possible to progress from cautious agnosticism by using a scenario rather than a forecasting approach: not posing the question 'what will happen?' but 'what could happen?' to various sectors in various parts of the world under various plausible assumptions about climate change. That is the approach adopted in this chapter.

3.3 As noted in Chapter 2, our concern is not just (or mainly) with the magnitude of change but with its rate. We have, in analysing implications of change for policy, to take account not only of levels of alteration in temperature and rainfall but also the speed of the process. As Tickell (1988) said 'The more perfectly adapted a society, like a species, to its particular environment, the less easy for that society—or species—to adapt itself in our over-stretched world. All change means dislocation. The rate of change is the key question we are least able to answer'.

3.4 In general, a fast change will be more difficult and costly to adjust to than a slow one. Both natural systems and social organisations have adapted to slow climate change in the past; it is the fact that future climate change is projected to happen so rapidly in historic terms that arouses such concern. And we must also consider variability because extreme climatic events have a disproportionate impact. If, for example, the intensity of tropical storms is to increase as some of the studies we have reviewed suggest, only one or two such storms could have an immense impact on the viability of some communities. For example Hurricane 'Bebe' in 1972 destroyed 95 per cent of the housing on the main island of Tuvalu; Hurricane 'David' in 1979 destroyed 80 per cent of Dominica's housing; Hurricane 'Isaac' in 1982 destroyed over half the housing in Tonga and well over half of agricultural production. Within the last twelve years alone Bangladesh has been hit by nine tropical cyclones, Vanuatu by five and Tonga, four (Lewis 1988a). Similarly, it has been stated that it would take only three closely grouped drought years with a severity like that of 1988 to eliminate the United States' grain surplus.

3.5 Many future problems will arise because of the uneven distribution of the economic and social costs and benefits of climate change. The unevennesss of distribution derives from two factors: a different incidence of the effects of climate change and different capacities to adapt. It is idle to speculate about 'winners' and 'losers'. But some countries may experience climate changes that will raise their productive potential and also have the resources to tap these opportunities. Many low income countries, on the other hand, are especially vulnerable since the overwhelming majority of their population depends on natural systems that are sensitive to climate. Moreover, low income countries face other pressures—notably rapid growth of population—which make environmental conditions fragile, and they have few options in terms of migration, or resources to invest in diversification. Unequal impacts will arise within countries too. Poorer groups will, in general, be more vulnerable to the adverse effects of climate change, because they occupy marginal agricultural land, live in disaster-prone areas where property values are low, or are less able to invest in adaptive measures. Another way of describing increased vulnerability is in terms of reduced options: a characteristic of poverty.

3.6 Distributional considerations should not, however, mask the fact that adjustment to climate change will be costly for all. The effects of changing levels of rainfall and temperature may partly cancel out between countries but those deriving from rapid rates of change and from greater variability are likely to be negative everywhere. Moreover, disadvantaged nations living alongside advantaged ones may well do more than cast envious eyes at their neighbours' good fortune. For example, some analyses suggests that the northern side of the Mediterranean basin may in future experience more favourable (moister) environmental conditions while aridity increases on the African shore where population increase is rapid: it is not difficult to deduce that people thus disadvantaged may seek to move to the areas of more favourable habitat (Le Houerou, 1989).

3.7 All development decisions related to climate change have to be taken against a background of the total national economy and social circumstances and goals. In many developing countries of the Commonwealth, rapid development is imperative to counter poverty and population growth; but the same factors are bringing mounting demands on finite natural resources. In many countries there is already severe pressure on natural ecosystems, such as forests, savannah, corals and mangrove; pollution is intensifying from a variety of sources; and resources needed for development—fresh water, food supplies, fish stocks— are under environmental stress. Climate change and sea level rise threaten the natural resource base even more than they undermine sustainable development.

3.8 A general conclusion must be that if this is not to happen, changing environment—including climate—must be allowed for in long term national planning. This requires taking a long term view of development—which is not helped by the use of economic methodologies which, by their employment of high discount rates, place small value on events several decades off. Many environmental resources are effectively non-renewable on the time-scales adopted by human societies, and accordingly should not be discounted. Unless these matters are attended to, there could be a substantial waste of resources which are already inadequate for development. This is especially so in small and vulnerable countries where the cumulative impact of even small and almost imperceptible changes could prove disastrous over a few decades.

3.9 An important part of the context against which these long term decisions have to be taken is the level of development. Where large scale poverty exists, as in many developing countries, a purely restrictive approach to the use of resources is not acceptable and is unlikely to work. A more flexible approach is called for that also takes into account the need for rapid economic progress. Combining conservation with rapid development will not be easy and climate change makes the reconciliation even more difficult to achieve. It is especially important, therefore, that the likely impacts of climate change should be understood at an early stage.

THE IMPACT OF CLIMATE CHANGE ON BIOMES AND ECOSYSTEMS

Ecological Patterns

3.10 The current distribution of plant and animal communities is a reflection of how different species and ecosystems have adapted to past climates. Future climate changes will affect the boundaries of ecosystems and the mix of species that compose them. This will have major implications for human activities that depend on natural ecosystems, particularly forests (for timber, firewood and natural medicines), fisheries, grasslands (for cattle and sheep raising) and coastal formations such as mangrove and coral.

3.11 The main biological communities, or biomes, can be defined in relation to temperature, precipitation and evaporation: precipitation ratio (Holdridge, 1967: Table 3.1). When past climate was substantially different from the present, as in the glacial and warm interglacial periods, there were major shifts in biome distribution (Bolin, Doos, Jäger and Warrick, 1986). Even in the more modest warming of around 1°C over present global temperatures in the period 800–1200 AD, Canadian forests extended well to the north of the present timber line and cereal cultivation flourished in Iceland and Norway up to 65°N. Coastal ecological patterns have also been subject to change: mangroves, which are sensitive to sea level rise, sedimentation, and the mix of fresh and saline water, and corals, whose growth rate varies with depth, water temperature, wave energy and nutrient supply, have been radically affected by localised and global sea level changes. Experience suggests how other ecosystems could be affected. Wetlands are an example: if rainfall were to rise in higher latitudes, peat formation would be encouraged while if the permafrost were to thaw over large areas creating new lakes, there would be a large ecological response, including changes in the flora and fauna of lake and river systems.

3.12 Very broadly, it can be asserted that a 1°C rise in mean air temperature can be offset—in mid latitude—by a latitudinal displacement of vegetation types polewards of some 100 to 150 km or by an upward vertical movement of 150 metres (MacArthur, 1972). Such a temperature increase represents the lower limit of the range of projections of global warming (1 to 2°C) we have been considering for the year 2030. In practice, changes in rainfall and the frequency of drought are likely to be as or more important for particular species. Another crucial, and unpredictable, influence is competition between species—including pests. Variable responses by resident and invading plants and animals are to be expected and this, in turn, affects the plants and animals that feed off them. In addition, prediction of future climate-induced changes is complicated by the fact that ecosystems are being affected simultaneously by other pollutants, such as acid rain on freshwater and forest systems, nitrogen oxides and oxidants in relation to forest growth and increased ultra violet radiation admitted by stratospheric ozone depletion affecting marine plankton. Carbon dioxide itself affects plants directly and differentially by stimulating plant photosynthesis and growth; the implications of this greater ecosystem activity—which could lead to greater stress if water is limited, if plant growth draws greater amounts of minerals from the soil or if species are near the margins of their range—has yet to be worked out but has important implications both for ecosystems and commercial agriculture.

Table 3.1: Broad Limits of Biome Distribution

Biome	Temperature Range (monthly means)	Precipitation and Seasonality
Tropical rainforest	33°C–18°C	2000–8000 mm, evenly spread
Tropical seasonal forest	33°C–18°C	1000–2500 mm, seasonal
Temperate forest	20°C–minus 5°C	750–2500 mm, well distributed
Boreal forest	15°C–minus 30°C	250–1500 mm, unavailable in winter
Savannah	25°C–20°C	900–1500 mm, even or seasonal
Temperate grassland	20°C–minus 10°C	250–1000 mm, seasonal
Desert and semidesert	35°C–minus 5°C	less than 250 mm, often highly irregular
Tundra	10°C in warmest month	less than 1000 mm, much as winter snow

Source: IUCN (1989)

3.13 Ecological response to climate change will depend on the rate of change as well as its magnitude. Animals and birds could migrate quite quickly, whereas for vegetation the process is slower. The ability of tree species to adapt by dispersion can be deduced from the historical record. This suggests a maximum spread, even for trees with light, wind-dispersed seeds, of 2 km a year or 80 km in 40 years (Bennett, 1986). On the arithmetic outlined above, this is well below the 100 to 150 km suggested as necessary to keep pace with a global temperature rise of 1 °C over this period, let alone larger temperature increases. In some cases, also, natural barriers—seas, oceans, mountains and deserts—would inhibit migration even if it were biologically feasible. The rate of change of the environment is crucial to other ecosystems too: for example, mangroves appear to be able to adapt to sea level rises of up to 8 cm per century, but not necessarily to the more rapid changes likely in future (Ellison, 1989). The ecological implications of sea level rise are discussed in more detail later.

3.14 How the global balance between ecosystem types changes in response to climate change will depend critically on the complex interactions between temperature, precipitation and soil discussed above. For example, although one simulation model (Parry, 1985) suggests that Arctic tundra could virtually disappear as a consequence of global warming, with the advance of the Boreal forest to the shores of the ocean, this is a statement of broad zonal potential only. In practice, forest would be likely to be excluded from many high-Arctic regions by the waterlogging of the ground (and active peat formation there) or by the thinness of the soils over rocky ridges. Similarly, the projection that Boreal coniferous forest would be largely replaced by mixed forest of more temperate character needs to be qualified by detailed assessment of the invasive and competitive ability of the species concerned. The figures in Table 3.2 are therefore to be treated as suggestions of overall potential change. What can be predicted is that rapid climate change is likely to lead to a broadening of the transition zones (ecotones) between communities and biomes, and an increased 'patchiness' in ecological pattern.

Species Loss

3.15 Many analyses suggest that the rate of extinction of species would increase substantially if climate changes rapidly and outstrips the capacity of biomes and ecosystems to adapt. There is a large element of speculation in such statements, because the calculations depend critically on the geographical pattern of change in relation to the geographical distribution of biological diversity and, as Chapter 2 indicates, we cannot make reliable statements about regional variation. However, the world already faces an unprecedented rate of destruction of its living heritage as a consequence of such human actions as tropical forest clearance, and climate change seems certain to exacerbate the process. There are likely to be significant consequent economic costs because of the loss of potential sources of genetic material for agriculture and of medicinal plants (McNeely, 1988).

Table 3.2: Effects of Changing Climate on Potential Extent of Forest and Other Major Biome Types
(assuming a doubling of CO_2)

	Major Biome Types (%) *Before*	*After*		*Forest Types* (%) *Before*	*After*
Forests	58.4	47.3	Tropical	25.0	40.0
Grasslands	17.7	28.9	Subtropical	16.0	14.0
Deserts	20.6	23.8	Warm Temperate	21.0	25.0
Tundra	3.3	–	Cool Temperate	15.0	20.0
			Boreal	23.0	1.0
	100.0	100.0		100.0	100.0

Source: Parry (1985)

3.16 Projections of climate change have particular significance for policy regarding national parks and protected areas, which are key sites for the conservation of biological diversity and may well also play a crucial part in the regulation of water flow in river catchments and as foci for tourist industries. At present some 4 per cent of the world's land area receives some kind of formal protection (although the enforcement on the ground is often far from adequate), and in many countries such areas are becoming islands of wildlife habitat in the midst of settled and farmed terrain. Analyses by the World Conservation Monitoring Centre (a joint venture of IUCN, UNEP and WWF) show that, of almost 3,000 such areas of over 1,000 hectares, few extend over the 200 to 300 km that would allow latitudinal adjustment to global warming of 2°C. However, over 60 per cent have vertical amplitude of over 300 metres which could, in principle, permit upward movement of component species—though the practicality of this depends on soil, terrain, rainfall and microclimate. Smaller protected areas, and those with little topographic diversity, clearly risk losing the ecosystems and species for which they were established. Where these areas are surrounded by intensive use the addition of new habitats is not an option. If reserves are to maintain their function of preserving a wide diversity of ecosystems—whether the existing or 'new' ecosystems—it seems likely that more intensive forms of management will be required, guided by strategies at national and global levels.

Forests and Forestry

3.17 The discussion above would lead us to expect that, with their relatively slow capacity to adjust by latitudinal migration, forests could be greatly affected by climate change, as regards both their extent and composition. Table 3.2 and most other analyses suggest that the total area potentially covered by forest might be expected to decline (largely because of the expansion of grassland and desert). This decline would, of course, be superimposed on the direct destruction of forests by human agency. To set against this factor, higher CO_2 concentrations could stimulate tree growth and improve water utilisation.

3.18 The coniferous Boreal forests of Canada and Northern Europe may face severe contraction as they are slowly invaded from the south by more aggressive broad leaved species while the northern margin of coniferous forests lags behind changing conditions (Sedjo and Solomon, 1989). Detailed studies emphasize the complexity of the processes involved, the importance of water and soil conditions and the role of competition between particular species. A study of North America, for example, suggests that, with global warming, spruce growth and productivity could increase in northerly areas (e.g. Northern Quebec) while maple and birch would displace spruce and aspen in more southerly areas (Paster and Post, 1988). Another study shows that a doubling of atmospheric CO_2 could shift zones of tolerance of North American trees some 500 km to the north, resulting, inter alia, in beech trees largely disappearing from the South Eastern United States (Davis, 1986). The temperate forests could be invaded from the south by grasslands and desert if temperature rises are associated with greater aridity in continental interiors. Warming and aridity together could also contribute to a higher incidence of forest fires as well as to less congenial growing conditions and a recent EPA study argues that forests in the drier, hotter, parts of the US could be wiped out over a 30 to 80 year period. Less work has been carried out in simulating the effects of climate change in tropical forests. Temperature increases alone would encourage their spread into higher latitudes but their growth is more closely linked to water availability than in temperate forests, and this, combined with direct human pressures on them, could make tropical forests vulnerable at the drier margins to the encroachment of grassland or savannah, including pastoral grazings. There could, indeed, be feed-back loops accentuating change via regional climate, for recent studies show that about 75 per cent of the rainfall in the Amazon basin (admittedly a unique case) arises through the cycle of transpiration from the vegetation, and deforestation would be likely materially to reduce the amount of moisture in the cycle. It is not clear how far similar conditions prevail elsewhere (e.g. the Zaire basin) (Myers, 1988).

3.19 The sensitivity of forest growth to climate change has major socio-economic implications. In many areas, forests play a key role in maintaining environmental stability and have a high economic value in consequence, even where they are not commercially exploited. For example, in montane tropical areas that could in future be liable to both higher temperature and rainfall, retention of catchment forest is of great importance as a regulator of run-off—to prevent increased erosion and downstream flooding—and to preserve local microclimate. The disastrous floods in Bangladesh, which gave added impetus to our inquiry in 1988, have been attributed in part to accelerated run-off of exceptionally heavy rain following deforestation in Nepal and other parts of the Himalayas. Such problems will be aggravated if upland deforestation continues.

3.20 Natural forest cropped on a sustained-yield basis for timber, fruits and meat for local consumption commonly contributes more annually to the total national economy in developing tropical countries than is gained by logging for timber followed by conversion to grazing land (Myers, 1986: McNeely, 1988) if the economic assessment is done correctly. Recognition of this fact together with better understanding of the role of forests as a stabilizer of climate and a sink for carbon dioxide is likely to lead to policies favouring retention of forests in many tropical countries, except where land is clearly suited to, and needed for, food or cash crop production. It is also likely to add to the case for reafforestation in temperate as well as tropical lands, with active encouragement to fast growing plantations. But forestry policy needs to be based on critical evaluation of the species that will be appropriate under the most probable future climate. One leading US forestry company (Weyerhauser) claims already to have built global warming assumptions into its 40 to 50 year planning horizon for plantations (Simon, 1986), and, given the long interval between planting and harvest, other commercial foresters will need to follow suit, taking advantage of advances in tree breeding and genetic engineering, if productivity in the long term is to be sustained. Given the long-term nature of forestry decisions, particular attention needs to be given to scientific research and policy development for this sector.

Fisheries

3.21 Marine ecosystems will also be affected by climate change and, of course, by the sea-level alterations discussed below. But the mechanisms which link climate change to fishing are complex and indirect—via ocean circulation and the availability of nutrients in the sea. Many 'nursery grounds' for commercially important fish are, however, located in shallow waters near coasts and mangrove, saltmarsh, coral reef and mud-flat systems, all likely to be seriously affected by sea level rise, are also important in this context. Since fish account for 20 per cent of the world's protein supply any impacts are important. Research has established a link between catch volumes and climatic conditions. The direct dependence of coastal fisheries off the Peruvian coast on water circulation patterns, and the devastating impact of the 'El Nino' Southern Oscillation, is a well known example of such sensitivites.

3.22 Some attempts have been made to forecast some of the changes which climate changes could bring (Sibley and Strickland, 1985). These suggest that an overall increase in yields could result from increased mean water temperature—subject to the relative abundance of predators and prey—and that, as with vegetation, there should be a poleward shift in fish populations. Another factor affecting fish yields should be the decrease in the extent of sea ice. However, a critical factor is the availability of nutrients and the consequent productivity of plankton, and this could be affected (positively in sub polar areas, negatively in sub tropical areas) by changes in the degree of vertical stability, or turbulence, in the warmer waters. Comparable factors will affect the distribution of fresh water fish that are sensitive to water temperature (for example, the brook trout of North America would face a substantially reduced habitat in more southerly areas) (Meisner, 1989).

3.23 Some studies of particular fisheries have shown—for example for the North American Great Lakes—that invasion by substantial numbers of new species could be a consequence of warming, resulting in dramatic alteration in the species composition of the fish fauna (Mandrak, 1989). While such a rearrangement of species should not be damaging to overall production there are warnings (in the Great Lakes again) of 'degrading synergism' between climate and other factors in ecosystems (Regier *et al*, 1989). Overall, global warming should result in the replacement of species less well adapted to warmer water by others, leading to some extinctions both in sea and fresh water habitats. Suffice it to say that climate change contributes a new element of uncertainty to an activity where there is already considerable difficulty in trading off human needs against environmental sustainability and the catches of fishing fleets of one country against others.

AGRICULTURE AND FOOD SUPPLIES

Climate and Crop Growth

3.24 There are widely differing estimates of the net effects on global agriculture of increased CO_2 and global warming. Some assessments have predicted deteriorating conditions in agriculture (Simon and

Kahn,1984); others have been more optimistic (Parry Carter and Konijn, 1988). Given the uncertainties involved and the different ways climate affects agriculture, this is not surprising.

3.25 A positive influence from global warming arises from the effect of the higher levels of atmospheric CO_2 on photosynthesis and plant growth. Limited laboratory experimental results suggest that a doubling of CO_2 concentration could cause a 10 to 50 per cent increase in the yields of a wide range of so-called C3 crops,[1] such as wheat, rice, potato, barley, cassava, oil seeds, beet sugar and most fruits and vegetables that collectively contribute about 80 per cent of world food supplies. A smaller increase of 0 to 10 per cent could come from a second group (the so-called C4 crops) including maize, sorghum, millet and cane sugar; and none from a minor third group (CAM) including pineapples (UNEP/GEMS, 1987; Warrick Gifford and Parry, 1986) (See Table 3.3). Laboratory experiments do not, however, reflect the complex conditions observed in nature where—for example—the growth of pests and weeds would compete with that of commercial crops. Also, more fertilizer may be required to achieve the potential increase in yield. While the results have to be treated with caution they do none the less suggest potential gains which could be substantial for some commodities.

Table 3.3: Estimates of Major Plant Yield Growth from Doubling CO_2 Concentration

	Type	*Per cent Increase*
Cotton	C 4	104
Sorghum	C 4	79
Wheat	C 3	38
Barley	C 3	36
Soya bean	C 3	17
Maize	C 4	16
Tomato	C 3	13
Rice	C 3	9
Clover	C 3	4

3.26 However, there is an interplay between temperature and CO_2. C4 plants evolved in the tropics and are especially well adapted to high

[1] C3 plants are so-named because a compound containing 3 atoms of carbon (3-phosphoglycerate) is the first product of carbon dioxide fixation in photosynthesis. In C4 plants a 4-carbon compound (oxaloacetate) is produced. CAM plants use both pathways (at different times) and are distinctive in being able to fix CO_2 in the dark (Raven, Evert and Eichhorn, 1986).

temperatures. Global warming must be expected to expand the area of dominance (in nature) and preference (in agriculture) for such species. Crop-climate models suggest that with no changes in rainfall or agricultural practice a warming of 2°C in Western Europe and North America could *reduce* yields of cereals by 3 to 17 per cent (Warrick, Gifford and Parry, 1986). The apparent contradiction with the results of laboratory studies arises because higher temperatures are associated with greater evapotranspiration and greater moisture stress. They also accelerate plant development and shorten the growth period of the plant. These factors need careful analysis, and the crucial importance of future rainfall levels is evident: increased precipitation would offset the losses while decreased precipitation would accentuate them (Warrick, 1988). In the northern hemisphere, also, any reductions in production would be at least partly offset as currently uncultivable areas become cultivable through the northward shift of the isotherms.

3.27 A warmer world is likely to be a generally wetter world and the increased rainfall should offset, to some degree, the effects on yields of higher evaporation rates caused by higher temperatures: this, by means of increased soil moisture, higher levels of groundwater and higher rates of water run-off for storage and irrigation purposes (Crosson, 1987). In practice, the position is complicated since it is the distribution of rain over time rather than the level which is often crucial. One major model suggests that the crude effect of global warming on the availability of water in mid-latitudes could be negative (Manabe and Wetherald, 1986). Another study suggests that, at least in the northern part of the mid-latitudes—in cool, temperate and cold regions—the water balance could be favourable to agriculture (Parry, Cater and Konijn, 1988); increased winter snow and spring melt, for example, would contribute to increased water supply early in the growing season. To some extent, irrigation can offset both changes in the average water balance and seasonal variations. But reduced precipitation and run-off will affect the long term viability of irrigation schemes. Small changes in rainfall can have, in fact, quite dramatic effects on the feasibility of irrigation. One study has suggested that a fall in rainfall of 20 per cent and an increase of evaporation of 15 per cent as a result of climate change could cut the area in which irrigation is feasible by 75 per cent (Nemec, 1988).

3.28 For rainfed agriculture, there is naturally a greater exposure to climatic variation. In tropical areas, the precise timing and severity of monsoon rain is particularly crucial. These factors define the growing season and the choice of crop varieties and agricultural practices employed. Even small changes in rainfall levels and patterns could have strongly negative effects on productivity in areas where agriculture is currently adapted to the rainfall. Most marginal agriculture does have

Box 3.1: Responses of Marginal Farmers to Drought Conditions in Developing Countries

Raise Yields	Diversification	Stocks of Wealth	Consumption Change
Soil conservation	Increase number of varieties of crops incl. cash crops	Improve storage	Purchase food
Irrigation	Disperse livestock	Sell off livestock	Donated food
Drought resistable crops (e.g. water melons)	Relay planting	Loans/borrowing	Wild foods
Change planting time (e.g. staggered planting)	Increase area planted/cultivated	Insurance	Reduce food for feasts, hospitality, etc.
Intercropping	Hunting and gathering for wild foods		
Fallow system	Mixed livestock herds or splitting herds		
Change and Increase inputs	Beer brewing		
More Weeding	Multiple/ scattered plots		
Thin crop stands	Ecological diversity (e.g. stream bank cultivations)		
Improve livestock	Seek wage labour or self-employment off-farm		

Source: Adapted from Parry, Carter and Konign (1988); Heijnen and Kates (1974); Mascarenhas (1989).

sophisticated 'coping mechanisms'—as shown in work on drought vulnerability in Africa and India (Jodha and Mascarenhas, 1985; Parry Carter and Konijn, 1988; Heijnen and Kates, 1974) (see Box 3.1). These mechanisms can be short term emergency measures (such as selling off livestock) or long term techniques for reducing risks (changing the crop and livestock mix; conserving land or water resources; combining crops of varying maturity and drought tolerance).

3.29 'Coping' strategies are, however, dependent on many factors and adverse conditions may put great strain on them and make it necessary for farmers to sacrifice output and efficiency for safety and diversity. Among these factors are:

- the duration and severity of drought (when a family has to sell productive assets prejudicing its long term ability to cope);
- environmental stress (population growth and pressure, land degradation and depletion of forest all affect future ability to cope; the Tanzanian Masai have, for example, lost much of that ability);
- poor households and those headed by women have fewer assets and less access to credit;
- the moisture gradient has a major effect on the coping ability of different farmers.

These various factors underline the dangers of relying on coping mechanisms, unaided, to deal with increased climatic variability.

3.30 The above factors—CO_2 increases, temperature and rainfall—interact with each other and with the natural environment in ways that are extremely difficult to predict. First, as well as crop growth, climate change could affect the growth of weeds, the spread of wind borne pests with changed atmospheric circulation patterns, the number of reproductive cycles and insect breeding conditions. Second, the effects of increased water run-off from higher rainfall can, especially where rainfall is irregular, result in erosion and serious flooding. Third, soil fertility, even with higher rainfall, could be affected by increased leaching of nutrients or by waterlogging. Fourth, higher temperatures could affect the frequency of fires. These indirect effects are neither necessarily positive or negative on aggregate but they have to be considered—and they add to the unpredictability of the outcome.

Adjustment and Economic Feedbacks

3.31 The effects of climate on agriculture are not limited to the effects of nature on yields but also depend on how farmers adapt, in turn, to these changes. At first sight, most farmers should be able to adjust to changes taking place slowly, over decades. They can adjust not only by changing crops but by switching between seasonal varieties of the same crop, or between varieties with different yields or different rain or thermal requirements. All of this assumes that farmers have the resources and knowledge to experiment and that the findings of agricultural R&D are widely disseminated—conditions which exist in developed, but not to the same extent in most developing countries. Similarly farmers can adjust by altering fertilizer applications and improving irrigation or drainage; again, their capacity to do this will vary.

3.32 One longer term factor affecting the ability of farmers to adjust crop patterns is the availability of new crop varieties. Typically, these take 10 to 15 years to develop. Swaminathan (1984), among others, expresses concern that there are considerable dangers from climate change and variability in a situation whereby only three crops—wheat, maize and rice—account for 80 per cent of cereal production and only around 30 species are used in any significant volume. He argues for a conscious strategy of making use of greater diversity in species and varieties. Others point to the fact that new scientifically produced varieties are more robust than traditional varieties and argue that current trends in plant research will facilitate climatic adaptation (Wortman and Cummings, 1987). But, given the long time lags between research and successful innovation, the process will have to be consciously planned.

3.33 There would be complex economic feedback effects with climate change. If the effect of climate change is to reduce supply locally or globally then, other things being equal, prices will rise leading to reduced demand and increased supply. In one study an induced drop in yields of 20 per cent would cut production by only 5 to 7 per cent if these secondary effects are considered (US Council on Environmental and Quality, 1980). The combination of output and price effects will also alter farm incomes—a significant widening of disparities could, in turn, affect patterns of migration and economic activities dependent upon agriculture. It is possible to use macro-economic models to trace such effects in a comprehensive way. A study of Saskatchewan, for example, showed that, in a CO_2 doubling scenario, wheat production could fall 18 per cent, farm incomes by 7 per cent and regional household purchasing power by 3.4 per cent (Parry, Carter and Konijn, 1988).

Regional Impacts, Food Security and Trade

3.34 Whatever the global impact of climate change on agriculture, it will undoubtedly affect the regional balance between and among countries. One predicted effect is a shift in cropping patterns including a significant spatial shift in crops 'of several hundred kilometres per °C change horizontally and over 100 metres per °C vertically' (Bolin, Doos, Jager and Warrick, 1986). Wheat, for example, could migrate north in high latitudes where soils are suitable.

3.35 While we have been careful to avoid making specific predictions about climate change in particular regions, there are grounds for being seriously concerned about the possible impact of global warming and climate change on the *semi-arid tropical areas*—including much of Sub-

Saharan Africa, N.E. Brazil and parts of India and Pakistan. As noted earlier, agriculture is closely geared to rainfall and depends not only on rain falling in a concentrated rainy season but on its timing and distribution within the season. Cropping patterns and agricultural patterns are finely adjusted to expectations of the rainfall regime; unexpected changes, not only droughts but minor alterations, could have major effects on yields (Warrick, Shugart and Antonovsky, 1986; Mather, 1979). The vulnerability of this agriculture to climate change derives not only from the high level of dependence on a narrow range of rainfall levels and patterns but also on the characteristic conditions of poverty, high population growth and environmental stress—including erosion and desertification; these conditions make adjustment to different agricultural practices difficult. The semi-arid regions are already characterised by widespread malnourishment and declining per capita food production and climate change could aggravate these if it were to increase the frequency or the severity of drought.

3.36 In the *humid tropics*, rainfall level and distribution is crucial to the performance of the main crop: rice. This sensitivity will depend on whether or not irrigation networks are in place; but, even where they are, some climate sensitivity remains to temperature and to rainfall as it affects run-off and ground-water levels. In general, less productive marginal lands are likely to be the most affected by climate change since, here, environmental stress will be greater, the hydrological balance more vulnerable to drought conditions and the people poorer and less well equipped to adapt. It has been suggested that, in addition to marginal rice growing areas, three other types of agriculture in the humid tropics tend to be attracted to marginal land and to be especially vulnerable to climate change: shifting cultivation; continuous cropping, primarily for subsistence, of such crops as maize, sorghum, cassava and beans; and cultivation of feed crops, such as manioc for export (Fukui, 1979).

3.37 Much more research has been done on the climate sensitivity of the *temperate regions*, in particular wheat and maize production. Here, one major consequence of global warming could be to permit improved cereal production in higher latitudes. But no less important is climatic variability—which has had a major effect in the USSR and on particular crops (e.g. causing high summer temperature scorching and affecting in particular maize). The most comprehensive and recent of the major studies on the effects of climate change suggests the following plausible scenarios (Parry, Carter and Konijn, 1988):

— significant increases in rice production in Japan, aggravating problems of surpluses;

- drier and windier conditions in the prairie wheat belt of the US and Canada, with the threat of 'dust bowl' conditions;
- a potential for substantially improved crop yields in the USSR, especially wheat, provided policies facilitate adaption to warmer conditions (such as a switch from spring wheat and rye to winter wheat);
- a considerable increase in the agricultural potential of some countries in the northern latitudes, Scandinavia, for example, whose agricultural policies are currently geared to a different set of (mainly social) priorities.

3.38 But, as we noted at the start, the discussion has to be set in an international and economic context. In temperate regions, agricultural technology has already made a major impact on overall yields—tripling maize yields and doubling wheat yields since 1950 in the US—and there is a high level of confidence that average yields and inter-annual consistency can be improved with continued technological advance in the face of climate change. Second, the economic context in those countries is one of overproduction (except in the USSR) caused by a combination of improving technology and government support. In the US and the EEC, active support is being given to withdrawing marginal land from production and there is recognition of the need to reduce subsidy, which will result in reduced production and higher prices in the short run. Thus, any possible shortfalls in production could be seen as much less of a problem than in the developing world.

3.39 In principle, international trade (and trade within larger countries such as India, China, the US and the USSR) should even out regional variations in the impact of climate on agriculture. In practice, it is not so easy to be sanguine that economic mechanisms will necessarily provide an equilibrating mechanism. Poor people, or poor countries, may not be able to afford food at the prevailing market price: this is why famines coexist with plenty. Similarly, poor people and poor countries are less well equipped to safeguard food security through stocking. Governments in food surplus countries have also traditionally used food trade and food aid for strategic as well as economic and humanitarian purposes. For these reasons, the vulnerability of agriculture in some, especially developing, countries to climate change remains a matter of major concern, and it underlines the importance of policies for food security, at both global and national levels, and of a suitable policy environment to encourage climatic adaptation, as discussed in the next chapter.

Rangelands and Pastoralism

3.40 While the main effect of climate change in agriculture will be experienced through changing crop yields, there will be an important secondary impact on grazing agriculture with changes in the coverage and species variety of grasslands. Roughly a quarter of the world's surface is grassland supporting roughly 1.3 billion livestock and contributing both to food supply—meat and dairy—and industrial raw materials—wool and leather. Two climatic effects are at work, operating in different directions (Riebsame, 1988). On one hand, grassland productivity magnifies the variability of rainfall (by a factor of 1.5 on average). On the other, animals dampen the effects of climate changes since they act as reservoirs of biomass; in some cases, as with camels and goats, their attraction to their owners is precisely that they are reliable and climate-insensitive. For this reason, nomadic pastoralists are usually better equipped than peasant farmers to cope with the higher incidence of drought that may be the fate of semi-arid areas; indeed, cattle are used as a hedge against climatic variability. However, there may be some serious hidden costs of climatic hazards. Pastoralists may be obliged to sacrifice production potential for reliability. One estimate is that production is already only 50 per cent of potential for this reason alone (Le Houerou, 1985). The tolerance of grazing animals has obvious limitations (as recent high mortalities in the Sahel demonstrated) and it is also more difficult to replace losses after drought (or flooding) than for farmers to replant after a bad harvest. Moreover, in many grazing lands, overstocking and erosion are already major problems which greater aridity or climatic variability would accentuate and in turn make future hazards harder to absorb. Some of the same considerations apply to commercial ranching but, as a study of cattle farming in Botswana has shown, private ranchers are able, through scientific farming, to adjust stock much more easily to the carrying capacity of grasslands under drought conditions, than are nomadic, subsistence, herdsmen on common grazing lands with fewer resources (Silitshena, 1985).

INFRASTRUCTURE

3.41 Many major construction and infrastructure systems require planning over many years, and sometimes decades. This planning generally assumes that the climate of the future will, on average, be similar to that in the recent past. Clearly this assumption is no longer valid. Climate change (and sea level rise) are likely to affect these processes of investment in water supplies, construction, energy generation and other components of the economy to some degree and, while the impact may not be large in any one case, the aggregate in national investment terms (or the costs of error) could be very great. The

Box 3.2: Climate Change and Water Resources

Climatic Impact Water Function	Annual Run-Off (Increase or Decrease)	Run-Off Frequency (Increase or Decrease)	Run-Off Seasonality (Less even)	Sediment Production (Greater)	Sea Level (Rising)
Water supply reservoirs	Increased yield in humid areas	Increased yield, more reliable in humid areas	Less even distribution, so reduced yield and reliability generally	Increased sediment, so loss of storage and reduced yield	Saline intrusion of aquifers
	Reduced yield in semi arid areas	Reduced yield and reliability due to more drought in semi arid areas			Flooding of reservoirs
Hydropower reservoirs	Increased generation in humid areas	Increased generation and firm load in humid areas	Reduced generation and firm load	Loss of storage and reduced generation from sediment	—
	Reduced generation in semi arid areas	Reduced firm load in semi arid areas			
Flood protection	Increased protection required in humid areas	Greater flood frequency in humid areas, increasing flood hazard	More frequent floods in humid areas. Greater wet season run off in semi arid areas. Flood hazard	Loss of reservoir storage. Increased deposition. Increases flood hazard	Serious hazard in low lying areas. Sea flooding frequency and severity increased
	Protection in semi arid areas needs to cope with infrequent severe floods	Fewer wet years in semi arid areas but flood severity could be greater			
Environment resources and water quality	Quality improved in humid areas	Quality improved in humid areas	Dry season water quality affected in semi arid areas	Water quality impaired by sedimentation	Ground water contamination by salt water.
	Quality reduced in semi arid areas	Quality impaired in semi arid areas			Saline infiltration into sewerage system
Navigation	Improved river and lake navigation in humid areas	Reduced risk of drying up in humid areas	—	Sedimentaiton reduces navigation	Affects viability of low lying port installations

Source: (inter alia) Williams (1987).

equations of decision clearly need to be adjusted to ensure that there is the best possible planning for the future. In this section we look particularly at water and energy supplies, but refer also to construction, transport and tourism where other significant impacts will be felt.

Water Resources

3.42 Climate change affects water supply both through rainfall and temperature (through evaporation) and water is a resource that serves not only domestic but industrial, agricultural, energy (hydro) and (river) transport functions. In November 1987, WMO convened a meeting at Norwich, UK, on 'Water Resources and Climate Change: Sensitivity of Water-Resource Systems to Climate Change and Variability' to study these impacts. The major impacts were seen as manifesting themselves as changes in the frequency and severity of droughts and floods. With respect to flooding, it is necessary to distinguish between upland areas and coastal lowlands. The latter are more vulnerable. The combination of possible sea-level rise, an increased run-off from upstream, and an increased frequency and severity of onshore winds, could prove particularly dangerous.

3.43 One major study (Mather and Feddema, 1986) has suggested that global warming could have the effect of diminishing water supply overall. While rainfall could increase in 8 or 10 of the 12 regions studied (depending on the model employed) most showed an increased rate of net water loss due to evaporation and a decrease in summer soil storage. It is only in the cool temperate and cold regions that the water balance generally improves. Given a starting point where 80 countries are said to be experiencing serious water shortages already, there could be severe negative consequences (World Commission, 1987). These could be aggravated if climate change does not merely reduce water availability but increases the rainfall variability in the form of flood and drought. Greater variability may also aggravate erosion so contributing to greater sedimentation of reservoirs and rivers.

3.44 There are particular reasons for concern about drought in arid and semi arid areas because of the large investment required to maintain a reliable water supply there (see Box 3.2). Changes in the frequency and severity of drought would have a wide impact: on agriculture, on drinking water supply, and on energy production. Countries dependent on extensive irrigation, such as India and parts of Africa could be particularly vulnerable here. It has been estimated that, to compensate for a 25 per cent reduction in precipitation, a 400 per cent increase in the size of reservoirs could be required for the same yield and reliability (Williams 1987). Increased use of ground water is not a long term solution in such areas because these resources are already over-exploited in many arid regions. For large numbers of people in developing countries there is no satisfactory system of water storage for domestic—let alone agricultural—purposes. The cost of reduced water supply is experienced as thirst or the labour of people—usually women—searching further afield for water bearing wells, rivers or tanks. And all of this assumes constant demand, whereas in a drier climate (or a wetter but hotter climate with a negative water balance) and with mounting human numbers water demand would rise.

3.45 Other effects of climate change on water supply include the impact on *hydropower*. Power supplies are affected not only by total water availability but variability—which affects the reliability of power at peak periods. *Flood protection*—afforded by levees and flood storage reservoirs—will be undermined both by sedimentation and flood frequency, to both of which climate change and variability can contribute. *Water quality* is affected by flow rates and turbidity. *River and lake navigation* is affected by water levels. The most ambitious survey to date traces the effects of water demand and supply on the regional economy of the Great Lakes through the impact on hydropower, shipping and navigation, fisheries, summer recreation, shoreline properties, new pipe and sewer sources, irrigation flows and sewage services (Cohen, 1989a).

3.46 It is, of course, possible to change the specifications of irrigation systems, dams, flood control systems and waterworks by adaptation or replacement but this has a cost which weighs especially heavily on resource poor countries; and there is uncertainty about future requirements in a context where investment decisions have a 30 to 50 year time horizon. The main policy implications for adapting to the impact of climate change on water supply relate to water management practices. Those which are well understood and attuned to water availability, which are resilient to present-day climate variability, and which are well-supported by correct land management practices will be most able to accommodate foreseeable climate change. This means that ongoing international programmes in water resources and/or climate such as those of WMO, UNESCO, FAO, UNEP, etc. which support such management practices are of continuing and increasing importance in the context of climate change.

Energy

3.47 The energy sector is affected both from the supply and demand sides (as well as being a source of greenhouse gases). On the supply side, we have already referred to hydropower; solar and wind power are obviously climate sensitive too, but are minor sources. Climate change in northern latitudes could open up currently ice-bound seas to offshore oil—or other mineral—exploration (though, on land, the balance of effects is less obviously helpful). In developing countries, a crucial factor is the availability of biomass for energy, notably wood for charcoal burners (in East and Central Africa an estimated two thirds of total energy consumption is for household cooking). A reduction of such supplies with greater aridity as well as pressure of growing demand could have a significant negative effect on the living standards of households, and, indirectly, raise commercial energy demand. On the demand side, higher temperatures and humidity would raise demand for air-conditioning. In northern latitudes, there is a direct connection between heating demand and the number of days a year spent below freezing point. At around freezing point, for every sustained 1°C rise in average temperature in the UK it has been estimated that space heating demand would fall by 10 per cent (Lough et al, 1983). Energy demand would fall if this is not offset by increased demand for summer cooling or by a predilection for warmer houses in winter. Cloud and wind conditions also have a major influence on energy demand. Overall, it is estimated that a third of energy used in North America and half that in the UK and Denmark is a direct or indirect consequence of climate. For countries such as Canada which rely heavily on climate sensitive power supplies (hydro) and where residential and commercial space heating are required for several months each year, the impact of climate change on the energy sector could be very large, even ignoring the need for changing energy policy to reduce greenhouse gas emissions. Because of the economic linkages to other industries moreover, the revenues flowing to this energy industry can have widespread economic impact. Climate extremes from a mild to a severe winter can cause a fifty per cent variation in industry revenues in Canada. Conservation, which is the most cost-effective way to reduce carbon dioxide emissions is, thus, likely to have a significant impact on the whole field of energy planning. In particular, energy generation cycles and tariffs will require review if global warming switches peak demands in some countries from winter heating to summer cooling.

Tourism

3.48 Tourism is very largely driven by climate-related factors. People travel in search of sunshine and warm seas; to view wildlife; to explore coral reefs; or to cruise and enjoy historical monuments under conditions of warmth and no more than intermittent rainfall. If climate change destroys the interest of national parks, or blights resorts with excessive heat or over-frequent storms, the tourist industry will redistribute itself and the resorts so disadvantaged will suffer. In recent years we have seen signs of such readjustment following small and late snowfalls in certain Alpine winter resorts and increased summer temperatures during peak holiday months in Malta. Such adjustments are clearly of real concern to Commonwealth states that derive a significant part of their foreign earnings from tourism. For many small states in the Pacific, Caribbean and Indian Ocean this concern is all the greater since the climate impact will be coupled with the impact of rising sea level.

Construction and Transport

3.49 *Building design* could be radically affected by climate change and from the recognition that energy conservation is a vital priority.

Building specifications in many countries already prescribe for particular insulation, lighting and ventilation standards. Techniques are available to reduce lighting and heating costs through more sophisticated time controls and more efficient products. The future is likely to see increased attention to all of them. In *urban infrastructure*, sewerage systems and storm drainage will need review to ensure they can accommodate likely changes in rainfall. Of particular concern is the ability of buildings, dams, and other structures to withstand extreme events such as hurricanes or floods if these were to become more severe or frequent, as they may in some tropical countries. Changes in sea ice distribution in the Arctic could radically affect *maritime transport* around North America. Finally, *transport* is likely to be affected both by the direct impact of climatic events (flooding, fog, ice or snow) and by demands for enhanced economy in the use of fossil fuels (which could augment pressures for more efficient systems and for public transport at the expense of energy-demanding, low-occupancy, private vehicles). Hence this whole sector is sensitive to climate change scenarios and to possible remedial measures in many ways.

Wider Socio-Economic Effects

3.50 It is important that a focus should be maintained on those sectors where a natural process of adjustment to climate is exceptionally difficult because of ecologically imposed limitations (forests), the high lead times involved in major investment decisions (water supply; energy), the physical limits of human adaptability of intrinsic importance (food supplies). Most other climate impacts are more likely to be easily assimilated though the overall capacity of societies to adjust will clearly depend on other environmental and economic stress factors. There are some comprehensive studies which pick up the complexities of the effects and the climate sensitivity of particular sectors (Department of Environment, 1988; Maunder, 1986; Maunder and Ausubel, 1985; Parry and Read, 1988).

3.51 Climate is an important influence on *human health*. While there is currently more concern over the health effects of higher ultraviolet radiation from ozone layer depletion, it is possible to indicate several probable and major effects of climate change caused by greenhouse emissions (Weihe, 1988; White and Hertz-Picciotto, 1985; de Sylva, 1988):

— many diseases are a side effect of malnutrition and thirst which could be aggravated by the negative agricultural and water supply impacts of climate change, especially in developing countries where poverty and disease are already associated with adverse environmental conditions. Droughts, floods or other extreme events would accentuate these problems;

- a warmer world should, other things being equal, be more conducive to the spread of airborne and waterborne communicable diseases especially where greater humidity is associated with warming—triggering faster reproduction and survival of pathogenic bacteria, viruses, parasites and their vectors. Hookworm, schistosomiasis, encephalitis, poliomyelitis, hepatitis B, tetanus, cholera and meningitis all flourish in conditions that seem likely to become more persistent. Malaria carrying mosquitoes may well invade new areas, such as the uplands of Papua New Guinea, as a result of global warming (Hulm, 1989);
- some diseases are directly heat related, particularly cardiovascular diseases, and for those in high risk groups, exposure to temperatures above 27°C is regarded as particularly critical (Tromp, 1980);
- some new strains of disease may flourish against which current preventive techniques are ineffective. An example is the spread of malaria; mosquitoes develop more rapidly in higher temperatures. A new type of malaria in Madagascar has recently killed tens of thousands of people and one explanation for its appearance is the warming of the Madagascar highlands by an average 0.8°C (The Economist, 1988).

3.52 *Manufacturing* is affected by climate change in as much as it affects key inputs (water and forests for paper manufacture, for example), and the physical conditions of production and consumer demand for climate sensitive items (garments, air-conditioning, central heating, etc.). These factors are sufficiently important for 'industrial meteorology' to have emerged as a study specialisation (Maunder, 1986).

3.53 *Employment and Wages* might usefully be singled out as distinct factors though they derive from the biophysical effects of climate change. Losses of agricultural output due to long term trends or increased frequency of disasters do not simply translate into less food availability (since imports into the region or country can satisfy demand) but into lost jobs and incomes (which may in turn lead to reduced purchasing power and hunger). A consequence of the disastrous 1975 frost in Brazil which destroyed 300 million coffee bushes—a third of the total—was that 600,000 peasants and workers were made unemployed, most of whom left the region.

3.54 A further factor worth mentioning is the possible effects on *security and defence spending.* While any discussion in this area is bound to be highly speculative this could ultimately prove the most important, and dangerous, consequence of climate change. The World Commission on Environment and Development Report (1987) has already shown how environmental stress can contribute to military tension—the Horn of Africa is a classic case. Involuntary mass migration; competition for fresh water supplies where river headwaters are shared between countries; and competition for fishing stocks where depletion or migration of fish are consequent upon climate change: all are potential sources of friction.

3.55 In general, gradual climate change, even at the historically unprecedented rate expected, may be too slow to be noted by most societies. Research has shown that even where quite radical local climate change has occurred the local population is unaware of it (Farhar-Pilgrim, 1985, on St. Louis where rainfall increased 30 per cent over 30 years). What does bring home the impact of climate change, and its associated costs, is the incidence of *disasters*. We have earlier suggested that global warming could be associated with a greater severity of hurricanes; drought in mid-Continental, semi-arid, areas; river flooding, where rainfall is heavier or more irregular; and the disasters associated with sea level rise discussed below. Many of the costs of disasters are borne by the poor who typically live in marginal, disaster-prone areas. For those who can afford to insure, greater disaster proneness implies an overall increase in the cost; even in the UK which has a relatively stable climate, weather related insurance claims are estimated to account for 40 per cent of the total in a 'normal' year (Parry and Read, 1988).

IMPACT OF SEA LEVEL RISE

3.56 The economic and social consequences of rising sea level are best considered separately. Reasonable confidence can be attributed to a predicted range of global mean sea level rise at future dates, and the physical consequences can be inferred from local topography, though subsidence, erosion and coastal deposition can radically affect the topographical assumptions. There is now a substantial body of studies available which analyse, often in very considerable detail, the likely sea level rise effects on, inter alia, the USA (Barth and Titus, 1984; Titus, 1987; Mehta and Cushman, 1989), Canada (Environment Canada, 1987, 1988) and Australia (Pearman, 1988). Less work has been done so far on developing countries but this Expert Group has generated data on Bangladesh, Guyana, the Maldives and Pacific atolls; and a Task Team of the Association of South Pacific Environmental Institutions has evaluated the potential impact of climate change on the island states of the South Pacific region (Hulm, 1989; Pernetta et al, 1988; Pernetta and Hughes, 1989). These studies suggest that there are distinct problems, and policy options, for delta areas, as opposed to atoll strands and coastal plains and these are therefore considered separately before we summarise the broad economic and social impacts.

The Vulnerability and Importance of Coastal Ecosystems

3.57 As indicated in Chapter 2, many low-lying coastal areas depend for their protection against waves and storms on natural systems, notably coral reefs, mangrove woodland and intertidal marshes. All have a capacity for upward growth in response to rising sea levels: in the former by the deposition of limestone by coral organisms (thereby fixing carbon in a semi-permanent sink) and in the two latter by the trapping of sediment. The precise response to particular rates of rise depends critically on temperature, water depth, wave energy, nutrient availability and sediment deposition.

3.58 Corals grow most rapidly (about 10mm per year) in tropical seas with depths of 5 to 10 metres. At 30 metres the rate declines to only 15-40 per cent of that near the surface. Exposed reef fronts also grow more slowly (3 to 6mm per year), as do reefs in cooler seas like those around Hawaii where rates may be as low as 1-5mm per year at 10 metres depth in the northern islands. Pollution and sediment deposition as a consequence of engineering work can damage reefs severely at considerable distances from the sites of direct disturbance (Grigg and Epp, 1989).

3.59 The impact of sea level rise on reefs is likely to depend not only on its rate but its duration. At the height of the melting of the ice caps of the last glaciation, the sea level rise of some two metres per century outpaced the growth capacity of all the reefs in the world. Even those growing at around 10mm per year would be submerged 10 metres in 1,000 years and in 3,000-4,000 years would have dropped below the 'critical depth' at which coral is killed. There are many shallow banks in the Pacific below the depth at which corals can survive which probably represent atolls submerged in this period. Modern studies (Hopley and Kinsey, 1985) suggest that over longer time scales reefs have the potential for a maximum vertical accumulation rate of 8mm per year (or 80cm per century), which is considerably less than the higher limit of projected sea level rise. But conversely, it is clear that drastic destruction of coral reefs requires a sea level rise that is both rapid and prolonged. If, therefore, the greenhouse effect can be brought under control within a century, and if pollution and disturbance from engineering works are strictly limited, most reefs should survive. Sea level rise over a short period is, indeed, likely to be beneficial to reefs whose surfaces have reached low water mark, because the surfaces of such reefs, at present dominated by non-coralline organisms such as algae, will be recolonised by coral. The warmer seas should favour coral growth near the limits of distribution, while it is unlikely that sea temperature will reach the limit of 30°C at which coral bleaching has been observed on parts of the Australian Great Barrier Reef (Hopley and Kinsey, 1988).

3.60 Temperature is the most important factor in determining the global distribution of mangroves, which are generally confined to frost-free regions (except where warm currents create favourable local climates). A global mean temperature rise would therefore be likely to cause an expansion in the zone where mangroves grow, especially as the projected upper temperatures will be below the thermal stress limits of these plants (37° to 38°C). Increased rainfall and run-off would also stimulate mangroves since they prefer low to moderate salinities. The other crucial factors would be the rate of sea level rise and coastal topography and sediment supply. A sustained rise of 100cm per century would be beyond the tolerance of these plants, but a sea level rise of at least 8cm and possibly 10 to 25cm per century they should keep pace with (Snedaker and Parkinson, 1985; Ellison, 1989).

3.61 Salt marsh survival also depends critically on the combination of rate and duration of sea level rise, and on the avoidance of excessive human disturbance and the shutting off of nutrient and sediment supply. Such protection is important on economic grounds. All these coastal formations are important nursery areas for fish and other food animals. The estimated value of salt marsh systems in this respect on the east coast of the United States is around $100 per hectare per year (McNeely, 1988). As coastal defences such wetlands have immense value: their retention in Boston Harbour is said to have realised savings of US$17 million in flood protection alone (Hair, 1988). We conclude that careful ecological management of these coastal zone formations should form a central element in national precautions against sea level rise.

Deltas and Flooding

3.62 The major deltas could be acutely affected by sea level rise since they are, for the most part, very low-lying, unprotected from the sea and also densely populated and agriculturally productive. Among the deltas that could be seriously affected are those of the Nile in Egypt, Ganges in Bangladesh, the Yangtse and Hwang Ho in China, the Mekong in Indo-China, the Irrawady in Burma, the Indus in Pakistan, the Niger in Nigeria, the Parana, Magdalena, Orinoco and Amazon in South America, the Mississippi in the US and the Po in Europe. Among these, the two with the greatest potential for disaster are the Nile and the Ganges. A sea rise of 50cm would inundate an area of the Nile delta currently holding 16 per cent of Egypt's population and a higher population of productive farmland. The threats to Bangladesh are even more serious since the dangers of inundation are compounded by the threat of cyclonic storm surges one of which killed an estimated 250,000 people in 1970 (Mahtab, 1989; Brammer, 1987).

3.63 Like other deltaic areas, that of the Ganges-Brahmaputra is highly unstable—each year large areas of land are formed by new alluvial deposition and other areas are eroded by shifting channels. These processes are at present being radically affected by increased rates of deposition as a result of ecological changes in the upper reaches of the rivers, and this has contributed to increased severity of flooding. Earthquakes also have a major influence on deposition rates. The saline limit is also moving inland due to long term processes (punctuated by large annual variations) which have been aggravated by upstream damming and irrigation—though monsoon rainfall is usually sufficient to desalinise topsoil for the rainy season at least. The Sunderbans mangrove swamps and some other natural vegetation areas act as an important natural defence against the sea and appear to be deteriorating due to growing salinity and human activities. Another important dynamic influence has been a major intensification in agriculture in the delta with double and triple cropping, aided by irrigation, fertilizers and pesticides. This picture of broad trends does scant justice to the great complexity and dynamism of physical and human changes in the delta: processes that are more rapid and probably more important than sea level rise itself.

3.64 Near the coast, the impact of sea level will be felt not in isolation but as a result of interaction with other powerful geomorphological forces in the Meghna estuary. It is consequently not possible to predict which areas would be made more vulnerable to regular or occasionally catastrophic sea flooding. Some analysts consider that the most serious impacts of sea level rise will be felt upstream since sea level rise would raise river levels upstream of the delta and in turn raise the height of levees. Associated with this would be an increase in the depth of seasonal flooding by seasonal rainfall across the inland flood plains. A general increase in levees and flood deposition would in turn impede drainage. These processes could add to the severity of flooding in general and in particular could increase the risk, and advance the timing, of major catastrophic channel shifts that are predicted even without sea level rise.

3.65 Among other consequences of sea level rise could be further inland penetration of salinity particularly in those areas where river flows have been reduced by human activity—and salinity would, in turn, affect dry season cropping. Another is damage to mangrove forests, leading in turn to pressures to realise this highly vulnerable land for human settlement. The overall position is in many respects very unclear in its local detail because of the inherent instability of physical and ecological processes in the delta and it is this which makes any planning of long term adjustment to sea level rise profoundly difficult for the Bangladesh authorities. Any ambitious plan to raise the elevation of settlements or to erect sea-defences could be rendered ineffective or even counter productive by major changes in river sedimentation and channels.

3.66 While stressing the complexities of the processes involved, the potential damage which sea level rise could inflict on the already vulnerable Bangladesh economy and society is potentially immense, and we have endeavoured to capture some of the main impacts in Box 3.3.

3.67 While the costal delta of Bangladesh is the most serious source of concern in the Commonwealth, others deltas are vulnerable. Within Papua New Guinea, for example, the mangrove swamps fringing the deltas on the Gulf of Papua comprise some of the largest areas of unexploited mangrove forest in the world, and would be affected by sea level rise (Pernetta and Osborne, 1989).

Coastal Lowlands

3.68 The dangerous element of instability which is characteristic of delta formation is less of a problem for coastal lowlands like those of part of England (the Wash, the Thames, and Severn Estuaries), Holland, Eastern France (the Loire and Garonne estuaries), Spain (the Gulf of Cadiz), the Eastern United States (particularly the Carolinas, Florida and the Gulf of Texas), the Yucatan peninsula (Mexico and Belize), Eastern Africa (Mozambique and Tanzania), India (the South East and Kutch), West Malaysia, Indonesia (Sumatra and West Irian) among others. But these areas have particular problems in that they are often at or below mean sea level and—because of low elevation—small changes in sea level could flood large areas. In Papua New Guinea, rising sea level is considered likely to flood a quarter of the country's 17,000km of coastline, 40 per cent of which is made up of deltas and flood plains at the mouth of rivers (Hulm, 1989). In Florida, a 50cm sea level rise would cause a 15km coastal retreat in some areas, and saline intrusion over much of the Everglades, where mangrove woodland would replace present forests (Snedaker and Parkinson, 1985). There would be serious implications for property values, tourism, commerce, estuarine environment and fisheries (Snedaker and de Sylva, 1987). There would also be considerable impact on coastal nature reserves, and sites of conservation interest of which some 725 have been listed in the area of NW Europe between Northern Denmark and Southern Spain (including the UK) (Hollis *et al*, 1989).

3.69 We looked in particular detail at the case of *Guyana* where the coastal plains that occupy less than 3 per cent of the land area house 90 per cent of the 900,000 population. The plain lies below high tide level and is liable to inundation and erosion by the sea and also to flooding by run-off from the hills behind. Sea defences were created in the late 18th and early 19th century, later strengthened by sea dams. A Secretariat study (Camacho, 1988) shows that the sea-defences and (mainly) gravity drainage system already face severe problems of erosion and general deterioration and would be unable to contain rising sea level. Without improved coastal protection, a rise in sea level would mean:

Box 3.3: Impact of 1-metre Sea Level Rise on Bangladesh

The following estimates were made of the effects of an increase in the mean sea level of 1 metre. The local effects are a complex balance of subsidence and uplifting and an average 10 cm subsidence is assumed to the middle of next century. Because of lack of more disaggregated topographical maps a 1 metre mean sea level rise was considered (90 cm on static sea level and 10 cm subsidence).

1. In the *coastal areas* there would be inundation of 2,000 sq km, 16 per cent of Bangladesh's total area and 14 per cent of the net cropped area. The socio-economic consequences would involve:
   - displacement of 10 per cent of Bangladesh (current) population of 100 million.
   - loss of land currently producing two mn tonnes a year of rice, 400,000 tonnes of vegetables, 200,000 tonnes of sugar, 100,000 tonnes of pulses and accommodating 3.7 million cattle, sheep and goats.
   - loss of 1.9 million homes, 1,470 km of railways, 10,300 bridges, 700 km of metalled road and 19.800 km of unmetalled roads, *inter alia*.
   - output loss estimated equivalent to 13 per cent of GDP and loss of assets of circa 450 billion taka.

2. In low lying *mainland areas*, inundation would also be increased from the 'back water effect', though the impact is not quantified.

— most of the agricultural areas would be inundated by sea water, thereby salinising the soils and putting those areas out of cultivation;
— agro-industry would collapse as sugar factories, rice mills and other smaller industries became affected and had to close;
— residential areas on the coast would become uninhabitable as housing, water supply, sewerage, power supply, telephone services and other communications became unserviceable;
— infrastructure in the coastal area would to a very large extent cease to function due to constant flooding.

3.70 More specifically Camacho argues that: 'the area where most of the population live would be below mean sea level (m.s.l.) if there was a rise of 0.50 metres, but a large part of the agricultural area would still be above m.s.l. and would continue to get gravity drainage for reduced

3. The *Sunderbans mangrove forests,* stretching over 400,000 hectares would be destroyed by increasing salinity, then inundation.

4. *Salinity* problems, already serious, could be aggravated with implications for drinking water (especially Khulna and Chittagong) agricultural yields (especially for vegetables) and industrial facilities (eg power stations).

5. *Coastal Structures.* The existing 58 polder embankments would need heightening and strengthening, as would drainage systems. Estimated cost, 18 billion taka.

6. *Disasters.* The above effects do not include the potentially catastrophic consequences of:
   — more extreme and/or more frequent storm surges consequent upon tropical storms like those in 1970 that killed perhaps 250,000 people, and in November 1988 (30,000 killed).
   — the possibility of different rainfall patterns on river flows and, thus, vulnerability to river flooding, like that in September 1988, which inundated 85 per cent of the land area and affected 45 million people.

Natural calamities appear to be increasing in frequency with or without climate change and sea level rise.

Source: Mahtab (1989)

drainage periods. However, the indications are that a rise in m.s.l. of 1.50 metres would affect virtually the whole agricultural area and mean that pumped drainage would be required in all coastal areas even if adequate coastal protection were put in place'. The underlying stability of the coastal area—and a virtual absence of extreme events such as hurricanes—means that it is also possible to consider various sea-defence options and (as in various studies of the East and South coast of the US) engage in serious long term planning for sea level rise.

Low-Lying Coral Atoll Islands

3.71 A particular focus of concern has been the future of low lying coral atoll islands which include several nation states—the Maldives, Tuvalu, Kiribati (except Banaba)—and several other territories—Tokelau, the Cocos and Keeling Islands—which in their entirety rarely rise over two or three metres from the sea. There are also many parts of territories—the northern Cook Islands, some islands of Tonga, and the low coastal plains of many high volcanic islands—where some of the same effects can be observed. The Group has commissioned detailed work in respect of Kiribati, Tuvalu, Tonga and the Maldives, and Hulm (1989) gives added information about other South Pacific locations.

3.72 These islands arouse concern on several grounds. First, their very low elevation means that their whole future could be endangered by sea level rise. Second, even a small increase in sea level could result in proportionately large land losses since typically their circumference is very large in relation to their existing land area. Third, many of these small island states are already highly vulnerable to natural disasters and that vulnerability could be increased.

3.73 More specifically, a detailed survey of Nuku'alofa, for example, which houses 20 per cent of Tonga's 100,000 population, shows that simply on the basis of mean sea level it would lose 15 per cent of its area from a 50 cm sea level rise and 38 per cent from a 1.5 metre rise (Lewis, 1988). A particular concern of the Maldives is that the island housing the international airport would be regularly flooded at high seasonal tides by a sea level rise of around 0.5 metres (Edwards, 1989). However the position in these and other islands is not static; there is a constant process of small scale erosion and accretion often combined with underlying subsidence or elevation of land. While in some areas sea level rise may actually regenerate coral growth on large areas of flat reef near to present sea level (Hopley and Kinsley, 1988), there must be concern that the natural rate of coral formation (impeded in some cases by human activities) will in other areas be slow, relative to sea level rise, so undermining the limited natural protection against sea flooding that exists. At the same time, erosion will reduce the area of land of the atolls especially those areas that have recently been reclaimed from the sea.

3.74 Superimposed on the slow changes are catastrophic events. There have been storms in which waves have passed across islands up to 8 metres above their tidal levels, wiping out population and habitats alike. Hurricane "Bebe" in 1972 sent waves of up to 15 metres onto the main island of Tuvalu, destroying most of the economy. The storm surges in the Maldives in 1987, even though smaller than this, caused considerable damage to the capital island and to the airport. For any increase in the sea level, the damage inflicted by such storm surges will obviously be greater. If hurricanes and cyclones were to be more severe as a result of climate change, the islands would face a double hazard.

3.75 A further, specific, anxiety relates to the penetration of saltwater into groundwater supplies. Islands above a certain size—roughly 1.5 hectares and 200 metres in diameter—normally contain freshwater lenses floating on salt water. In some islands, these lenses are being seriously affected by marine and human processes but sea level rise would aggravate the problem—a 20 per cent reduction in island width could reduce by half the volume of freshwater, while freshwater would disappear from smaller islands. This has obvious implications for drinking water and also for agriculture, particularly that which depends on pits like taro farming in the Pacific and Indian ocean islands.

Socio-Economic Consequences

3.76 While there are different types of ecology and community affected in different ways by sea level rise, there are some major, common impacts. For developing countries, the main consequences relate to the *agricultural* economy deriving from loss of, or change in use of, agricultural land. The kind of changes described in relation to Bangladesh, for example, where there could be deeper flooding of the interior flood plain, would lead to a major reduction in the areas suitable for the dominant strain of paddy (and jute) and require a shift to lower yielding varieties. Major irrigation schemes—like Chandpur—would need protection and better drainage. Use of high yielding varieties could be more hazardous in the deeper floodwater. In the low lying coastal plains of Guyana what is at stake is almost the entire agricultural output of the coastal area—sugar, rice and other crops—and those processing activities dependent on it. In the Pacific islands, a major source of food consists of pulaka, taro and other root crops grown in pits which might well be made unviable by sea level rise, requiring diversification to other sources of food (fish, vegetables etc).

3.77 Potentially of larger significance in economic terms are the large *urban and industrial developments* that have been built on low lying delta or other coastal sites and face a greater threat of inundation from periodic floods in the absence of stronger sea defences. In our Guyana study, 70 per cent of estimated annualised losses from flooding relate to housing. In Bangladesh, the predicted increase in tidal and flood lands would require major investment in raised rural settlement mounds, and in raising land (together with embankments and artificial drainage) in large urban settlements such as Barisal and Khulna if flooding is not to become more frequent and disastrous. Other major examples of low lying cities include Calcutta, Shanghai, Bangkok, Jakarta, Tokyo, Osaka, London, Rotterdam, Venice and New Orleans. In some cases cities have sea defence systems that do not appear to take into account the possibility of sea level rise; in others, forced drainage is already required to cope with subsidence to below normal tidal levels (eg. the Koto delta of Tokyo). Urban drainage systems could be affected by greater salt erosion of pipes as groundwater level rises. Some facilities are particularly vulnerable—for example airports constructed on landfills in bays, often with minimum elevation. Some power plants and industrial complexes are built very close to sea level to take advantage of sea water for cooling.

3.78 Sea level rise could have significant effects on *water management*. In many coastal regions, and on small low lying islands, a careful balance has to be struck between pumping more fresh ground water and risking saltwater intrusion into the waterbearing aquifer. Sea level rise will adversely affect that balance, especially in drought conditions, often in a context where demand is rising rapidly. There is a rough rule of thumb that saline water advances through estuaries and tidal rivers at the rate of 1 km for a 10 cm rise in mean sea level. Also, existing water management in low lying areas—through tidal drainage systems—may no longer be viable or become much more expensive, in terms of pump capacity or energy required, to operate. *Shipping and ports facilities* would be affected. Ports are constructed on assumptions about patterns and levels of sedimentation which would change with higher sea levels. The coastal structures such as locks, bridges, water intakes and outlets might require strengthening or higher levels of maintenance.

3.79 Some other effects are less obvious but potentially significant. *Hazardous waste* has often been buried in low lying sites. In the United States, there are reported to be 1100 active hazardous waste disposal sites within floodplains and there have been several environmental disasters caused by flooding already. *Offshore oil platforms* are built on assumptions about sea depth, allowing for subsidence, and the risk of exceptional peak waves; these assumptions would change. *Recreational beaches,* which serve as the basis for much of the international tourist industry, could face more rapid erosion. There is a rough rule of thumb (the Brunn rule) that sandy beaches exposed to ocean waves would lose 1 metre, or more, for a 1 cm rise in sea level. All these various impacts will effect different communities in different ways. Some of those of particular concern to the Maldives are summaried in Box 3.4. Writing of Britain, Hollis et al (1989) comment that 'it is ironic that many of the existing holiday beaches would disappear just as the climate was becoming like that of present-day Biarritz'.

Choices

3.80 The economic costs (there are few, if any, identifiable benefits) of sea level rise are complicated by the fact that affected societies have—depending on their resources—choices. They can retreat, accept the losses and adapt to changed circumstances; or they can erect sea defences and/or design (or strengthen) structures to face a higher sea level. The choice will obviously have to be made on a site basis and there will be a complex array of options. The choice to retreat rather than defend a coastal installation will depend on the extent of expected damage (though this presents problems of valuation), the costs of defensive or adaptive alternatives and the resources of the community concerned. Timing is a crucial factor—it will be much cheaper in resource terms to replace an installation at the end of its natural life than prematurely. Both economic and engineering considerations will determine whether it is more effective to design defences and drainage systems to accommodate future sea level rise or to ignore it and adjust specifications subsequently; some evidence strongly suggests the former (Titus et al, 1987). But much design work concerning the sea hinges on risks and possibilities rather than expected averages: in particular the acceptability of risking the probability of disastrous floods. Different societies will necessarily put different values on such risk reflecting their different abilities to safeguard life and property. And there will be widely different assessments of the risks and possibilities.

3.81 Technically a variety of choices is available. For sea defence these include sea walls or dykes (levees); storm surge barriers (like the Dutch delta project and the Thames barrier); and, with more limited objectives, off-shore breakwaters and revetments. In many contexts natural sea defences are crucially important and a central part of any defence strategy has to be to prevent damage to these. A classic case is the coral reefs that defend atoll islands (Edwards, 1989); the best sea defence may be to stop these being damaged by mining and dynamiting and the development of alternative building material technology.

Box 3.4: Potential Impacts of Sea Level Rise on the Republic of Maldives

The inundation of the international airport and also the capital island, Male, by exceptionally large waves in April 1987, and of another low lying island (Thulhaadhoo) in June/July 1988, has highlighted the vulnerability of low lying atoll states to sea level rise. The Maldives lies almost entirely within 3.5 metres of mean sea level (msl). Most habitation, industry and infrastructure lies within 0.8 to 2 metres of msl.

The context is one of growing concern about the need for environmental management in general, particularly regarding the pressures on ground water reservoirs and land use and other consequences of the dense population of some islands (40 per cent of the population of 180,000—1985 figure—live in 8 of the 203 islands) and a population growth of 3.1 per cent.

Sea level rise could put further severe strains on the country:

— *agriculture.* Taro crops, the traditional staple, are grown in pits dug about 40 cm above msl. These pits would have to be raised or abandoned.
— *tourism* provides 17 per cent of GDP and 20 per cent of government revenues. The industry depends on the international airport at Hulule which is 1.2 metres above msl and is barely defended from the sea, or defensible. Small resort islands would be increasingly vulnerable.
— *reclamation* has added 75 hectares to the original 108 hectares of Male, and also to some other islands, mainly for housing. Most is under 1 metre above msl and is vulnerable to flooding unless protected at a cost of $1,000 to $1,800 per metre of coast. Our study estimates the true cost of reclamation, with defences, as $335,000 per hectare.

Source: Edwards (1989).

Should a process of retreat be necessary it can be handled in a variety of ways: by writing-off buildings and land as the sea approaches and floods increase; avoiding (and preventing) new construction and settlement in vulnerable areas; or making partial adaptations to extend the life of valuable installations. Water management systems involve choices between gravity and pump drainage. Resettlement can be gradual or sudden, planned or involuntary. We discuss how different countries can formulate strategies in Chapter 4.

Conclusions

3.82 To the extent that is is possible to identify the socio-economic effects of climate change, developing countries are especially vulnerable on a variety of counts. Their economies are more dependent on climatically sensitive natural resources—natural eco-systems, like forests, as well as farming and fishing. Environmental stress of various kinds is already acute in many areas and climate change could aggravate problems which would be handled without undue strain in richer societies. Many of the adaptations that would be required to reduce the costs of climate change—sea defences; agricultural and forestry research; intensified management of nature reservoirs; relocation of towns and industrial complexes; adaptation or redesign of dams and irrigation systems—may be beyond the resources of many poorer countries. So, while adjustment imposes costs on all, they are differentially severe for many developing countries.

3.83 At the risk of over-simplification, we try to summarise in Table 3.4 what are the main areas of potential vulnerability to climate change in the Commonwealth. Even in the absence of any reliable 'map' of the likely impacts of climate change on a regional or national basis it is possible to make inferences from what is already known about climate vulnerability. We would argue for particular concentration of research on climate impacts in respect of three types of country in particular:

- small island states, many of which face the threat of both sea level rise and of more severe hurricanes and whose smallness and lack of diversity makes them ill-equipped to handle disasters.
- areas of semi-arid, rain-fed agriculture in Africa and South Asia whose 'coping mechanisms' in the face of climate variability are already under great strain without the additional burden of adjusting to new climatic patterns.
- densely populated deltas in low income countries, notably Bangladesh, where sea level rise adds a new element of instability and uncertainty to an environment which is already hazardous and under stress.

Table 3.4: Climate Change Concerns by Region

Region	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Major Climatic Impacts	Sub-Saharan Africa	Indian Sub-Continent	S.E. Asia	Mediterranean	Indian Ocean, Caribbean and Pacific Islands	N.W. Europe	Canada	Australia New Zealand
Average rainfall (could be positive or negative)	xxxx Rain crucial to agriculture and water supply especially in semi arid areas	xxxx As in Africa	xx More diversified economies than Africa/Asia	xxx Water supply a major concern (e.g. Malta)	xx Fresh water supply often a concern	x Diversified economies. Agriculture and water supply could be affected	xx Affects major agricultural sectors and hydro power	xx Australia has substantial dry farming areas
Higher temperature	xx Increased evaporation loss. Spread of tropical diseases	xx As in (1)	x As in (1)	x Some impact on tourism and water supply	x As in (1) and (4)	x Forest fires. Lake levels reduced	xxx Major shift of ice belt and boreal forest. Forest fires	xx Forest fires especially
Frequency of drought	xxxx Especially in semi-arid areas	xxxx In rainfed agricultural areas	xx As in (2)	xx Domestic water supplies	xx As in (4)	xx As in (4)	xxx Cereals in Mid-West	xxx Especially in semi-arid areas
Other aspects of variability (frequency of river flood)	x	xxxx Critical for Indus/Ganges basin	xxx Mekong and tributaries	xx Nile floods	x Flash floods on larger islands	x	xx Floods in Northern areas (snow melt)	xx Flash floods (Australia)
Lower frequency of frost	x Cash crops in cool highlands	-	-	-	-	x Less crop damage	xxx Greater Perma frost area-construction activity	x Some in mountain areas
Greater intensity of tropical storms	xx Indian Ocean coast	xxxx Cyclones in Bay of Bengal	xxx Typhoons	x	xxxx Hurricane intensity	x	x	xx Cyclones in Northern areas
Sea Level Rise	xx Some delta regions, mangroves and coral reefs affected	xxxx Ganges and Indus delta especially	xx Vulnerable areas in Indo China, Malaysia, Indonesia	xxxx Nile delta Also recreation beaches and tourism	xxxx Maldives, Pacific atolls, etc.	xxx Britain, Holland	x Great Lakes and Maritime East and West Coast	xx Recreation beaches, sea level resorts, coral reefs.

Key: xxxx Priority concern xxx Substantial concern xx concern x Some but lesser concern

Note: The classification is based on highly speculative guesses as to impacts and to their weighting. The severity of concern reflects several different factors: the likelihood of change taking place; the importance of climate sensitive activities in the region concerned; and their capacity to adjust (hence poorest countries have most obviously greater levels of concern for a given change).

Source: Commonwealth Secretariat

Chapter 4

Policy Responses to Climate Change and Sea-Level Rise

Introduction: Approaches to Policy

4.1 Our Group was established because the Commonwealth Heads of Government considered that there was a prima facie case for reviewing their policies so as to protect their nations against possible difficulties created by climate change and sea level rise, and to enhance international co-operation within the Commonwealth and on a wider scale. Our terms of reference specifically require us to review the measures countries should take to protect themselves against disasters and to plan forward so as to avoid problems. We were also instructed to consider how countries most likely to face adverse effects could be assisted; how the international community could review unresolved scientific and policy questions; and how international action could limit man-made climate change by acting on underlying causes.

4.2 These terms of reference, and our own analyses, combine to lead us to reject a policy of doing nothing while waiting to see whether climate change or sea level rise manifest themselves so obviously that response is inevitable. Such an approach has been followed all too often by governments in the past (for example over acid rain and motor vehicle emissions). We reject it here for five reasons:

(a) there are some signs, reviewed in Chapter 2, that these changes are already happening;

(b) it is clear that the delays in the system between the initiation of control action and the elimination of an effect will be measured in decades, and delay now can only magnify the scale of the ultimate damage and emergency and the attendant costs;

(c) it is also clear that public concern has reached the point at which it would be politically difficult for governments to remain inactive even if they were to deduce that current uncertainties are too great to bear the costs (which inevitably occur sooner rather than later) of taking preventive measures;

(d) international policies are already being pursued on an increasing scale: the need is to co-ordinate them and make them more effective, not to delay them;

(e) most of the actions advocated for coping with climate change have other benefits that make them desirable in their own right, and justifiable even under present circumstances of uncertainty.

4.3 We are encouraged in this approach by the fact that virtually all the analyses we have seen, from both governmental and non-governmental sources, concur in their basic assessments and in their advocacy of action now to prepare adaptation strategies, policies to limit greenhouse gas emissions, and enhancement of the machinery for international evaluation and co-operative acton (e.g. UNEP/Beijer Institute, 1989; Woods Hole, 1989; Mintzer 1987; EPA 1989; Boyle 1988; NRDC, 1989).

4.4 We believe that new and bold policies, backed by more resources than hitherto, are expected by the governments and peoples of the world and that it is our part to propose these for the Commonwealth in terms that are forward looking but realistic. We believe that we should especially emphasise actions that can be taken now, within existing national and international machinery (especially in the Commonwealth). Of course, the nations of the Commonwealth together contribute only a small part of the greenhouse effect, but action by those countries is worthwhile because of the benefits they will secure through preparedness and the influence they can exert if they pursue a well-informed and consistent line. The Commonwealth is an unusual assemblage of nations in that its membership cuts across the major regional groups and its members could therefore promote a harmonised approach in the several groups.

4.5 In the remainder of this Chapter we suggest a number of measures that Commonwealth governments could take. They fall under three thematic headings:

(a) Measures to enhance knowledge, understanding and awareness;

(b) Measures to avoid the worst impacts of climate change and sea level rise, and to adapt to those that cannot be avoided;

(c) Measures to deal with the causes of these changes, thereby slowing and eventually halting them.

4.6 Action within the first of these themes should concentrate especially on the reduction of uncertainty, through the acquisition of better data about weather and climate, better science, more advanced models, and predictions that are more sharply focussed. We are, at present, advocating action within an envelope of uncertainty. That uncertainty must be reduced, so that the action is increasingly fitted to need. At the same time, we are very conscious that many of the statements made today are alarming to a public that is insufficiently aware of the scientific facts. That is why we advocate action to disseminate the best information available among governments and public, so that social decisions carry the broadest possible consensus.

4.7 Action within the second theme is essentially precautionary. It involves assessment of the vulnerability of national environments to the most probable projections of climate change and sea level rise, and a judgement of how far public and private actions should be modified to avoid undue risk. In contrast, action within the third theme is remedial: it involves measures to reduce emissions of greenhouse gases.

4.8 Action in respect of all three themes will need to be taken at national and international level. We deal with both categories under our three main headings. But there are particular actions that need to be taken at the level of the Commonwealth as a whole, or in still wider international fora, and we address these in a separate section at the end of this Chapter.

4.9 While we place research, leading to the reduction of uncertainty, high on our list of priorities, we are clear that action cannot wait on the deliberations of science. As in the case of international agreements to phase out the manufacture and use of chlorofluorocarbons, control action and further scientific and technical research have to proceed side by side, but in mutual awareness. Policies must be capable of adapatation to take account of the latest results of research and monitoring, while the scientific programmes must be responsive to policy needs. This argues for flexibility in the management of both action and research, and good communication between the agents of both.

MEASURES TO ENHANCE KNOWLEDGE, UNDERSTANDING AND AWARENESS

National and International Research and Monitoring

4.10 For governments to develop and apply sensible policies, they need to be informed themselves. It is important that, acting collectively and individually, they are all able to contribute to, and draw on, research and monitoring of their own climate. As we stressed in Chapter

2, the regional or national impact of global climate change may vary considerably and little can usefully be said at present about the implications for particular countries. Only by better research and modelling will a clearer picture emerge. This needs to be done at national level and *every country should take adequate steps to monitor and evaluate its own climate conditions.* This is particularly important in relation to sea level rise, where the implications for particular communities can be more exactly assessed provided that there is knowledge of unique features of topography, tidal patterns, and land subsidence or elevation which have to be evaluated locally; we have described in Box 4.1, in relation to Kiribati, the kind of data collection and analysis that may be necessary for one small state. We have also endeavoured to indicate in Box 4.2 some particular information needs in the Commonwealth at large. We appreciate that many developing countries have only small meteorological services and scientific communities and *we recommend that assistance be made available to them to strengthen their capaciy to undertake such work.*

4.11 At the same time, care of historic archives of observational data is crucial, since these provide a background against which future change can be evaluated. There is an international project on Data Rescue (DARE) which is collecting such information and ensuring its long-term preservation and *we recommend that all Commonwealth countries should collaborate in this venture.*

4.12 National research and monitoring clearly needs to be designed and coordinated so that the resulting data and evaluations fit together on a regional or wider international scale. The periodic conferences of Commonwealth Meteorological Officers and the Commonwealth Secretariat have important parts to play here. *We recommend that the capacity of the Secretariat be strengthened in order to facilitate this co-operation. We also recommend that Commonwealth members be encouraged, and, where necessary assisted, to participate effectively in the WMO CLICOM project, which provides both a comprehensive system for monitoring climate change and a network linking national data management centres.*

4.13 Many governments are in the process of establishing National Environmental Data Centres to hold information about environmental resources and trends. Others (such as Canada) have a series of linked centres holding various kinds of specialised information. The establishment of centres is being discussed in Bangladesh, Kenya, Uganda and as a joint venture between Botswana, Zambia and Zimbabwe. *We recommend that governments establishing such centres incorporate data on useful indicators of environmental change and link them to National Climate Monitoring Centres so that correlations can be established.*

Box 4.1: Data Priorities: Needs of Low Lying Atoll Islands —The Case of Kiribati

Although the potential consequences of sea level rise are serious, the present situation is not an immediate crisis as some of the effects will take decades to have a major impact on any but the most vulnerable islands. An early priority however is to ensure that the islanders and their government are fully informed as to the changes taking place. The following is a suggested programme of action that is specific but has a wider applicability than for Kiribati alone:

1. Further anaylsis of the tide gauge records in the Gilbert, Phoenix and Line Islands should be carried out in order to determine whether the sea has been or is rising in Kiribati.

2. In order to get a longer record of recent water level changes, studies should be carried out on certain living corals, such as the Porites microatolls, which are sensitive to water level changes. These should be calibrated with the tide gauge records.

3. Much more extensive surveys, involving measurements of elevations and water levels, further to this study, should be undertaken, and the methodology developed in this report applied to determine the relative vulnerability of all the islands in Kiribati.

4. Island groundwater resources should be surveyed and evaluated. Such an evaluation should aim to determine the size of the potable water resource and its variability over time. These surveys to be carried out in conjunction with the topographic surveys mentioned above and with land resources surveys.

5. The present land use and environmental data base is inadequate for planning purposes e.g. topographic maps do not exist for all islands. Attention should be given to the establishment of an environmental monitoring and evaluation section within the government to inventory the existing material, co-ordinate resources, and to identify additional requirements for planning and management purposes.

Source: McLean (1989).

4.14 Monitoring needs to be linked to evaluation at the international level. In Chapter 1 and Annex 3 we refer to several of the exercises now afoot, and especially to the Intergovernmental Panel on Climate Change (IPCC). The process of consultation in the IPCC is designed to

Box 4.2: Current Commonwealth Capabilities and Needs in Respect of Climate Monitoring

Climatological Networks and Data Processing

All Commonwealth countries have an observing network with data fed into the Global Telecommunications System. The only countries considered as not needing technical assistance to improve their operations are Australia, Canada, New Zealand, Trinidad and Tobago and the UK. Several are scheduled for training and new installations under the CLICOM systems in 1988/89: Barbados, Belize, Botswana, Jamaica, Lesotho, Malawi, Malaysia, Mauritius, Seychelles, Sierra Leone, Sri Lanka, Swaziland, Tanzania, Vanuatu, Zambia and Zimbabwe. The following Commonwealth countries will not have CLICOM systems by the end of 1989: Antigua and Barbuda, Bahamas, Bangladesh, Cyprus, Grenada, Guyana, India, Kiribati, Nauru, St Kitts and Nevis, St Lucia, St Vincent and the Grenadines, Singapore, Solomon Islands, Tonga, Tuvalu and Western Samoa.

Ozone and Greenhouse Gas Monitoring (Global Atmosphere Watch—WMO)

Assistance is suggested to enable a growing number of sites to carry out surface ozone analysis at low cost. Existing centres suggested as a basis for this work are in India (Ahmedabad, Kodaikanal); Australia (Hobart, Macquairie Island); New Zealand (Christchurch); Seychelles (Mahè); Kenya (Nairobi); Singapore; UK (Eskdalemuir, Lerwick); St Helena. A number of sites in tropical regions are needed to fill major gaps in networks for measuring GHGs.

Sea Level Observations

The IOC's Global Sea Level Observing System (GLOSS) is designed to provide a comprehensive range of sea level data. In addition to uncompleted stations in the territory of Australia, New Zealand and the UK (Antarctic), help may be needed to complete the network by implementing planned stations in *inter alia:* Tanzania (Mtwara, Ihambane, Pemba); Seychelles (Agalega Is.); Mauritius (Rodrigues); India (Port Blair—Andamans, Minicoy—Laccadives); PNG (Alotau, Vanimo, Dani); Jamaica (Port Royal), Bahamas (Bimini); Ghana (Tema); Nigeria (Lagos).

Cyclone Warning

The following are considered to need assistance in establishing or improving national tropical cyclone warning systems.

Malaysia	Malawi
Bangladesh	Mauritius

Source: The above assessments have been made by the World

Maldives	Seychelles
Sri Lanka	Swaziland
	United Republic of Tanzania
	Zimbabwe
Papua New Guinea	Bahamas
Solomon Islands	Barbados
Vanuatu	Belize
Kiribati	British Caribbean Territories*
Tonga	Dominica
Tuvalu	Jamaica
Western Samoa	St Lucia
Cook Islands	Trinidad and Tobago
Niue	Antigua and Barbuda
Pitcairn	Grenada
Tokelau	St Christopher and Nevis
	St Vincent and Grenadines

*comprises Anguilla, Cayman Islands, Montserrat, Turks and Caicos, British Virgin Islands

Flood Warning

The following are considered in particular need of help in regard to flood forecasting and warning: Gambia, Malawi, Belize, Bangladesh, Sri Lanka, Jamaica, Mauritius and the Caribbean (cyclone related flash floods); and PNG (but considerable help being received).

World Climate Research Programme Data

The following priority requirements have been identified from strategically located Commonwealth countries:

- INSAAT Data (Satellite monitoring data by India)
- Radiation Climatology Baseline Stations (needed for monitoring—recommended in Australia, Canada, New Zealand)
- Rainfall validation (sites recommended in Australia and UK)
- Tropical Ocean—Global Atmosphere upper-air station network (work to be strengthened in Cook Island and Sri Lanka and initiated in Pitcairn Is.)
- Tropical Ocean-Global Atmosphere tidal gauge network (strengthen work programme/new equipment in India, Bahamas, Turks & Caicos)

Meteorological Organisation for the Commonwealth Secretariat.

produce a comprehensive review of existing research and an evaluation of its implications. The IPCC is also the proper forum in which governments should identify priority areas for strengthened and coordinated international research and monitoring on the greenhouse gas issue, and the socio-economic impacts of global warming and sea level rise. We are confident that the IPCC itself will, in its deliberations, take full account of the work of other international scientific fora such as the World Climate Programme and the non-governmental International Geosphere Biosphere Programme. We shall not try to second-guess the Panel. *We recommend that all Commonwealth governments collaborate with the IPCC and encourage participation of their national professional experts in its work, and that the Commonwealth should establish a mechanism in the shape of the Standing Group discussed in para. 4.68 in the proposed Commonwealth Plan of Action and by the strengthening of the Secretariat, so that the implications of the IPCC's findings for member countries can be discussed in a Commonwealth context.*

Enhancing Public Awareness

4.15 The evidence summarized in Chapter 2 and 3 indicates that societies will have to adjust to climate change at a much greater speed than in the past. Significant changes will be needed both at the level of individuals—in diet, farming practices, consumption and energy use patterns, and the home, work and travel environment—and of governments, the latter particularly in respect of policies to maintain large-scale infrastructure such as coastal defences, forest management, agricultural support, fresh water supply, energy generation and health care. The magnitude of the adjustments required is unpredictable, so there is, at present, little by way of precise indicators on which governments can base anticipatory adjustment policies. Moreover, these policies are unlikely to address climate change and sea level rise in isolation from the other major environmental changes arising from mounting human pressures on natural resources and leading to such phenomena as soil loss and erosion, desertification and deforestation. Whatever the context, however, essential action is unlikely to be taken without political will, and this must in turn depend on public commitment. Action by consumers will be needed on many fronts, for example to demand energy-efficient vehicles, well-insulated homes, 'clean' energy supplies and reafforestation.

4.16 Public co-operation and support are more likely if there is a balanced, long-term, campaign to build public awareness of the implications of climate change and sea level rise and of the actions needing to be taken to respond to them. International action is more likely to be effective if information flows smoothly between governments. International organisations, especially United Nations bodies like UNEP, UNESCO and WMO and world-wide non-governmental organisations like IUCN, can do much more than at present to state the case for the concerted international action that the world needs. *We recommend:*

(a) *That Commonwealth governments, national media, national NGOs and educational institutions review and where necessary enhance their machinery for informing the public in their countries of the facts relating to climate change and sea level rise, and the actions citizens should take in response;*

(b) *That Commonwealth governments should exchange data, assessments and plans for responding to climate change and sea level rise, including making use of the machinery of the Secretariat for this purpose;*

(c) *That Commonwealth governments should press the various international organisations to develop and publicise positive programmes and assessments that will promote concerted international action to combat climate change and sea level rise.*

MEASURES TO ADAPT

4.17 Most countries have national development strategies, commonly backed by more specific environment or conservation strategies and regional or local plans. These are commonly based on the assumption that the climate in the next two or three decades will remain the same as in the decades just past. Yet development strategies commonly depend for their sustainability on water supplies, river flow and other factors which are in fact highly sensitive to climate. There is now good evidence that in many regions of the world climate change and sea level rise are highly likely. There must be consequent implications for national plans and strategies of many kinds, and for the detailed policies adopted for sectors of the national economy such as agriculture, forestry, fishery, soil and ecosystem conservation, tourism, energy generation, water resource management, housing, transport and health care. Revision of such plans and policies may avert wasted investment, damage through the misuse of resources, and human suffering. The purpose of this section of the report is to evaluate the case for changes of policy, both generally and sectorally.

National Strategies and Plans

4.18 The existing national plans and national Conservation Strategies, the latter prepared as a consequence of the World Conservation Strategy; (IUCN, UNEP and WWF, 1980) are essentially compendia of knowledge about national environmental resources, and statements of priority for their sustainable use. In this respect they give effect also to the recommendation of the World Commission on Environment and Development (WCED, 1987) that a broad philosophy of sustainable development should be translated into practical measures designed to meet the needs of local communities (who must participate in the process of formulation). Such Strategies have been prepared, or are in preparation, for 23 Commonwealth countries. Virtually all members of the Commonwealth have other national plans or strategies. A few (such as New Zealand) have already embarked on an analysis of how climate change and sea level rise may affect their national situation (Royal Society of New Zealand, 1988). *We recommend that Commonwealth governments examine the sensitivity of the assumptions underlying their national environmental, conservation, development, resource management and land use strategies and plans to the most plausible new scenarios of climate-change and sea level rise, and make adjustments where these would clearly be prudent. Assistance will be necessary to allow some Commonwealth members to undertake this task.*

4.19 Such national evaluation needs to be paralleled locally and within the private sector. Vast sums are involved, in aggregate, in site-specific decisions to invest in sea defences or drainage systems and factories, homes, roads and other facilities. Private investors in domestic property commonly take out mortgages on the assumption that the value of their purchases will at least remain stable (in real terms) over a period of decades. Public authorities also invest in reservoirs, roads and other structures on the assumption of a design life of at least 50 years. Climate change and sea level rise could bring the validity of such assumptions into question unless the issue is faced at the outset and structures are either sited to avoid problems or designed to withstand plausible change. We recognise, however, that substantial difficulties could well arise in practice. Should zoning regulations provide for rising sea level for example? If the regulations underestimate the extent of future changes, then loss of property and, possibly, life would result; if they over-estimate it, then losses could be inflicted as a result of costs unnecessarily incurred in resettlement, or by property owners from blight and unrealised development potential. Another question is how long term investment decisions can be adapted in a consistent way to reflect the success or failure of measures to control greenhouse gases. A haphazard and ad hoc approach by private and public agencies to long term investment decisions could result in much confusion and inefficiency. *We recommend that both in respect of approaches to land-use planning and criteria for long term investment decisions, governments review the procedures that their agencies, local authorities and the private sector should adopt. These national procedures should be developed in dialogue with the professions and communities affected, so that they carry as much consensus as possible. We* *further recommend that Commonwealth governments exchange the results of their national analyses using the Secretariat as appropriate.*

Measures to Safeguard Biological Diversity and Natural Forests

4.20 We have stressed in Chapter 3 that rapid climate change could inflict severe damage on natural forests and other ecosystems because of the inability of species to redistribute themselves fast enough, or the lack of contiguous potential habitats. The consequence could be an acceleration in the already worrying rate of loss of the earth's biological diversity, including species of potential economic significance. The loss of forests could be particularly damaging both because of the value of their produce when managed for sustainable yield and if the result was the accelerated run-off of water and increased incidence of flash floods. Forest conservation and, where practicable, extension, is in any event, desirable because of the contribution that forests make to reducing the 'greenhouse effect' by abstracting and holding carbon. *We recommend that the authorities in those countries whose major forest ecosystems could be seriously affected by climate change should promote research on the adaptability of tree species and consider measures, including assistance to promote the redistribution of key species, so that damage is minimised.* We recommend that national conservation authorities, with the assistance of the International Union for Conservation of Nature and Natural Resources (IUCN) evaluate the adequacy of national protected area networks to conserve their floras and faunas under likely future climate regimes, adjusting these networks where need arises and adjustment is practicable. *We urge member governments of the Commonwealth, in this connection, to give support to the World Conference on Protected Areas, to be held by IUCN in 1992, and to the negotiation of an International Convention on the Conservation of Biological Diversity, being prepared by IUCN and UNEP.*

4.21 A particular responsibility falls on public authorities responsible for maintaining National Parks, Nature Reserves and other protected areas, and for nature conservation generally, especially in the tropical developing countries. As we explain in Chapter 3, these protected areas are crucial to the conservation of the earth's biological (including ecological and genetic) diversity, but few of them are large enough or sufficiently varied topographically to retain the full range of species for which they were established in the face of substantial climate change. It is unrealistic to expect a substantial expansion of these protected areas, given the human pressure on natural resources that has already made a number of them islands of habitat in a transformed landscape. Accordingly, it is important also to develop sustainable development processes in the adjacent regions which allow pockets of semi-natural habitat and species that are not in direct conflict with human activities to persist there.

Agriculture

4.22 For many farmers—at least those who are well informed about the changes that are taking place and who have the resources to adapt—gradual adjustment will be a feasible option. Except for forestry and some tree crops the investment cycle is short and farmers should be able to switch cropping patterns: that is, changing the mix of crops and planting varieties with better characteristics. But climate change will still pose considerable problems for agriculture, especially rainfed marginal farming. Our analysis (for example in East Africa) suggests that such agriculture is particularly vulnerable to climatic variability and it would be very difficult to adapt through progressive adjustment to an increasing frequency of extreme events (Mascarenhas, 1989). This underlines the importance of enhancing research work on crops like sorghum, millet and cassava that have good properties in helping subsistence farmers cope with climatic variability (for example by improving sorghum dehulling and milling technology) and on drought-tolerant cash crops like sunflowers and finding cheap feeds for livestock in drought-prone areas. Furthermore existing technologies and management practices may be insufficient in some contexts and new options required. Agricultural research and development has a long lead time: perhaps 20 to 40 years for establishing a major new crop: 7 to 9 years for a new variety achieved through genetic development; 15 to 50 years for new forage varieties (Decker et al, 1985). Adjustment options also depend on the availability of a wide variety of crop varieties which is, currently, in danger of contracting through processes of agricultural specialisation and species extinction. *We recommend that, in order to maintain maximum flexibility, priority should be given by national, regional and global agricultural research programmes to enlarging long term options for adjustment to changing climate, and gathering and conserving genetic materials and knowledge of plants, animals and agricultural practices that have been valuable under conditions of uncertainty and climatic variability. A particular focus of research could be on varieties that could derive maximum benefit from higher CO_2 concentrations in the atmosphere.*

4.23 It is not only in respect of new or more appropriate crop varieties that long term research is required. Radical changes of land use—from, say, crops to grazing land—that may result from greater vulnerability to climatic variation will require long term planning, re-equipment and restructuring unless major distress is to occur in farming communities. Also, the time horizons for the training of new generations of agricultural extension workers are quite long. *We recommend that govern-*

ments should incorporate into their agricultural extension, training and credit schemes a greater awareness of the implications of climatic change. This would include a closer study of how farmers can be helped to cope with climatic variability through farm management techniques that incorporate efficient use of water and soil, and aggregate crop diversification.

4.24 Greater climatic variability and changing climate will lead to new patterns of food production and, for some countries, greater dependence on imported supplies. The resultant uncertainties underline the importance of adequate national and international systems of buffer stocking and other forms of food security (Slater and Lewin, 1981). The experience of famine in Africa in the 1980s has graphically underlined the vulnerability of poor, marginal, farmers engaged in rain-fed agriculture and normadic pastoralism and the importance of stronger food security systems. The experience of Zimbabwe in withstanding three years of drought without loss of life and little or no food imports attests to the value of strategic reserves. *We recommend that such food security systems be strengthened and take into account the additional demands that may be placed on them by climate change.* Box 4.3 illustrates some of the initiatives now being taken.

4.25 An underlying theme of our analysis in Chapter 3 is that low income developing countries are likely to find the process of adjustment to climate change particularly difficult since a much higher proportion of the population depends on agriculture and other climate-sensitive, resource-based activities and since both individuals and governments have fewer resources to invest in long term adjustment strategies rather than the pursuit of short term survival. Unless there is an active, internationally supported programme to strengthen it, work on the particular needs of tropical agricultural systems will be neglected. Further, future climate change is but one of several factors that need to be taken into consideration in looking at policies to ensure the long term sustainability of agriculture. A good policy environment that provides farmers in these conditions with incentives both to produce more and to adopt sound conservational practices is obviously necessary to ensure that they are well placed to cope with changing climatic conditions.

Coastal Zone Management and Sea Level Rise

4.26 The effects of rising sea level on coastal systems are complex and include temporary and permanent flooding, increased risks of storm surge damage, saline intrusion and increased erosion. At risk are estuaries and coastal wetlands, mangroves, coral atolls, beaches, as well as human land uses as described in the various studies carried out for

Box 4.3: African Government Responses to Disasters, Food Insecurities and Climate Hazards

Several African countries have now developed strategies for handling climate extremes in the aftermath of the disasters of the 1980s.

1. **The Ethiopian Drought Early Warning System** is targeted for three critical roles and types of users:
   - farmers and farm support agencies to help them make early adjustments in response to climate:
   - relief workers, to prepare early food distribution to vulnerable group
   - those analysing past crises.

2. **The SADCC Regional Early Warning System** aims to
   - co-ordinate early warning activities among government agencies;
   - improve objective measurement of crop area and yields;
   - install a system for monitoring food crop conditions during the cropping season as well as for monitoring the general food situation;
   - provide SADCC with regional food security information based on data from national units.

3. **Agro-meteorology** plans are underway to incorporate agro-meteorological data in forecasting using satellite imagery and computer based analysis. National units exist in **Tanzania, Zambia** and **Botswana.**

4. Kenya, too, has made a significant response to the impacts of climate variability. **The Sessional Paper on Food Policy** has among its objectives.
   - emphasising drought-resistant crops such as sorghum and millet;
   - improved monitoring and forecasting of weather conditions;
   - improved dissemination of weather trends.

Source: Mascarenhas (1989).

this report (see Chapter 3). These studies show why even a small sea level rise of say 20 to 30 cms by 2030 could have very significant implications for some countries. It should be stressed however that sea level rise is only one factor that influences coastal zones and various human activities—such as mining or dynamiting coral reefs—can also be extremely damaging as well as making coasts more vulnerable to rising sea level. Because of the interaction between these various factors, natural occurrences such as land subsidence and elevation, the specific ways that rising sea level will be manifest and the places that are vulnerable are not yet well defined. Nor are the range of options available to prevent or adapt to such changes, and their costs and benefits, clearly identified. Often in countries presently experiencing problems of relative sea level rise, the response proceeds piecemeal, with little attention to long-term planning for the preservation and development of coastal resources. We therefore recommend two major activities that individual nations could undertake to improve planning. *First, all governments should endeavour to identify—and developing countries should be helped to identify—areas of vulnerability to the effects of sea level rise based on detailed survey data and plausible global assumptions about the likely rise.* Second, *all governments should take initiatives to develop national coastal zone management policy. This should include consideration of sea level rise analysis leading to a full range of options (including land use regulation, engineering works, managed flooding) that could be implemented to deal with the future threat.* Guidance in development of comprehensive coastal zone management policy will be necessary and the Commonwealth Science Council, among other agencies, can provide assistance.

4.27 One option that might well emerge from such an assessment is to prevent loss of settled and cultivated land, and this will require coastal defence measures. Various steps are involved in planning, including consideration of types of sea defences, their dimensions, construction materials and phasing; water resource management (gravity or pump drainage); design of ports and navigation systems and avoidance of damage to natural sea defences such as coral reefs, mangroves, marshes, and dune and shingle systems. The case study prepared for the Secretariat on Guyana provides an example of the kind of exercise governments might embark upon at this stage as a precursor to detailed engineering studies (see Box 4.4). This study underlines two key points of importance. The first is that anticipatory planning and a staged programme of works accompanied by continued monitoring and feasibility analysis are much preferable both to doing nothing—and suffering the costs of flooding—or to belated, once and for all, construction projects. Second, it is possible, using local experience and expertise in constructing sea defence and drainage systems, to improvise relatively

Box 4.4: Sea Defence Options for Low Lying States: Guyana

An engineering and economic survey was carried out for Guyana on the assumption of a 0.25 metres sea rise by 2020; 0.50 metres by 2040 and 1.5 metres by 2090.

It concluded that without a long term—30 to 40 year—programme for raising and strengthening coastal protection and improved drainage, there could be a serious loss of agricultural land, agro-industry, housing and infrastructure. Most of the population lives 0.50 metres above mean sea level. Retreat to higher land is not seen as providing a rapid solution but will take place gradually over a long period.

A phased programme of work is recommended as follows:

* careful monitoring of sea level, detailed hydrographic and hydrological surveys and a full feasibility study for a long term programme
* short term (5 year) construction programme for enhancing flood protection and drainage programmes. This involves land acquisition; building new embankments; raising and strengthening existing embankments including remodelling and raising existing sea walls. An outline estimate of a five year programme, including feasibility analysis, puts the cost at $22 mn (US)
* strengthening embankments further with boulder revetments
* after the five year programme, enhancing the existing gravity drainage system by, for example, rehabilitating and remodelling outfall sluices
* in the longer term, 20 to 25 years hence, extending pumped drainage and installing new and larger pumping systems.

Source: Camacho (1988).

inexpensive, but effective, protection. While Guyana's future sea defences will rely heavily on major investments undertaken in the past, it is possible to suggest how the system can be modestly improved. The Guyana first stage programme is costed at $22 million over 5 years. This is a very large sum for Guyana but it contrasts with the current programme in the Netherlands, where defences for a similar, dyke-protected, low lying industrial country are costed at $8 billion. *We* *recommend that low lying developing countries should try to draw on the experience of other developing countries in relation to sea defences rather than necessarily accept design specifications based on industrial country experience. The Commonwealth and other international organizations could facilitate such "South-South" transfer of knowledge.*

4.28 In some cases, particularly *small low lying coral atolls,* sea defences are not a cost-effective option even if they are technically feasible, which may be in doubt (in many cases the sea would simply rise through the porous rock of the islands themselves). In relation to the Maldives for example extensive sea defence systems are seen as technically dubious and economically unjustifiable (Edwards, 1989). Similarly, the papers commissioned on Tuvalu, Tonga and Kiribati (Lewis 1988; Maclean, 1989) see little merit in what Lewis disapprovingly calls "citadels in the sea". *We recommend therefore that small island states consider proposals for major sea defence systems with extreme caution and only proceed when all other options are exhausted and a positive social and economic benefit-cost outcome is demonstrated.*

4.29 Our analysis of vulnerable low lying states suggests to us that there are a good many, low cost, adaptation mechanisms that could provide a viable option for the forseeable future unless the more extreme forecasts are realised (see Box 4.5). Such strategies should always include an assessment of the potential for maintaining natural defences with their own economic value in the shape of mangroves, reefs and marshes. *We recommend that such states be encouraged and assisted to devise adaptation strategies in such fields as beach management to maintain natural sediment replenishment, crop diversification, modified construction standards, rainwater collection, improved environmental health programmes, in-filling low lying lagoons and pits, prevention of erosion and efficient disaster preparedness systems.* In many instances indigenous foods and medicines, building forms and societal structures are well adapted to the needs of climatic adjustment and are underused.

4.30 A similar conclusion emerges from the study of vulnerable *deltaic areas* of which the most seriously threatened—by a combination of river and sea flooding—is Bangladesh (Mahtab, 1989; Brammer, 1987). Experience has shown that flood protection through constructing new and modified embankments can often be extremely expensive and ineffective, or even counter productive. At best it provides a partial solution. The Bangladesh study by Mahtab (1989) recommends *allowing low lying land to be flooded on a controlled basis to accelerate the siltation/land accretion process. We would commend that this option be investigated in detail as a basis for strategic planning.*

Box 4.5: A Strategy for Adjustment to Sea Level Rise: A Pacific Atoll

A Secretariat study of Pacific atolls predicts a serious deterioration in the quality of life on some low lying atolls (Tuvalu, Kiribati, Tonga) and greater proneness to disasters in the event of significant sea level rise. Abandonment of low lying islands is regarded as unacceptable except in *extremis* and probably unnecessary. Large scale sea defences are regarded as too expensive and simply inappropriate. In any event, the uncertainties about the magnitude of future sea level rise underline the need for considering modest steps that could be taken now and may be attractive on broader grounds. An adaptation strategy has been recommended on the following lines for Tuvalu but has wider application:

* diversify *food supply* from traditional pulaka, taro and other crops grown in pits to sweet potatoes, fish and vegetables
* revise *construction* standards to incorporate raised floors and better wind resistance
* replace ground water dependence with better *water* collection from rain (UNDP and Save the Children Fund are already assisting)
* to anticipate growing *health* hazards, improve preventive health programmes and improve storage facilities to lessen dependence on salt
* *landfilling* of waste pits and inland lagoons to create land (and reduce health hazards)
* stabilise and strengthen the *tropical cyclone* protection bank
* stronger commitment to protect *coral reefs* and prevent *coast erosion*
* *information and training* are needed to raise local consciousness (already quite strong) of the dangers, and also of ameliorative options
* modest and gradual *emigration* (not abandonment) to relieve population pressure
* increase tropical cyclone *early warning and preparedness* capability.

If sea level rise is no more than, say, 50 cm by the middle of next century, Tuvalu and other islands could adjust, by means of self help together with aid from supportive donors.

Source: Lewis (1988*b*).

In practice a combination of techniques will have to be adopted including embankments to protect urban areas. If controlled flooding were to be used, in the flood plains and low lying coastal areas (including the Sunderbans mangrove forest), a major network of sluice gates, fish passes and drainage pumps will be needed to permit maximum possible siltation with minimum flood damage. *We recommend that Bangladesh's aid donors should consider with the Bangladesh Government whether such a programme is feasible and how it might be organised and funded.*

4.31 We have already emphasised the importance of protecting natural systems that provide resilience to coastal areas such as coral, mangrove, costal dunes and wetlands. This may well involve action to prevent interference with these natural systems by—for example—the use of explosives or coral mining on reefs, dredging or in-filling swamp areas or cutting of mangroves. It may also involve enhancing their ability to keep pace with a rising sea by hydrologically sound management of coastal sediment movements. Finally, it may demand curbs on encroachment by development from the landward side of the zones occupied by these formations. These are important elements in an integrated approach to coastal zone management which governments should endeavour to adopt.

4.32 If a decision is made to retreat from some or all of a threatened area, a policy framework will need to be designed which incorporates land use planning to inhibit (or prevent) new development in the area, resettlement of those displaced, rebuilding of facilities and compensation to assist resettlement. It is recognised that while, in industrial countries, this problem can be dealt with on a planned basis using zoning controls, in developing countries there is much spontaneous, technically illegal, squatting in coastal and riverine margins, marsh and waterlogged areas, coastal plains and deltas and it is these people who are at greatest risk. Our studies have identified vulnerable coastal areas of Bangladesh, and possibly some small islands, as areas where some resettlement is likely to be necessary and *we recommend that the governments concerned start to plan the process, with a view to seeking overseas assistance both for finance and help with resettling any displaced population.* We emphasise the need to handle resettlement projects with immense sensitivity to the feelings of the people concerned, recognising the need for full dialogue and training in the new life styles relocation may involve and careful integration of those moved into the communities with which they are associated. We would however stress that, for most low-lying states total abandonment of land is a very long term option and probably unnecessary. The scenario of countries such as Maldives, Kiribati and Tuvalu having to be given up for habitation is only relevant on the most extreme and long term forecasts and careless use of these scenarios is a source of unnecessary alarm.

Disaster Management

4.33 We have argued that global warming—accompanied by greater climatic variability—could be the cause of more severe disasters: drought, hurricanes, and storm surges causing sea flooding (there is an unresolved controversy over whether greater severity or frequency is more likely). Adaptation could take two forms. One is to reduce vulnerability to disasters through careful attention to building design, the location of settlements and economic diversification. The other is to ensure that when disaster strikes there is adequate shelter; services are capable of being maintained and mobilised quickly; food and medical equipment are available to be brought to the scene; and rapid rehabilitation arranged. There is now a lot of experience of managing disasters and there is good appreciation of the best practices that should be followed. While adequate warning systems for tropical cyclones, storm surges and floods require *regional* co-operation, for example within WMO's five regional tropical cyclone bodies, preparedness systems must be developed at a national level. *We recommend that all governments of countries prone to climate-related disasters should review and improve or institute comprehensive systems of disaster warnings and preparedness. International agencies including the Commonwealth Secretariat, should be prepared to give well co-ordinated assistance in formulating such systems as well as in disaster relief and rehabilitation.* The impending International Decade for Natural Disaster Reduction (1990-99) should be a focus of these efforts.

4.34 In preparing international support for disaster management, an underlying assumption must be that—with the important exception of Bangladesh which has a uniquely high level of disaster vulnerability—the most serious *proportional* impact of natural disasters is in small states, some of which have seen well over half their housing stock and crops wiped out by hurricanes. And particularly in relation to sea level rise and associated flooding, it is simply a matter of arithmetic that the ratio of threatened circumference to surface area is highest in small island states. Particularly in the light of the Commonwealth's distinctive membership, *we recommend that high priority be given to disaster warning and preparedness in small island states, as well as to the great needs of Bangladesh.*

PREVENTIVE MEASURES FOR GREENHOUSE GAS EMISSIONS

Policy Scenarios

4.35 How willing governments are to deal with global warming by preventive action naturally depends on their own political priorities and their ability to extract themselves from short term preoccupations. We believe however that, globally, *there should be two over-riding policy objectives. The first is to maintain a brisk tempo of economic growth targeted to overcome third world poverty.* The World Commission on Environment and Development (WCED, 1987) argued that developing countries should realistically aim for 5 per cent GDP growth—averaging 3 per cent per capita growth—and that seems to us of the right order of magnitude. Industrial countries, including Eastern Europe, will probably wish to continue growth in excess of 2 per cent, and nearer 3 per cent a year, provided this growth can be put on a sustainable basis. But a *second objective must be to reduce substantially the commitment to global warming implied by the continuing emission of greenhouse gases.* It has been suggested (by the Toronto Conference) that a target rate of warming of 0.1°C per decade should be adopted—about a third of the expected rate of warming by 2030. This seems to us on the one hand unduly arbitrary and precise given the uncertainties in the scientific predictions, and on the other, only acceptable as an interim target pending measures that will bring the process of warming to a halt. But of the need to cut the warming commitment substantially, there is no doubt. The issue is how rapidly it can be reduced and the level of ultimate stability.

4.36 One approach is to look at some of the scenarios currently being considered by the international community. The Expert Group on Emission Scenarios of the IPCC's Response Strategies Working Group has been working on three alternative scenarios:

a) an increase in the greenhouse effect equivalent to a doubling of pre-industrial CO_2 concentration by 2030;

b) a doubling equivalent by 2060;

c) a doubling equivalent by 2090.

In each case, approximate stability is achieved thereafter.

4.37 The models developed by the group incorporated the effect of estimated change in population, GNP, energy demand and supply, control technology, CFC controls, deforestation and agriculture and, for each year, provided an analysis based on higher or lower rates of economic growth. The results demonstrate that the targets set by the Group could in theory be attained by a number of different routes. A key challenge is to break the link between high rates of economic growth and high greenhouse gas emission. Timing is crucial: if measures to meet the

2090 target begin in 2000 a gradual CO_2 reduction of about 20 per cent will suffice whereas if controls do not begin until 2020, a 75 per cent reduction would be needed.

4.38 Specifically, how can rapid growth and moderated global warming be achieved simultaneously? The clue lies in energy efficiency and the shift in aggregate consumption between developed and developing countries. In developing countries energy consumption is bound to rise rapidly with increasing growth and development since development is strongly linked to primary production and because of the substitution of non-commercial by commercial energy (a process which—in the case of wood burning in particular—is environmentally desirable in itself). By contrast, growth in developed countries should become less energy intensive with the spread of information technology. The scenario of 'climate stabilisation' described in Box 4.6 seeks to reconcile our two major objectives set out above (the CO_2 doubling envisaged there is between (b) and (c) on the IPCC scale of possibilities). The conditions required are however severe: an unprecedented intensification of energy efficiency; phasing out both CFC and eventually coal use entirely; much higher real energy prices; and a much bigger role for renewable fuels and nuclear. On the other hand, the price of inaction has been assessed by the same author, who suggests, that with unchanged policy from today, the additional global warming commitment by 2075 could be as much as 2.5 to 8°C. While we do not necessarily endorse all the details of the scenario suggested, it seems to us to suggest an approach consistent with a desirable outcome.

4.39 While we do not underestimate the importance of greenhouse gases other than CO_2, especially the CFCs, it is clear that the focus of any preventive policies must be CO_2 emissions, and the energy sector, which are (both) expected to contribute over 50 per cent of global warming in the 1980-2030 period (see Ch 2). Various long term energy scenarios have been suggested based on different assumptions (see Table 4.1). Of these, those that lead to global energy consumption of much over 15TW by 2030 (from the base level of around 10TW) are not consistent with a moderation of global warming. Those that assume a global per capita income growth of under 2 per cent, or even 2.5 per cent, are not consistent with development and a reduction in third world poverty. Only one of the scenarios satisfies both conditions (Goldenberg *et al,* 1987) and, like the scenario in Box 4.6, assumes a sharp reduction in per capita, and total, energy consumption in industrial countries due to a combination of energy efficiency and a shift in the structure of developed countries' economies away from high energy consuming industries towards information based industry and services. At the same time there is some increase (by 25 per cent) in per capita energy consumption in the developing world—leading the developing world to overtake the industrial world as energy consumers

Box 4.6: A Climate Stabilisation Scenario

There are many possible long term climate change scenarios. While we have no particular commitment to the arithmetic of this one, we are attracted to its underlying assumptions which provide for rapid growth in the developing world and a significant slowing down of global warming. The details are less important than the broad thrust of policy proposed.

The underlying policy objectives of the scenario are:

* to maintain rapid economic growth globally, and strongly rising per capita incomes in the third world. Global per capita income continues to rise by 2.7 per cent per annum Global population is held to a 'low' projection of 8 billion by 2075 from 5 billion today. Average per capita incomes in developing countries reaches current Western European levels by 2025/2030.
* to slow down global warming to 'acceptable' limits, doubling of CO_2 is postponed beyond 2075. The scenario assumes equilibrium warming of only 0.6 to 1.7°C from *additional* activities by 2060 (on top of warming already committed).

To realise these ambitious objectives, the scenario author calculates that the following conditions need to be met:

* annual growth in energy efficiency of roughly 1.7 to 2.4 per cent in industrial countries and 1.4 to 2.3 per cent in developing countries. This is about double the rate of growth of energy efficiency in the last decade (1 per cent).
* specifically in industrial countries, energy efficiency of transport is assumed to improve 50 to 60 per cent by 2025; the energy intensity of industry to fall by 15-50 per cent; household and office building energy intensity to fall by 45-75 per cent. Overall, per capita energy use in industrial countries falls at 0.35 per cent per annum; rises in developing countries by 0.8 per cent; and rises globally by 0.7 per cent per annum.
* Coal prices and/or taxes rise sharply and use of coal as thermal power fuel ceases by 2075 to be replaced by natural gas, hydro, biomass, solar or nuclear energy. Gas and oil prices rise four times in real terms.
* Deforestation slows and is reversed by 2025.
* The Montreal Protocol is extended to reduce industrial country CFC use to zero by 2020 and developing country use to zero by 2050.

Source: Mintzer (1989).

within the next 30 years. But, even at that point, their per capita energy consumption is still well under half that of the industrial world. Table 4.2 shows the large discrepancy in per capita energy consumption between developed and developing countries, particularly for commercial energy. Development is bound to reduce that disparity as developing countries industrialise, replace non-commercial by commercial energy and extend to all their citizens some of the basic amenities—such as domestic lighting and commercial energy for cooking—that richer countries have long taken for granted.

4.40 The conclusion that clearly emerges is that, if room is to be left for adequate economic growth, particularly in developing countries, effective action to halt the greenhouse effect requires a much more stringent approach to energy conservation and a greater emphasis on non-fossil fuels.

National Options for Reducing CO_2 Emissions

4.41 Recent analyses for the United Kingdom—see Box 4.7—have examined how far it might be possible to reduce national carbon emissions to 50 per cent of the 1988 levels by 2020 which means a reduction of 130 million tonnes per annum from the projected level of 210 m.t. assuming continuing growth in energy consumption. In one of the exercises, the options examined appear together to be capable of delivering this target, but it must be emphasised that there are complex interactions between the options, and may present practical, economic and presentational difficulties. There are also different combinations possible, depending on the willingness to use more nuclear power. These conclusions parallel assessments made for other developed countries. For example, in the United States, the NRDC (1987) assessment of the means for reducing national CO_2 emissions by 20 per cent by 2000 comes up with a mixture of enhancement of efficiency of energy use in building, lighting, appliances, industry and vehicles (14.8 per cent), use of renewable energy (2.8 per cent) and forestry and urban tree planting (4.5 per cent), giving a total of 22.1 per cent saving which could rise rapidly to over 30 per cent by energetic pursuit of the same basket of options. Clearly some options are capable of substantially contributing to reduction of CO_2 emissions, but all need thorough world analysis from a technical and economic standpoint as well as from that of public acceptability. *We recommend that all developed countries in the Commonwealth conduct such analyses and discuss the conclusions that result.*

Energy Efficiency and Conservation

4.42 It is clear from virtually all the analyses that have been undertaken that the prospect for a major economy in CO_2 emissions lies in greater efficiency in the producton of energy and its end use. This, therefore, is a good place to start since it has benefits other than its contribution to alleviating the 'greenhouse gas problem': also reducing problems of 'acid rain' and pollution more generally. There is little debate over the general desirability of energy efficiency, though there is debate over its technical and economic feasibility and over the contribution from different sectors.

Table 4.1: A Comparison of Selected Global Energy Studies

		1980 (base year)	1	2	3	4	5	6
	GDP Growth per capita per cent	-	3.0	1.1	1.2	1.6	2.0	2.1
Total primary Energy consumption (TW/Yr)	World	10.3	11.2	5.3	14.4	18.8	24.7	35.2
	Industrial countries	7.0	3.9	3.6	7.2	12.7	14.8	20.1
Per capita Energy consumption (TW/Yr)	World	2.3	1.61	0.65	1.81	2.55	3.2	4.41
	Industrial countries	6.3	3.15	2.28	4.64	8.52	9.67	12.9
	World Population (bn.)	4.43	6.95	7.98	7.98	7.36	7.72	7.98
	Projection Year	-	2020	2030	2030	2025	2020	2030

Note: Data selected from Goldenberg, J *et al,* (1985).

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4.43 Substantial improvements have already occurred—at least, in developed countries, where energy saving technologies have been

Table 4.2: Global Distribution of Energy[a]

Region/Country	Population (Millions)	Per Capita Energy Use—Commercial									Total Energy Commercial (million Tons Coal Equiv)	Non-Commercial Energy Use[e] (as of total energy use)
		Liquids[b]		Gases[c]		Solids[d]		Hydro and Nuclear				
		Kg Coal Equiv	Percentage of Total	Kg Coal Equiv	Percentage of Total	Kg Coal Equiv	Percentage of Total	Kg Coal Equiv	Percentage of Total	Kg Coal Equiv		
World	4,919.5	752	40	425	22	627	33	90	5	1,896	9,332	15
Industrial Market Economies	797.2	2,685	47	1,275	22	1,445	25	375	6	5,770	4,600	-
United States	240.1	4,250	45	2,360	25	2,490	26	390	4	9,489	2,278	2
Western Europe	353.2	2,060	48	840	19	1,050	24	360	8	4,298	1,518	-
Japan	121.4	2,042	56	466	13	858	24	259	7	3,625	440	-
Centrally Planned Europe	397.2	1,649	26	2,130	34	2,290	37	150	2	6,220	2,469	-
Developing Market Economies	2,583.9	305	53	82	14	160	28	28	5	578	1,493	52
Brazil	138.5	465	61	27	4	97	13	172	22	760	105	34
India	772.6	69	25	9	4	185	68	9	3	272	210	52
Bangladesh	100.8	22	35	40	62	1	2	1	1	62	6	69
Africa[f]	539.7	162	64	63	25	16	6	11	5	252	136	80
China	1,057.2	97	14	18	3	580	82	11	2	706	743	36

[a] Unless otherwise indicated, data is from United Nations "Energy Statistics Yearbook," 1986: U.N. 1988. Is for commercial energy only.

[b] Liquids are composed of consumption of energy petroleum products including feedstocks, natural gasolene, condensate, refinery gas and input of crude petroleum to thermal power plants.

[c] Gases include the consumption of natural gas, net imports and changes in stocks of gas-works and coke-oven gas.

[d] Solids comprise primary forms of solid fuel (hard coal lignite, peat and shale, net imports and changes in stocks of secondary fuels).

[e] Estimated based on 1980 figures. (Hall Bennard and Moss. Biomass for Energy in Developing Countries.)

[f] excludes South Africa.

Box 4.7: Options for Reducing British CO_2 Emissions

Target: 50 per cent reduction in 1988 emissions over the period, 1988–2020
(reduction from projected 210 million tonnes per annum in 2020 to 80 million)

Option	*Estimate 1 % of target*	*Estimate 2 % of target*
1. Reafforestation (area increased from 10 per cent of the UK to 25 per cent)	2	2
2. Generate energy from organic wastes	2	1
3. Energy conservation (better building insulation; more efficient lighting; more efficient motors; more efficient vehicle design; improved building and process control; combined heat and power)	40	40
4. Less CO_2-producing fuels use in transport (conversion to gas)	11	5
5. Remove CO_2 from power station fumes (not yet proven)	2	2
6. Renewable energy sources (bio fuels, wind, hydro, tidal, waves, geothermal)	7	7
7. Nuclear	22	11
8. Fuel substitution (e.g. gas for coal)	14	12
9. Unaccounted for	–	20

Source: Currie, 1989; Dale 1989

available and affordable. Between 1973 and 1985, total energy use per capita in OECD countries fell 6 per cent while per capita GDP rose 21 per cent. In Japan, there was a fall in per capita energy use of 6 per cent while per capita GDP rose 46 per cent. Provided high, real, energy prices continue to provide an energy-saving incentive, the US Department of Energy has argued that increasing energy efficiency could reduce CO_2 emissions by 60 per cent by 2050—around 1 per cent a year—and other widely quoted studies suggest a 70 per cent cut is feasible by 2030—that is by 2 per cent a year, as in the decade after the oil crisis (Lovings, 1981). This is consistent with the 'stabilisation' scenario sketched earlier but goes beyond the data for the UK in Box 4.7. A potential for further, large energy saving exists in power plant technology (mainly from cogeneration of heat and power); a switch in economic structure to less energy-intensive high-tech industries and services; more energy-efficient homes and offices (ranging from energy efficient light bulbs to better heat insulation) and less-fuel-consuming cars and domestic appliances.

4.44 In developing countries, however, there has been no discernible slowdown in energy consumption per unit of GDP since the 1970's oil price increase. Per capita energy use has grown by 3.5 per cent per annum since the mid-1970s. In part, this reflects healthy developments: rapid economic growth in Asia; reduced reliance on non-commercial, mainly wood, fuel; increased industrialisation; economic diversification. But future energy consumption growth of this order (which would take developing country consumption from 2 TW to 15 TW in 2020) will be difficult to sustain economically even if it were acceptable environmentally. It relies primarily on fossil fuels. Moreover, there is abundant evidence of wasteful energy production, transmission and use, whether by highly inefficient wood burners in poor households or energy intensive industrial processes. In industry, in particular, there is scope for substantial improvement. By contrast, households generally need more energy for lighting, cooling and refrigeration—even if some economies are possible. It has been estimated that a recognised basket of basic needs in developing countries could be met with an increase of only 20 per cent in per capita energy use if efficient methods were used, whereas without them the increase would have to be 100 per cent (Goldenberg *et al*, 1987).

4.45 We accept the weight of evidence which suggests that improved energy efficiency can play a key role in reducing CO_2 emissions in developed and developing countries. But without active support for energy-saving technologies—in terms of R&D, promotion, extension services and, in some cases, use of tax incentives or direct subsidisation—the adoption of better practices will lag well behind technical possibilities. *We strongly recommend, therefore, that all governments should give energy conservation and efficiency high priority in policy and planning; provide direct support or fiscal incentives to research, development and applications of energy conservation and low energy technology; and in some cases impose technical standards that will compel greater energy efficiency. Further, given the growing importance of developing countries in* CO_2 *emissions, we also believe it is vital to give* *priority to ways of helping them to adopt energy efficient methods through capital aid and technical assistance. A particular focus of technical assistance might be training in designing energy efficient systems for agriculture, industry, construction and commercial building.*

Taxes, Prices and CO_2

4.46 An important ingredient in policies designed to encourage energy efficiency and substitution of fossil fuels by other forms of energy could be the use of taxes and/or user charges designed to curb the consumption of CO_2 emitting fuels and to finance alternatives. In addition, the windfall gains—or economic 'rents'—from higher energy prices would accrue to non-fossil fuel producers and thereby act as an incentive to them to increase their activities. Some consideration is already being given in some countries to the idea of a 'carbon tax', or variants of it, to be introduced either nationally or as part of a multilateral approach. We do not believe that the analysis has yet come to the point at which a major new initiative of this kind could win general acceptance. But energy pricing policies and fiscal measures can undoubtedly be used in a more general way to provide a major incentive for energy efficiency.

Energy Generation with Reduced CO_2 Emission

4.47 In our judgement, energy conservation is the most efficient and economic way of reducing carbon dioxide emissions. But another approach is to generate electricity using techniques that emit less, or no, CO_2. The options here are:

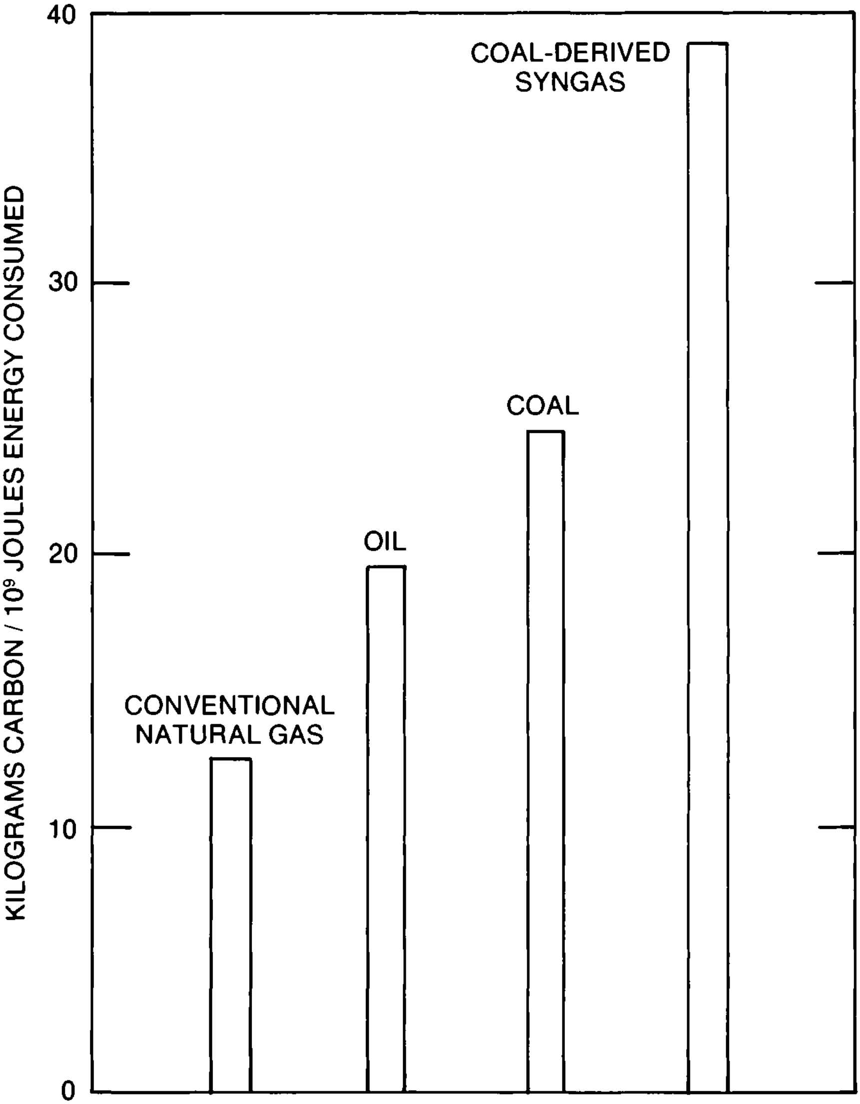
(a) the increased use of fuels that emit less CO_2 per unit of energy produced than coal;

(b) the increased use of 'renewable' sources of energy;

(c) the increased use of nuclear power.

4.48 For a given amount of energy generated, natural gas produces 60 per cent and oil 80 per cent of the carbon dioxide that coal does (Figure 4.1). However, substitution is only practicable if natural gas is available on economically favourable terms. Where this is the case, such substitution is obviously desirable, especially to avoid the waste of energy and needless augmentation of the greenhouse effect that occurs when gas emitted as a by-product of oil extraction is 'flared' (or burned) off. Some developing countries, notably India, are now actively seeking to maximise the use of such natural gas for power generation and industrial purposes. *We recommend that Commonwealth countries should, where practicable, substitute natural gas for coal as a basis for energy*

Figure 4.1: Different Fuels and Carbon Emissions



Source: Koomanoff, F A (1988), US Department of Energy.

generation and should make special efforts to prevent flaring of such gas in significant quantities.

4.49 One possible way of reducing carbon dioxide emissions while maintaining the familiar and established use of fossil fuels to generate electricity would be to filter the CO_2 out of the flue gases prior to discharge. This is technically possible, but the carbon removed still has to be disposed of—for example by pumping or dumping a calcium carbonate slurry into the oceans or into cavities on land. Such disposal would present other environmental problems, and even sympathetic reviews of the likely technologies describe the cost as 'astronomical' (Simon, 1986). *We recommend that this option should not be given priority attention at the present time.*

4.50 The possibilities of using non-conventional energy sources—such as solar, wind, geothermal and tidal power—have been discussed extensively over the recent decades but they have yet to be adopted on a wide scale and most are only economic in particular local circumstances (wind power, for example, is most attractive on exposed coasts and islands). Advances are being made—the cost of photovoltaic cells has fallen to under a quarter of its 1980 level as production has multiplied tenfold; solar heating for domestic use is widely used in some countries (Cyprus, some Caribbean islands) and solar cookers have been designed and marketed in several developing countries—but not rapidly enough to alter the energy picture in this century at least. Of more traditional sources, major hydropower schemes provide energy on a substantial scale in some countries, but there are often major environmental arguments against extending its use. Geothermal sources have only proved attractive in a few restricted areas and commercial biomass utilisation (most commonly to produce alcohol used as a transport fuel) is practicable only in areas with a surplus of plant production. *We recommend that Commonwealth governments continue to develop a range of renewable energy sources, and to exchange knowledge of suitable technologies, but we emphasise that assistance will be required to enable many developing countries to apply these, especially where capital costs are high (as with major hydropower projects).*

4.51 The most difficult issues arise in connection with the substitution of nuclear power, which has no CO_2 (or SO_2 or NO_x) emissions. Despite these attractions, there is widespread public aversion and political resistance to nuclear power stations in many countries, especially in the aftermath of the Chernobyl disaster which demonstrated that a nuclear reactor failure—unlike that of any other energy source—could have a sudden and widespread impact on environment across a continent. Moreover, the disposal of nuclear wastes has still not been achieved to the satisfaction of public opinion. Granted the continuing spiral of investment in safety, there are doubts about the economic viability of additional nuclear capacity at the kind of energy price levels now prevailing globally. How these safety, environmental, economic and other (e.g. security) factors should be weighed is a matter that calls for political as much as technical judgement, and remains a controversial issue in two Commonweath countries: Canada and the UK. The view taken by the World Commission on Environment and Development and by the Toronto Conference was that nuclear power could play a part in reducing CO_2 emissions, if these problems of safety, waste disposal and prevention of nuclear weapons proliferation could be solved. We consider that such solutions (which must satisfy the informed public as well as experts) are unlikely in the short term. We also consider that nuclear power is unlikely to be a practical option in most developing countries because of the large initial investment and the continuing need for substantial resosources of trained manpower (though we note that India has an expanding programme). Accordingly, we do not believe that nuclear energy will contribute on any large scale to the reduction in greenhouse gas emissions. *We recommend that those Commonwealth countries that are committed to the expansion of nuclear power pay added attention to the need to reassure their publics and international opinion by demonstrating the safety of reactors and of waste disposal systems.*

4.52 Our analyses indicate that humanity will have, as a matter of prudence, to stabilise its combustion of fossil fuels as one component of action to stabilise atmospheric greenhouse gas concentrations. The preceding paragraphs demonstrate, however, a dilemma summed up in the colloquial comment that 'there's no such thing as a free lunch'. There is no readily available cheap—let alone free—alternative energy available. Moreover, apart from energy conservation, which is clearly acceptable to everyone provided the price is tolerable, no alternative avoids opposition from some quarters. Nuclear power is the subject of widespread public concern, and among some sectors, hostility. Large hydropower schemes are opposed because they commonly inundate fertile lowlands or forests, intrude into cherished landscapes, and displace human communities. Estuarine tidal barrages are unpopular because of their impact on intertidal wetlands. Extensive use of wind generators would be likely to excite opposition because areas of high wind exposure are often also sites of high landscape quality. At present, fossil fuels, despite being the source of a range of major atmospheric pollutants (sulphur and nitrogen oxides, mercury and particulates as well as CO_2) are familiar and relatively cheap. Major industries (such as mining) depend on their continued use. Policies to reduce fossil fuel consumption have to be designed with the recognition that there are no easy alternatives. *We recommend that Commonwealth governments, as a part of the campaign of public awareness advocated above, hold informed debate on the optimal national energy generation policies, taking all the needs, costs and benefits into account.*

Reductions in CO_2 Concentrations Through Forests

4.53 Deforestation is said to be the source of between 10 per cent and 30 per cent of the carbon dioxide released annually to the atmosphere by human agency (Chapter 2). Halting—or slowing—the process is attractive for many reasons. First, a significant input of CO_2 would be reduced or stopped. Second, there are good reasons for believing that national economies in tropical forest countries would secure optimal economic returns, maintained indefinitely, from the sustainable use of forest as sources of selectively-extracted timber, nuts and other fruits, medicinal plants, wild animal protein and other products, while the retention of the forest also reduces water run-off and helps to stabilise river flow. Where forests have been cleared, cultivation has not been generally easy to sustain on the bare land, pasture production has been low, and soil erosion a problem. While there are, of course, tracts of land in many tropical countries where conversion to agriculture is inevitable and right, there are many other areas where national economic interest and the global interest in reducing greenhouse warming combine to favour forest retention. However, such policies are impracticable unless there is assistance for programmes of sustainable development that meet the needs of the growing numbers of poor people who are encroaching on the forest in the search for land to cultivate. *We recommend an increasing effort within the Commonwealth to maintain as much as possible of existing forest, and (except in areas designated for special protection) to utilise them in a sustainable way for the benefit of local and national communities.*

4.54 There are various estimates of the contribution that programmes of reafforestation would make to halting global warming. These are based on calculations which suggest that 1–2 billion tonnes of carbon would be removed from the atmosphere annually for each 100 million hectares of forest planted, the process of extraction continuing for the 30 years or so during which the trees continued to grow actively (Myers, 1989). Such an area appears vast (it is equivalent to the UK, France and the Federal Republic of Germany added together) but is about equivalent to the amount of 'wasted land' already cleared but not settled within the tropical forest zone. Reforestation might well be the most economically productive use of such land. In addition, in many areas that are used and settled, agroforestry (a mingling of tree, bush and herbaceous crops) offers the attraction of high productivity, a wide range of useful produce, erosion control and enhanced CO_2 uptake. While we accept that reafforestation cannot reach the immense scales suggested above in the foreseeable future, *we recommend that Commonwealth countries, as part of their national land use and conservation* *strategies, identify areas where reafforestation is the most rational policy, and pursue it, with assistance where necessary.*

Action Against Other Greenhouse Gases

4.55 The contribution of other 'greenhouse gases' to global warming has been emphasised in Chapter 2. By 2030, the combined warming effect of these gases—CFCs, nitrous oxide, tropospheric ozone and methane—could be as great as that of CO_2.

4.56 In respect of one group of these gases—the CFCs—a major step forward has been taken as a result of the Montreal Protocol which provides an international framework for regulatory measures to stabilise, then reduce, global production (Usher, 1989). The greenhouse gas role of CFCs was not specifically taken into account in the Protocol, under which CFC (and halon) regulation relates to their ozone depleting potential. Nonetheless, there is an indirect benefit from measures to reduce CFCs and the definition of 'acceptable' substitutes refers to their total environmental effect. *We recommend that the definition of acceptability of the substitutes should specifically take into account their potential contribution to global warming.*

4.57 It is too soon to judge the effectiveness of the Protocol. Conferences in London and Helsinki in 1989 have, however, agreed on the need for strengthening of the Protocol and the acceleration of its implementation, with the aim of the earliest practicable elimination of CFCs and other substances which deplete the ozone layer. Reservations have been voiced by several countries with regard to the disparity in the permissible levels of per capita consumption implicit in the Protocol and the inadequacy of arrangements for technology transfer. *We recommend that all governments ratify the Protocol, strengthened where necessary to ensure an equitable sharing of the costs of implementation, to provide effective financial and other arrangements for technology transfer, and to hasten the process of elimination of ozone-depleting, greenhouse-gas chemicals.*

4.58 Consideration of policy measures to address other greenhouse gases is much less advanced. For the main sources of *methane* emission—ruminant animals, rice paddies and marshes—little can be done without radical intervention in natural or agricultural processes that would scarcely be justified by the scale of the problems originating fom this source. In some cases, intervention could be counterproductive in agricultural terms (reducing rice yields), or in environmental terms (eliminating ecologically beneficial marsh land). However, there are some useful initiatives that could be taken. In developed countries, considerable quantities of methane are emitted from domestic and other refuse disposed of in landfill. If this organic waste or methane were utilised for energy generation or heating, coal would be saved and CO_2 dioxide emissions reduced. In the energy sector, methane emissions could be reduced and efficiency enhanced by reducing leakages from natural gas distribution systems. *We recommend that governments take appropriate measures to these ends, concentrating on methane losses from industry, refuse disposal and gas distribution.*

4.59 *Nitrous oxide* originates, in large part (about two thirds), in the burning of fossil fuels—where policy remedies parallel those related to CO_2. The remainder is due to woodburning and the use of mineral fertilizers. While lower fertilizer applications will usually result in lower farm yields, there is some agricultural research—which we believe should be encouraged—which suggests that additional chemicals (nitrapyrim) can suppress nitrous oxide emissions. *Tropospheric ozone* originates largely from chemical reactions involving unburnt or volatile hydrocarbons and nitrogen oxides in the presence of sunlight: emissions from gasoline-fuelled motor vehicles are believed to be a major source of these chemicals. Tropospheric ozone concentrations are increasing rapidly in many developed countries, where the gas is a cause of damage to trees and sensitive crops, and action is therefore doubly justifiable. Many countries are adopting catalytic converters which cut hydrocarbon and nitrogen oxide emissions from automobiles and this policy is to be welcomed. The ideal solution is one which combines this pollution control with enhanced vehicle fuel efficiency, thereby reducing carbon emissions. *We recommend Commonwealth governments to continue to support research on more economical and less polluting vehicles, and to press action forward by setting stringent standards in this field.*

Co-ordination of International Action to Combat Causes of Climate Change and Sea Level Rise

4.60 While action to curb emissions of greenhouse gases must be taken nationally, it needs to be planned and co-ordinated internationally, for this is a global problem that will only be solved by concerted action based on common commitment. The Montreal Protocol to the Vienna Convention on the Protection of the Ozone Layer provides for the control of the manufacture and use of CFCs, and we have already commented on that in paras 4.56 and 4.57.

4.61 The United Nations General Assembly, the Governing Council of UNEP, and the WMO Council have now all unanimously adopted resolutions which will lead to the negotiation of a Framework Convention on Climate. The Convention will be developed after the IPCC

Report is available in 1990, and it will be followed by specific Protocols dealing, *inter alia,* with action to curb emissions of greenhouse gases. All members of the Commonwealth have endorsed these actions by their participation in the unanimous adoption by the 43rd Session of the UN General Assembly of a resolution introduced by Malta and they will have every opportunity to participate in the subsequent negotiations. We welcome these signs of progress but emphasise that they should not delay action at national or international level to enhance knowledge of the greenhouse phenomenon, to evaluate its impact, and to develop and apply energy conservation and other measures that will reduce greenhouse gas emissions. The negotiation of specific Protocols that will apply quantitative limits to carbon dioxide emissions is likely to take time; there are potential conflicts of interest between different groups of energy producers; and more progress is needed in the development of new technologies. The funding of the transfer of such technology to the developing countries is also likely to demand protracted discussion. *We therefore recommend that while Commonwealth governments lend active support to the negotiation of the Framework Convention on Climate and its Protocols, they also press forward vigorously with the immediate actions proposed elsewhere in this report.*

The Special Role of the Commonwealth

4.62 We have considered the role that the Commonwealth can play, bearing in mind the need for the activities of international agencies to be co-ordinated and duplication avoided. We suggest that a positive role for the Commonwealth can be identified building on some of its unique characteristics, and especially the involvement of its members in all the major groups of nations within the UN and other systems.

4.63 The Commonwealth provides an informal network of political and professional contacts, covering a wide range of developed and developing countries, which can be used to stimulate and organise collaborative work and dialogue. The regular meetings of Common wealth Meteorologists — a low key, low cost, affair supported by the UK Meteorological Office — is a good example of this kind of activity. *We welcome, in particular, the meeting of Commonwealth Meteorological Organisations to be held in advance of the 1990 World Climate Conference, and we recommend that similar meetings be held to exchange views in advance of other key meetings, such as those of the IPCC, in which Commonwealth governments are playing a leading part.*

4.64 We believe that environmental issues will continue to attract political attention at the highest level in the coming years and that climate change and sea level rise will figure prominently in those concerns. *We therefore recommend that Commonwealth Environment*

Ministers should also hold periodic meetings, to exchange views on matters of mutual concern, identify priorities for concerted action, and plan necessary measures.

4.65 The Commonwealth, and especially the Secretariat, has developed a particular focus of interest in the problems of small states. As we have seen, some small island states are especially vulnerable to rising sea level (and other natural disasters such as hurricanes). One affected Commonwealth member, Tuvalu, is one of the world's smallest states in population terms (though its exclusive economic zone puts it among the largest in the area). The Commonwealth can usefully serve as a forum where the concerns of such states are given true and proper consideration. *We recommend that the Commonwealth should deepen its work on the vulnerability of small states to give particular attention to problems resulting from climate change, sea level rise and related disasters. Particularly important is the work of the Science Council which has expanded its activities in this area (building on existing programmes in coastal zone management, disaster management and environmental assessement).*

4.66 Given the limited resources of the Secretariat, it is important that maximum synergy be achieved between its various activities. We suggest looking in particular at how its growing role in environmental issues (including climate) might be dovetailed with the ambitious programme of distance learning. *We recommend a close look at how distance learning in the Commonwealth can promote environmental education.*

4.67 The technical assistance arm of the Secretariat, the CFTC, has acquired a reputation for providing help to developing countries rapidly and with the minimum of red tape and also for promoting an exchange of expertise among Commonwealth developing countries (small scale solar energy is an example). There are several areas related to the impact of climate change where moderate amounts of timely assistance could have considerable benefits—for example a systems approach to energy conservation and non-conventional energy sources; the organisation of disaster management plans; training of meteorological personnel. *We have identified a detailed programme (Box 4.2), specifically in the meteorological field which could benefit both individual countries and global monitoring systems and we commend it as a basis for bilateral assistance or multilateral assistance through the CFTC. More generally, we recommend that the Commonwealth Secretary-General should investigate how the Commonwealth can best mobilise technical assistance in relation to climate change and sea level rise, bearing in mind the work of other agencies.*

4.68 Finally, we consider that the machinery of the Secretariat will need modest strengthening to respond to these new demands. We believe that it may also be helpful to establish a small non-representative Standing Expert Group to advise the Secretariat, evaluate particular issues as they arise, and carry forward our own work. *We recommend the creation of such a Standing Group, and the establishment of a post or posts in the Secretariat charged specifically with responsibility for environmental concerns.*

Conclusion

4.69 We are aware that the number and scope of our recommendations may appear daunting, and we do not pretend that all have the same immediacy or weight. We have summarized the key issues in the draft Action Plan for the Commonwealth which is attached to the Executive Summary of our Report. *We commend this Action Plan to the Commonwealth Heads of Government—for action!*

Annex 1

Members of Expert Group on Climate Change and Sea Level Rise

Dr. Martin Holdgate (Chairman, UK)	Director General, International Union for Conservation of Nature and Natural Resources (IUCN). Former Chief Scientist, Department of Environment, UK.
Mr. Jim Bruce (Canada)	Acting Deputy Secretary-General, World Meteorological Organisation.
Mr. R. F. Camacho (Guyana)	Independent Consultant. Irrigation Consultant to FAO. Former Associate of Sir William Halcrow & Partners; and Director of Drainage and Irrigation (Guyana).
Dr. Nitin Desai (India)	Secretary and Chief Economic Adviser, Ministry of Finance, India. Former Economic Adviser to the Brundtland Commission.
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Dr. O. Mascarenhas (Tanzania)	Director, Information and Documentation Services, University of Dar es Salaam.
Dr. W. J. Maunder (New Zealand)	Consultant to Beijer Institute. Former Director of New Zealand Meteorological Service.
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Mr. Samuel Tewungwa (Uganda)	Programme Officer, IPCC (GEMS/PAC).

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Mr. P. Unwin	Deputy Secretary-General (Economic)

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Mr. Prem Arjoon	Senior Economics Officer

Annex 2

Terms of Reference

(a) to consider (i) the substantial volume of scientific evidence and assessment concerning recent changes in climate—particularly global warming—and projections of possible changes which may reasonably be expected; and (ii) possible underlying causes, with particular reference to man-made contributions from, *inter alia,* changing patterns and levels of energy use;

(b) against this background, to evaluate the environmental, social and economic impacts of such climate changes particularly on small islands and low-lying regions, primarily in terms of sea-level rise and flooding but also of other phenomena which should be taken into account so far as possible stating relative probabilities and significances;

(c) to review what effective, practical and feasible protective measures can be taken by the countries likely to be affected by sea level rise and flooding and other impacts of environmental changes, not only as regards protection against disaster but also as regards forward planning;

(d) to consider what measures the international community needs to take collectively to complement the measures which countries take individually. Specific attention should be given to ways of assisting those countries most likely to face adverse effects; the best ways in which the international community can further study and review unresolved scientific and policy questions; possible international action to limit man-made climate change by acting on underlying causes.

Annex 3

Leading Institutions and Fora Involved in Climate Change and Sea Level Rise

I. COLLABORATIVE PROGRAMMES

The Inter-Governmental Panel on Climate Change (IPCC)[1]
The Inter-Governmental Panel was first requested at the 10th Congress of the Tenth World Meteorological Congress in 1987 and followed up by the WMO Executive Council and the UNEP Governing Council. The IPCC was established to report to the governing bodies of WMO and UNEP with three specific tasks:

(i) to assess the scientific information related to the various aspects of the climate change issue;
(ii) to evaluate the environmental and socio-economic impacts of climate change;
(iii) to formulate realistic response strategies for the management of the greenhouse issue.

The first session of the IPCC in November 1988 established three working groups:

— Working Group I under the Chairmanship of Dr. J. Houghton, Director General of the British Meteorological Office, is responsible for assessing all available scientific information on factors affecting climate change including greenhouse gases, responses to these factors of the atmosphere-ocean-land-ice system, assessment of current capabilities of modelling global and regional climate change and their predictability, past climate

1. Tewungwa, S.: *Note on the Inter-Governmental Panel on Climate Change* Report of the First Session of the IPCC Bureau. Reports of IPCC Working Groups I, II and III.

record and presently observed climate anomalies, projections of future climate and sea level and the timing of changes. Its reports will identify the range of projections and their regional variations, gaps and uncertainties.

— Working Group II under the Chairmanship of Professor Israel of the USSR is reviewing environmental and socio-economic impacts of climate change in an integrated manner. The Group is also expected to address the evaluation of impacts on a regional and national scale of climate warming and sea level rise, the latter especially in the coastal and island areas; on agriculture, forestry, health, energy and water resources; and in relation to floods, droughts and desertification.

— Working Group III under the Chairmanship of Dr Bernthal of the USA is concerned with the policy dimension and, in particular, future emissions of greenhouse gases, impacts of changing technology, sources and sinks, adaptation to climate change, strategies to control or reduce emissions and other human activities that may have an impact on climate (e.g. deforestation, changing land-use) and their social and economic implications, including legal matters.

To oversee the work of the IPCC there is an intergovernmental bureau chaired by Professor Bolin of Sweden, and a Secretariat located in the WMO.

The World Climate Programme (WCP)

This programme is operated by the World Meteorological Organisation (WMO) jointly with the United Nations Environment Programme (UNEP), the International Oceanic Commission (IOC) of UNESCO and the International Council of Scientific Unions (ICSU). Initiated in 1979, as a result of the First World Climate Conference, it provides an institutional framework for research and data collection, specifically to improve understanding of national and global climatic systems, and to assess its likely impacts. The programme promoted much of the technical material which served as a basis for the Villach (1985) and Bellagio (1987) Conferences[1]. It has several specific components.

(i) **World Climate Data Programme** which assists countries in setting up data systems and acquiring processing capability in a way that could help economic policy-making.

(ii) **World Climate Applications Programme** provides for transfer of technology to using climate information to plan agricultural activities, energy, transportation, human settlements, etc. An important example of the Programme's work was a joint WMO-

1. UNDP/ICSU/WMO (1987) International Conference on the Assessment of the Role of CO_2 and of other Greenhouse Gases (GHGs) in Climate Variations and Associated Impacts. Villach, Austria.

UNEP-WHO project on Climate and Human Health, including a major symposium in Leningrad in 1986.

(iii) **World Climate Research Programme**—coordinated by WMO, ICSU and the IOC—is designed to understand the nature of the earth's climate system in order to (a) increase the predictive capacity of weather forecasts on a seasonal or monthly basis and (b) assess the impact of man's influence on global climate change. It includes such major projects as Tropical Oceans and Global Atmosphere (TOGA), a study of the El Nino phenomenon, and the World Ocean Circulation Experiment (WOCE).

(iv) **World Climate Impact Studies Programme** has undertaken projects and set up expert groups to study the socio-economic impact of climate fluctuations and change, for example:

(a) A UNEP project on the socio-economic impact of climate change has focused on Malaysia, Thailand and Indonesia. This was an integrated systemic project which considered the impact on food production, rubber production and coastal ecosystems of climate change.

(b) A three-year co-operative programme between UNEP and the Netherlands Government has studied the impact of sea level rise on society. The first phase established an inventory of areas most vulnerable to sea level rise and a set of criteria for determining high risk areas. The second phase is undertaking in-depth case studies in the Maldives, Bangladesh, *inter alia.*

The International Geosphere Biosphere Programme (IGBP)[1]

This programme; of the International Council of Scientific Unions (ICSU) was established in 1986 to 'describe and understand the interactive physical, chemical and biological processes that regulate the total Earth system . . . the changes that are occurring in this system, and the manner in which they are influenced by human actions'. This programme builds upon and integrates other scientific work by ICSU, especially through its Scientific Committee on Problems of the Environment (SCOPE).

The first meeting of the Special Committee of IGBP took place in July 1987 and identified special themes that will guide the IGBP's future work:

— documenting and predicting climate change,
— observing and improving understanding of dominant forcing functions,
— improving understanding of interactive phenomena in the total Earth system,

1. Global Change Report No. 4, 1988. *IGBP Plan of Action.*

- assessing effects of global change that have major implications for renewable and non-renewable resources.

As regards SCOPE, it has pursued work on bio-geochemical cycles in relation to the global climate cycles (SCOPE 13, 16 and 23) and more specifically in relation to climate change impacts (SCOPE 29).

There was a major review meeting of IGBP in Stockholm in the autumn of 1988. This meeting considered the need for a wide range of studies including an examination of the interactions in both polar zones, between ocean and atmosphere and between soil and air (also reviewed at an international meeting on Soils and the Greenhouse Effect, held at Wageningen, Netherlands, in August 1989).

The Advisory Group on Greenhouse Gases (AGGG)

This was established jointly by WMO, UNEP and ICSU to ensure adequate follow-up to the recommendations of the 1985 (Villach) International Conference on the Assessment of the Role of Carbon Dioxide and other Greenhouse Gases in Climate Variations and Associated Impacts. The AGGG, which is chaired by Professor K Hare of Canada, compiles biennial reviews of international and regional studies related to greenhouse gases as well as periodic assessments of the rates of increase in the concentration of greenhouse gases and their effects.

II MULTILATERAL INSTITUTIONS

UNEP is centrally involved in climate change issues through its participation in the IPCC, the World Climate Programme and the AGGG.

It has also been directly involved as the lead agency in the implementation of the Vienna Convention and then the Montreal Protocol on Substances that Deplete the Ozone Layer. While the Montreal Protocol is concerned with the effects of CFC's on the ozone layer it is noted in the preamble that parties to the Protocol are 'conscious of the potential climatic effects of emissions of these substances'.

As part of its contribution to the World Climate Impact Studies Programme, UNEP had developed various regional projects on climate and sea level rise:

- UNEP's *Oceans and Coastal Area Programme Activity Centre (OCA/PAC)* is examining the implications of climate change on a variety of marine ecosystems. In the Mediterranean basin for example, the project is examining the physical impact of sea level rise on current land use and the ecological impact on natural and agricultural production systems of likely temperature rises — resulting in the Split Conference of October 1988 (UNEP report reference UNEP(OCA)/WG.2/25).
- The *Caribbean Environment Programme* of UNEP has, with other agencies, looked at the possible implications of sea level

rise and climate change in relation to the Caribbean, and published a substantial report on that subject.

— It has also sponsored work directly in relation to climatology such as ISLSCP (International Satellite Land Surface Climatology Project).

WMO, the World Meteorological Organisation, is the UN agency responsible for the co-ordination of scientific measurements and studies of the global atmosphere and the climate it produces. Since 1979 it has been the lead agency for co-ordination of the World Climate Programme.

One important contribution worth highlighting is the Climate System Monitoring (CSM) Project of the World Climate Data Programme (WCDP)—designed to provide meteorological services with synthesised information on the state of the climate system. The development and speed of the CLICOM (a simple computerised climate data management system) and DARE (a historical data rescue project) are all of great importance for developing countries.

WMO has some closely related programmes such as:

— The *Global Atmosphere Watch,* for measuring changes in the chemical composition of the global atmosphere, includes the Global Ozone Observing System and the Background and Pollution Monitoring Network which includes greenhouse gases and chemical composition of precipitation.

— The *Tropical Cyclone Programme* with its five regional bodies covering the main areas affected by cyclones (typhoons, hurricanes) for the purpose of exchanging information to enable better prediction and warning.

— *Agrometeorological* activities to improve the use of meteorological and climatological information to reduce crop losses and improve food security, through, for example, Drought Monitoring Centres (Nairobi, Harare).

A major focus for WMO's work, and that of the international community generally on climate, will be the *Second World Climate Conference,* to be held in Geneva, November 1990, to assess the developments in global understanding of climate a decade after the first Conference, and take the next steps towards a global framework convention on climate change.

The World Bank is important in influencing projects and policies as the main multilateral lending institution. It has established an Environment Department and is taking environmental considerations more seriously in its work.

The United Nations Development Programme (UNDP) is significantly increasing its technical co-operation support for climate change studies and measurements, for adoption of national projects and policies to respond to this issue.

UNDP, with WMO, the Economic Commission for Africa and UNEP, is planning to set up, in Niger, an African Centre for Meteorological Applications for Development. This would aim to strengthen long range weather predictions and climate analysis for Africa.

UNESCO is involved in climate through the *International Oceanographic Commission (IOC)*. The IOC is a collaborating partner in the World Climate Programme and has several specific areas of relevant interest:

- co-ordination of the Global Sea Level Monitoring System (GLOSS) which monitors and analyses sea level data, backed up by technical assistance efforts where necessary for countries needing such assistance,
- work on marine science and ocean services for development, together with a major assistance programme to enhance the marine science capabilities of developing countries.

The EEC has carried out work as part of its Climatology and Natural Hazards Research programme. The Commission has also carried out a far-reaching appraisal of the issue in general: 'Greenhouse Issue and The Community' (X1/674/88) and 'Commission Work Programme Concerning the Evaluation of Policy Options to deal with the "Greenhouse issue" ' (X1/803/88).

UN regional programmes have carried out work that bears upon the climate issue:

- *The Economic Commission for Europe* has looked in detail at energy reserves and supplies, alternative energy scenarios and energy conservation and has specifically addressed the 'greenhouse' gas issue through its work on the Interrelationships between Environmental and Energy Policies (ECE/Energy/13) and 'Implications of Carbon-dioxide induced climate change for electricity production' (EC/GE.4/R.75/Add 1 and 2).
- *ESCAP* has considered marine environmental management and coastal ecosystems at a regional workshop in Bangladesh, February 1984.

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