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 It is clear from the analysis in Chapter 2 that this assumption is no longer valid.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 (%)			*Forest Types (%)*	
	Before	*After*		*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 land-fills 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 Major Climatic Impacts	(1) Sub-Saharan Africa	(2) Indian Sub-Continent	(3) S.E. Asia	(4) Mediterranean	(5) Indian Ocean, Caribbean and Pacific Islands	(6) N.W. Europe	(7) Canada	(8) 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