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Climate. Stern Review: The Economics of Climate Change

Nicholas Stern
British Government

Stern Review
The Economics of Climate Change

Excerpts from Part II:

The Impacts of Climate Change on Growth and Development, Chapter 3 and Chapter 4
by Sir Nicholas Stern

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The following pages are taken from the Stern Review, commissioned by HM Treasury. These pages do not include the full text of Chapters 3 and 4, but the numbering of the footnotes remains as in the original.
Some of the tables and figures have been omitted.

To see the full report go to www.hm-treasury.gov.uk

Sir Nicholas Stern is former Chief Economist and Senior Vice President of the World Bank and is now an advisor to the British Government on climate change.

Table 3.1 Highlights of possible climate impacts discussed in this chapter

Temp Rise	Water	Food	Health	Land	Environment	Abrupt and Large-Scale Impacts
1°C	Small glaciers in the Andes disappear completely threatening water supplies for 50 million people	Modest increases in cereal yields in temperate regions	At least 300,000 people each year die from climate-related diseases (predominantly diarrhea, malaria, andmalnutrition) Reduction in winter mortality in higher latitudes (Northern Europe, USA)	Permafrost thawing damages building and roads in parts of Canada and Russia	At least 10% of land species facing extinction (according to one estimate) 80% bleaching of coral reefs, including Great Barrier Reef	Atlantic Thermohaline Circulation starts to weaken
2°C	Potentially 20-30% decrease in water availability in some vulnerable regions, e.g. Southern Africa and Mediterranean	Sharp declines in crop yield in tropical regions (5-10% in Africa)	40-60 million more people exposed to malaria in Africa	Up to 10 million more people affected by coastal flooding each year.	15-40% of species facing extinction (according to one estimate) High risk of extinction of Arctic species, including polar bear and caribou	Potential for Greenland ice sheet to begin melting irreversibly, accelerating sea level rise and committing world to an eventual 7 m sea level rise. Rising risk of abrupt changes to atmospheric circulations, e.g. the monsoon Rising risk of collapse of West Antarctic Ice SheetRising risk of collapse of Atlantic Thermohaline CIrculation
3°C	In Southern Europe, serious drought occur once every 10 years 1-4 billion more people suffer water shortages, while 1-5 billion gain water, which may increase flood risk	150-500 additional millions as risk of hunger (if carbon fertilization weak) Agricultural yields in higher latitudes likely to peak	1-3 million more people die from malnutrition (if carbon fertilization weak)	1-170 million more people affected by coastal flooding each year	20-50% of species facing extinction (according to one estimate), including 25-60% mammals, 30-40% birds and 15-70% butterflies in South Africa Onset of Amazon forest collapse (some models only)	
4°C	Potentially 30-50% decrease in water availability in Southern Africa and Mediterranean	Agriculture yields decline by 15-35% in Africa, and entire regions our of production (e.g. parts of Australia)	Up to 80 million more people exposed to malaria in Africa	7-300 million more people affected by coastal flooding each year	Loss of around half Arctic tundra Around half of all the world's nature reserves cannot fulfill objectives	
5°C	Possible disappearance of large glaciers in Himalayas, affecting one-quarter of China's population and hundreds of millions in India	Continued increase in ocean acidity seriously disrupting marine ecosystems and possibly fish stocks		Sea level rise threatens small islands, low-lying coastal areas (Florida) and major world cities such as New York, London and Tokyo		
More than 5°C	The latest science suggests that the Earth's average temperature will rise by even more than 5 or 6°C if emissions continue to grow and positive feedbacks amplify the warming effect of greenhouse gases (e.g. release of carbon dioxide from soils or methane from permafrost). This level of global temperature rise would be equivalent to the amount of warming that occurred between the last age and today – and is likely to lead to major disruption and large-scale movement of population. Such "socially contingent" effects could be catastrophic, but are currently very hard to capture with current models as temperatures would be so far outside human experience.					

Note:This table shows illustrative impacts at different degrees of warming. Some of the uncertainty is captured in the ranges shown, but there will be additional uncertainties about the exact size of impacts (more detail in Box 3.2). Temperatures represent increases relative to pre-industrial levels. At each temperature, the impacts are expressed for a 1°C band around the central temperature, e.g. 1°C represents the range 0.5-1.5°C etc. Numbers of people affected at different temperatures assume population and GDP scenarios for the 2080s from the Intergovernmental Panel on Climate Change (IPCC). Figures generally assume adaptation at the level of an individual or firm, but not economy-wide adaptation as due to policy intervention.

CHAPTER 3

3.1 Introduction

This chapter examines the increasingly serious impacts on people as the world warms.

Climate change is a serious and urgent issue. The Earth has already warmed by 0.7°C since around 1900 and is committed to further warming over coming decades simply due to past emissions. On current trends, average global temperatures could rise by 2–3°C within the next fifty years or so, with several degrees more in the pipeline by the end of the century if emissions continue to grow.

This chapter examines how the physical changes in climate . . . affect the essential components of lives and livelihoods of people around the world — water supply, food production, human health, availability of land, and ecosystems. It looks in particular at how these impacts intensify with increasing amounts of warming. The latest science suggests that the Earth's average temperature will rise by even more than 5 or 6°C if feedbacks amplify the warming effect of greenhouse gases through the release of carbon dioxide from soils or methane from permafrost. . . . Throughout the chapter, changes in global mean temperature are expressed relative to pre-industrial levels (1750–1850).

The chapter builds up a comprehensive picture of impacts by incorporating two effects that are not usually included in existing studies (extreme events and threshold effects at higher temperatures). In general, impact studies have focused predominantly on changes in average conditions and rarely examine the consequences of increased variability and more extreme weather. In addition, almost all impact studies have only considered global temperature rises up to 4 or 5°C and therefore do not take account of threshold effects that could be triggered by temperatures higher than 5 or 6°C.

- **Extreme weather events.** Climate change is likely to increase the costs imposed by extreme weather, both by shifting the probability distribution upwards (more heatwaves, but fewer cold-snaps) and by intensifying the water cycle, so that severe floods, droughts and storms occur more often.[2] Even if the shape of the distribution of temperatures does not change, an upward shift in the distribution as a whole will disproportionately increase the probability of exceeding damaging temperature thresholds.[3] Changes in the variability of climate in the future are more uncertain, but could have very significant impacts on lives and livelihoods. For example, India's economy and social infrastructure are finely tuned to the remarkable stability of the monsoon, with the result that fluctuations in the strength of the monsoon both year-to-year and within a single season can lead to significant flooding or drought, with significant repercussions for the economy.[4]

- **Non-linear changes and threshold effects at higher temperatures (convexity).** The impacts of climate change will become increasingly severe at higher temperatures, particularly because of rising risks of triggering abrupt and large-scale changes, such as melting of the Greenland ice sheet or loss of the Amazon forest. Few studies have examined the shape of the damage function at higher temperatures, even though the latest science suggests that temperatures are 5 or 6°C or higher are plausible because of feedbacks that amplify warming. For some sectors, damages may increase much faster than temperatures rise, so that the damage curve becomes convex — the consequences of moving from 4 to 5°C are much greater than the consequences of moving from 2 to 3°C. For example, hurricane damages increase as a cube (or more) of wind-speed, which itself scales closely with sea temperatures. Theory suggests impacts in several key sectors will increase strongly at higher temperatures, although there is not enough direct quantitative evidence on the impacts at higher temperatures.

The combined effect of impacts across several sectors could be very damaging and further amplify the consequences of climate change. Little work has been done to quantify these interactions, but the potential consequences could be substantial. For example, in some tropical regions, the combined effect of loss of native pollinators, greater risks of pest outbreaks, reduced water supply, and greater incidence of heatwaves could lead to much greater declines in food production than through the individual effects themselves.

The consequences of climate change will depend on how the physical impacts interact with socio-economic factors. Population movement and growth will often exacerbate the impacts by increasing society's exposure to environmental stresses (for example, more people living by the coast) and reducing the amount of resource available per person (for example, less food per person and causing greater food shortages).[5] In contrast, economic growth often reduces vulnerability to climate change (for example, better nutrition or health care; Chapter 4) and increases society's ability to adapt to the impacts (for example, availability of technology to make crops more drought-tolerant; Chapter 20). This chapter focuses on studies that in general calculate impacts by superimposing climate change onto a future world that has developed economically and socially and comparing it to the same future world without climate change (Box 3.2 for further details). Most of the studies generally assume adaptation at the level of an individual or firm, but not economy-wide adaptations due to policy intervention.

3.2 Water

People will feel the impact of climate change most strongly through changes in the distribution of water around the world and its seasonal and annual variability.

Water is an essential resource for all life and a requirement for good health and sanitation. It is a critical input for almost all production and essential for sustainable growth and poverty reduction.[12] The location of water around the world is a critical determinant of livelihoods. Globally, around 70 % of all freshwater supply is used for irrigating crops and providing food. 22% is used for manufacturing and energy (cooling power stations and producing hydro-electric power), while only 8% is used directly by households and businesses for drinking, sanitation, and recreation.[13]

Climate change will alter patterns of water availability by intensifying the water cycle.[14] Droughts and floods will become more severe in many areas. There will be more rain at high latitudes, less rain in the dry subtropics, and uncertain but probably substantial changes in tropical areas.[15] Hotter land surface temperatures induce more powerful evaporation and hence more intense rainfall, with increased risk of flash flooding.

Differences in water availability between regions will become increasingly pronounced. Areas that are already relatively dry, such as the Mediterranean basin and parts of Southern Africa and South America, are likely to experience further decreases in water availability, for example several (but not all) climate models predict up to 30% decrease in annual runoff in these regions for a 2°C global temperature rise and 40–50% for 4°C.[16] In contrast, South Asia and parts of Northern Europe and Russia are likely to experience increases in water availability (runoff), for example a 10–20% increase for a 2°C temperature rise and slightly greater increases for 4°C, according to several climate models.

These changes in the annual volume of water each region receives mask another critical element of climate change — its impact on year-to-year and seasonal variability. An increase in annual river flows is not necessarily beneficial, particularly in highly seasonal climates, because: (1) there may not be sufficient storage to hold the extra water for use during the dry season,[17] and (2) rivers may flood more frequently.[18] In dry regions, where runoff one-year-in-ten can be less than 20% of the average annual amount, understanding the impacts of climate change on variability of water supplies is perhaps even more crucial. One recent study from the Hadley Centre predicts that the proportion of land area experiencing severe droughts at any one time will increase from around 10% today to 40% for a warming of 3 to 4°C, and the proportion of land area experiencing extreme droughts will increase from 3% to 30%.[19] In Southern Europe, serious droughts may occur every 10 years with a 3°C rise in global temperatures instead of every 100 years if today's climate persisted.[20]

As the water cycle intensifies, billions of people will lose or gain water. Some risk becoming newly or further water stressed, while others see increases in water availability. Seasonal and annual variability in water supply will determine the consequences for people through floods or droughts.

Around one-third of today's global population live in countries experiencing moderate to high water stress, and 1.1 billion people lack access to safe water (Box 3.3 for an explanation of water stress). Water stress is a useful indicator of water availability but does not necessarily reflect access to safe water. Even without climate change, population growth by itself may result in several billion more people living in areas of more limited water availability.

The effects of rising temperatures against a background of a growing population are likely to cause changes in the water status of billions of people. According to one study, temperature rises of 2°C will result in 1–4 billion people experiencing growing water shortages, predominantly in Africa, the Middle East, Southern Europe, and parts of South and Central America.[21] In these regions, water management is already crucial for their growth and development. Considerably more effort and expense will be required on top of existing practices to meet people's demand for water. At the same time, 1– 5 billion people, mostly in South and East Asia, may receive more water.[22] However, much of the extra water will come during the wet season and will only be useful for alleviating shortages in the dry season if storage could be created (at a cost). The additional water could also give rise to more serious flooding during the wet season.

Melting glaciers and loss of mountain snow will increase flood risk during the wet season and threaten dry-season water supplies to one-sixth of the world's population (over one billion people today).

Climate change will have serious consequences for people who depend heavily on glacier meltwater to maintain supplies during the dry season, including large parts of the Indian sub-continent, over quarter of a billion people in China, and tens of millions in the Andes.[23]Initially, water flows may increase in the spring as the glacier melts more rapidly. This may increase the risk of damaging glacial lake outburst floods, especially in the Himalayas,[24]and also lead to shortages later in the year. In the long run dry-season water will disappear permanently once the glacier has completely melted. Parts of the developed world that rely on mountain snowmelt (Western USA, Canadian prairies, Western Europe) will also have their summer water supply affected, unless storage capacity is increased to capture the "early water."

In the Himalaya-Hindu Kush region, meltwater from glaciers feeds seven of Asia's largest rivers, including 70% of the summer flow in the Ganges, which provides water to around 500 million people. In China, 23% of the population (250 million people) lives in the western region that depends principally on glacier meltwater. Virtually all glaciers are showing substantial melting in China, where spring stream-flows have advanced by nearly one month since records began. In the tropical Andes in South America, the area covered by glaciers has been reduced by nearly one-quarter in the past 30 years. Some small glaciers are likely to disappear completely in the next decade given current trends.[25] Many large cities such as La Paz, Lima and Quito and up to 40% of agriculture in Andean valleys rely on glacier meltwater supplies. Up to 50 million people in this region will be affected by loss of dry-season water.[26]

Box 3.2 Assumptions and scenarios used in impact studies

This chapter bases much of its detailed analysis on a series of papers prepared by Prof. Martin Parry and colleagues ("FastTrack"), one of the few that clearly sets out the assumptions used and explores different sources of uncertainty.[6]

Climate change scenarios. Climate models produce different regional patterns of temperature and rainfall (especially). The original "FastTrack" studies were based on outputs of the Hadley Centre climate model. However, in some cases the analyses have been updated to examine sensitivity to a range of different climate models.[7] Other science uncertainties, such as the link between greenhouse gas concentrations and global temperatures, were not directly examined by the work.

Socio-economic scenarios. The studies carefully separated out the effects of climate change from socio-economic effects, such as growing wealth or population size. In these studies, population and GDP per capita grew on the basis of four socio-economic pathways, as described by the IPCC (see table below).[8]The effects of climate change were calculated by comparing a future world with and without climate change (but with socio-economic development in every case). Changing socio-economic factors alongside climate may be crucial because: (1) a growing population will increase society's exposure to stress from malnutrition, water shortages and coastal flooding, while (2) growing wealth will reduce vulnerability to climate change, for example by developing crops that are more drought-tolerant. Other impact studies superimpose climate change in a future world where population and GDP remain constant at today's levels. These studies are perhaps less realistic, but still provide a useful indication of the scale of the impacts and may be easier to interpret.

Summary characteristics of IPCC socio-economic scenarios (numbers in brackets for 2100)

IPCC Scenarios	**A1 FI**	**A2**	**B1**	**B2**
Name	World Markets	National Enterprise	Global Sustainability	Local Stweardship
Population growth	Low (7 billion)	High (15 billion)	Low (7 billion)	Medium (710billion)
World growth[9]	Very high, 3.5% p.a. ($550 trillion)	Medium, 2% p.a. (S243 trillion)	Hgh, 2.75% p.a. ($328 trillion)	Medium, 2% p.a. ($235trillion)
Degree of convergence ration of GDP per capita in rich vs. poor countries [10]	High (1.6)	Low (4.2)	High (1.8)	Medium (13.0)
Emissions	High	Medium High	Low	Medium Low

Adaptation assumptions. Clarity over adaptation is critical for work on the impacts of climate change, because large amounts of adaptation would reduce the overall damages caused by climate change (net of costs of adaptation). Within the literature, the picture remains mixed: some studies assume no adaptation, many studies assume individual (or "autonomous") adaptation, while other studies assume an "efficient" adaptation response where the costs of adaptation plus the costs of residual damages are minimised over time.[11] Unless otherwise stated, the results presented assume adaptation at the level of an individual or firm ("autonomous"), but not economy-wide. Such adaptations are likely to occur gradually as the impacts are felt but that require little policy intervention (more details in Part V). This provides the "policy

3.3 Food

In tropical regions, even small amounts of warming will lead to declines in yield. In higher latitudes, crop yields may increase initially for moderate increases in temperature but then fall. Higher temperatures will lead to substantial declines in cereal production around the world, particularly if the carbon fertilisation effect is smaller than previously thought, as some recent studies suggest.

Food production will be particularly sensitive to climate change, because crop yields depend in large part on prevailing climate conditions (temperature and rainfall patterns). Agriculture currently accounts for 24% of world output, employs 22% of the global population, and occupies 40% of the land area. 75% of the poorest people in the world (the one billion people who live on less than $1 a day) live in rural areas and rely on agriculture for their livelihood.[29]

Low levels of warming in mid to high latitudes (US, Europe, Australia, Siberia and some parts of China) may improve the conditions for crop growth by extending the growing season[30]and/or opening up new areas for agriculture. Further warming will have increasingly negative impacts — the classic "hill function" — as damaging temperature thresholds are reached more often and water shortages limit growth in regions such as Southern Europe and Western USA.[31] High temperature episodes can reduce yields by up to half if they coincide with a critical phase in the crop cycle like flowering.[32]

The impacts of climate change on agriculture depend crucially on the size of the "carbon fertilisation" effect. Carbon dioxide is a basic building block for plant growth. Rising concentrations in the atmosphere may enhance the initial benefits of warming and even offset reductions in yield due to heat and water stress. Work based on the original predictions for the carbon fertilisation effect suggests that yields of several cereals (wheat and rice in particular) will increase for 2 or 3°C of warming globally, according to some models, but then start to fall once temperatures reach 3 or 4°C.[33] Maize shows greater declines in yield with rising temperatures because its different physiology makes it less responsive to the direct effects of rising carbon dioxide. Correspondingly, world cereal production only falls marginally (1–2%) for warming up to 4°C.[34] But the latest analysis from crops grown in more realistic field conditions suggests that the effect is likely to be no more than half that typically included in crop models.[35] When a weak carbon fertilisation effect is used, worldwide cereal production declines by 5% for a 2°C rise in temperature and 10% for a 4°C rise. By 4°C, entire regions may be too hot and dry to grow crops, including parts of Australia. Agricultural collapse across large areas of the world is possible at even higher temperatures (5 or 6°C) but clear empirical evidence is still limited.

While agriculture in higher-latitude developed countries is likely to benefit from moderate warming (2–3°C), even small amounts of climate change in tropical regions will lead to declines in yield. Here crops are already close to critical temperature thresholds[36] and many countries have limited capacity to make economy-wide adjustments to farming patterns. The impacts will be strongest across Africa and Western Asia (including the Middle East), where yields of the predominant regional crops may fall by 25–35% (weak carbon fertilisation) or 15–20% (strong carbon fertilisation) once temperatures reach 3 or 4°C. Maize-based agriculture in tropical regions, such as parts of Africa and Central America, is likely to suffer substantial declines, because maize has a different physiology to most crops and is less responsive to the direct effects of rising carbon dioxide.[37]

Many of the effects of climate change on agriculture will depend on the degree of adaptation (see Part V), which itself will be determined by income levels, market structure, and farming type, such as rain-fed or irrigated.[38] Studies that take a more optimistic view of adaptation and assume that a substantial amount of land at higher latitudes becomes suitable for production find more positive effects of climate change on yield.[39] But the transition costs are often ignored and the movement of population required to make this form of adaptation a reality could be very disruptive. At the same time, many existing estimates do not include the impacts of short-term weather events, such as floods, droughts and heatwaves. These have only recently been incorporated into crop models, but are likely to have additional negative impacts on crop production (Table 3.2). Expansion of agricultural land at the expense of natural vegetation may itself exert additional effects on local climates with tropical deforestation leading to rainfall reductions because of less moisture being returned to the atmosphere once trees are removed.[40]

Footnotes to 3.1

2. "Extreme events" occur when a climate variable (e.g. temperature or rainfall) exceeds a particular threshold, e.g. two standard deviations from the mean.
3. In looking at the effects on crop yields of severe weather during the Little Ice Age, Prof Martin Parry (1978) argued that the frequency of extreme events would change dramatically as a result of even a small change in the mean climate and that the probability of two successive extremes is even more sensitive to small changes in the mean. Often a single extreme event is easy to withstand, but a second in succession could be far more devastating. In a follow-up paper, Tom Wigley (1985) demonstrated these effects on extremes mathematically.
4. Based on a technical paper prepared for the Stern Review by Challinor *et al.* (2006b).
5. This will also depend on efficiency of use as well.

Footnotes to 3.2

12. Grey and Sadoff (2006) make a strong case for water resources being at the heart of economic growth and development. They show how in the late 19th and early 20th centuries, industrialised countries invested heavily in water infrastructure and institutions to facilitate strong economic growth. In least developed economies, climate variability and extremes are often quite marked, while the capacity to manage water is generally more limited.
13. World Water Development Report (2006)
14. Further detail in Chapter 1 - rising temperatures increase the water holding capacity of the air, so that more water will evaporate from the land in dry areas of the world. But where it rains, the water will fall in more intense bursts.
15. At the same time, rising carbon dioxide levels will cause plants to use less water (a consequence of the carbon fertilisation effect – see Box 3.4 later) and this could increase water availability in some areas. Gedney *et al.* (2006) found that suppression of plant transpiration due to the direct effects of carbon dioxide on the closure of plant stomata (the pores on the leaves of plants) could explain a significant amount of the increase in global continental runoff over the 20th century.
16. From Arnell (2006a); runoff, the amount of water that flows over the land surface, not only represents potential changes in water availability to people, but also provides a useful indication of whether communities will need to invest in infrastructure to help manage patterns of water supply (more details in Box 3.3).
17. Arnell (2006a)
18. Milly *et al.* (2002)

19. Burke *et al.* (2006) using the Hadley Centre climate model (HadCM3). Drought was assessed with the Palmer Drought Severity Index (PDSI), with severe and extreme droughts classed as PDSI of less than 3.3 and 4.0, respectively.
20. Lehner *et al.* (2001)
21. Warren *et al.* (2006) have prepared these results, based on the original analysis of Arnell (2004) for the 2080s. The results are based on hydrology models driven by monthly data from five different climate models. The results do not include adaptation and thus only represent "potential water stress".
22. The large ranges come about from differences in the predictions of the five different climate models – particularly for tropical areas where the impacts are uncertain due to the dominant influence of the El Niño and the monsoon and the difficulty of predicting interactions with climate change.
23. Barnett *et al.* (2005) have comprehensively reviewed the glacier/water supply impacts. There are 1 billion people in snowmelt regions today, and potentially 1.5 billion by 2050. In a warmer world, runoff from snowmelt will occur earlier in the spring or winter, leading to reduced flows in the summer and autumn when additional supplies will be most needed.
24. Nepal is particularly vulnerable to glacial lake outburst floods – catastrophic discharges of large volumes of water following the breach of the natural dams that contain glacial lakes (described in Agrawala *et al.* 2005). The most significant flood occurred in 1985. A surge of water and debris up to 15 m high flooded down the Bhote Koshi and Dudh Koshi rivers. At its peak the discharge was 2000 m3/s, up to four times greater than the maximum monsoon flood level. The flood destroyed the almost-completed Namche Small Hydro Project (cost $1 billion), 14 bridges, many major roads and vast tracts of arable land.
25. Reported in Coudrain *et al.* (2005)
26. Nagy et al. (2006).

Footnotes to Box 3.2

6. Special Issue of Global Environmental Change, Volume 14, April 2004 - further details on the new analysis are available from Warren *et al.* (2006). Risk and uncertainty are often used interchangeably, but in a formal sense, risk covers situations when the probabilities are known and uncertainty when the probabilities are not known.
7. See, for example, Arnell (2006a)
8. IPCC (2000)
9. In 1990 US $
10. Problematic as based on Market Exchange Rates
11. For example, many integrated assessment models – details in Chapter 7

Footnotes to 3.3

29. FAO World Agriculture report (Bruinsma 2003 ed.)
30. Plants also develop faster at warmer temperatures such that the duration from seedling emergence to crop harvest becomes shorter as temperatures warm, allowing less time for plant growth. This effect varies with both species and cultivar. With appropriate selection of cultivar, effective use of the extended growing season can be made.
31. Previous crop studies use a quadratic functional form, where yields are increasing in temperature up to an "optimal" level when further temperature increases become harmful (for example Mendelsohn *et al.* 1994). A crucial implicit assumption behind the quadratic functional form is symmetry around the optimum: temperature deviations above and below the "optimal" level give equivalent yield reductions. However, recent studies (e.g. Schlenker and Roberts 2006) have shown that the relationship is highly asymmetric, where temperature increases above the "optimal" level are much more harmful than comparable deviations below it. This has strong implications for climate change, as continued temperature increases can result in accelerating yield reductions.
32. Evidence reviewed in Slingo *et al.* (2005); Ciais *et al.* (2005)
33. The impacts depend crucially on the distribution of warming over land (Chapter 1). In general, higher latitudes and continental regions will experience temperature increases significantly greater than the global average. For a global average warming of around 4°C, the oceans and coasts generally warm by around 3°C, the mid-latitudes warm by more than 5°C and the poles by around 8°C.

34. Warren *et al.* (2006) have prepared this analysis, based on the original work of Parry *et al.* (2004). More detail on method and assumptions are set out in Box 3.4. Production declines less than yields with increasing temperature because more land area at higher latitudes becomes more suitable for agriculture.
35. New analysis by Long *et al.* (2006) showed that the high-end estimates (25 – 30%) were largely based on studies of crops grown in greenhouses or field chambers, while analysis of studies of crops grown in near-field conditions suggest that the benefits of carbon dioxide may be significantly less, e.g. no more than half.
36. The optimum temperature for crop growth is typically around 25 - 30°C, while the lethal temperature is usually around 40°C.
37. Other staple crops in Africa (millet and sorghum) are also relatively unresponsive to the carbon fertilisation effect. They all show a small positive response because they require less water to grow.
38. Types of adaptation discussed by Parry *et al.* (2005)
39. For example Fischer *et al.* (2005)
40. These effects are not yet routinely considered in climate models or impacts studies (Betts 2005).

CHAPTER 4

4 Implications of Climate Change for Development

Key Messages

Climate change poses a real threat to the developing world. Unchecked it will become a major obstacle to continued poverty reduction.

Developing countries are especially vulnerable to climate change because of their geographic exposure, low incomes, and greater reliance on climate sensitive sectors such as agriculture. Ethiopia, for example, already has far greater hydrological variability than North America but less than 1% of the artificial water storage capacity per capita. Together these mean that impacts are proportionally greater and the ability to adapt smaller.

Many developing countries are already struggling to cope with their current climate. For low-income countries, major natural disasters today can cost an average of 5% of GDP.

Health and agricultural incomes will be under particular threat from climate change. For example:

- Falling farm incomes will increase poverty and reduce the ability of households to invest in a better future and force them to use up meagre savings just to survive.
- Millions of people will potentially be at risk of climate-driven heat stress, flooding, malnutrition, water related disease and vector borne diseases. For example, dengue transmission in South America may increase by 2 to 5 fold by the 2050s.
- The cost of climate change in India and South East Asia could be as high as a 9-13% loss in GDP by 2100 compared with what could have been achieved in a world without climate change. Up to an additional 145–220 million people could be living on less than $2 a day and there could be an additional 165,000 to 250,000 child deaths per year in South Asia and sub-Saharan Africa by 2100 (due to income losses alone).

Severe deterioration in the local climate could lead, in some parts of the developing world, to mass migration and conflict, especially as another 2–3 billion people are added to the developing world's population in the next few decades:

- Rising sea levels, advancing desertification and other climate-driver changes could drive millions of people to migrate: more than a fifth of Bangladesh could be under water with a 1m rise in sea levels — a possibility by the end of the century.
- Drought and other climate-related shocks risk sparking conflict and violence, with West Africa and the Nile Basin particularly vulnerable given their high water interdependence.

These risks place an even greater premium on fostering growth and development to reduce the vulnerability of developing countries to climate change.

However, little can now be done to change the likely adverse effects that some developing countries will face in the next few decades, and so some adaptation will be essential. Strong and early mitigation is the only way to avoid some of the more severe impacts that could occur in the second half of this century.

4.1 Introduction

While all regions will eventually feel the effects of climate change, it will have a disproportionately harmful effect on developing countries — and in particular poor communities who are already living at or close to the margins of survival. Changes in the climate will amplify the existing challenges posed by tropical geography, a heavy dependence on agriculture, rapid population growth, poverty, and a limited capacity to cope with an uncertain climate. The world is already likely to fall short of the Millennium Development Goals for 2015 in many regions of the world (see Box 4.1 for the Goals). Climate change threatens the long-term sustainability of development progress.

Box 4.1 Millennium Development Goals

In September 2000, 189 countries signed the United Nations Millennium Declaration. In so doing, they agreed on the fundamental dimensions of development, translated into an international blueprint for poverty reduction. This is encapsulated by the Millennium Development Goals that are focused on a target date of 2015:

- Halve extreme poverty and hunger
- Achieve universal primary education
- Empower women and promote equality between women and men
- Reduce under five mortality by two thirds
- Reduce maternal mortality by three-quarters
- Reverse the spread of diseases, especially HIV/AIDS and malaria
- Ensure environmental sustainability
- Create a global partnership for development, with targets for aid, trade and debt relief

But it is important to recognise that the scale of future climate impacts will vary between regions, countries and people. The last 30 years or so has already seen strong advances in many developing countries on income, health and education. Those developing countries that continue to experience rapid growth will be much better placed to deal with the consequences of climate change. Other areas, predominantly low-income countries, where growth is stagnating may find their vulnerability increases.

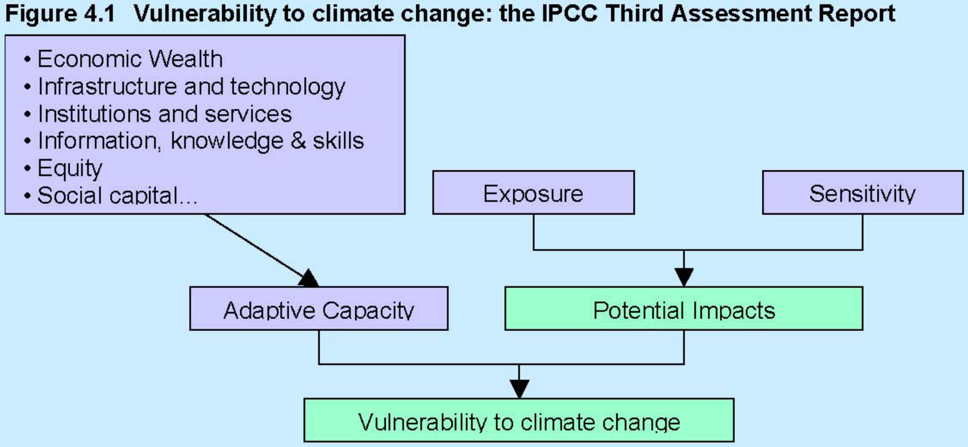
The challenge now is to limit the damage, both by mitigation and adaptation. It is vital therefore to understand just how, and how much, climate change is likely to slow development progress. The chapter begins by examining the processes by which climate change impacts will be felt in developing counties. Section 4.2 considers what it is about the starting position of these countries that makes them vulnerable to the physical changes set out in Chapter 3. Understanding why developing countries are especially vulnerable is critical to understanding how best to improve their ability to deal with climate change (discussed in Chapter 20 [not included here]). Sections 4.3 and 4.4 move on to consider the consequences of a changing climate on health, income and growth. The first part of the analysis draws on evidence from past and current exposure to climate variability to show how vulnerable groups are affected by a hostile climate. The second summarises key regional impacts. Section 4.5 explores the potential effects on future growth and income levels, which in turn affect the numbers of people living below poverty thresholds as well as the child mortality rate. The chapter concludes with Section 4.6 reviewing the possible consequences for migration, displacement and risk of conflict resulting from the socio-economic and environmental pressures of climate change.

4.2 The vulnerability of developing countries to a changing climate

Developing countries are especially vulnerable to the physical impacts of climate change because of their exposure to an already fragile environment, an economic structure that is highly sensitive to an adverse and changing climate, and low incomes that constrain their ability to adapt.

The effects of climate change on economies and societies will vary greatly over the world. The circumstances of each country — its initial climate, socio-economic conditions, and growth prospects — will shape the scale of the social, economic and environmental effects of climate change. Vulnerability to climate change can be classified as: *exposure* to changes in the climate, *sensitivity* — the degree to which a system is affected by or responsive to climate stimuli,[2] and *adaptive capacity* — the ability to prepare for, respond to and tackle the effects of climate change. This is illustrated in Figure 4.1. Developing countries score poorly on all three criteria. This section provides a brief overview of some of the key vulnerabilities facing many developing countries. Unless these vulnerabilities are overcome they are likely to increase the risk and scale of damaging impacts posed by climate change.

Figure 4.1 Vulnerability to climate change: the IPCC Third Assessment Report



Source: redrawn from Ionescu et al (2005)

Exposure: The geography of many developing countries leaves them especially vulnerable to climate change.

Geographical exposure plays an important role in determining a country's growth and development prospects. Many developing countries are located in tropical areas. As a result, they already endure climate extremes (such as those that accompany the monsoon and El Niño and La Niña cycles), intra and interannual variability in rainfall,[3] and very high temperatures. India, for example, experienced peak temperatures of between 45°C and 49°C during the pre-monsoon months of 2003.[4] Geographical conditions have been identified as important contributors to lower levels of growth in developing countries. If rainfall — that arrives only in a single season in many tropical areas — fails for example, a country will be left dry for over a year with powerful implications for their agricultural sector. This occurred in India in 2002 when the monsoon rains failed, resulting in a seasonal rainfall deficit of 19% and causing large losses of agricultural production and a drop of over 3% in India's GDP.[5] Recent analysis has led Nordhaus to conclude that "tropical geography has a substantial negative impact on output density and output per capita compared to temperate regions".[6] Sachs, similarly, argues that poor soils, the presence of pests and parasites, higher crop respiration rates due to warmer temperatures, and difficulty in water availability and control explain much of the tropical disadvantage in agriculture.[7] Climate change is predicted to make these conditions even more challenging, with the range of possible physical impacts set out in Chapter 3. Even slight variations in the climate can have very large costs in developing countries as many places are close to the upper temperature tolerance of activities such as crop production. Put anther way, climate change will have a disproportionately damaging impact on developing countries due, in part at least, to their location in low latitudes, the amount and variability of rainfall they receive, and the fact that they are "already too hot".[8] [Graphic omitted, Figure 4.2 omitted.]

Sensitivity: Developing economies are very sensitive to the direct impacts of climate change given their heavy dependence on agriculture and ecosystems, rapid population growth and concentration of millions of people in slum and squatter settlements, and low health levels.

Dependence on agriculture: Agriculture and related activities are crucial to many developing countries, in particular for low income or semi-subsistence economies. The rural sector contributes 21% of GDP in India, for example, rising to 39% in a country like Malawi,[9] whilst 61% and 64% of people in South Asia and sub-Saharan Africa are employed in the rural sector.[10] This concentration of economic activities in the rural sector — and in some cases around just a few commodities — is associated with low levels of income, as illustrated in Figure 4.2.[11][not included here]. The concentration of activities in one sector also limits flexibility to switch to less climate-sensitive activities such as manufacturing and services. The agricultural sector is one of the most at risk to the damaging impacts of climate change — and indeed current extreme climate variability — in developing countries, as discussed in Chapter 3.

Dependence on vulnerable ecosystems: All humans depend on the services provided by natural systems. However, environmental assets and the services they provide are especially important for poor people, ranging from the provision of subsistence products and market income, to food security and health services.[12] Poor people are consequently highly sensitive to the degradation and destruction of these natural assets and systems by climate change. For example, dieback of large areas of forest — some climate models show strong drying over the Amazon if global temperature increases by more than 2°C, for example — would affect many of the one billion or more people who depend to varying degrees on forests for their livelihoods (Table 4.1).[13]

Table 4.1 Direct roles of forests in household livelihood strategies

Poverty aspects	Function	Description
Safety net	Insurance	Food and cash income in periods of unexpected food and income shortfall
Support current comsumption	Gap-filling	Regular (seasonal, for example) shortfall of food and income
	Regular subsistence uses	Fuelwood, wild meat, medicinal plants, and so on
	Low-return cash activities	A wide range of extractive of “soft management acitvities, normally in economies witrh low market integration
Poverty reduction	Diversified forest strategies	Forest activities that are maintained in economies with high market integration
	Specialized forest strategies	Forest activities that form the majority of the cash income in local economies with high market integration
	Payment for environmental services	DIrect transfers to local communities from offsite beneficiaries

Source: Classification based on Arnold (2001), Kaimowitz (2002), Angelsen and Wunder (2003), and Belcher, Ruiz-perez, and Achdiawan (2003)

Population growth and rapid urbanisation: Over the next few decades, another 2-3 billion people will be added to the world’s population, virtually all of them in developing countries.[14] This will add to the existing strain on natural resources — and the social fabric — in many poor countries, and expose a greater number of people to the effects of climate change. Greater effort is required to encourage lower rates of population growth. Development on the MDG dimensions (in particular income, the education of women, and reproductive health) is the most powerful and sustainable way to approach population growth.[15]

Developing countries are also undergoing rapid urbanisation, and the trend is set to continue as populations grow. The number of people living in cities in developing countries is predicted to rise from 43% in 2005 to 56% by 2030.[16] In Africa, for example, the 500km coast between Accra and the Niger delta will likely become a continuous urban megalopolis with more than 50 million people by 2020.[17] It does not follow from this that policies to slow urbanisation are desirable. Urbanisation is closely linked to economic growth and it can provide opportunities for reducing poverty and decreasing vulnerability to climate change.[18] Nonetheless, many of those migrating to cities live in poor conditions — often on marginal land — and are particularly vulnerable because of their limited access clean water, sanitation, and location in flood-prone areas.[19] In Latin America, for example, where urbanisation has gone far further than in Africa or Asia, more and more people are likely be forced to locate in cheaper, hazard prone areas such as floodplains or steep slopes.

Food insecurity, malnutrition and health*:* Approximately 40% of the population of sub-Saharan Africa is undernourished, largely because of the poor diet and severe and repeated infections that afflict poor people.[20] Even if the Millennium Development Goals are met, more than 400 million people could be suffering from chronic hunger in 2015.[21] Malnutrition is a health outcome in itself, but it also lowers natural resistance to infectious diseases by weakening the immune system. This is a challenge today — malnutrition was associated with 54% of child deaths in developing countries in 2001 (10.8 million children),. Climate change will potentially exacerbate this vulnerability as a greater number of malaria carrying mosquitoes move into previously uninfected areas. This is likely to generate higher morbidity and mortality rates among people suffering from malnutrition than among food-secure people.

Adaptive capacity: People will adapt to changes in the climate as far as their resources and knowledge allow. But developing countries lack the infrastructure (most notably in the area of water supply and management), financial means, and access to public services that would otherwise help them adapt.

Poor water-related infrastructure and management: Developing countries are highly dependent on water — the most climate-sensitive economic resource — for their growth and development. Water is a key input to agriculture, industry, energy and transport and is essential for domestic purposes. Irrigation and effective water management will be very important in helping to reduce and manage the effects of climate change on agriculture.[22] But many developing countries have low investment in irrigation systems, dams, and ground water. For example, Ethiopia has less than 1% of the artificial water storage capacity per capita of North America, despite having to manage far greater hydrological variability.[23] Many developing countries do not have enough water storage to manage annual water demand based on the current average seasonal rainfall cycle, as illustrated in Table 4.2 [not shown here]. This will become an even greater bind with a future, less predictable cycle.

In addition, inappropriate water pricing and subsidised electricity tariffs that encourage the excessive use of groundwater pumping (for agricultural use, for example) also increase vulnerability to changing climatic conditions. For example, 104 of Mexico's 653 aquifers (that provide half the water consumed in the country) drain faster than they can replenish themselves, with 60% of the withdrawals being for irrigation.[25] Similarly, water tables are falling in some drought-affected districts of Pakistan by up to 3 meters per year, with water now available only at depths of 200-300 meters.[26] The consequences of inadequate investment in water-related infrastructure and poor management are important given that most climate change impacts are mediated through water (as discussed in Chapter 3).

Low incomes and underdeveloped financial markets: In many developing countries the capacity of poor people to withstand extreme weather events such as a drought is constrained both by low income levels and by limited access to credit, loans or insurance (in terms of access and affordability).[27] These constraints are likely to become worse as wet and dry seasons become increasingly difficult to predict with climate change.[28] This is often exacerbated by weak social safety nets that leave the poorest people very vulnerable to climate shocks. At the national level, many low-income countries have limited financial reserves to cushion the economy against natural disasters,[29] coupled with underdeveloped financial markets and weak links to world financial markets that limit the ability to diversify risk or obtain or reallocate financial resources. Less than 1% of the total losses from natural disasters, for example, were insured in low-income countries during the period 1985 to 1999.[30]

Poor public services: Inadequate resources and poor governance (including corruption) often result in poor provision of public services. Early warning systems for extreme weather conditions, education programmes raising awareness of climate change, and preventive measures and control programmes for diseases spread by vectors or caused by poor nutrition are examples of public services that would help to manage and cope with the effects of climate change but receive weak support and attention in developing countries.

Implications for future vulnerability of different growth pathways.

The following sections assume current levels of vulnerabilities in the developing world. However, some parts of the developing world may look very different by the end of the century. If development progress is strong, then much of Asia and Latin America may be middle income or above, with substantial progress also being made in Africa. Growth and development should equip these countries to better manage climate change, and possibly avoid some of the most adverse impacts. For example, if there are more resources to build protection against rising sea levels, and economies become more diversified. But the extent to which these countries will be able to cope with climate change will depend on the scale of future impacts, and hence the action today to curb greenhouse gas emissions.

Further, the speed of climate change over the next few decades will — in part — determine the ability of developing countries to develop and grow. Climate change is likely to lead to an increase in extreme weather events.[31] Evidence (discussed below) shows that extreme climate variability can set back growth and development prospects in the poorest countries. If climatic shocks do become more intense and frequent before these countries have been able to reduce their vulnerability, long-term growth potential could be called into question. And some developing countries are already exposed to the damaging impacts of climate change that, in extreme cases such as Tuvalu, have already constrained their long-term development prospects.

4.3 Direct implications of climate change for health, livelihoods and growth: what can be learnt from natural disasters?

The impact of climate change on poor countries is likely to be severe through both the effects of extreme weather events and a longer-term decline in the

environment. The impact of previous extreme weather events provides an insight into the potential consequences of climate change.

Many developing countries are already struggling to cope with their current climate. Both the economic costs of natural disasters and their frequency have increased dramatically in the recent past. Global losses from weather related disasters amounted to a total of around $83 billion during the 1970s, increasing to a total of around $440 billion in the 1990s with the number of 'great natural catastrophe' events increasing from 29 to 74 between those decades.[32] The financial costs of extreme weather events represent a greater proportion of GDP loss in developing countries, even if the absolute costs are more in developed countries given the higher monetary value of infrastructure.[33] And over 96% of all disaster related deaths worldwide in recent years have occurred in developing countries. Climatic shocks can — and do — cause setbacks to economic and social development in developing countries. The IMF, for example, estimates costs of over 5% of GDP per large disaster on average in low-income countries between 1997 and 2001.[34]

Climate change will exacerbate the existing vulnerability of developing countries to an often difficult and changing climate. This section focuses on those aspects that will likely feel the largest impacts: health, livelihoods and growth. The analysis draws on evidence from past and current exposure to climate variability to demonstrate the mechanisms at work.

Despite some beneficial effects in colder regions, climate change is expected to worsen health outcomes substantially.

Climate change will alter the distribution and incidence of climate-related health impacts, ranging from a reduction in cold-related deaths to greater mortality and illness associated with heat stress, droughts and floods. Equally the geographic incidence of illnesses such as malaria will change.

As noted in Chapter 3, if there is no change in malaria control efforts, an additional 40 to 60 million people in Africa could be exposed to malaria with a 2°C rise in temperature, increasing to 70 to 80 million at 3 - 4°C.[35] Though some regions such as parts of West Africa may experience a reduction in exposure to vector borne diseases (see Chapter 3), previously unaffected regions may not have appropriate health systems to cope with and control malaria outbreaks. For poor people in slums, a greater prevalence of malaria — or cholera — may lead to higher mortality rates given poor sanitation and water quality, as well as malnutrition. In Delhi, for example, gastroenteritis cases increased by 25% during a recent heat wave as slum dwellers had to drink contaminated water.[36]

The additional heath risks will not only cost lives, but also increase poverty. Malnutrition, for example, reduces peoples' capacity to work and affects a child's mental development and educational achievements with life-long effects. The drought in Zimbabwe in 2000, for example, is estimated to have contributed to a loss of 7-12% of lifetime earnings for the children who suffered from malnutrition.[37] Managing the consequences of these health impacts can in itself lead to further impoverishment.

Households face higher personal health expenditures through clinic fees, anti-malarial drugs and burials, for example. This was seen in the case of Vietnam where rising health expenditures were found to have pushed about 3.5% of the population into absolute poverty in both 1993 and 1998.[38] The effects can be macroeconomic in scale: malaria is estimated to have reduced growth in the most-affected countries by 1.3% per year.[39]

Falling agricultural output and deteriorating conditions in rural areas caused by climate change will directly increase poverty of households in poor countries.

Current experience of extreme weather events underlines how devastating droughts and floods can be for household incomes. For example:

- In North-Eastern Ethiopia, drought induced losses in crop and livestock between 1998 – 2000 were estimated at $266 per household — greater than the annual average cash income for more than 75% of households in the study region;[40]
- In Ecuador the 1997-98 El Niño contributed to a loss of harvest and rise in unemployment that together increased poverty incidence by 10 percentage points in the affected municipalities.[41]

These immediate impacts are often compounded by the rising cost of food - following the drought in Zimbabwe in 1991-92, for example, food prices increased by 72%[42] — and loss of environmental assets and ecosystems that would otherwise provide a safety net for poor people.

These risks and the scale of impacts may increase with climate change if people remain highly exposed to the agricultural sector and have limited resources to invest in water management or crop development. As discussed in Chapter 1, climate change is likely to result in more heatwaves, droughts, and severe floods. In addition to these short-term shocks in output, climate change also risks a long-term decline in agricultural productivity in tropical regions. As Chapter 3 notes, yields of the key crops across Africa and Western Asia may fall by between 15% to 35% or 5% to 20% (assuming a weak or high carbon fertilisation respectively) once temperatures reach 3 or 4°C. Such a decline in productivity would pose a real challenge for the poorest countries, especially those already facing water scarcity. In sub-Saharan Africa, for example, only 4% of arable land is currently irrigated and the effects of climate change may constrain the long-term feasibility of this investment.[43] Some extreme scenarios suggest that by 2100 the Nile could face a decrease in flow of up to 75%,[44] with normal irrigation practices having been found to cease when annual flow is reduced by more than 20%.[45]

Strategies to manage the risks and impacts of an adverse climate can lock people into long-term poverty traps.

The survival strategies adopted by poor people to cope with a changing climate may damage their long-term prospects. Equally, if there is a risk of more frequent extreme weather events, then households may also have shorter periods in which to recover, thus increasing the possibility of being pushed into a poverty-trap (as illustrated in Figure 4.4[not included here]).[46] There are two aspects to this:

Risk-managing: Poor households may switch to low risk crops. In India, for example, poor households have been found to allocate a larger share of land to safer traditional varieties of rice and castor than to riskier but high-return varieties. This response in itself can reduce the average income of these people. Households in Tanzania that allocated more of their land to sweet potatoes (a low return, low risk crop), for example, were found to have a lower return per adult.[47]

Risk-coping: Poor households may also be forced to sell their only assets (such as cattle and land). This can then compromise their long-term prospects as they are unable to educate their children, or raise levels of income over time. Following the 1991-92 droughts in Zimbabwe, many households had to sell their goats that were intended as a form of savings to pay, for example, for secondary education.[48] [49] Alternatively, to try and avoid permanent destitution households may decide to reduce their current consumption levels. This strategy can have long-term effects on health and human capital.[50] Reductions in consumption levels during a drought in Zimbabwe, for example, led to permanent and irreversible growth losses among children - losses that would reduce their future educational and economic achievement.[51]

Climate change and variability cuts the revenues and increases the spending of nations, worsening their budget situation.

Dealing with climate change and extreme variability will also place a strain on government budgets, as illustrated in the case of Zimbabwe following the drought of 1991-92. The severity of the effect on government revenues will in part depend on the structure of the economy. For example, the drought in southern Africa in 1991-92 resulted in a fall in income of over 8% in Malawi where agriculture contributed 45% of GDP at the time, but only 2% of GDP in South Africa where just 5% of GDP was obtained from agriculture.[52]Climate change will also necessitate an increase in spending at the national level to deal with the aftermath of extreme weather events and the consequences of a gradual reduction in food and water supplies. For example, the logistical costs of importing cereal into drought affected southern African countries in 1991-92 alone were $500million.[53]In some cases, the expenditure requirements may be beyond the government's capacity. This was the case following Hurricane Mitch in 1998 where the Honduras government (with a GNP of $850 per capita) faced reconstruction costs equivalent to $1250 per capita.[54]

4.6 Population movement and risk of conflict

Greater resource scarcity, desertification, risks of droughts and floods, and rising sea levels could drive many millions of people to migrate – a last-resort adaptation for individuals, but one that could be very costly to them and the world.

The impacts of climate change, coupled with population growth in developing countries, will exert significant pressure for cross-border and internal population movement. There is already evidence of the pressure that an adverse climate can impose for migration. Approximately 7 million people migrated in order to obtain relief food out of the 80 million considered to be semi-starving in sub-Saharan Africa primarily due to environmental factors.[93]

Millions of people could be compelled to move between countries and regions, to seek new sources of water and food if these fall below critical thresholds. Rising sea levels may force others to move out of low-lying coastal zones. For example, if sea levels rise by 1 metre (a possible scenario by the end of the century, Chapter 3) and no dyke enforcement measures are taken, more than one-fifth of Bangladesh may be under water for example.[94] And atolls and small islands are at particular risk of displacement with the added danger of complete abandonment. As one indication of this, the government of Tuvalu have already begun negotiating migration rights to New Zealand in the event of serious climate change impacts.[95]

The total number of people at risk of displacement or migration in developing countries is very large. This ranges from the millions of people at risk of malnutrition and lack of clean water to those currently living in flood plains. Worldwide, nearly 200 million people today live in coastal flood zones that are at risk; in South Asia alone, the number exceeds 60 million people.[96] In addition, there are potentially between 30 to 200 million people at risk of hunger with temperature rises of 2 to 3°C — rising to 250 to 550 million people with a 3°C warming;[97] and between 0.7 to 4.4 billion people who will experience growing water shortages with a temperature rise of 2°C,[98] as discussed in Chapter 3.

The exact number of people who will actually be displaced or forced to migrate will depend on the level of investment, planning and resources at a government's disposal to defend these areas or provide access to public services and food aid. The Thames Barrier, for example, protects large parts of London. In Shanghai and Tokyo, flood defences and pumped drainage prevent flooding of areas lying below normal tides.

Protection is expensive, however, particularly relative to income levels in developing countries. A project to construct 8,000 kilometres of river dykes in Bangladesh — a country with a GNI of $61 billion is costing $10 billion. These high costs will discourage governments from investing. Defensive investments must be made early to be effective, but they may be politically unpopular if they would divert large amounts of money from programmes with more immediate impact such as infrastructure, health and education.

Drought and other climate-related shocks may spark conflict and violence, as they have done already in many parts of Africa.

The effects of climate change — particularly when coupled with rapid population growth, and existing economic, political, ethnic or religious tensions - could be a contributory factor in both national and cross-border conflicts in some developing countries.

Long-term climate deterioration (such as rising temperatures and sea levels) will exacerbate the competition for resources and may contribute to forced dislocation and migration that can generate destabilising pressures and tensions in neighbouring areas.

Increased climate variability (such as periods of intense rain to prolonged dry periods) can result in adverse growth shocks and cause higher risks of conflict as work opportunities are reduced, making recruitment into rebel groups much easier. Support for this relationship has been provided by empirical work in Africa, using rainfall shocks as an instrument for growth shocks.[99]

Adverse climatic conditions already make societies more prone to violence and conflict across the developing world, both internally and cross-border. Long periods of drought in the 1970s and 1980s in Sudan's Northern Darfur State, for example, resulted in deep, widespread poverty and, along with many other factors such as a breakdown in methods of coping with drought, has been identified by some studies as a contributor to the current crisis there.[100] Whilst climate change can contribute to the risk of conflict, however, it is very unlikely to be the single driving factor. Empirical evidence shows that a changing and hostile climate has resulted in tension and conflict in some countries but not others. The risk of climate change sparking conflict is far greater if other factors such as poor governance and political instability, ethnic tensions and, in the case of declining water availability, high water interdependence are already present. In light of this, West Africa, the Nile Basin and Central Asia have been identified as regions potentially at risk of future tension and conflict. Box 4.6 indicates areas vulnerable to future tension and past conflicts where an adverse climate has played an important role.

Box 4.6 Future risks and past conflicts

Future risks

- *West Africa:* Whilst there is still much uncertainty surrounding the future changes in rainfall in this part of the world, the region is already exposed to declining average annual rainfall (ranging from 10% in the wet tropical zone to more than 30% in the Sahelian zone since the early 1970s) and falling discharge in major river systems of between 40 to 60% on average. Changes of this magnitude already give some indication of the magnitude of risks in the future given that we have only seen 0.7°C increase and 3°C or 4°C more could be on the way in the next 100 to 150 years. The implications of this are amplified by both the high water interdependence in the region - 17 countries share 25 transboundary watercourses – and plans by many of the countries to invest in large dams that will both increase water withdrawals and change natural water allocation patterns between riparian countries.[101] The region faces a serious risk of water-related conflict in the future if cooperative mechanisms are not agreed.[102]

- *The Nile:* Ten countries share the Nile.[103] While Egypt is water scarce and almost entirely dependent on water originating from the upstream Nile basin countries, approximately 70% of the Nile's waters flow from the Ethiopian highlands. Climate change threatens an increase in competition for water in the region, compounded by rapid population growth that will increase demand for water. The population of the ten Nile countries is projected to increase from 280 million in 2000 to 860 million by 2050. A recent study by Strzepek et al (2001) found a propensity for lower Nile flows in 8 out of 8 climate scenarios, with impacts ranging from no change to a roughly 40% reduction in flows by 2025 to over 60% by 2050 in 3 of the flow scenarios.[104] Regional cooperation will be critical to avoid future climate-driven conflict and tension in the region.

Past conflicts

• *National conflict*: Drought in Mali in the 1970s and 1980s damaged the pastoral livelihoods of the semi-nomadic Tuareg. This resulted in many people having to seek refuge in camps or urban areas where they experienced social and economic marginalisation or migrated to other countries. On their return to Mali, these people faced unemployment and marginalisation which, coupled with the lack of social support networks for returning migrants, continuing drought and competition for resources between nomadic and settles peoples (among many other things), helped create the conditions for the 'Second Tuareg Rebellion' in 1990. A similar scenario has played out in the Horn of Africa,[105] and may now be replicating itself in northern Nigeria, where low rainfall combined with land-use pressures have reduced the productivity of grazing lands, and herders are responding by migrating southward into farm areas.[106]

• *Cross-border conflict:* Following repeated droughts in the Senegal River Basin in the 1970s-80s, the Senegal River Basin Development Authority was created by Mali, Mauritania and Senegal with the mandate of developing and implementing a major water infrastructure programme. Following the commissioning and completion of agreed dams, conflict erupted between Senegal and Mauritania when the river started to recede from adjacent floodplains. The dispute and tension escalated with hundreds of Senegalese residents being killed in Mauritania and a curfew imposed by both Governments such that 75,000 Senegalese and 150,000 Mauritanians were repatriated by June 1989. Diplomatic relationships between the two countries were restored in 1992, but a virtual wall has effectively been erected along the river.[107]Drought has also caused conflict between Ugandan and Kenyan pastoralists, and has led Ethiopian troops to move up north to stop the Somalis crossing the border in search of pasture and water for their livestock.[108] Similarly, extreme weather events in 2000 that affected approximately 3 million people in Bangladesh resulted in migration and violence as tribal people in North India clashed with emigrating Bangladeshis.[109]

Footnotes to 4.1

1. The physical effects of climate change are predicted to become progressively more significant by the2050s with a 2 to 3°C warming, as explained in Chapter 3.

Footnotes to 4.2

2. IPCC (2001). The classification of *sensitivity* is similar to *susceptibility* to climate change, the degree to which a system is open, liable, or sensitive to climate stimuli.
3. Intra-annual variability refers to rainfall concentrated in a single season, whilst interannual variability refers to large differences in the annual total of rainfall. The latter may be driven by phenomena such asthe El Nino/Southern Oscillation (ENSO) or longer-term climate shifts such as those that caused the ongoing drought in the African Sahel. Brown and Lall (2006)
4. De et al (2005)

5. Challinor et al (2006). The scale of losses in the agricultural sector is indicated by the fact that this sector contributed just over one fifth of GDP at the time.
6. Nordhaus (2006). Approximately 20% of the difference in per capita output between tropical Africa and two industrial regions is attributed to geography according to Nordhaus' model and analysis.
7. Sachs (2001a)
8. Mendelsohn et al (2006)
9. World Bank (2006a) using 2004 data
10. ILO (2005). The employment figures are given as a share of total employment, 2005.
11. For example, the Central African Republic derives more than 50% of its export earnings from cotton alone (1997/99). Commission for Africa (2005)
12. Natural medicines, for example, are often the only source of medicine for poor people and can help reduce national costs of supplying medical provisions in developing countries. The ratio of traditional healers to western-trained doctors is approximately 150:1 in some African countries for example. UNEP-WCMC (2006)
13. Vedeld et al (2004). This effect on the Amazon has been found with the Hadley Centre model, as reported in Cox *et al.* (2000), and several other climate models (Scholze *et al.* 2006) as discussed in Chapter 3.
14. World Bank (2003b)
15. Stern et al (2005)
16. World Population Prospects (2004); and World Urbanization Prospects (2005).
17. Hewawasam (2002)
18. For example, proximity and economies of scale enable cost-effective and efficient targeting and provision of basic infrastructure and services.
19. Approximately 72% of Africa's urban inhabitants now live in slums and squatter settlements for example (Commission for Africa, 2005)
20. WHO (2005). Poverty impacts a person's standard of living, the environmental conditions in which they live, and their ability to meet basic needs such as food, housing and health care that in turn affects their level of nutrition.
21. One of the MDGs is to halve, between 1990 and 2015, the proportion of people who suffer from hunger. In 2002 there were 815 million hungry people in the developing world, 9 million less than in 1990. (UN, 2005)
22. Irrigation plays an important role in improving returns from land, with studies identifying an increase in cropping intensity of 30% with the use of irrigation (Commission for Africa, 2005). Similarly, effective water management enables water to be stored for multiple uses, increases the reliability of water services, reduces peak flows and increases off-peak flows, and reduces the risk of water-related shocks and damage (World Bank, 2006b).
23. World Bank (2006c)

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25. International Commission on Irrigation and Drainage (2005)
26. Roy (2006)
27. An estimated 2.5 billion low income people globally do not have access to bank accounts, with less than 20% of people in many African countries having access (compared to 90-95% of people in the developed world) (CGAP, 2004). Poor people are typically constrained by their lack of collateral to offer lenders, unclear property rights, insufficient information to enable lenders to judge credit risk, volatile incomes, and lack of financial literacy, among other things.
28. The incomes of poor people will become less predictable, making them less able to guarantee the returns that are needed to pay back loans, while insurers will face higher risks and losses making them even less willing to cover those most in need.
29. IMF (2003)
30. Freeman et al (2002)
31. For example, a recent study from the Hadley Centre shows that the proportion of land experiencing extreme droughts is predicted to increase from 3% today to 30% for a warming of around 4°C, and severe droughts at any one time will increase from 10% today to 40% (discussed in Chapters 1 and 3).

Footnotes to 4.3

32. Data extracted from Munich Re (2004). These figures are calculated on the basis of the occurrence and consequences of 'great natural disasters'. This definition is in line with that used

by the United Nations and includes those events that over-stretch the ability of the affected regions to help themselves. As a rule, this is the case when there are thousands of fatalities, when hundreds of thousands of people are made homeless or when the overall losses and/or insured losses reach exceptional orders of magnitude. While increases in wealth and population growth account for a proportion of this increase, it cannot explain it all (see Chapter 5 for more details). The losses are given in constant 2003 values.

33. The true cost of disasters for developing countries is often undervalued. Much of the data on the costs of natural disasters is compiled by reinsurance companies and focused on economic losses rather than livelihood losses, and is unlikely to capture the effect of slow-onset and small-scale disasters and the impact these have on households. Furthermore, the assessments typically do not capture the cumulative economic losses as they are based on snapshots in time. Benson and Clay (2004)
34. IMF (2003)
35. Warren et al (2006)
36. Huq and Reid (2005)
37. Alderman et al (2003)
38. Wagstaff and van Doorslaer (2003)
39. These results were estimated after controlling for initial poverty, economic policy, tropical location and life expectancy (using different time frames). Sachs and Gallup (2001)
40. Carter et al (2004)
41. Vos et al (1999)
42. IMF (2003). This was largely due to the higher price of food that had to be imported following a drought induced reduction in agricultural output, as described in Box 4.2, coupled with an increase in inflation to 46%.
43. Commission for Africa (2005)
44. Strzepek et al (2001)
45. Cited in Nkomo et al (2006)
46. This refers to a minimum asset threshold beyond which people are unable to build up their productive assets, educate their children and improve their economic position over time. Carter et al (2005)
47. Dercon (2003). Households with an average livestock holding in Tanzania were found to allocate 20% less of their land to sweet potatoes than a household with no liquid assets, with the return per adult of the wealthiest group being 25% higher for the crop portfolio compared to the poorest quintile.
48. Hicks (1993)
49. A household survey in eight peasant associations in Ethiopia found that distressed sales of livestock following the drought in 1999 sold for less than 50% of the normal price. Carter et al (2004)
50. People can be pushed below a critical nutritional level whereby no productive activity is possible, with little scope for recovery given dependence on their own labour following the loss or depletion of their physical assets. Dasgupta and Ray (1986)
51. Hoddinott (2004)
52. IMF (2003); World Bank (2006a)
53. Benson and Clay (2004). Similarly the climatically less severe 1994/95 drought involved costs of US$1 billion in cereal losses (due to higher prices in a tighter international cereal market).
54. ODI (2005)

Footnotes to 4.4

56. Information based largely on Challinor et al (2006). See also Roy (2006)
57. As ever it is difficult to attribute an outside event to climate change but the evidence is strong that the severity of such events is likely to increase.

Footnotes to section 4.4

58. Challinor et al (2006). 70% was the maximum reduction in yield that came from the study, in northern regions. Reductions in the 30-60% range were found over much of India. Strictly speaking these results are for groundnut only, although many annual crops are expected to

behave similarly. The study was based on an SRES A2 scenario. The values assume no adaptation.

59. Challinor et al (2006)
60. Information based largely on Nkomo et al (2006)
61. The regions at risk of climate change were identified by looking at the possibility of losses in length of growing period that was used as an integrator of changing temperatures and rainfall to 2050. This was projected by downscaling the outputs from several coupled Atmosphere-Ocean General Circulation Models for four different scenarios of the future using the SRES scenarios of the IPCC. Several different combinations of GCM and scenario were used. The vulnerability indicator was derived from the weighted sum of the following four components: 1) public health expenditure and food security issues; 2) human diseases and governance; 3) Human Poverty Index and internal renewable water resources; and 4) market access and soil degradation. (Thornton et al, 2006)
62. Cited in Warren et al (2006) based on the original analysis of Parry et al. (2004). These figures assume future socio-economic development, but no carbon fertilisation effect, as discussed in Chapter 3.
63. McClean et al (2005). This is estimated using the Hadley Centre third generation coupled ocean-atmosphere General Circulation Model.
64. van Lieshout et al (2004)
65. Republic of South Africa (2000) cited in Nkomo et al (2006)
66. Strzepek et al (2001)
67. Gambia (2003) and Republic of Kenya (2002) cited in Nkomo et al (2006)
68. Information based on Nagy et al (2006)
69. El Nino-Southern Oscillation events (as discussed in Chapter 1).
70. Jones and Thornton (2003), cited in Nagy et al (2006)
71. Information based on Erda and Ji (2006)
72. Tang Guoping et al (2000)
73. NBSC (2005)
74. Warren et al (2006)
75. Warren et al (2006)
76. Increased agricultural productivity has been identified as a key factor in reducing poverty and inequality. This is based on work undertaken by Bourguignon and Morrisson (1998) using data from a broad sample of developing countries in the early 1970s and mid 1980s. Evidence from Zambia, for example, suggests that an extra US$1.5 of income is generated in other businesses for every $1 of farm income. Hazel and Hojjati (1995). Similarly, Block and Timer (1994) estimated an agricultural multiplier in Kenya of 1.64 versus a non-agricultural multiplier of 1.23 in Kenya.
77. Cited in Roy (2006)
78. World Bank (2006c)
79. World Bank (2006c). The model shows growth projections dropping 38% when historical levels of hydrological variability are assumed, relative to the same model's results when average annual rainfall is assumed in all years. Hydrological variability included drought, floods and normal variability of 20% around the mean.
80. This model picks up the aggregate impacts of climate change on a range of market sectors such as agriculture. The estimates used in this analysis are based on the impact of climate change on market sectors. PAGE2002 allows examination of either market impacts only (as used here to ensure no double counting of poverty impacts) or market plus non-market impacts. These estimates and further details on the PAGE2002 model are given in Chapter 6.
81. The baseline-climate-change scenario is based largely on scientific evidence in the Third Assessment Report of the IPCC, in which global mean temperature increases to 3.9°C in 2100 (see Chapter 6 for more detail).
82. Using the IPCC A2 SRES baseline
83. In the high-climate-change scenario, global mean temperature increases to 4.3°C in 2100. The high-climate-scenario is designed to explore the impacts that may be seen if the level of temperature change is pushed to higher levels through positive feedbacks in the climate system, as suggested by recent studies (see Chapter 1 and Chapter 6 for more detail).
84. Other factors – such as changes in income distribution – that may also affect poverty levels or child mortality are assumed to be constant.
85. Ravallion (2001)
86. Kraay (2005)
87. World Bank (2000)

88. The formulae express the level of poverty as a function of the poverty line, average household income and the distribution of income. The $2 poverty line is used throughout.
89. This figure is obtained from a cross-country regression of rates of growth in mean household expenditure per capita on GDP per capita. Ravaillion (2003)
90. It is important to note that income alone does not determine health outcomes, efficient public programmes and access to education for women are also important factors, for example. Furthermore, the way in which GDP per capita changes (for example if there is a change in the distribution of income that coincides with the change in national income) can affect the impact it has on health.
91. Analysis demonstrates the health effects today of slowing or negative per capita growth. For example, in 1990, over 900,000 infant deaths would have been prevented had developing countries been able to maintain the same rate of growth in the 1980s as in the period 1960-80 (assuming an elasticity of -0.4), rather than the slow or negative growth they in fact experienced. The effects were particularly significant in African and Latin America, where growth was lower by 2.5% on average (Pritchett and Summers, 1993).
92. The elasticity is assumed to be a constant across countries and over time, consistent with econometric evidence (such as Kakwani (1993)). However, the average elasticity of child mortality with respect to GDP over a period of time will typically not be the same as the actual elasticity that applies on a year-to-year basis, even if the latter is assumed constant, because of compounding.

Footnotes to 4.6

93. Myers (2005)
94. Nicholls (1995) and Anwar (2000/2001)
95. Barnett and Adger (2003)
96. Warren *et al.* (2006) analysing data from Nicholls (2004), Nicholls and Tol (2006) and Nicholls and Lowe (2006). This is calculated on the basis of the number of people that are exposed each year to storm surge elevation that has a one in a thousand year chance of occurring. These odds and the numbers explored could be rising rapidly. This has already been demonstrated in the case of heat waves in Southern Europe where the chance of having a summer as hot as in 2003 that in the past would be expected to occur once every 1000 years, will be commonplace by the middle of the century due to climate change, as discussed in Chapter 5.
97. Warren et al. (2006) based on the original analysis of Parry *et al.* (2004).
98. Warren et al. (2006) based on the original analysis of Arnell (2004) for the 2080s.
99. Miguel et al (2004), Collier and Hoeffler (2002), Hendrix and Glaser (2005) and Levy et al (2005)
100. University for Peace Africa Programme (2005)
101. For example, there are 20 plans in place to build large dams along the Niger River alone.
102. Niasse (2005)
103. Ethiopia, the Sudan, Egypt, Kenya, Uganda, Burundi, Tanzania, Rwanda, the Democratic Republic of Congo and Eritrea.
104. Strzepek et al (2001). Whilst there is general agreement regarding an increase in temperature ` with climate change that will lead to greater losses to evaporation, there is more uncertainty regarding the direction and magnitude of future changes in rainfall. This is due to large differences in climate model rainfall predictions.
105. Meier and Bond (2005)
106. AIACC (2005)
107. Niasse (2005)
108. Christian Aid (2006)
109. Tanzier el al (2002)

References

Full references are available online at www.hm-treasury.gov.uk