7

Industry, settlement and society

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Executive summary

Climate-change vulnerabilities of industry, settlement and society are mainly related to extreme weather events rather than to gradual climate change (very high confidence).
The significance of gradual climate change, e.g., increases in the mean temperature, lies mainly in changes in the intensity and frequency of extreme events, although gradual changes can also be associated with thresholds beyond which impacts become significant, such as in the capacities of infrastructures. [7.2, 7.4]

Aside from major extreme events and thresholds, climate change is seldom the main factor in considering stresses on the sustainability of industry, settlements and society (very high confidence).
The significance of climate change (positive or negative) lies in its interactions with other non-climate sources of change and stress, and its impacts should be considered in such a multi-cause context. [7.1.3, 7.2, 7.4]

Vulnerabilities to climate change depend considerably on specific geographic, sectoral and social contexts (very high confidence).
They are not reliably estimated by large-scale (aggregate) modelling and estimation. [7.2, 7.4]

Vulnerabilities of industry, infrastructures, settlements and society to climate change are generally greater in certain high-risk locations, particularly coastal and riverine areas, and areas whose economies are closely linked with climate-sensitive resources, such as agricultural and forest product industries, water demands and tourism; these vulnerabilities tend to be localised but are often large and growing (high confidence).
For example, rapid urbanisation in most low and middle income nations, often in relatively high-risk areas, is placing an increasing proportion of their economies and populations at risk. [7.3, 7.4, 7.5]

Where extreme weather events become more intense and/or more frequent with climate change, the economic and social costs of those events will increase (high confidence).
Experience indicates that costs of major events can range from several percent of annual regional gross domestic product (GDP) and income generation in very large regions with very large economies to more than 25% in smaller areas that are affected by the events. Climate-change impacts spread from directly impacted areas and sectors to other areas and sectors through extensive and complex linkages. [7.4, 7.5]

Poor communities can be especially vulnerable, in particular those concentrated in relatively high-risk areas (high confidence).
They tend to have more limited adaptive capacities, and are more dependent on climate-sensitive resources such as local water and food supplies. [7.2, 7.4, 5.4]

Industry, settlements and society are often capable of considerable adaptation, depending heavily on the competence and capacity of individuals, communities, enterprises and local governments, together with access to financial and other resources (very high confidence).
But that capacity has limits, especially when confronted by climate changes that are relatively extreme or persistent. [7.4.3, 7.6]

Although most adaptations reflect local circumstances, adaptation strategies for industry and settlement and, to a lesser degree, for society, can be supported by linkages with national and global systems that increase potentials and resources for action (very high confidence). [7.6.6]

7.1 Introduction

7.1.1 Key issues

Climate change and sustainable development are linked through their interactions in industries, human settlements and society. Many of the forces shaping carbon *emissions* – such as economic growth, technological transformations, demographic shifts, lifestyles and governance structures – also underlie diverse pathways of development, explaining in part why industrialised countries account for the highest share of carbon emissions. The same drivers are also related to climate-change *impacts*, explaining in part why some regions and sectors, especially from the developing world, are more vulnerable to climate change than others because they lack financial, institutional and infrastructural capacities to cope with the associated stresses (O'Brien and Leichenko, 2003). Settlements and industry are often key focal points for linkages between mitigation and adaptation; for instance, efficient buildings can help in adapting to changing climate by providing protection against warming, while this adaptation may involve increased or decreased energy use and greenhouse gas emissions associated with cooling based on electricity (Hough, 2004); and society is a key to responses based on democratic processes of government.

Industries, settlements and human society are accustomed to variability in environmental conditions, and in many ways they have become resilient to it when it is a part of their normal experience. Environmental changes that are more extreme or persistent than that experience, however, can lead to vulnerabilities, especially if the changes are not foreseen and/or if capacities for adaptation are limited; and the IPCC Third Assessment Report (IPCC, 2001) reported that climate change would increase the magnitude and frequency of weather extremes.

The central issues for industry, settlement and society are whether climate-change impacts are likely to require responses that go beyond normal adaptations to varying conditions, if so, for whom, and under what conditions responses are likely to be sufficient to avoid serious effects on people and the sustainability of their ways of life. Recent experiences such as Hurricane Katrina suggest that these issues are salient for developed as well as developing countries (Figure 7.1).

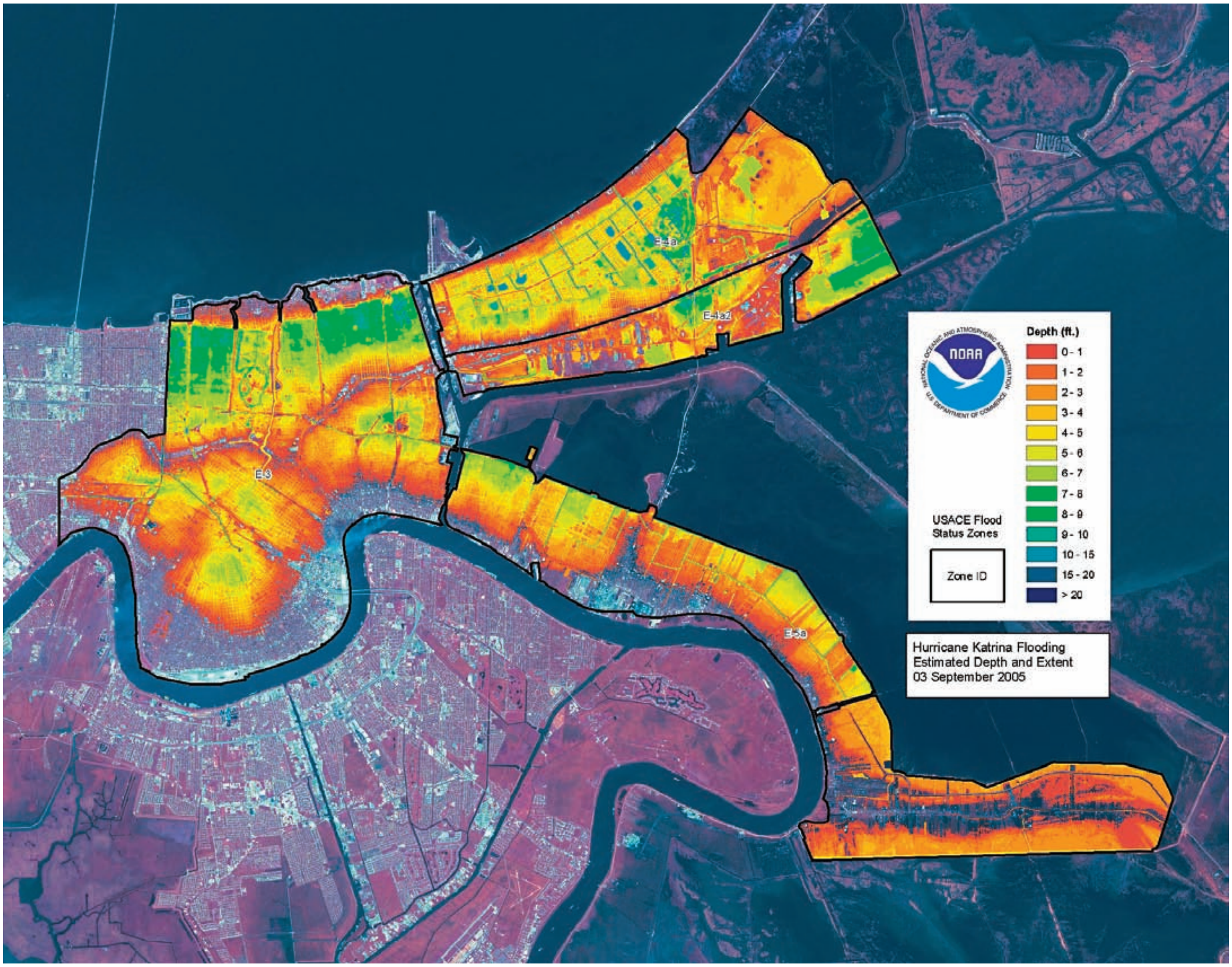

Figure 7.1. *Flood depths in New Orleans, USA, on 3 September, 2005, five days after flooding from Hurricane Katrina, in feet (0.3 m) (Source: www.katrina.noaa.gov/maps/maps.html).*

Scale matters in at least three ways in assessing the impacts of climate change on industry, settlement and society. First, climate change is one of a set of multiple stresses operating at diverse scales in space and through time. Second, both the exposure to climate change and the distribution of climate-sensitive settlements and industrial sectors vary greatly across geographic scale. The primary social and economic conditions that influence adaptive capacity also differ with scale, such as access to financial resources. One could say, for instance, that at a national scale industrialised countries such as the UK and Norway can cope with most kinds of gradual climate change, but focusing on more localised differences can show considerable variability in stresses and capacities to adapt (Environment Canada, 1997; Kates and Wilbanks, 2003; London Climate Change Partnership, 2004; O'Brien et al., 2004; Kirshen et al., 2006). Third, temporal scale is a critical determinant of the capacity of human systems to adapt to climate change; for instance, rapid changes are usually more difficult to absorb without painful costs than gradual change (Section 7.4; Chapter 17).

7.1.2 Scope of the chapter

Guidance for the preparation of the IPCC Fourth Assessment Report requested particular attention by this chapter to five systems of interest: industry, services, utilities/infrastructure, human settlement and social issues. Chapter 5 of the report deals with impacts and adaptation on the food, fibre and forest products sectors, and Chapters 9 to 16 deal with impacts and adaptation in global regions.

Chapter 7's topic of 'industry, settlement and society' is clearly very broad; and many of the components of the chapter, such as industry and services, settlements, financial and social issues, are so heterogeneous that each could be the subject of a separate chapter. Very briefly, however, the chapter will summarise and assess the literature relevant to the impacts of climate change on the structure, functioning, and relationships of all of these components of human systems potentially affected by climate change, positively or negatively.

The chapter (1) identifies current and potential vulnerabilities and positive or negative impacts of climate change on industrial, service and infrastructure sectors, human settlements and human societies; (2) assesses the current knowledge about the costs of possible impacts; and (3) considers possible adaptive responses. In general, it emphasises that climate-change impacts, adaptation potentials, and vulnerabilities are context-specific, related to the characteristics and development pathways of the location or sector involved.

7.1.3 Human systems in context

Human systems include social, economic and institutional structures and processes. Related to industry, settlement and society, these systems are diverse and dynamic, expressed at the individual level through livelihoods. They tend to revolve around such aims of humanity as survival, security, well-being, equity and progress; and in these regards weather and climate are often of secondary importance as sources of benefits or stresses. More important are such issues as access to financial resources, institutional capacities and potentials for conflict (Ocampo and Martin, 2003; Thomas and Twyman, 2005) and such stresses as rapid urbanisation, disease and terrorism. It is in its complex interactions with these kinds of social contexts that climate change can make a difference, easing or aggravating multiple stresses and in some cases potentially pushing a multi-stressed human system across a threshold of sustainability (Wilbanks, 2003b).

In most cases, climate (and thus climate change) affects human systems in three principal ways. First, it provides a context for climate-sensitive human activities ranging from agriculture to tourism. For instance, rivers fed by rainfall enable irrigation and transportation and can enrich or damage landscapes. Second, climate affects the cost of maintaining climate-controlled internal environments for human life and activity; clearly, higher temperatures increase costs of cooling and reduce costs of heating. Third, climate interacts with other types of stresses on human systems, in some cases reducing stresses but in other cases exacerbating them. For example, drought can contribute to rural-urban migration, which, combined with population growth, increases stress on urban infrastructures and socio-economic conditions. In all of these connections, effects can be positive as well as negative; but extreme climate events and other abrupt changes tend to affect human systems more severely than gradual change, because they offer less time for adaptation, although gradual changes may also reach thresholds at which effects are notable.

7.1.4 Conclusions of the IPCC Third Assessment Report

The Third Assessment Report of IPCC Working Group II (TAR) included a chapter on Human Settlements, Energy, and Industry (Scott et al., 2001) and also a separate chapter on Insurance and Other Financial Services (Vellinga et al., 2001). Together, these two chapters in TAR correspond to a part of this one chapter in the Fourth Assessment Report; a substantial part of this chapter is devoted to subject matter not directly addressed in previous IPCC reports (e.g., services, infrastructures and social issues).

The first of the TAR chapters (Chapter 7) was largely devoted to impact issues for human settlements, concluding that settlements are vulnerable to effects of climate change in three major ways: through economic sectors affected by changes in input resource productivity or market demands for goods and services, through impacts on certain physical infrastructures, and through impacts of weather and extreme events on the health of populations. It also concluded that vulnerability tends to be a function mainly of three factors: location (coastal and riverine areas at most risk), economy (those dependent on weather-related sectors at most risk), and size (larger settlements at greater aggregate risk but having more resources for impact prevention and adaptation). The most direct risks are from flooding and landslides due to increases in rainfall intensity and from sea-level rise and storm surges in coastal areas. Although some areas are at particular risk, urban flooding could be a problem in any settlement where drainage infrastructures are inadequate, especially where informal settlement areas lack urban services and adaptive capacities. Rapid urbanisation in relatively high-risk areas is a special concern, because it concentrates people and assets and is generally increasing global and regional vulnerability to climate-change impacts. Other dimensions of vulnerability include general regional vulnerabilities to impacts (e.g., in polar regions), lack of economic diversification and fragile urban infrastructures.

Possible impacts of climate change on financial institutions and risk financing were the focus of a separate chapter (Chapter 8) in the TAR. This chapter concluded that climate change is likely to raise the actuarial uncertainty in catastrophe risk assessment, placing upward pressure on insurance premiums and possibly leading to reductions in risk coverage. It identified a significant rise in the costs of losses from meteorological disasters since the early 1980s which, as has been confirmed by the AR4 (see Chapter 1), appeared to reflect an increase in catastrophe occurrence over and above the rise in values, exposures, and vulnerabilities.

7.2 Current sensitivity/vulnerability

A frequent objective of human societies is to reduce their sensitivity to weather and climate, for example, by controlling the climate in buildings within which people live, shop and work or by controlling the channels and flows of rivers or the configurations of sea coasts. Recent experience with weather variability, however, reminds us that - at least at feasible levels of investment and technological development - human control over climate-related aspects of nature can be limited (see Box 7.4).

In fact, sensitivities of human systems to climate and climate change abound:

1. Environmental quality is a case in point, where weather and climate can affect air and water pollution and, in cases of extreme events, exposures to wastes that are hazardous to health. Consider the interaction between the ambient air

temperature of an urban area and its concentration of ozone, which can have adverse health implications (Hogrefe et al., 2004; Section 7.4.2.4; Chapter 8), or effects of hurricane flooding on exposures to health threats (Marris, 2005).

2. Linkage systems, such as transportation and transmission systems for industry and settlements (e.g., water, food supply, energy, information systems and waste disposal), are important in delivering ecosystem and other services to support human well-being, and can be subject to climate-related extreme events such as floods, landslides, fire and severe storms. Such exposed infrastructures as bridges and electricity transmission networks are especially vulnerable, as in the experience of Hurricane Georges in 1998, which threatened port and oil storage facilities in the Dominican Republic (REC, 2004), or the 2005 experience with Hurricane Katrina (Box 7.4; Section 7.4.2.3).
3. Other physical infrastructures can be affected by weather and climate as well. For example, the rate of deterioration of external shells of building structures is weather-related, depending on the materials used, and buildings are affected by water-logging related to precipitation patterns. Another kind of impact is on demands for physical infrastructures; for instance, demands for water supplies and energy supplies related to temperature.
4. Social systems are also vulnerable, especially to extreme events (e.g., Box 7.1). Storms and floods can damage homes and other shelters and disrupt social networks and means to sustain livelihoods; and risks of such impacts shape structures for emergency preparedness, especially where impacted populations have a strong influence on policy-making. Climate is related to the quality of life in complex ways, including recreational patterns, and changes in temperature and humidity can change health care challenges and requirements (Chapter 8). For instance, it has been estimated that of the 131 million people affected by natural disasters in Asia in 2004, 97% were affected by weather-related disasters. Exposures in highly-populated coastal and riverine areas and small island nations have been especially significant (ADRC et al., 2005). Moreover, some references suggest relationships between weather and climate on the one hand and social stresses on the other, especially in urban areas where the poor lack access to climate-controlled shelters (e.g., the term 'long, hot summers' associated in the 1960s in the United States with summer urban riots; also see Arsenault, 1984 and Box 7.1). In some cases, tolerance for climatic variation is limited, for example in tightly-coupled urban systems where low capacity drinking water systems have limited resilience in the face of drought or population growth, not only in developing countries but also in industrialised countries. Another case is the sensitivity of energy production to heatwaves and drought (Box 7.1; Section 7.4.2.1).
5. Climate can be a factor in an area's comparative advantage for economic production and growth. Climate affects some of an area's assets for economic production and services, from agricultural and fibre products (Chapter 5) to tourist attractions. Climate also affects costs of business operation, e.g., costs of climate control in office, production and storage buildings. Not only can climate affect an area's own economic patterns; it can also affect the competitive position of its markets and competitors, and thus affect prospects for local employment and individual livelihoods. Many workers are 'marginal', whose livelihoods can be especially sensitive to any changes in conditions affecting local economies.
6. Impacts of climate on industry, settlements and society can be either direct or indirect. For instance, temperature

Box 7.1. Impacts of the 2003 heatwave in Europe

The Summer 2003 heatwave in Western Europe affected settlements and economic services in a variety of ways. Economically, this extreme weather event created stress on health, water supplies, food storage and energy systems. In France, electricity became scarce, construction productivity fell, and the cold storage systems of 25-30% of all food-related establishments were found to be inadequate (Létard et al., 2004). The punctuality of the French railways fell to 77%, from 87% twelve months previously, incurring €1 to €3 million (US$1.25 to 3.75 million) in additional compensation payments, an increase of 7-20% compared with the usual annual total. Sales of clothing were 8.9% lower than usual in August, but sales of bottled water increased by 18%, and of ice cream by 14%. The tourist industry in Northern France benefited, but in the South it suffered (Létard et al., 2004).

Impacts of the heatwave were mainly health- and health-service related (see Chapter 8); but they were also associated with settlement and social conditions, from inadequate climate conditioning in buildings to the fact that many of the dead were elderly people, left alone while their families were on vacation. Electricity demand increased with the high heat levels; but electricity production was undermined by the facts that the temperature of rivers rose, reducing the cooling efficiency of thermal power plants (conventional and nuclear) and that flows of rivers were diminished; six power plants were shut down completely (Létard et al., 2004). If the heatwave had continued, as much as 30% of national power production would have been at risk (Létard et al., 2004). The crisis illustrated how infrastructure can be unable to deal with complex, relatively sudden environmental challenges (Lagadec, 2004).

increases can affect air pollutant concentrations in urban areas, which in turn change exposures to respiratory problems in the population, which then impact health care systems (Chapter 8). Tropical storms can affect the livelihoods and economies of coastal communities through effects on coral reefs, mangroves and other coastal ecosystems (Adger et al., 2005a). Tracing out such second, third, and higher-order indirect impacts, especially in advance, is a significant challenge.

7. Impacts are not equally experienced by every portion of an industrial structure or a population. Some industrial sectors and the very young, the very old and the very poor tend to be more vulnerable to climate impacts than the general economy and population (Box 7.1; Section 7.4.2.5). Some of these differences are also regional, more problematic in developing regions and intricately related to development processes (ISDR, 2004).

Current sensitivities to climate change are briefly summarised in Chapter 1 of this Fourth Assessment Report, and in a number of cases they are relevant for the Millennium Development Goals (for a brief discussion of MDGs in the context of possible climate-change impacts on industry, settlement and society see Section 7.6; also Chapter 20).

Tourism is an example of an economic sector where there has been substantial recent research to understand its sensitivity to climate (Besancenot, 1989; Gomez-Martin, 2005); the emphasis on climate change is, however, more recent (Scott et al., 2005a, b). For example, travel decisions are often based on a desire for warm and sunny environments, while winter tourism builds on expectations of snow and snow-covered landscapes (Chapter 14, Section 14.4.7; Chapter 12, Section 12.4.9; Chapter 11, Section 11.4.9). Tourism is thus sensitive to a range of climate variables such as temperature, hours of sunshine, precipitation, humidity, and storm intensity and frequency (Matzarakis and de Frietas, 2001; Matzarakis et al., 2004), along with the consequences that may follow, such as fires, floods, landslides, coastal erosion and disease outbreaks.

7.3 Assumptions about future trends

Defining possible future socio-economic conditions is a key to understanding future vulnerabilities to climatic change and assessing the capacity to adapt in the face of new risks and opportunities. A range of tools, including scenarios and storylines, has been used to develop characterisations of the future (Chapter 2). While specific characterisations have been developed for vulnerability and adaptation studies in certain climate-sensitive sectors (for example, Arnell et al., 2004; Nicholls, 2004), few characterisations have been developed that relate specifically to climate impacts as they could affect industry, settlement and society. Where such characterisations have been done (e.g., NACC, 2000; London Climate Change Partnership, 2004; Raskin et al., 2005), they have common roots in the perspectives embedded in the IPCC Special Report on Emissions Scenarios (SRES; Nakićenović and Swart, 2000; see also Chapter 2, Section 2.4.6). Drivers in the SRES scenarios – population, economic growth, technology and governance – are all highly relevant for the development of industry, settlement and society.

A key future condition, for instance, is human population and its distribution. According to the latest United Nations projections (i.e., post-SRES), even as the rate of population growth continues to decline, the world's total population will rise substantially. The total is expected to reach between 8.7 and 9.3 billion in 2030 (UN, 2004). More than half these people live in urban centres, and practically all live in settlements, many depending on industry, services and infrastructures for jobs, well-being and mobility. Most population growth will take place in cities, largely in urban areas of developing countries, especially from Asia and Africa (Table 7.1). Some mega-cities will grow very substantially, but the major population growth will take place in medium cities of 1 to 5 million people and in small cities of under 500,000 people, which still represent half of the world population (Table 7.1, see also UN-Habitat, 2003).

Table 7.1. *Urban indicators.*

	Percentage urban				Percent of the world's urban population living in the region				Percent of urban population in different size-class of urban centre, 2000				
Year	1950	1975	2000	2030*	1950	1975	2000	2030*	Under 0.5 m	0.5-1 m	1-5 m	5-10 m	10 m +
Northern America	63.9	73.9	79.1	86.7	15.0	11.9	8.8	7.1	37.4	11.0	34.3	5.4	11.9
Latin America and the Caribbean	42.0	61.2	75.4	84.3	9.6	13.0	13.9	12.4	49.8	9.0	21.7	4.9	14.7
Oceania	62.0	71.5	70.5	73.8	1.1	1.0	0.8	0.6	41.9	0	58.1	0	0
Europe	50.5	67.9	71.7	78.3	37.8	29.2	18.4	11.1	67.8	9.8	15.1	5.4	1.9
Asia	16.8	24.0	37.1	54.1	32.0	37.9	47.9	53.7	49.0	10.0	22.6	8.8	9.7
Africa	14.7	25.4	36.2	50.7	4.5	7.0	10.3	15.1	60.2	9.6	22.1	4.6	3.5
WORLD	29.0	37.2	46.8	59.9	100	100	100	100	52.6	9.8	22.4	6.8	8.4

* These are obviously speculative (projections based largely on extrapolating past trends) and, since any nation's or region's level of urbanisation is strongly associated with their per capita income, economic performance between 2000 and 2030 will have a strong influence on the extent to which regional populations continue to urbanise. Source: taken from or derived from statistics in United Nations (2006).

Features of development relevant to adaptation, such as access to resources, location and institutional capacity, are likely to be predominantly urban and to be determined by differences in economic growth and access to assets, which tend to be increasingly unequal (e.g., the income gap between the richest and the poorest 20% of the world population went from a factor of 32 to 78 between 1970 and 2000: UN-Habitat, 2003). It is estimated that one third of the world's urban population (923.9 million) live in "overcrowded and unserviced slums, often situated on marginal and dangerous land" (i.e., steep slopes, food plains, and industrial zones), and that 43% are in developing countries (UN-Habitat, 2003). It is projected that in the next 30 years "the total number of slum dwellers will increase to about 2 billion, if firm and concrete action is not taken" (UN-Habitat, 2003).

Risk-prone settlements such as in coastal areas are expected to experience not only increases in weather-related disasters (CRED, 2005) but also major increases in population, urban area and economic activity, especially in developing countries (Chapter 6). Growing population and wealth in exposed coastal locations could result in increased economic and social damage, both in developing and developed countries (Pielke et al., 2005; Box 7.4).

Global economic growth projections in SRES and SRES-derived scenarios (Chapter 2) vary significantly - more than population projections. Under low-growth scenarios (A2 and B2), world GDP would double by 2020 and increase more than 10-fold by 2100. Under a high-growth scenario (A1), world GDP would nearly triple by 2020 and grow over 25-fold by 2100. Under all these scenarios, more valuable assets and activities are likely to become exposed to climate risks, but it is assumed that the economic potential to respond will also vastly increase. Economic development will be central to adaptive capacity (Toth and Wilbanks, 2004). SRES scenarios also assume convergence of national per capita incomes, which is contrary to historical tendencies for income gaps between the rich and the poor to increase. While the ratio of per capita incomes in developed as compared with developing countries stood at 16.1 in 1990, SRES scenarios assume a narrowing of this ratio to between 8.4 and 6.2 in 2020, and between 3.0 and 1.5 in 2100. Smaller differences in relative incomes are likely to have important consequences for the perception of climate vulnerability and for the pattern of response.

Because it is potentially highly dynamic, the treatment of technology varies greatly between global scenario exercises. For instance, three qualitatively-different technology scenarios were developed for SRES scenario A1 alone (A1FI, A1T and A1B). An even broader universe of technological change scenarios can be developed for global and downscaled national, regional and sectoral scenarios (e.g., Berkhout and Hertin, 2002). In this chapter we make no specific assumptions about the rate and direction of technological change into the future, recognising that very wide ranges of potentials will exist at the local and organisational levels at which climate vulnerability and responses will often be shaped, and also that the knowledge base referenced in the chapter reflects a range of assumptions about future trends. Governance is likewise a topic about which different scenario families make divergent assumptions. The SRES scenarios include both globally-integrated systems of economic and political and sustainability governance, as well as more fragmented, regionalised systems. The Global Scenarios Group set of scenarios include characterisations in which institutions and governance as we know them persist with minor reform; 'barbarisation' scenarios consider futures in which "absolute poverty increases and the gap between rich and poor …[and] national governments lose relevance and power relative to trans-national corporations and global market forces…" (Gallopin et al., 1997); 'great transitions' scenarios contain storylines in which sustainable development becomes an organising principle in governance. In this chapter we also have made no specific assumptions about the nature of future pattern of governance, while recognising that institutional capacity will be central to adaptive capacity (Section 7.6.5; also see Chapter 2).

7.4 Key future impacts and vulnerabilities

The ability to project how climate change may affect industry, settlement and society is limited by uncertainties about climate change itself at a relatively fine-grained geographical and sectoral scale and also by uncertainties about trends in human systems over the next century *regardless of climate change* (Chapter 2). In some cases, uncertainties about socio-economic factors such as technological and institutional change over many decades undermine the feasibility of comparing future prospects involving *considerable* climate change with prospects involving *relatively little* climate change. Typically, therefore, research often focuses on vulnerabilities to impacts of climate change (defined as the degree to which a system, subsystem or system component is likely to experience harm due to exposure to a perturbation or source of stress (Turner et al., 2003a; also see Clark et al., 2000) rather than on projections of impacts of change on evolving socio-economic systems, especially in the longer run.

Furthermore, climate change will not often be a primary factor in changes for industry, settlement and society. Instead, it will have an impact by modifying other more significant aspects of ongoing socio-economic changes. This may have either an exacerbating or an ameliorating effect in influencing overall vulnerabilities to multi-causal change. It is especially difficult to associate levels of climate-change impacts or their costs with a specified number of degrees of mean global warming or with a particular time horizon such as 2050 or 2080, when so many of the main drivers of impacts and costs are not directly climate-related, even though they may be climate-associated, and when impacts are often highly localised. Some projections have been made for particular sectors or areas and they are cited in appropriate sections below; but in general they should be considered with caution, especially for longer-range futures.

7.4.1 General effects

Certain kinds of effects follow from particular manifestations of climate change, wherever those phenomena occur. For example, increased precipitation in already well-watered areas can increase concerns about drainage and water-logging

(Parkinson and Mark, 2005), while reduced precipitation in areas already subject to water shortages could lead to infrastructure crises. Sea-level rise will affect land uses and physical infrastructures in coastal areas. Changes in conditions can affect requirements for public health services (Chapter 8), water supplies (Chapter 3) and energy services (such as space heating and cooling). Effects can either be cumulative (additive), as in losses of property, or systematic (affecting underlying processes), as in damages to institutions or systems of production (Turner et al., 1990). Even very gradual changes can be associated with thresholds at which the resilience of human systems switches from adequate to inadequate, such as water-supply infrastructures faced with shrinking water availability. Parry et al. (2001), for instance, estimate that many tens of millions of the world's population are at risk of hunger due to climate change, and billions are at risk of water shortages.

Besides gradual changes in climate, human systems are affected by a change in the magnitude, frequency and/or intensity of storms and other extreme weather events, as well as changes in their location. In fact, some assessments suggest that many impact issues are more directly associated with climatic *extremes* than with *averages* (NACC, 2000). Of some concern is the possibility of abrupt climate changes (Chapter 19), which could be associated with locally or regionally catastrophic impacts if they were to occur.

Although localities differ, interactions between climate change and human systems are often substantively different for relatively developed, industrialised countries versus less developed countries and regions. In many cases, it appears that possible negative impacts of climate change pose risks of higher total *monetary* damages in industrialised areas (i.e., currency valuations of property damages) but higher total *human* damages in less-developed areas (i.e., losses of life and dislocations of population) – although such events as Hurricane Katrina show that there are exceptions (Section 7.4.2.5) for developed countries, and monetary damages in developing countries may represent a larger share of their GDP.

Not all implications of possible climate change are negative. For instance, along with possible carbon fertilisation effects and a longer growing season (Chapter 5), many mid- and upper-latitude areas see quality-of-life benefits from winter warming, and some areas welcome changes in precipitation patterns, although such changes could have other social consequences. The greater proportion of the research literature, however, is related to possible adverse impacts. Climate impact concerns include environmental quality (e.g., more ozone, water-logging or salinisation), linkage systems (e.g., threats to water and power supplies), societal infrastructures (e.g., changed energy/water/health requirements, disruptive severe weather events, reductions in resources for other social needs and maintaining sustainable livelihoods, environmental migration (Box 7.2), placing blame for adverse effects, changes in local ecologies that undermine a sense of place), physical infrastructures (e.g., flooding, storm damage, changes in the rate of deterioration of materials, changed requirements for water or energy supply), and economic infrastructures and comparative advantages (e.g., costs and/or risks increased, markets or competitors affected).

Box 7.2. Environmental migration

Migration, usually temporary and often from rural to urban areas, is a common response to calamities such as floods and famines (Mortimore, 1989), and large numbers of displaced people are a likely consequence of extreme events. Their numbers could increase, and so could the likelihood of their migration becoming permanent, if such events increase in frequency. Yet, disaggregating the causes of migration is highly problematic, not least since individual migrants may have multiple motivations and be displaced by multiple factors (Black, 2001). For example, studies of displacement within Bangladesh and to neighbouring India have drawn obvious links to increased flood hazard as a result of climate change. But such migration also needs to be placed in the context of changing economic opportunities in the two countries and in the emerging mega-city of Dhaka, rising aspirations of the rural poor in Bangladesh, and rules on land inheritance and an ongoing process of land alienation in Bangladesh (Abrar and Azad, 2004).

Estimates of the number of people who may become environmental migrants are, at best, guesswork since (a) migrations in areas impacted by climate change are not one-way and permanent, but multi-directional and often temporary or episodic; (b) the reasons for migration are often multiple and complex, and do not relate straightforwardly to climate variability and change; (c) in many cases migration is a longstanding response to *seasonal* variability in environmental conditions, it also represents a strategy to *accumulate* wealth or to seek a route out of poverty, a strategy with benefits for both the receiving and original country or region; (d) there are few reliable censuses or surveys in many key parts of the world on which to base such estimates (e.g., Africa); and (e) there is a lack of agreement on what an environmental migrant is anyway (Unruh et al., 2004; Eakin, 2006).

An argument can also be made that rising ethnic conflicts can be linked to competition over natural resources that are increasingly scarce as a result of climate change, but many other intervening and contributing causes of inter- and intra-group conflict need to be taken into account. For example, major environmentally-influenced conflicts in Africa have more to do with relative abundance of resources, e.g., oil, diamonds, cobalt, and gold, than with scarcity (Fairhead, 2004). This suggests caution in the prediction of such conflicts as a result of climate change.

Economic sectors, settlements and social groups can also be affected by climate change response policies. For instance, certain greenhouse-gas stabilisation strategies can affect economies whose development paths are dependent on abundant local fossil-fuel resources, including economic sectors involved in mining and fuel supply as well as fuel use. In this sense, relationships between climate-change impacts and sustainable development (IPCC Working Group II) are linked with discussions of climate-change mitigation approaches (IPCC Working Group III).

In many cases, the importance of climate-change effects on human systems seems to depend on the geographic (or sectoral) scale of attention (Abler, 2003; Wilbanks, 2003a). At the scale of a large nation or region, at least in most industrialised nations, the economic value of sectors and locations with low levels of vulnerability to climate change greatly exceeds the economic value of sectors and locations with high levels of vulnerability, and the capacity of a complex large economy to absorb climate-related impacts is often considerable. In many cases, therefore, estimates of aggregate damages of climate change (other than major abrupt changes) are often rather small as a percentage of economic production (e.g., Mendelsohn, 2001). On the other hand, at a more detailed scale, from a small region to a small country, many specific localities, sectors and societies can be highly vulnerable, at least to possible low-probability/high-consequence impacts; and potential impacts can amount to very severe damages. It appears that large-regional or national estimates of possible impacts may give a different picture of vulnerabilities than an aggregation of vulnerabilities defined at a small-regional or local scale.

7.4.2 Systems of interest

The specified systems of interest for Chapter 7 are industry, services, utilities/infrastructure, human settlement and social issues.

7.4.2.1 Industry

Industrial sectors are generally thought to be less vulnerable to the impacts of climate change than other sectors, such as agriculture and water services. This is in part because their sensitivity to climatic variability and change is considered to be comparatively lower and, in part, because industry is seen as having a high capacity to adapt in response to changes in climate. The major exceptions are industrial facilities located in climate-sensitive areas (such as coasts and floodplains), industrial sectors dependent on climate-sensitive inputs (such as food processing) and industrial sectors with long-lived capital assets (Ruth et al., 2004).

We define industry as including manufacturing, transport, energy supply and demand, mining, construction and related informal production activities. Other sectors sometimes included in industrial classifications, such as wholesale and retail trade, communications, and real estate and business activities, are included in the categories of services and infrastructure (below). Together, industry and economic services account for more than 95% of GDP in highly-developed economies and between 50 and 80% of GDP in less-developed economies (World Bank, 2006), and they are very often at the heart of the economic base of a location for employment stability and growth.

Industrial activities are, however, vulnerable to direct impacts such as temperature and precipitation changes. For instance, weather-related road accidents translate into annual losses of at least Canadian $1 billion annually in Canada, while more than a quarter of air travel delays in the United States are weather-related (Andrey and Mills, 2003). Buildings are also affected by higher temperatures during hot spells (Livermore, 2005). Moreover, facilities across a range of industrial sectors are often located in areas vulnerable to extreme weather events (including flooding, drought, high winds), as the Hurricane Katrina event clearly demonstrated. Where extreme events threaten linkage infrastructures such as bridges, roads, pipelines or transmission networks, industry can experience substantial economic losses. In other cases, climate change could lead to reductions in the direct vulnerability of industry and infrastructures. For instance, fewer freeze-thaw cycles in temperate regions would lead to less deterioration of road and runway surfaces (Mills and Andrey, 2002). There exist relatively few quantified assessments of these direct impacts, suggesting an important role for new research (Eddowes et al., 2003).

Less direct impacts on industry can also be significant. For instance, sectors dependent on climate-sensitive inputs for their raw materials, such as the food processing and pulp and paper sectors, are likely to experience changes in sources of major inputs. In the longer term, as the impacts of climate change become more pronounced, regional patterns of comparative advantage of industries closely related to climate-sensitive inputs could be affected, influencing regional shifts in production (Easterling et al., 2004). Industrial producers will also be influenced indirectly by regulatory and market changes made in response to climate change. These may influence locational and technology choices, as well affecting costs and demand for goods and services. For instance, increased demand for space cooling may be one result of higher peak summer temperatures (Valor et al., 2001; Giannakopoulos and Psiloglou, 2006). A range of direct (awareness of changing weather-related conditions) and indirect (changing policy, regulation and behaviour) impacts on three different classes of industry is identified in Table 7.2.

In developing countries, besides modern production activities embedded in global supply chains, industry includes a greater proportion of enterprises that are small-scale, traditional and informally organised. Impacts of climate change on these businesses are likely to depend on the determinants identified in the TAR: location in vulnerable areas, dependence on inputs sensitive to climate, and access to resources to support adaptive actions. Many of these activities will be less concerned with climate risks and will have a high capacity to adapt, while others will become more vulnerable to direct and indirect impacts of climate change.

An example of an industrial sector particularly sensitive to climate change is energy (e.g., Hewer, 2006; Chapter 12, Section 12.4.8.1). Climate change is likely to affect both energy use and energy production in many parts of the world. Some of the possible impacts are rather obvious. Where the climate warms due to climate change, less heating will be needed for industrial,

Table 7.2. *Direct and indirect climate change impacts on industry.*

Sector	Direct impacts	Indirect impacts	References
Built Environment: Construction, civil engineering	Energy costs External fabric of buildings Structural integrity Construction process Service infrastructure	Climate-driven standards and regulations Changing consumer awareness and preferences	Consodine, 2000; Graves and Phillipson, 2000; Sanders and Phillipson, 2003; Spence et al., 2004; Brewer, 2005; Kirshen et al., 2006
Infrastructure Industries: Energy, water, telecommunications, transport (see Section 7.4.2.3)	Structural integrity of infrastructures Operations and capacity Control systems	Changing average and peak demand Rising standards of service	Eddowes et al., 2003; UK Water Industry Research, 2004; Fowler et al, 2005
Natural Resource Intensive Industries: Pulp and paper, food processing, etc.	Risks to and higher costs of input resources Changing regional pattern of production	Supply chain shifts and disruption Changing lifestyles influencing demand	Anon, 2004; Broadmeadow et al., 2005

commercial and residential buildings, and cooling demands will increase (Cartalis et al., 2001), with changes varying by region and by season. Net energy demand at a national scale, however, will be influenced by the structure of energy supply. The main source of energy for cooling is electricity, while coal, oil, gas, biomass and electricity are used for space heating. Regions with substantial requirements for both cooling and heating could find that net annual electricity demands increase while demands for other heating energy sources decline (Hadley et al., 2006). Critical factors for the USA are the relative efficiency of space cooling in summer compared to space heating in winter, and the relative distribution of populations within the U.S. in colder northern or warmer southern regions. Seasonal variation in total demand is also important. In some cases, due to infrastructure limitations, peak demand could go beyond the maximum capacity of the transmission system.

Tol (2002a, b) estimated the effects of climate change on the demand for global energy, extrapolating from a simple country-specific (United Kingdom) model that relates the energy used for heating or cooling to degree days, per capita income, and energy efficiency. According to Tol, by 2100 benefits (reduced heating) will be about 0.75% of gross domestic product (GDP) and damages (increased cooling) will be approximately 0.45%, although it is possible that migration from heating-intensive to cooling-intensive regions could affect such comparisons in some areas.

In addition to *demand*-side impacts, energy *production* is also likely to be affected by climate change. Except for impacts of extreme weather events, research evidence is more limited than for energy consumption; but climate change could affect energy production and supply (a) if extreme weather events become more intense, (b) where regions dependent on water supplies for hydropower and/or thermal powerplant cooling face reductions in water supplies, (c) where changed conditions affect facility siting decisions, and (d) where conditions change (positively or negatively) for biomass, windpower or solar energy production.

For instance, the TAR (Chapter 7) concluded that hydropower generation is likely to be impacted because it is sensitive to the amount, timing and geographical pattern of precipitation as well as temperature (rain or snow, timing of melting). Reduced stream flows are expected to jeopardise hydropower production in some areas, whereas greater stream flows, depending on their timing, might be beneficial (Casola et al., 2005; Voisin et al., 2006). According to Breslow and Sailor (2002), climate variability and long term climate change should be considered in siting wind power facilities (also see Hewer, 2006). Extreme weather events could threaten coastal energy infrastructures (e.g., Box 7.4) and electricity transmission and distribution infrastructures. Moreover, soil subsidence caused by the melting of permafrost is a risk to gas and oil pipelines, electrical transmission towers, nuclear-power plants and natural gas processing plants in the Arctic region (Nelson et al., 2001). Structural failures in transportation and industrial infrastructure are becoming more common as a result of permafrost melting in northern Russia, the effects being more serious in the discontinuous permafrost zone (ACIA, 2004).

Policies for reducing greenhouse gas (GHG) emissions are expected to affect the energy sector in many countries. For instance, Kainuma et al. (2004) compared a global reference scenario with six different GHG reduction scenarios. In the reference scenario under which emissions continue to grow, the use of coal increases from 18% in 2000 to 48% in 2100. In aggressive mitigation scenarios, the world's final energy demand drops to nearly one-half of that in the reference scenario in 2100, mainly associated with reducing coal use. Kuik (2003) has found a trade-off between economic efficiency, energy security and carbon dependency for the EU.

7.4.2.2 Services

Services include a wide variety of human needs, activities and systems, related both to meeting consumer needs and to employment in the service activities themselves. This section includes brief discussions of possible climate-change effects on trade, retail and commercial services, tourism and risk financing/insurance as illustrations of the implications of climate change – not implying that these sectors are the only ones that could be affected, negatively or positively.

7.4.2.2.1 Trade

Possible impacts of climate change on inter-regional trade are still rather speculative. Climate change could affect trade by reshaping regional comparative advantage related to (a) general climate-related influences (Figure 7.2), such as on agricultural production, (b) exposure to extreme events combined with a lack of capacity to cope with them, and/or (c) effects of climate-change mitigation policies that might create markets for emission-reduction alternatives. In an era of increased globalisation, small changes in price structures (including transportation costs) could have amplified effects on regional economies and employment. Beyond actual climate-change impacts, a perception of future impacts or regulatory initiatives could also affect investment and trade.

Climate change may also disrupt transport activities that are important to national supplies (and travellers) as well as international trade. For instance, extreme events may temporarily close ports or transport routes and damage infrastructure critical to trade. Increases in the frequency or magnitude of extreme weather events could amplify the costs to transport companies and state authorities from closed roads, train delays and cancellations, and other interruptions of activities (O'Brien et al., 2004). It appears that there could be linkages between climate-change scenarios and international trade scenarios, such as a number of regional and sub-regional free trade agreements, although research on this topic is lacking.

7.4.2.2.2 Retail and commercial services

Retail and other commercial services have often been neglected in climate-change impact studies. Climate change has the potential to affect every link in the supply chain, including the efficiency of the distribution network, the health and comfort of the workforce (Chapter 8), and patterns of consumption. Many of the services can be more difficult to move than industrial facilities, because their locations are focused on where the people are. In addition, climate-change policies could raise industrial and transportation costs, alter world trade patterns, and necessitate changes in infrastructure and design technology. As one example, distribution networks for commercial activities would be affected in a variety of ways by changing winter road conditions (e.g., ACIA, 2004) and negatively affected by an increase in hazardous weather events. Strong winds can unbalance high-sided vehicles on roads and bridges, and may delay the passage of goods by sea. Transportation routes in permafrost zones may be negatively affected by higher temperatures which would shorten the winter-road season (Instanes et al., 2005). Coastal infrastructure and distribution facilities are vulnerable to inundation and flood damage. In contrast, transportation of bulk freight by inland waterways, such as the Rhine, can be disrupted during droughts (Parry, 2000). Further, climate variation creates short-term shifts in patterns of consumption within specific retail markets, such as the clothing and footwear market (Agnew and Palutikof, 1999). However, most impacts entail transfers within the economy (Subak et al., 2000) and are transitory.

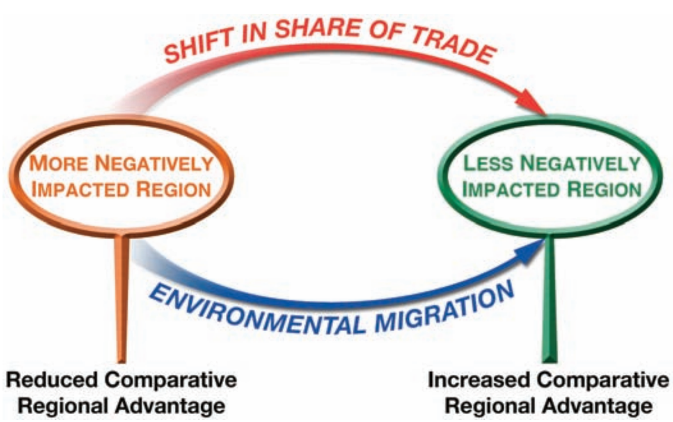

Figure 7.2. *General effects of climate change on international trade: greater net benefits from climate change are likely to show trade benefits, along with environmental in-migration.*

Perishable commodities are one of the most climate-sensitive retail markets (Lin and Chen, 2003). It is possible that climate change will alter the sourcing and processing of agricultural produce; and climate-change policies (e.g., a carbon tax or an emissions offset payment) may further alter the geographical distribution of raw materials and product markets.

7.4.2.2.3 Tourism

A substantial research literature has assessed the consequences of climate change for international tourist flows (e.g., Agnew and Viner, 2001; Hamilton et al., 2005), for the tourist industries of nations (Becken, 2005; Ceron and Dubois, 2005), destinations (Belle and Bramwell, 2005), attractions, such as national parks (Jones and Scott, 2007; Chapter 14, Section 14.4.7), and tourism activities (Perry, 2004; Jones et al., 2006) or sectors of tourism such as ski-tourism (e.g., Elsasser and Burki, 2002; Fukushima et al., 2003; Hamilton et al., 2003).

Likely effects of climate change on tourism vary widely according to location, including both direct and indirect effects. Regarding direct effects, climate change in temperate and high latitude countries seems to mean a poleward shift in conditions favourable to many forms of tourism (Chapter 15). This might, for instance, lead to more domestic tourism in north-west Europe (Chapter 12, Section 12.4.9; Agnew and Viner, 2001; Maddison, 2001) and in the middle latitudes of North America (Chapter 14, Section 14.4.7). If winters turn out to be milder but wet and windy, however, the gains to be expected are less obvious (Ceron, 2000). Areas dependent on the availability of snow are among those most vulnerable to global warming (Chapter 11, Sections 11.4.9; Chapter 12, Section 12.4.9; Chapter 14, Section 14.4.7). In summer, destinations already hot could become uncomfortable (Chapter 12, Section 12.5.9). Tropical destinations might not suffer as much from an increase in temperatures, since tourists might expect warm climates as long as indoor comfort is assured – with implications for greenhouse gas emissions (Gössling and Hall, 2005). For low-lying islands, sea-level rise and increasingly frequent and intense weather extremes might become of great importance in the future (Chapter 16, Section 16.4.2). Extreme climate events, such as tropical storms, could have substantial effects on tourist infrastructure and the economies of small-island states (London, 2004).

Indirect effects include changes in the availability of water and costs of space cooling, but at least as significant could be changes in the landscape of areas of tourist interest, which could be positive or negative (Braun et al.,1999; Uyarra et al., 2005; Chapter 14, Section 14.4.7). Warmer climates open up the possibility of extending exotic environments (such as palm trees in western Europe), which could be considered by some tourists as positive but could lead to a spatial extension and amplification of water- and vector-borne diseases. Droughts and the extension of arid environments (and the effects of extreme weather events) might discourage tourists, although it is not entirely clear what they consider to be unacceptable. In tropical environments, destruction due to extreme weather events (buildings, coral reefs, trees and plants) is a concern, but vegetation and landscape tend to recover relatively quickly with the notable exception of eroded beaches and damaged coral reefs. One indirect factor of considerable importance is energy prices, which affect both the cost of providing comfort in tourist areas and the cost of travelling to them (Becken et al., 2001). This effect can be especially significant for smaller, tourist-oriented countries, often in the developing world; for instance, receipts from international tourism account for 39% of GDP in the Bahamas, but only 2.4% for France (World Tourism Organization, 2003).

The environmental context in which tourism will operate in the future involves considerable uncertainties. The range of possible scenarios is great, and there have been some attempts to link the future of tourist activities to SRES scenarios (Chapter 14, Section 14.4.7; Chapter 11, Section 11.4.9) . In these scenarios, tourist reactions to climate change are assumed to be constant, notwithstanding the fact that these responses are currently not satisfactorily understood.

7.4.2.2.4 Insurance

Insurance is a major service sector with the potential to be directly affected by any increase in damages associated with climate change, such as more intense and/or frequent extreme weather events (see Box 7.3). While a number of lines of insurance have some potential to be affected by catastrophe losses, the principal impacts are expected to be on property lines.

As the actuarial analysis of recent loss experience is typically an inadequate guide to catastrophe risk, since the 1990s probabilistic 'catastrophe' modelling software has become employed by insurers for pricing and managing portfolios of property catastrophe risk (Grossi and Kunreuther, 2005). At the start of 2006, the five-year forward-looking activity rate employed in the most widely used Hurricane Catastrophe Model was increased relative to mean historical rates with an acknowledgement that some contribution to this increase is likely to reflect climate change (Muir Wood et al., 2006).

Within the risk market, reinsurers tend to be more pessimistic about catastrophe risk-costs than the insurers who are ceding the risk, and this perspective has been highlighted by statements from reinsurers going back more than a decade warning of the potential impacts of climate change (Swiss Re, 2004; Munich Re, 2005). However, in 2006, insurers also began to communicate directly with their policyholders regarding the rising costs of claims attributed to climate change (Allianz and World Wildlife Fund, 2006; Crichton, 2006).

The specific insurance risk coverages currently available within a country will have been shaped by the impact of past catastrophes. Because of the high concentration of losses where, over the past 50-60 years, there have been catastrophic floods, private sector flood insurance is generally restricted (or even unavailable), so that in many developed countries governments have put in place alternative state-backed flood insurance schemes (Swiss Re, 1998).

In both developed and developing countries, property insurance coverage will expand with economic growth. If overall risk increases under climate change, the insurance industry can be expected to grow in the volume of premium collected, claims paid and, potentially, income (where insurers overcome consumer and regulatory pressures to restrict increases in insurance rates, and where catastrophe loss cost increases are appropriately anticipated and modelled). However, market dislocations are also likely, as in 2006 when, unable for regulatory reasons to pass on higher technical hurricane risk costs, U.S. insurers declined to cover homeowners and businesses at the highest-risk coastal locations, thereby undermining the real estate market and forcing government intervention in structuring some alternative insurance provision (Freer, 2006).

After a decade of rising losses (from both natural and man-made catastrophes), insurance is generally becoming more restrictive in what is covered. Insurance rates in many areas rose after 2001 so that, while the 2004 year was the worst (up to that time) for U.S. catastrophe losses, it was also the most profitable year ever for U.S. insurers (Dyson, 2005). However, the years 2001 to 2005 were not so profitable for reinsurers, although increases in prices saw significant new capital entering the market in 2002 and 2005, while 2006 appeared a benign year for losses.

Where increased risk costs lead insurers to reduce the availability of insurance, there will be impacts on local and regional economies, including housing and industrial activity,

Box 7.3. The impact of recent hurricane losses

The US$15.5 billion insurance loss of Hurricane Andrew in 1992 (US$45 billion adjusted to 2005 values and exposures) remains an exemplar of the consequences on the insurance industry of a catastrophe more severe than had been anticipated, leading to the insolvency of 12 insurance companies and significant market disruption. However, after major adjustments, including the widespread use of catastrophe models, the private insurance market re-expanded its role, so that in the four hurricanes of 2004 (with a total market loss of around US$29 billion from the U.S., Caribbean and Gulf Energy sectors) only one small U.S. insurance company failed, and there was little impact on reinsurance rates, largely because state-backed insurance and reinsurance mechanisms in Florida absorbed a significant proportion of the loss. However, a far greater proportion of the US$60 billion of insured losses from the 2005 hurricanes in Mexico, the energy sector in the Gulf of Mexico and the USA fell onto the international reinsurance market, leading to at least two situations where medium-sized reinsurers could not remain independently viable. Following more than 250,000 flood claims in 2005 related to Hurricanes Katrina, Rita and Wilma, the U.S. federal National Flood Insurance Program would have gone bankrupt without being given the ability to borrow an additional US$20.8 billion from the U.S. Treasury.

unless government expands its risk protection roles. In particular in developed countries, governments are also likely to be the principal funders of risk mitigation measures (e.g., flood defences) that can help ensure that properties remain insurable. In the developing world, the role of insurers and governments in offering risk protection is generally limited (Mills, 2004).

The use of insurance is far lower in developing and newly-developed countries (Enz, 2000), as insurance reflects wealth protection that typically lags a generation behind wealth generation. As highlighted by events such as 2005 Hurricane Stan in Mexico and Guatemala, individuals bear the majority of the risk and manage it through the solidarity of family and other networks, if at all. However, once development is underway, insurance typically expands faster than the growth in GDP. With this in mind there has been a focus on promoting 'micro-insurance' to reduce people's financial vulnerability when linked with the broader agenda of risk reduction (ProVention Consortium, 2004; Abels and Bullen, 2005), sometimes with the first instalment of the premium paid by the non-governmental organisation (NGO), e.g., in an insurance scheme against cyclones offered in eastern Andhra Pradesh and Orissa.

For the finance sector, climate change-related risks are increasingly considered for specific 'susceptible' sectors such as hydroelectric projects, irrigation and agriculture, and tourism (UNEP, 2002). In high carbon-emitting sectors, such as power generation and petrochemicals, future company valuations could also become affected by threatened litigation around climate-change impacts (Kiernan, 2005). Some specialised investment entities, and in particular hedge funds, take positions around climate related risks, via investments in reinsurance and insurance companies, resource prices such as oil and gas with the potential to be affected by Gulf hurricanes, and through participation in alternative risk transfer products, e.g., insurance-linked securities such as catastrophe bonds and weather derivatives (see Jewson et al., 2005).

7.4.2.3 Utilities/infrastructure

Infrastructures are systems designed to meet relatively general human needs, often through largely or entirely public utility-type institutions. Infrastructures for industry, settlements and society include both 'physical' (such as water, sanitation, energy, transportation and communication systems) and 'institutional' (such as shelter, health care, food supply, security, and fire services and other forms of emergency protection). In many instances, such 'physical' and 'institutional' infrastructures are linked. For example, in New York City adaptations of the physical water supply systems to possible water supply variability are dependent on changes within the institutions that manage them; conversely, institutions such as health care are dependent to some degree on adjustments in physical infrastructures to maintain effective service delivery (Rosenzweig and Solecki, 2001a).

These infrastructures are vulnerable to climate change in different ways and to different degrees, depending on their state of development, their resilience and their adaptability. In general, floods induce more physical damage, while drought and heatwaves tend to have impacts on infrastructure systems that are more indirect.

Often, the institutional infrastructure is less vulnerable as it embodies less fixed investment and is more readily adapted within the time-scale of climate change. Moreover, the effect of climate change on institutional infrastructure can be small or even result in an improvement in its resilience; for example, it could help to trigger an adaptive response (e.g., Bigio, 2003).

There are many points at which impacts on the different infrastructure sectors interact. For instance, failure of flood defences can interrupt power supplies, which in turn puts water and wastewater pumping stations out of action. On the other hand, this means that measures to protect one sector can also help to safeguard the others.

7.4.2.3.1 Water supplies

Climate change, in terms of change in the means or variability, could affect water supply systems in a number of ways. It could affect water *demand*. Increased temperatures and changes in precipitation can contribute to increases in water demand, for drinking, for cooling systems and for garden watering (Kirshen, 2002). If climate change contributes to the failure of small local water sources, such as hand-dug wells, or to inward migration, this may also cause increased demand on regional water supplies. It could also affect water *availability*. Changes in precipitation patterns may lead to reductions in river flows, falling groundwater tables and, in coastal areas, to saline intrusion in rivers and groundwater, and the loss of meltwater will reduce river flows at key times of year in parts of Asia and Latin America (Chapter 3, Section 3.4.3). Furthermore, climate change could *damage the system* itself, including erosion of pipelines by unusually heavy rainfall.

Water supplies have a life of many years and so are designed with spare capacity to respond to future growth in demand. Allowance is also made for anticipated variations in demand with the seasons and with the time of day. From the point of view of the impacts of climate change, therefore, most water supply systems are quite able to cope with the relatively small changes in mean temperature and precipitation which are anticipated for many decades, except at the margin where a change in the mean requires a significant change in the design or technology of the water supply system, e.g., where reduced precipitation makes additional reservoirs necessary (Harman et al., 2005) or leads to saline intrusion into the lower reaches of a river. An example is in southern Africa (Ruosteenoja et al., 2003), where the city of Beira in Mozambique is already extending its 50 km pumping main a further 5 km inland to be certain of freshwater.

More dramatic impacts on water supplies are liable to be felt under extremes of weather that could arise as a result of climate change, particularly drought and flooding. Even where water-resource constraints, rather than system capacity, affect water-supply functioning during droughts, this often results from how the resource is allocated rather than absolute insufficiency. Domestic water consumption, which represents only 2% of global abstraction (Shiklomanov, 2000), is dwarfed by the far greater quantities required for agriculture. Water supply systems, such as those for large coastal cities, are often downstream of other major users and so are the first to suffer when rivers dry up. Under Integrated Water Resource Management, such urban areas would receive priority in allocation, because the value of municipal water use is so much greater than agricultural water use, and therefore they can afford to pay a premium price for the water (Dinar et al., 1997).

In many countries, additional investment is likely to be needed to counter increasing water resource constraints due to climate change. For example, Severn-Trent, one of the nine English water companies, has estimated that its output is likely to fall by 180 Megalitres/day (roughly 9% of the total) by 2030 due to climate change, making a new reservoir necessary to maintain the supply to Birmingham (Environment Agency, 2004). However, such changes will only become a major problem where they are rapid compared to the normal rate of water supply expansion, and where systems have insufficient spare capacity, as in many developing countries.

During the last century, mean precipitation in all four seasons of the year has tended to decrease in all the main arid and semi-arid regions of the world, e.g., northern Chile and the Brazilian North-East, West Africa and Ethiopia, the drier parts of Southern Africa and Western China (Folland et al., 2001). If these trends continue, water resource limitations will become more severe in precisely those parts of the world where they are already most likely to be critical (Rhode, 1999).

Flooding by rivers and tidal surges can do lasting damage to water supplies. Water supply abstraction and treatment works are sited beside rivers, because it is not technically advisable to pump raw water for long distances. They are therefore often the first items of infrastructure to be affected by floods. While sedimentation tanks and filter beds may be solid enough to suffer only marginal damage, electrical switchgear and pump motors require substantial repairs after floods, which cannot normally be accomplished in less than two weeks. In severe riverine floods with high flow velocities, pipelines may also be damaged, requiring more extensive repair work.

7.4.2.3.2 Sanitation and urban drainage

Some of the considerations applying to water supply also apply to sewered sanitation and drainage systems, but in general the effect of climate change on sanitation is likely to be less than on water supply. When water supplies cease to function, sewered sanitation also becomes unusable. Sewer outfalls are usually into rivers or the sea, and so they and any sewage treatment works are exposed to damage during floods (PAHO, 1998). In developing countries, sewage treatment works are usually absent (WHO/Unicef, 2000) or involve stabilisation ponds, which are relatively robust. Sea-level rise will affect the functioning of sea outfalls, but the rise is slow enough for the outfalls to be adapted to the changed conditions at modest expense, by pumping if necessary. Storm drainage systems are also unlikely to suffer serious storm damage, but they will be overloaded more often if heavy storms become more frequent, causing local flooding. The main impact of climate change on on-site sanitation systems such as pit latrines is likely to be through flood damage. However, they are more properly considered as part of the housing stock rather than items of community infrastructure. The main significance of sanitation here is that sanitation infrastructures (or the lack of them) are the main determinant of the contamination of urban flood water with faecal material, presenting a substantial threat of enteric disease (Ahern et al., 2005).

7.4.2.3.3 Transport, power and communications infrastructures

A general increase in temperature and a higher frequency of hot summers are likely to result in an increase in buckled rails and rutted roads, which involve substantial disruption and repair costs (London Climate Change Partnership, 2004). In temperate zones, less salting and gritting will be required, and railway points will freeze less often. Most adaptations to these changes can be made gradually in the course of routine maintenance, for instance by the use of more heat-resistant grades of road metal when resurfacing. Transport infrastructure is more vulnerable to effects of extreme local climatic events than to changes in the mean. For instance, 14% of the annual repair and maintenance budget of the newly-built 760 km Konkan Railway in India is spent repairing damage to track, bridges and cuttings due to extreme weather events such as rain-induced landslides. This amounts to more than Rs. 40 million, or roughly US$1 million annually. In spite of preventive targeting of vulnerable stretches of the line, operations must be suspended for an average of seven days each rainy season because of such damage (Shukla et al., 2005). Parry (2000) provides an assessment of the impact of severe local storms on road transportation, much of which also applies to rail.

Of all the possible impacts on transportation, the greatest in terms of cost is that of flooding. The cost of delays and lost trips would be relatively small compared with damage to the infrastructure and to other property (Kirshen et al., 2006). In the last ten years, there have been four cases when flooding of urban underground rail systems have caused damage worth more than €10 m (US$13m) and numerous cases of lesser damage (Compton et al., 2002)

Infrastructure for power transmission and communications is subject to much the same considerations. It is vulnerable to high winds and ice storms when in the form of suspended overhead cables and cell phone transmission masts, but is reasonably resilient when buried underground, although burial is significantly more expensive. In developing countries, a common cause of death associated with extreme weather events in urban areas is electrocution by fallen power cables (Few et al., 2004). Such infrastructure can usually be repaired at a fraction of the cost of repairing roads, bridges and railway lines, and in much less time, but its disruption can seriously hinder the emergency response to an extreme event.

7.4.2.4 Human settlement

Climate change is almost certain to affect human settlements, large and small, in a variety of significant ways. Settlements are important because they are where most of the world's population live, often in concentrations that imply vulnerabilities to location-specific events and processes and, like industry and certain other sectors of concern, they are distinctive in the presence of physical capital (buildings, infrastructures) that may be slow to change.

Beyond the general perspectives of TAR (see Section 7.1.4), a growing number of case studies of larger settlements indicate that climate change is likely to increase heat stress in summers while reducing cold-weather stresses in winter. It is likely to change precipitation patterns and water availability, to lead to rising sea levels in coastal locations, and to increase risks of extreme weather events, such as severe storms and flooding, although some kinds of extreme events could decrease, such as blizzards and ice storms (see city references below; Klein et al., 2003; London Climate Change Partnership, 2004; Sherbinin et al., 2006).

Extreme weather events associated with climate change pose particular challenges to human settlements, because assets and populations in both developed and developing countries are increasingly located in coastal areas, slopes, ravines and other risk-prone regions (Freeman and Warner, 2001; Bigio, 2003; UN-Habitat, 2003). The population in the near-coastal zone (i.e., within 100 m elevation and 100 km distance of the coast) has been calculated at between 600 million and 1.2 billion; 10% to 23% of the world's population (Adger et al., 2005b; McGranahan et al., 2006). Globally, coastal populations are expected to increase rapidly, while coastal settlements are at increased risk of climate change-influenced sea-level rise (Chapter 6). Informal settlements within urban areas of developing-country cities are especially vulnerable, as they tend to be built on hazardous sites and to be susceptible to floods, landslides and other climate-related disasters (Cross, 2001; UN-Habitat, 2003).

Several recent assessments have considered vulnerabilities of rapidly growing and/or large urban areas to climate change. Examples include cities in the developed and developing world such as Hamilton City, New Zealand (Jollands et al., 2005), London (London Climate Change Partnership, 2004; Holman et al., 2005), New York (Rosenzweig and Solecki, 2001a, b), Boston (Kirshen et al., 2007), Mumbai, Rio de Janeiro, Shanghai (Sherbinin et al., 2006), Krakow (Twardosz, 1996), Caracas (Sanderson, 2000), Cochin (ORNL/CUSAT, 2003), Greater Santa Fe (Clichevsky, 2003), Mexico City, Sao Paolo, Manila, Tokyo (Wisner, 2003), and Seattle (Office of Seattle Auditor, 2005).

Climate change is likely to interact with and possibly exacerbate ongoing environmental change and environmental pressures in settlements. In areas such as the Gulf Coast of the United States, for example, land subsidence is expected to add to apparent sea-level rise. For New York City, sea-level rise will accelerate the inundation of coastal wetlands, threaten vital infrastructure and water supplies, augment summertime energy demand, and affect public health (Rosenzweig and Solecki, 2001a; Knowlton et al., 2004; Kinney et al., 2006). Significant costs of coastal and riverine flooding are possible in the Boston metropolitan area (Kirshen et al., 2006). Climate change, a city's building conditions, and poor sanitation and waste treatment could coalesce to affect the local quality of life and economic activity of such cities as Mumbai, Rio de Janeiro and Shanghai (Sherbinin et al., 2006). In addition, for cities that play leading roles in regional or global economies, such as New York, effects could be felt at the national and international scales via disruptions of business activities linked to other places (Solecki and Rosenzweig, 2007).

Sea-level rise could raise a wide range of issues in coastal areas. Studies in the New York City metropolitan area have projected that climate-change impacts associated with expectations that sea level will rise, could reduce the return period of the flood associated with the 100-year storm to 19 to 68 years on average, by the 2050s, and to 4 to 60 years by the 2080s (Rosenzweig and Solecki, 2001a), jeopardising low-lying buildings and transportation systems. Similar impacts are expected in the eastern Caribbean, Mumbai, Rio de Janeiro and Shanghai, where coastal infrastructure, population and economic activities could be vulnerable to sea-level rise (Lewsey et al., 2004; Sherbinin et al., 2006). Due to a long coastline and extensive low-lying coastal areas, projected sea-level rise in Estonia and the Baltic Sea region could endanger natural ecosystems, cover beach areas high in recreational value, and cause environmental contamination (Kont et al., 2003).

Another body of evidence suggests that human settlements, coastal and otherwise, are affected by climate change-related shifts in precipitation. Concerns include increased flooding potential from more sizeable rain events (Shepherd et al., 2002). Conversely, as suggested by the TAR, any change in climate that reduces precipitation and impairs underground water resource replenishment would be a very serious concern for some human settlements, particularly in arid and semi-arid areas (Rhode, 1999), in settlements with human-induced water scarcity (Romero Lankao, 2006), and in regions dependent on melted snowpack and glaciers (Chapter 1, Box 1.1; Chapter 12, Section 12.4.3; Chapter 13, Section 13.6.2).

A wider range of health implications of climate change also can affect settlements. For example, besides heat stress and respiratory distress from air quality, changes in temperature, precipitation and/or humidity affect environments for water- and vector-borne diseases and create conditions for disease outbreaks (see Chapters 4 and 8). Projections of climate-change impacts in New York City show significant increases in respiratory-related diseases and hospitalisation (Rosenzweig and Solecki, 2001a).

With growing urbanisation and development of modern industry, air quality and haze have become more salient issues in urban areas. Many cities in the world, especially in developing countries, are experiencing air pollution problems, such as Buenos Aires, London, Chongqing, Lanzhou, Mexico City and São Paulo. How climate change might interact with these problems is not clear as a general rule, although temperature increases would be expected to aggravate ozone pollution in many cities (e.g., Molina and Molina, 2002; Kinney et al., 2006). A study evaluating the effects of changing global climate on regional ozone of 15 cities in the U.S. finds, for instance, that average summertime daily maximum ozone concentrations could increase by 2.7 parts per billion (ppb) for a 5-year span in the 2020s and 4.2 ppb for a 5-year span in the 2050s. As a result, more people (especially the elderly and young) might be forced to restrict outdoor activities (NRDC, 2004).

Another issue is urban heat island (UHI) effects: higher temperatures occur in urban areas than in outlying rural areas because of diurnal cycles of absorption and later re-radiation of solar energy and (to a much lesser extent) heat generation from built/paved physical structures. The causes of UHI are complex, as is the interaction between atmospheric processes at different scales (Oke, 1982). UHI can affect the climatic comfort of the urban population, potentially related to health, labour productivity and leisure activities; there are also economic effects, such as the additional cost of climate control within buildings, and environmental effects, such as the formation of smog in cities and the degradation of green spaces. Even such small coastal towns as Aveiro in Portugal have been shown to create a heat island (Pinho and Orgaz, 2000). Rosenzweig et al. (2005) found that climate change based on downscaled general circulation model (GCM) projections would exacerbate the New York City UHI by increasing baseline temperatures and reducing local wind speeds.

In sum, settlements are vulnerable to impacts that can be exacerbated by direct climate changes (e.g., severe storms and associated coastal and riverine flooding, especially when combined with sea-level rise, snow storms and freezes, and fire). Yet climate change is not the only stress on human settlements, but rather it coalesces with *other* stresses, such as scarcity of water or governance structures that are inadequate even in the absence of climate change (Feng et al., 2006; Sherbinin et al., 2006; Solecki and Rosenzweig, 2007). Such phenomena as unmet resource requirements, congestion, poverty, political and economic inequity, and insecurity can be serious enough in some settlements (UN-Habitat, 2003) that any significant additional stress could be the trigger for serious disruptive events and impacts. Other stresses may include institutional and jurisdictional fragmentation, limited revenue streams for public-sector roles, and inflexible patterns of land use (UNISDR, 2004). These types of stress do not take the same form in every city and community, nor are they equally severe everywhere. Many of the places where people live across the world are under pressure from some combination of continuing growth, pervasive inequity, jurisdictional fragmentation, fiscal strains and aging infrastructure (UN-Habitat, 2003).

7.4.2.5 Social issues

Social system vulnerabilities to impacts of climate variability and change are often related to geographical location. For instance, indigenous societies in polar regions and settlements close to glaciers in Latin America and in Europe are already experiencing threats to their traditional livelihoods (Chapter 12, Section 12.4.3; Chapter 13, Section 13.6.2). Low-lying island nations are also threatened (Chapter 16). Rising temperatures in mountain areas, and in temperate zones needing space-heating during the winter may result in energy cost savings for their populations (Section 7.4.2.1). On the other hand, areas relying on electric fans or air-conditioning may see increased pressures on household budgets as average temperatures rise.

It is increasingly recognised that social impacts associated with climate change will be mainly determined by how the changes interact with economic, social and institutional processes to exacerbate or ameliorate stresses associated with human and ecological systems (Turner et al., 2003b; Adger et al., 2005b; NRC, 2006). As studies undertaken in Latin America, Asia, Africa and the Arctic show, climate change is not the only stress on rural and urban livelihoods. The livelihoods of the Inuit in the Arctic are threatened by multiple stresses (e.g., loss of traditional food sources, growing dependence upon distant fish markets and externally driven values and attitudes). These processes could overtax their adaptive capacity, reduce the role of kinship and family as the centre of social organisation around fishing, and lead to divisions within and between fisher and hunter organisations (Turner et al., 2003b; ACIA, 2004). Rural communities do struggle daily with scarce resources, with insufficient access to commercial markets for their products, and with development policies and other institutional barriers, which frequently limit their ability to cope with extreme climate events (O'Brien et al., 2004; Eakin, 2006). Similarly, in urban settlements, climate change could coalesce with other processes and factors, such as land subsidence due to groundwater withdrawal, the poor condition of many buildings and infrastructures, weak governance structures, and modest income levels, to impact on peoples' livelihoods (Wood and Salway, 2000; Bull-Kamanga et al., 2003; Sherbinin et al., 2006).

The vulnerability of human societies to climate change could vary with economic, social and institutional conditions: particularly socio-economic diversity within urban and rural settlements and their productive sectors, linkage systems and infrastructure (Eakin, 2006; O'Brien et al., 2006). In already-warm areas exposed to further warming, for instance, less-advantaged populations are less likely to have access to air-conditioning in homes and workplaces. Urban neighbourhoods that are well served by health facilities and public utilities, or have additional economic and technical resources, are better equipped to deal with weather extremes than poor and informal settlement areas, and their actions can affect the poor as well (Sherbinin et al., 2006). Relatively-wealthy market-oriented farmers can afford more expensive deep-well pumps. In coastal settlements, large-scale fishing entrepreneurs can afford to relocate or diversify. By contrast, poverty and marginalisation raise serious issues for impacts and responses, including the following:

a. The poor, who make up half of the world's population and earn less than US$2 a day (UN-Habitat, 2003), cannot afford adaptation mechanisms such as air-conditioning, heating or climate-risk insurance (which is unavailable or significantly restricted in most developing countries). The poor depend on water, energy, transportation and other public infrastructures which, when affected by climate-related disasters, are not immediately replaced (Freeman and Warner, 2001). Instead, they base their responses on diversification of their livelihoods or on remittances and other social assets (Klinenberg, 2002; Wolmer and Scoones, 2003; Eakin 2006). In many countries, recent reductions in services and support from central governments have decreased the resources available to provide adequate preparedness and protection (UN-Habitat, 2003; Eakin and Lemos, 2006). This does not necessarily mean that "the poor are lost"; they have other coping mechanisms (see Section 7.6), but climate change might go beyond what traditional coping mechanisms can handle (Wolmer and Scoones, 2003).
b. Especially in developing countries, where more than 90% of the deaths related to natural disasters occur (UNISDR, 2004) and 43% of the urban slums are located (UN-Habitat, 2003), the poor tend to live in informal settlements, with irregular land tenure and self-built substandard houses, lacking adequate water, drainage and other public services and often situated in risk-prone areas (Romero Lankao et al., 2005). Events such as the December 1999 flash floods and

landslides in Caracas, killing nearly 30,000, and the 2001 severe flooding in Cape Town, damaging 15,641 informal dwellings, show us that the poor in these countries are the most likely to be killed or harmed by extreme weather-related events (Sherbinin et al., 2006). During 1985 and 1999 the world's wealthiest nations suffered 57.3% of the measured economic losses due to disasters, about 2.5% of their GDP. The world's poorest countries suffered 24.4% of the economic toll of disasters, but this represented 13.4% of their combined GDP (ADRC et al., 2005).

c. Impacts of climate change are likely to be felt most acutely not only by the poor, but also by certain segments of the population, such as the elderly, the very young, the powerless, indigenous people, and recent immigrants, particularly if they are linguistically isolated, i.e., those most dependent on public support. Impacts will also differ according to gender (Cannon, 2002; Klinenberg, 2002; Box 7.4). This happens particularly in developing countries, where gendered cultural expectations, such as women undertaking multiple tasks at home, persist (Wood and Salway, 2000), and the ratios of women affected or killed by climate-related disasters to the total population are already higher than in developed nations (ADRC et al., 2005).

Government/institutional capacities and resources could also be affected by climate change. Examples from Mexico City, Tokyo, Los Angeles and Manila include requirements for public health care, disaster risk reduction, land-use management, social services to the elderly, public transportation, and even public security, where climate-related stresses are associated with uncoordinated planning, legal barriers, staffing shortages and other institutional constrains (Wisner, 2003; UNISDR, 2004). Where budgets of local or regional governments are affected by increased demands, such effects can lead to calls for either increases in revenue bases or reductions in other government expenditures, which implies a vulnerability of governance systems to climate change (Freeman and Warner, 2001). The disruption of social networks and solidarity by extreme weather events and repeated lower impact events can reduce resilience (Thomas and Twyman, 2005). As sources of stress multiply and magnify in consequence of global climate change, the resilience of already overextended economic, political and administrative institutions will tend to decrease, especially in the most impoverished regions. As Hurricane Katrina has shown, it is likely that if things go wrong people will blame "the Government" (Sherbinin et al., 2006). To avoid such outcomes, governance systems are likely to react to perceptions of growing stresses through regulation and strengthening of emergency management systems (Christie and Hanlon, 2001).

7.4.3 Key vulnerabilities

As a general statement about a wide diversity of circumstances, the major climate-change vulnerabilities of industries, settlements and societies are:

1. vulnerabilities to extreme weather and climate events, particularly if abrupt major climate change should occur, along with possible thresholds associated with more gradual changes;
2. vulnerabilities to climate change as one aspect of a larger multi-stress context: relationships between climate change and thresholds of stress in other regards;
3. vulnerabilities of particular geographical areas such as coastal and riverine areas vulnerable to flooding and continental locations where changes have particular impacts on human livelihoods; most vulnerable are likely to be populations in areas where subsistence is at the margin of viability or near boundaries between major ecological zones, such as tundra thawing in polar regions and shifts in ecosystem boundaries along the margins of the Sahel that may undergo significant shifts in climate;
4. vulnerabilities of particular populations with limited resources for coping with and adapting to climate-change impacts;
5. vulnerabilities of particular economic sectors sensitive to climate conditions, such as tourism, risk financing and agro-industry.

All of these concerns can be linked both with direct effects and indirect effects through inter-connections and linkages, both between systems (such as flooding and health) and between locations.

Most key vulnerabilities are related to (a) climate phenomena that exceed thresholds for adaptation, i.e., extreme weather events and/or abrupt climate change, often related to the magnitude and rate of climate change (see Box 7.4), and (b) limited access to resources (financial, technical, human, institutional) to cope, rooted in issues of development context. Most key vulnerabilities are relatively localised, in terms of geographic location, sectoral focus and segments of the population affected, although the literature to support such detailed findings about potential impacts is very limited. Based on the information summarised in the sections above (Table 7.3), key vulnerabilities of industry, settlement and society include the following, each characterised by a level of confidence.

- Interactions between climate change and urbanisation: most notably in developing countries, where urbanisation is often focused in vulnerable areas (e.g., coastal), especially when mega-cities and rapidly growing mid-sized cities approach possible thresholds of sustainability (very high confidence).
- Interactions between climate change and global economic growth: relevant stresses are linked not only to impacts of climate change on such things as resource supply and waste management but also to impacts of climate change response policies, which could affect development paths by requiring higher cost fuel choices (high confidence).
- Increasingly strong and complex global linkages: climate-change effects cascade through expanding series of international trade, migration and communication patterns to produce a variety of indirect effects, some of which may be unanticipated, especially if the globalised economy becomes less resilient and more interdependent (very high confidence).
- Fixed physical infrastructures that are important in meeting human needs: infrastructures susceptible to damage from extreme weather events or sea-level rise and/or infrastructures already close to being inadequate, where an additional source of stress could push the system over a threshold of failure (high confidence).

Table 7.3. *Selected examples of current and projected climate-change impacts on industry, settlement and society and their interaction with other processes.*

Climate Driven Phenomena	Evidence for Current Impact/ Vulnerability	Other Processes/ Stresses	Projected Future Impact/ Vulnerability	Zones, Groups Affected
a) Changes in extremes				
Tropical cyclones, storm surge	Flood and wind casualties and damages; economic losses: transport, tourism, infrastructure (e.g., energy, transport), insurance (7.4.2; 7.4.3; Box 7.3; 7.5)	Land use/ population density in flood-prone areas; flood defences; institutional capacities	Increased vulnerability in storm-prone coastal areas; possible effects on settlements, health, tourism, economic and transportation systems, buildings and infrastructures	Coastal areas, settlements and activities; regions and populations with limited capacities and resources; fixed infrastructures; insurance sector
Extreme rainfall, riverine floods	Erosion/landslides; land flooding; settlements; transportation systems; infrastructure (7.4.2) (see regional Chapters)	As for tropical cyclones and storm surge, plus drainage infrastructure	As for tropical cyclones and storm surge, plus drainage infrastructure	As for tropical cyclones and storm surge, plus flood plains
Heat or cold-waves	Effects on human health; social stability; requirements for energy, water and other services (e.g., water or food storage), infrastructures (e.g., energy transportation) (7.2; Box 7.1; 7.4.2.2; 7.4.2.3)	Building design and internal temperature control; social contexts; institutional capacities	Increased vulnerabilities in some regions and populations; health effects; changes in energy requirements	Mid-latitude areas; elderly, very young, ill and/or very poor populations
Drought	Water availability, livelihoods; energy generation; migration,; transportation in water bodies (7.4.2.2; 7.4.2.3; 7.4.2.5)	Water systems; competing water uses; energy demand; water demand constraints	Water resource challenges in affected areas; shifts in locations of population and economic activities; additional investments in water supply	Semi-arid and arid regions; poor areas and populations; areas with human-induced water scarcity
b) Changes in means				
Temperature	Energy demands and costs; urban air quality; thawing of permafrost soils; tourism and recreation; retail consumption; livelihoods; loss of melt water (7.4.2.1; 7.4.2.2; 7.4.2.4; 7.4.2.5)	Demographic and economic changes; land-use changes; technological innovations; air pollution; institutional capacities	Shifts in energy demand; worsening of air quality; impacts on settlements and livelihoods depending on melt water; threats to settlements/infrastructure from thawing permafrost soils in some regions	Very diverse, but greater vulnerabilities in places and populations with more limited capacities and resources for adaptation
Precipitation	Agricultural livelihoods; saline intrusion; tourism; water infrastructures; energy supplies (7.4.2.1; 7.4.2.2; 7.4.2.3)	Competition from other regions/sectors. Water resource allocation	Depending on the region, vulnerabilities in some areas to effects of precipitation increases (e.g., flooding, but could be positive) and in some areas to decreases (see drought above)	Poor regions and populations
Saline intrusion	Effects on water infrastructures (7.4.2.3)	Trends in groundwater withdrawal	Increased vulnerabilities in coastal areas	Low-lying coastal areas, especially those with limited capacities and resources
Sea-level rise	Coastal land uses; flood risk, water logging; water infrastructures (7.4.2.3; 7.4.2.4)	Trends in coastal development, settlement and land uses	Long-term increases in vulnerabilities of low-lying coastal areas	As for saline intrusion,
c) Abrupt climate change				
	Analyses of potentials	Demographic, economic, and technological changes; institutional developments	Possible significant effects on most places and populations in the world, at least for a limited time	Most zones and groups

Orange shading indicates very significant in some areas and/or sectors; yellow indicates significant; white indicates that significance is less-clearly established.

- Interactions with governmental and social/cultural structures that are already stressed in some places by other kinds of change: examples include population pressure and limited economic resources, where in some cases structures could become no longer viable when climate change is added as a further stress (medium confidence).

In all of these cases, the valuation of vulnerabilities depends considerably on the development context. For instance, vulnerabilities in more developed areas are often focused on physical assets and infrastructures and their economic value and replacement costs, along with linkages to global markets, while vulnerabilities in less developed areas are often focused on human populations and institutions, which need different metrics for valuation. On the other hand, vulnerabilities to physical and economic costs can have a greater proportional impact in developing areas.

Although it would be useful to be able to associate such general vulnerabilities with particular impact criteria, climate-change scenarios, and/or time frames, the current knowledge base does not support such specificity with an adequate level of confidence.

7.5 Costs and other socio-economic issues

Costs or benefits of climate change-related impacts on industry, settlements and society are difficult to estimate. Reasons include the facts that effects to date that are clearly attributable to climate change are limited, most of the relatively small number of estimates of macroeconomic costs of climate change refer to total economies rather than to the more specific subject matter of this chapter, and generalising from scattered cases that are not necessarily representative of the global portfolio of situations is risky. Historical experience is of limited value when the potentially impacted systems are themselves changing (e.g., with global economic restructuring and development, and technological change), and many types of costs – especially to society – are poorly captured by monetary metrics. In many cases, the only current guides to projecting possible costs of climate change are costs associated with recent extreme weather events of types projected to increase in intensity and/or frequency, although this is only one kind of possible impact and cannot be assumed to be representative of aggregate costs and benefits of all aspects of climate change, including more gradual change.

Estimates of aggregate macroeconomic costs of climate change at a global scale (e.g., Smith et al., 2001) are not directly useful for this chapter, other than generally illustrating that because many locations, industrial sectors and settlements are not highly vulnerable, total monetary impacts at that scale might not be large in proportion to the global economy. As Section 7.4 indicates, however, vulnerabilities of or opportunities for particular localities and/or sectors and/or societies could be considerable. A possible example is climate-related contributions to changes already being experienced by societies and settlements in the Arctic, which include destabilised buildings, roads, airports and industrial facilities and other effects of permafrost conditions, requiring substantial rebuilding, maintenance and investments (ACIA, 2004). An impact assessment in the UK projected that annual weather-related damages to land uses and properties could increase by 3 to 9 times by the 2080s (Harman et al., 2005). More generally, as one specific aspect of vulnerabilities to climate change, possible economic costs of sea-level rise have been estimated, since exposures of coastal areas to a specified scenario can be analysed for costs of the change v. costs of protecting against the change; and effects of direct costs in coastal areas can be projected for other parts of a regional or national economy (Nicholls and Tol, 2006; Tol et al., 2006). Generally, these studies conclude that the costs of full protection are greater than the costs of losing land to sea-level rise, although they do not estimate non-monetary costs of social and cultural effects.

Recent climate-related extreme weather events have been associated with cost estimates for countries and economic sectors; and trends in these costs have been examined, especially by the reinsurance industry (e.g., Swiss Re, 2004; Munich Re, 2005; also Chapter 1, Section 1.3.8). According to these estimates, an increase in the intensity and/or frequency of weather-based natural disasters, such as hurricanes, floods or droughts, could be associated with very large costs to targeted regions in terms of economic losses and losses of life and disruptions of livelihoods, depending on such variables as the level of social and economic development, the economic value of property and infrastructure affected, capacities of local institutions to cope with the resulting stresses, and the effective use of risk reduction strategies. Estimates of impacts on a relatively small country's GDP in the year of the event range from 4 to 6% (Mozambique flooding: Cairncross and Alvarinho, 2006) to 3% (El Niño in Central America: www.eclac.cl/mexico/ and follow the link to 'desastres') to 7% (Hurricane Mitch in Honduras: Figure 7.3). Even though these macroeconomic impacts appear relatively minor, countries facing an emergency found it necessary to incur increased public spending and obtain significant support from the international donor community in order to meet the needs of affected populations. This increased fiscal imbalances and current account external deficits in many countries.

For specific regions and locales, of course, the impact on a local economy can be considerably greater (see Box 7.4). Estimates suggest that impacts can exceed GDP and gross capital formation in percentages that vary from less than 10% in larger, more developed and diversified impacted regions to more than 50% in less developed, less diversified, more natural resource-dependent regions (Zapata-Marti, 2004).

It seems likely that if extreme weather events become more intense and/or more frequent with climate change, GDP growth over time could be adversely affected unless investments are made in adaptation and resilience.

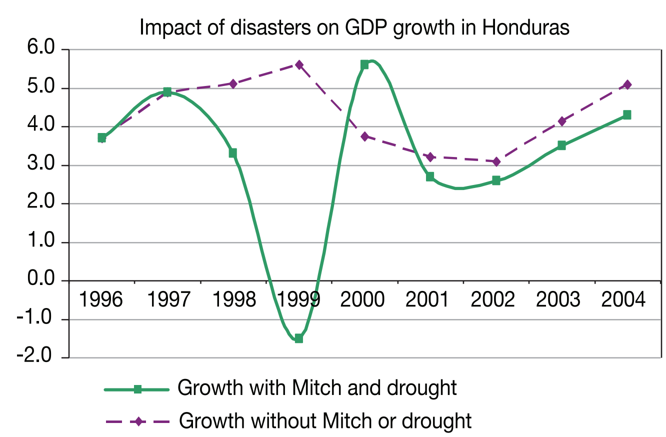

Figure 7.3. *Economic impact of Hurricane Mitch and the 1998 to 1999 drought on Honduras (http://siteresources.worldbank.org/INTDISMGMT/Resources/eclac_LAC&Asia.pdf).*

Box 7.4. Vulnerabilities to extreme weather events in megadeltas in a context of multiple stresses: the case of Hurricane Katrina

It is possible to say with a high level of confidence that sustainable development in some densely populated megadeltas of the world will be challenged by climate change, not only in developing countries but in developed countries also. The experience of the U.S. Gulf Coast with Hurricane Katrina in 2005 is a dramatic example of the impact of a tropical cyclone – of an intensity expected to become more common with climate change – on the demographic, social, and economic processes and stresses of a major city located in a megadelta.

In 2005, the city of New Orleans had a population of about half a million, located on the delta of the Mississippi River along the U.S. Gulf Coast. The city is subject not only to seasonal storms (Emanuel, 2005) but also to land subsidence at an average rate of 6 mm/yr rising to 10-15 mm/year or more (Dixon et al., 2006). Embanking the main river channel has led to a reduction in sedimentation leading to the loss of coastal wetlands that tend to reduce storm surge flood heights, while urban development throughout the 20th century has significantly increased land use and settlement in areas vulnerable to flooding. A number of studies of the protective levee system had indicated growing vulnerabilities to flooding, but actions were not taken to improve protection.

In late August 2005, Hurricane Katrina – which had been a Category 5 storm but weakened to Category 3 before landfall – moved onto the Louisiana and Mississippi coast with a storm surge, supplemented by waves, reaching up to 8.5 m above sea level along the southerly-facing shallow Mississippi Coast (see also Chapter 6, Box 6.4). In New Orleans, the surge reached around 5 m, overtopping and breaching sections of the city's 4.5 m defences, flooding 70 to 80% of New Orleans, with 55% of the city's properties inundated by more than 1.2 m of water and maximum flood depths up to 6 m. In Louisiana 1,101 people died, nearly all related to flooding, concentrated among the poor and elderly.

Across the whole region, there were 1.75 million private insurance claims, costing in excess of US$40 billion (Hartwig, 2006), while total economic costs are projected to be significantly in excess of US$100 billion. Katrina also exhausted the federally-backed National Flood Insurance Program (Hunter, 2006), which had to borrow US$20.8 billion from the Government to fund the Katrina residential flood claims. In New Orleans alone, while flooding of residential structures caused US$8 to 10 billion in losses, US$3 to 6 billion was uninsured. Of the flooded homes, 34,000 to 35,000 carried no flood insurance, including many that were not in a designated flood risk zone (Hartwig, 2006).

Beyond the locations directly affected by the storm, areas that hosted tens of thousands of evacuees had to provide shelter and schooling, while storm damage to the oil refineries and production facilities in the Gulf region raised highway vehicle fuel prices nationwide. Reconstruction costs have driven up the costs of building construction across the southern U.S., and federal government funding for many programmes was reduced because of commitments to provide financial support for hurricane damage recovery. Six months after Katrina, it was estimated that the population of New Orleans was 155,000, with this number projected to rise to 272,000 by September 2008; 56% of its pre-Katrina level (McCarthy et al., 2006).

Research has also considered costs of extreme weather-related events on certain sectors of interest, especially water-supply infrastructures. For instance, if reduced precipitation due to climate change were to result in an interruption of urban water supplies, effects could include disruptions of industrial activity as well as hardships for population, especially the poor, who have the fewest options for alternative supplies. The cost of extending pipelines is considerable, especially if it means that water treatment works also have to be relocated. As a rough working rule, the cost of construction of the abstraction and treatment works and the pumping main for an urban settlement's water supply is about half the cost of the entire system. The cost of flood damage is often even more considerable. For example, the catastrophic flooding of southern Mozambique in 2000 caused damage to water supplies which cost US$13.4 million to repair, or roughly US$50 per person directly affected, of the same order as the cost of providing them with water supplies in the first place (World Bank, 2000). Part of the explanation is that the damaged water supplies also served people whose homes were not directly affected by the flooding; this can be expected to occur in other floods. Nicholls (2004) has estimated that some 10 million people are affected annually by coastal flooding, and that this number is likely to increase until 2020 under all four SRES scenarios, largely because of the increase in the exposed population.

A longer-term concern for industry, settlements and society in developed countries is the prospect of abrupt climate change, which could exceed coping mechanisms in many settlements and societies that would be resilient to gradual climate change

(National Research Council, 2002). In such a case, fixed infrastructures are especially vulnerable, although the research literature is very limited.

Reliable estimates of costs associated with more gradual climate change are scarce, for reasons summarised above, although in some cases cost estimates of adaptation strategies are available (Chapter 17). In general, costs that can be addressed strategically over periods of time have different implications for industry, settlements and society than relatively sudden costs (e.g., Hallegatte et al., 2007). For a combination of gradual changes and extreme events, several recent studies indicate that climate change could reduce the rate of GDP growth over time unless vulnerabilities are addressed (Van Kooten, 2004; Stern, 2007).

The existing literature is, in these ways, useful in considering possible costs of climate change for industry, settlement and society; but it is not sufficient to estimate costs globally or regionally associated with any specific scenario of climate change. What can be said at the present time is that economic costs of extreme weather events at a large national or large regional scale, estimated as a percent of gross product in the year of the event, are unlikely to represent more than several percent of the value of the total economy, except for possible abrupt changes (high confidence), while net aggregate economic costs of extreme event impacts in smaller locations, especially in developing countries, could in the short run exceed 25% of the gross product in that year (high confidence). To the degree that these events increase in intensity and/or frequency, they will represent significant costs due to climate change. For industry, settlements and society, economic valuations of other costs and benefits associated with climate change are generally not yet available.

7.6 Adaptation: practices, options and constraints

7.6.1 General perspectives

Challenges to adapt to variations and changes in environmental conditions have been a part of every phase of human history, and human societies have generally been highly adaptable (Ausubel and Langford, 1997). Adaptations may be anticipatory or reactive, self-induced and decentralised or dependent on centrally-initiated policy changes and social collaboration, gradual and evolutionary or rooted in abrupt changes in settlement patterns or economic activity. Historically, adaptations to climate change have probably been most salient in coastal areas vulnerable to storms and flooding, such as the Netherlands, and in arid areas needing water supplies; but human settlements and activities exist in the most extreme environments on earth, which shows that the capacity to adapt to known conditions, given economic and human resources and access to knowledge, is considerable.

Adaptation strategies vary widely depending on the exposure of a place or sector to dimensions of climate change, its sensitivity to such changes, and its capacities to cope with the changes (Chapter 17). Some of the strategies are multi-sectoral, such as improving climate and weather forecasting at a local scale, emergency preparedness and public education. One example of cross-cutting adaptation is improving information and institutions for emergency preparedness. Systematic disaster preparedness at community level has helped reduce death tolls; for instance, new warning systems and evacuation procedures in Andhra Pradesh, India, reduced deaths from coastal tropical cyclones by 90%, comparing 1979 with 1977 (Winchester, 2000), and poor societies in other parts of the Bay of Bengal area have undertaken practical measures to reduce flood risks due to high levels of awareness and motivation among local communities. However, the effectiveness of such systems in reaching marginal populations, and their responses to such warnings, is uneven; and the timing of decisions to adapt affects the likely benefits.

Other strategies are focused on a sector, such as water, energy, tourism and health (see Chapters 3 and 8). Some are geographically focused, such as coastal area and floodplain adaptations, which can involve such initiatives as changing land uses in highly vulnerable areas and protecting critical areas. Adaptation, in fact, tends very often to be context-specific, within larger market and policy structures (Adger et al., 2005a), although it generally takes place within the larger context of globalisation (Benson and Clay, 2003; Sperling and Szekely, 2005).

There is a considerable literature on adaptations to climate *variation* and on vulnerabilities to *extreme events*, especially in developed countries; but research on potentials and costs of adaptation by industry, settlement and society to *climate change* is still in an early stage (Chapter 17). One challenge is that it is still difficult to project changes in particular places and sectors with much precision, whether by downscaling global climate models or by extrapolating from past experience with climate variation. Uncertainty about the distribution and timing of climate-change impacts at the local level makes judgments about the scale and timing of adaptation actions very difficult. Where there are co-benefits between climate-change adaptation and other economic or social objectives, there will be reasons for early action. In other cases, limits on predictability tend to delay adaptation (Wright and Erickson, 2003). In addition, there is little scientific basis as yet for assessing possible limits of adaptation, especially differences among locations and systems. In particular, the knowledge base about costs of adaptation is less well developed than the knowledge base about possible adaptation benefits. At least in some cases, costs might exceed actual benefits.

7.6.2 Industry

The extent to which potential vulnerabilities of industry are likely to motivate adaptation will depend to a large extent on the flexibility of business and on its capacity to adapt. In general, those industries with longer-lived capital assets (e.g., energy), fixed or weather-dependent resources (mining, food and agriculture), and extended supply chains (e.g., the retail-distribution industry) are likely to be more vulnerable to climate-change impacts. But many of these industries, especially in the industrialised world, are likely to have the technological and economic resources necessary both to recover from the impacts of extreme events (partly by sharing and spreading risk or by moving to safer locations), and to adapt over the longer term to more gradual changes. It is also clear that many other economic and social factors are likely to play a more important role in influencing innovation and change in industry than climate change. For many businesses, climate risk management can be integrated into overall business strategy and operations where it will be regarded as one among many issues that demand attention, to the degree that such adaptation is supported by investors and shareholders.

There is now considerable evidence emerging in Europe, North America and Japan that the construction and transportation sectors are paying attention to climate-change impacts and the need for adaptation (Lisø et al., 2003; Shimoda, 2003; Salagnac, 2004; Chapter 17, Section 17.2.2). As one example, the US$1 billion 12.9 km Confederation Bridge between New Brunswick and Prince Edward Island in Canada, which opened in 1997, was built one metre higher to accommodate anticipated sea-level rise over its 100-year lifespan (McKenzie and Parlee, 2003). A range of technical advice is now available to planners, architects and engineers on climate impacts risk assessment (Willows and Connell, 2003), including specialised advice on options for responding to these risks (Lancaster et al., 2004). A few early estimates of possible costs of adaptation measures are beginning to be available; for instance, O'Connell and Hargreaves (2004) show that measures to reduce wind damage, flood risk and indoor heat would add about 5% to the cost of a typical new house in New Zealand.

Business adaptations will be in response to both direct impacts (involving direct observations of risks and opportunities as a result of changing climatic conditions) and indirect impacts (including changing regulatory pressures and consumer demand) as illustrated in Table 7.2. Adaptations can also take a wide variety of forms. They may include changes in business processes, technologies or business models (Hertin et al., 2003), or changes in the location of activities. Many of these adaptations represent incremental adjustments to current business activities (Berkhout et al., 2006). For instance, techniques already exist for adapting buildings in response to greater risks of ground movement (deeper foundations), higher temperatures (passive and active cooling) and driving rain (building techniques and cladding technologies). Frequently these adaptations are relatively low-cost and represent best practice (ACIA, 2004). For more structural adaptations – such as choice of location for industrial facilities – planning guidance, government policy and risk management by insurers will play major roles.

Awareness, capabilities and access to resources that facilitate adaptation are likely to be much less widely available in less developed contexts, where industrial production often takes place in areas vulnerable to flooding, coastal erosion and land slips. Production is also more likely to be tied to natural resources affected by changing climates. Potentials for adaptation to climate change in informal sectors in developing countries depend largely on the context: e.g., the impacts involved, the sensitivity of the industrial activity to those impacts, and the resources available for coping. Examples of adaptive strategies could include relocating away from risk-prone locations, diversifying production activities, and reducing stresses associated with other operating conditions to add general resiliency. Informal industry employs minimal capital and few fixed assets, so that it usually adapts relatively quickly to gradual changes. But adaptations that are substantial may call for an awareness of threats and responses to them that go beyond historical experience, a willingness to depart from traditional activity patterns, and access to financial resources not normally available to some small producers.

The energy sector can adapt to climate-change vulnerabilities and impacts by anticipating possible impacts and taking steps to increase its resilience, e.g., by diversifying energy supply sources, expanding its linkages with other regions, and investing in technological change to further expand its portfolio of options (Hewer, 2006; Chapter 12, Section 12.5.8). This sector has impressive investment resources and experience with risk management, and it has the potential to be a leader in industrial adaptation initiatives, whether related to reducing risks associated with extreme events or coping with more gradual changes such as in water availability. On the other hand, many energy sector strategies involve high capital costs, and social acceptance of climate-change response alternatives that might imply higher energy prices could be limited. Adaptation prospects are likely to depend considerably on the availability of information about possible climate-change effects to inform decisions about adaptive management.

7.6.3 Services

Concerns about vulnerabilities and impacts for services are likewise concentrated on sectors especially sensitive to climate variation, such as recreation and tourism; and adaptations are also likely to be associated with changes in costs/prices, applications of technology, and attention to risk financing. For instance, wholesale and retail trades are likely to adapt by increasing or reducing space cooling and/or heating, by changing storage and distribution systems to reduce vulnerabilities, and by changing the consumer goods and services offered in particular locations. Some of these adaptations, although by no means all of them, could increase prices of goods and services to consumers.

Where climate change affects comparative advantages for regions in the global economy, trade patterns are likely to adapt largely through market mechanisms as the changes unfold rather than through strategies to reduce risk in anticipation of changes (Figure 7.2). In a general sense, there will be 'winners' and 'losers' as a result, potentially affecting economic growth and employment in both kinds of cases, which suggests the possible value of anticipatory planning and policy discourse. In many cases, building robust ties with the globalising economy could be a useful response to possible climate changes for places and societies built around small-scale social interactions and enterprises, because those ties could open up a wider range of possible alternatives for adaptation.

The short time-scales at which most commercial services operate allow great flexibility for adapting to climate change. Within the retail industry, it is likely that commerce will capitalise on long-term trends in consumer behaviour and lifestyle, relating to climate change through an expansion of markets for cooling equipment, and facilities and goods for outdoor recreation in temperate climates. Large injections of capital may be required to relocate commercial premises from low-lying areas vulnerable to flooding. In addition, technological investment will be required to reduce carbon emissions while maintaining competitive prowess in the global market. The most vulnerable are communities (particularly in developing countries) whose economy is based on the production and distribution of a restricted range of climate-sensitive commodities. For these communities, economic diversification should be a key response to reduce vulnerability.

The tourism sector may in some cases be able to adapt to long-term trends in climate change, such as increasing temperatures, at a cost, for instance by investing in snow-making equipment (see Chapter 14, Section 14.4.7), beach enhancement (see Chapter 6, Sections 6.5.2 and 6.6.1.1), or additional air-conditioning. The sustainability of some adaptation processes may be questionable: air-conditioning because of its energy use, snowmaking for its pressure on water resources or its costs (O'Brien et al., 2004). However, climate change is not likely to be linear, and the frequency and intensity of extreme climatic events, which affect not only the reality of risks, but also the subjective risk-perception of tourists, might become a far greater problem for the tourist industry. There are three categories of adaptation processes: technological, managerial and behavioural. While tourism providers tend to focus on the first two (preserving tourism assets, diversifying supply), tourists might rather change behaviour: they might visit new, suitable locations (for example snow-safe ski resorts at higher altitudes or in other regions) or they might travel during other periods of the year (for example, they might visit a site in spring instead of summer to avoid extreme temperatures). Awareness, adaptive capacities and strategies are likely to vary according to the wealth and the education of different categories of tourists and also among other stakeholders. For example, large tour operators should be able to adapt to changes in tourist destinations, as they are familiar with strategic planning, do not own the infrastructures and can, to some extent, shape demand through marketing.

Perhaps of even greater importance is the role of mobility in future tourism. Increasing prices for fuel and the need to reduce emissions might have substantial effects on transport availability and costs. For instance, the price of air transport, now the means of transport of 42% of all international tourists, is expected to rise in stabilisation scenarios (Gössling and Hall, 2005). This might call for adaptation in terms of leisure lifestyles, such as the substitution of long-distance travel by vacationing at home or nearby (Dubois and Ceron, 2005).

It also seems likely that tourism based on natural environments will see the most substantial changes due to climate change, including changes in economic costs (Gössling and Hall, 2005) and changes in travel flows. Tropical island nations and low-lying coastal areas may be especially vulnerable, as they might be affected by sea-level rise, changes in storm tracks and intensities (Chapter 16; Chapter 4, Section 4.2), changes in perceived climate-related risks, and changes in transport costs, all resulting in concomitant detrimental effects for their often tourism-based economies. In any of these cases, the implications are most notable for areas in which tourism represents a relatively large share of the local or regional economy, and these are areas where adaptation might represent a relatively significant need and a relatively significant cost.

The insurance sector has an important role to play in adaptation (Mills, 2004) as it is in the business of calculating risk costs and has begun to explore how risks can be expected to change into the future (Association of British Insurers, 2002). By communicating risk information to individual stakeholders, as through insurance pricing signals, insurers can help inform appropriate adaptive behaviours, although regulated markets or flat-rated insurance systems obstruct the transmission of the information required to motivate adaptation. Through reductions in premiums charged, insurance can also reward actions taken to reduce risk, such as by fitting hurricane shutters on a building or by the construction of local flood defences.

Where new risks are emerging, or known risks are increasing, new insurance coverages have been designed to help spread losses. Examples include the creation of weather derivatives, crop insurance and expanded property insurance coverage.

Generally, it is recognised that 'ex-ante' (before the fact) funding mechanisms in the form of insurance should be more beneficial for the affected community and the whole country's economy than ex-post (after the fact) mechanisms by means of credit, government subsidies or private donations. Only the ex-ante approach offers the surety of payments as well as the potential to influence the level of risk, through linking insurance prices and conditions with government policy on hazard mitigation, implementation, and supervision of building codes etc., thus reducing a country's financial vulnerability and giving improved prospects for investment and economic growth (Gurenko, 2004). However, in developing countries there are questions about the viability of such approaches, concerning who in a poor country is able to afford an ex-ante premium and how real reductions in risk can be achieved in a society with relatively low risk literacy (Linnerooth-Bayer et al., 2005). Other potential sources of developing country adaptation funding are discussed by Bouwer and Aerts (2006).

Besides incentivising adaptation, the insurance industry itself will need to adapt to stay financially healthy. The main threat is a combination of very high loss events in a short time period (as almost happened in September 2005 with Hurricane Rita heading for the city of Houston after Hurricane Katrina had hit New Orleans). Trends that contribute to increasing the robustness of the sector include better risk management, greater diversification, better risk and capital auditing, greater integration of insurance with other financial services, and improved tools to transfer risks out of the insurance market into the capital markets through catastrophe risk securitisations (European Environment Agency, 2004), which have seen significant increases in value issued since 2004.

The key vulnerability of the current system of risk-bearing concerns the non-availability or withdrawal of private insurance cover, in particular related to flood risk. However, the threat of withdrawal can itself be a spur for adaptation. Following the October-November 2000 floods in England and Wales, the Association of British Insurers negotiated an increased allocation of government expenditure on flood defences and a stakeholder role in decisions around future development in floodplains, by threatening to withdraw flood insurance from locations at greatest risk (Association of British Insurers, 2002). With expectations for rising levels of flood risk in developed countries, political pressures demand that if private insurance is withdrawn, state-backed alternatives should be created leading to increased liabilities for governments. Without such a backstop more significant adaptive measures may be triggered. In the northern Bahaman islands of Abaco and Grand Bahama (hit by three major hurricanes and their associated storm surges between 1999 and 2004), in 2005 flood insurance was withdrawn for some residential developments, ending the ability to raise a bank-loan mortgage. Without a state-backed alternative, houses became abandoned as their value collapsed (Woon and Rose, 2004). Meanwhile, builders have begun to construct new houses in the Bahamian coastal floodplain on concrete stilts, bringing some properties back into the domain of insurability. Similar adaptive outcomes can be expected in other coastal regions affected by increasing flood risk.

7.6.4 Utilities/infrastructure

The most general form of adaptation by infrastructures vulnerable to impacts of climate change is investment in increased resilience, for instance in new sources of water supply for urban areas. Most fields of infrastructure management, including water, sanitation, transportation and energy management, incorporate vulnerabilities to changing trends of supply and demand, and risks of disturbances in their normal planning.

In a situation where climate change, observed or projected, indicates a need for different patterns or priorities in infrastructure planning and investment, common strategies are likely to include increases in reserve margins and other types of backup capacity, attention to system designs that allow adaptation and modification without major redesign and that can handle more extreme conditions for operation. In many cases an issue is tradeoffs between capital costs and operating expenditures.

With regard to infrastructure where adaptation requires long lead times, such as water supply, there is evidence that adaptation to climate change is already taking place. An example would be the planning of British water companies mentioned in Section 7.4.2.3.1 above, undertaken at the behest of the UK Environment Agency (Environment Agency, 2004). Another would be the decision taken in 2004 to install a desalination plant to supplement the dwindling flows available for water supply for the city of Perth, Australia (Chapter 11, Section 11.6).

The infrastructure whose adaptation is especially important for the reduction of key vulnerabilities is that installed for flood protection. For example, London (UK) is protected from major flooding by a combination of tidal defences, including the Thames Barrier, and river defences upstream of the Barrier. The current standard for the tidal defences is about a 2000 to 1 chance of flooding in any year or 0.05% risk of flooding, and this is anticipated to decline to its original design standard of a 1000 to 1 chance, or 0.1% risk of flooding, as sea level rises, by 2030. The defences are being reviewed, in the light of expected climate changes. Preliminary estimates of the cost of providing a 0.1% standard through to the year 2100 show that a major investment in London's flood defence infrastructure of the order of UK£4 billion will be required within the next 40 years (London Climate Change Partnership, 2004). The capacity of storm drainage systems will also need to be increased to prevent local flooding by increasingly intense storms (UK Water Industry Research, 2004).

7.6.5 Human settlement

Adaptation strategies for human settlements, large and small, include assuring effective governance, increasing the resilience of physical and linkage infrastructures, changing settlement locations over a period of time, changing settlement form, reducing heat-island effects, reducing emissions and industry effluents as well as improving waste handling, providing financial mechanisms for increasing resiliency, targeting assistance programmes for especially impacted segments of the population, and adopting sustainable community development practices (Wilbanks et al., 2005). The choice of strategies from among the options depends in part on their relationships with other social and ecological processes (O'Brien and Leichenko, 2000) and the general level of economic development, but recent research indicates that adaptation can make a significant difference; for instance, the New York climate impact assessment projects significant increases in heat-related deaths (Rosenzweig and Solecki, 2001a), based on historical relationships, while the Boston CLIMB assessment (Kirshen et al., 2007) projects that heat-related deaths will decline because of adaptation over the coming century.

The recent case study of London demonstrates that climate change could bring opportunities as well as challenges, depending on socio-economic conditions, institutional settings, and cultural and consumer values (London Climate Change Partnership, 2004). One of the opportunities, especially in growing settlements, is to work towards a more sustainable city and to improve the quality of life for residents (Box 7.5). This can be achieved by making sure that urban planning takes into account the construction density, the distribution and impact of heat emissions, transportation patterns, and green spaces that can reduce not only heat-island effects.

Models have been established to predict the impact of urban thermal property manipulation strategies resulting from albedo and vegetation changes (Akbari et al., 1997) and urban form manipulation (Emmanuel, 2005). The diurnal air temperature inside urban wooded sites and the cooling effect of trees on urban streets and courtyards, and of groves and lawns, has been extensively quantified in Tel-Aviv, Israel (Shashua-Bar and Hoffman, 2002, 2004). For the Los Angeles region, several studies (Taha, 1996; Taha et al., 1997) projected the effects of increasing citywide albedo levels on mitigating the regional heat island (California's South Coast Air Basin, or SoCAB). A doubling of the surface albedo or a doubling of vegetative cover were each projected to reduce air temperature by approximately 2°C. Moreover, the study area was projected to experience a decrease in ozone concentration.

Other adaptive responses by settlements to concerns about climate change tend to focus on institutional development, often including improved structures for co-ordination between individual settlements and other parties, such as enhanced

Box 7.5. Climate-change adaptation and local government

Threats and opportunities presented by climate change are typically focused at a local scale; and it makes sense for local authorities, including mayors, to consider adaptive responses. Climate change can threaten lives, property, environmental quality and future prosperity by increasing the risk of storms, flooding, landslides, heatwaves and drought and by overloading water, drainage and energy supply systems.

Local governments around the world already play a part in climate-change mitigation, but they can also play a role in adaptation (see Chapter 14, Section 14.5.1; Chapter 18, Section 18.7.2), as guarantors of public services and as facilitators, mobilising stakeholders – such as local businesses, developers, utilities, insurers, educational institutions and community organisations – to contribute their technical and even financial resources to a joint initiative, such as the one formed for London (London Climate Change Partnership, 2004).

In many cases, in fact, good governance is a key to climate-change risk management strategies. For example, effective zoning can prevent the encroachment of housing on slopes prone to erosion and landslides; and adequate investment in and maintenance of infrastructure will make the settlement less vulnerable to weather extremes.

regional water supply planning and infrastructure development (Rosenzweig and Solecki, 2001a; Bulkeley and Betsill, 2003). Often, settlements exist in a splintered political landscape that makes coherent collaborative adaptation strategies difficult to contemplate. Policy responses and planning decisions are also hampered by the reactive nature of much policymaking and by the failure to co-ordinate across relevant professional disciplines, related mainly to current obvious problems, when climate change is viewed as a long-term issue with considerable uncertainty.

One approach for improving the understanding of how settlements may respond to climate-change impacts is to consider 'analogues' - circumstances in recent history when those settlements have confronted other environmental management challenges. In Vietnam for example villagers have been forced over the centuries to clean, repair and strengthen their irrigation channels and sea dykes before the start of every annual tropical storm season (UNISDR, 2004). In many cases, settlements have acted under the pressure of immediate crises to seek solutions by going beyond their own borders. Cities such as Mexico City have both drawn upon water from and sent sewage water to hinterlands outside their boundaries to deal with weather-related water scarcity and floods. These actions have imposed externalities on those hinterlands (Romero Lankao, 2006).

7.6.6 Social issues

There has been a recent shift in perceptions of how settlements and society can better adapt to climate related disasters, away from humanitarian and post-disaster actions toward more anticipatory integrative risk reduction measures that include environmental management, structural measures, protection of critical facilities, land-use planning, financial instruments and early warning systems (UNISDR, 2004). These strategies recognise (a) linkages between risks, vulnerability and development, (b) the importance of creating community assets and capacity to face sudden and slow onset disasters, (c) the key role of a democratic implementation of such strategies, and (d) the need to relate those actions to sustainability goals (UNISDR, 2004; Velásquez, 2005). This approach is practised successfully in countries such as the Philippines, Bangladesh, India, Cuba, Vietnam, Malaysia, Switzerland and France (UNISDR, 2004). In Manizales and Medellin, Colombia, and Uganda, for example, the economic damage and death toll due to landslides and floods has diminished noticeably, thanks to actions such as reforestation, improved drainage systems, poverty reduction and decentralisation of risk avoidance planning (Velásquez, 2005). On the other hand, the experience of a disaster is likely to reduce the adaptive capacity of the affected society for a time; adaptive capacity is often reduced during periods of recovery.

The most difficult challenges occur when decision makers lack training and access to information about climate-change implications, risk management and possible responses, when fiscal constrains limit local flexibility, and when infrastructure, technological and institutional capacities for coping with any major challenge are inadequate (UN-Habitat, 2003). However, in the best-case scenarios, policy focusing on adaptation has the potential to create positive synergies between outcomes (better managed natural and social systems) and processes (governance that promotes democratic decision making, participatory management strategies, equity, transparency and accountability), which in turn will result in more resilient systems (UNISDR, 2004; Adger et al., 2005b).

Yet adaptation is not limited to purposeful actions to reduce societies' sensibility to climate change, alter the exposure of the system to it, and increase the resilience of the system to it (Smit et al., 2000). It also includes spontaneous actions which can be implemented at different scales, from individuals to systems, and are not uniform. Individual adaptations may not produce systemic adaptation, and adaptation at a system level may not benefit all individuals (Thomas and Twyman, 2005). Indeed, some adaptations (e.g., warning systems) may not reach poor communities or not fit their information needs (Ferguson, 2003). They may increase the vulnerability of some peoples and places. For example, coastal planning for increased erosion rates includes engineering decisions that potentially impact neighbouring coastal settlements through sediment transport and other physical processes (Adger et al., 2006). As climate change and adaptation becomes a widespread need, there is likely to be competition for resources – investment in one place, sector or risk will reduce the funds available for others, and possibly reduce funding for other social needs (Winchester, 2000).

One challenge to both private (including businesses and NGOs) and public actors is how to build adaptive capacity in the context of current institutional reforms, new trade agreements and changing relationships between the private and public sectors (Lemos and Agrawal, 2003), including roles of environmental organisations. On the one hand, the emergence of new governance structures at the global level (such as the United Nations Framework Convention on Climate Change - UNFCCC) and across the public-private divide (such as public-private partnerships) has provided new tools for policy design and implementation that may build adaptive capacity (Mitchell and Romero Lankao, 2004; Sperling and Szekely, 2005; Eakin and Lemos, 2006). On the other hand, a transfer of authority from the state to lower levels (through decentralisation and privatisation), in some cases related to developments with international regimes and organisations, may have diminished national government capacities to implement adaptation policies (Jessop, 2002; UN-Habitat, 2003). For example, while decentralisation in Latin America, in principle, allows for better decision-making at the local level, it also constrains the state's ability to regulate and distribute critical resources to adaptation (Eakin and Lemos, 2006). Similarly, West African pastoral Peulhs or Fulbes lost access to water and pastures at the hands of settled agricultural people who gained local power in the process of decentralisation (Van Dijk et al., 2004). In contrast, the design of participatory, integrated and decentralised institutions such as in Brazil's recent water reform is likely to build adaptive capacity to climate change in settlements and societies by improving availability and access to technology, involving stakeholders, and encouraging sustainable resource use (Lemos and Oliveira, 2004).

Adaptive capacity is highly uneven across human societies (Adger et al., 2005a, 2006). Among communities that rely on the exploration of natural resources, adaptation practices may benefit some parts of the community more than others. Even within countries with seemingly high capacities to adapt (based on aggregate national indicators for GDP, education levels and technology), there are likely to be some regions and groups that face barriers and constraints to adaptation (O'Brien et al., 2006). For a discussion of strategies for reducing vulnerabilities of the poor to climate change through adaptation, see UNDP et al. (2003).

Among rural communities in Africa and Latin America, one strategy to build adaptive capacity has been to diversify livelihood strategies (Thomas and Twyman, 2005; Eakin, 2006). Rural settlements can cope with a seasonal downturn in rainfall or a mid-season drought by moving livestock, harvesting water, shifting crop mixes and migrating (Scoones et al., 1996); however, without occasional high rainfall periods, and without institutional support, longer-term livelihood sustainability is severely compromised (Eakin, 2006; Eakin and Lemos, 2006). Measures focussed on reducing poverty and increasing access to resources (e.g., the referred landslide management programmes) may enhance the resilience of affected communities or economic sectors.

7.6.7 Key adaptation issues

The central issues for adaptation to climate change by industry, settlements and society are (a) impact types and magnitudes and their associated adaptation requirements, (b) potential contributions by adaptation strategies to reducing stresses and impacts, (c) costs of adaptation strategies relative to benefits, and (d) limits of adaptation in reducing stresses and impacts under realistically conceivable sets of policy and investment conditions (Downing, 2003). Underlying all of these issues, of course, is the larger issue of the adaptive *capacity* of a population, a community, or an organisation: the degree to which it can (or is likely to) act, through individual agency or collective policies, to reduce stresses and increase coping capacities (Chapter 17). In many cases, this capacity differs significantly between developing and developed countries, and it may differ considerably among locations, economic sectors and populations even within the same region (Millennium Ecosystem Assessment, 2005).

Many of the possibly-impacted activities and groups addressed by this chapter are capable of being highly adaptable over time, given information to inform awareness of possible risks and opportunities and financial and human resources for responses (Chapter 17). In some cases, adaptations to possible climate changes can offer opportunities for positive impacts, especially where those actions also address other adaptive management issues (Chapter 20). The knowledge base on disaster response suggests that a number of approaches may be helpful in enhancing and facilitating adaptive behaviour: systems to provide advance warning of changes, especially extreme events; institutional structures that facilitate collective action and provide external linkages; economic systems that offer access to alternatives; increased attention to adaptive structures that are locally appropriate, geographically and/or sectorally; contingency planning and risk financing, which may include strategic stockpiles; incorporating climate-change vulnerability into land-use planning and environmental management for the long term; public awareness/capacity building regarding risks of climate-change impacts; and in some cases physical facility investment, such as flood walls, beach restoration or emergency shelters.

Although the research literatures on adaptation prospects for industry, settlement and society are as yet rather limited, it appears that:

1. Prospects for adaptation depend on the magnitude and rate of climate change: adaptation is more feasible when climate change is moderate and gradual than when it is massive and/or abrupt. However, actual adaptation strategies and measures are often triggered by relatively extreme weather events (high confidence).
2. Climate-change adaptation strategies are inseparable from increasingly strong and complex global linkages. Industrial planning, human settlements and social development are not isolated from changes in other systems or scales. The urban and rural are interconnected, as are developed and developing societies. This issue is becoming more salient as the globalised economy becomes more interdependent. Adaptation decisions for local activities owned or controlled by external systems involve different processes from adaptation decisions for local activities that are under local control (high confidence).
3. Climate change is one of many challenges to human institutions to manage risks. In any society, institutions have developed risk management mechanisms for such purposes,

from family and community self-help to insurance and re-insurance. It is not clear whether, where and to what degree existing risk management structures are adequate for climate change; but these institutions have considerable potential to be foundations for a number of kinds of adaptations (high confidence).

4. Adaptation actions can be effective in achieving their specific goals, but they may have other effects as well. These might be unintended consequences (e.g., increased flood risk downstream), reducing support for mitigation (e.g., higher energy demand with air-conditioning), or reducing resources available to address vulnerabilities elsewhere (e.g., budget constraints affecting other development goals). The benefits of adaptation may be delayed or not realised at all, for example, when design standards are raised to protect against a storm of a certain magnitude that does not occur for another fifty years, if then (medium confidence).

7.7 Conclusions: implications for sustainable development

Sustainable development is largely about people, their well-being, and equity in their relationships with each other, in a context where nature-society imbalances can threaten economic and social stability. Because climate change, its drivers, its impacts and its policy responses will interact with economic production and services, human settlements and human societies, climate change is likely to be a significant factor in the sustainable development of many areas (e.g., Downing, 2002). Simply stated, climate change has the potential to affect many aspects of human development, positively or negatively, depending on the geographic location, the economic sector, and the level of economic and social development already attained (e.g., regarding particular vulnerabilities of the poor, see Dow and Wilbanks, 2003). Because settlements and industry are often focal points for both mitigation and adaptation policy-making and action, these interactions are likely to be at the heart of many kinds of development-oriented responses to concerns about climate change.

In most cases, with the Arctic being a notable exception (ACIA, 2004), these connections between climate change and sustainable development will only *begin* to emerge in the next decade or two (e.g., during the period embraced by the Millennium Development Goals) as a result of significant impacts that can be attributed to climate change. But industry, settlements and societies will be important foci of mitigation actions and adaptations involving land uses and capital investments with relatively long lifetimes. In the meantime, however, actions that address challenges of climate <u>variability</u>, including extreme events, contribute to environmental risk management as well as reducing possible impacts of climate <u>change</u>.

The most serious issues for sustainable development associated with climate-change impacts on the subjects of this chapter are: (a) threats to vulnerable regions and localities from gradual ecological changes leading to impact thresholds and extreme events that could disrupt the sustainability of societies and cultures, with particular attention to coastal areas in current storm tracks and to economies and societies in polar areas, dry land areas and low-lying islands, and (b) threats to fragile social and environmental systems, both from abrupt climate changes and thresholds associated with more gradual climate changes that would exceed the adaptive capacities of affected sectors, locations and societies. Examples include effects on resource supply for urban and industrial growth and waste management (e.g., flooding). As a very general rule, sensitivities of more-developed economies to the implications of climate change are less than in developing economies; but effects of crossing thresholds of sustainability could be especially large in developed economies whose structures are relatively rigid rather than adaptable. In the case of either developed or developing countries, social system inertia may delay adaptive responses when experienced climate change is gradual and moderate.

In general, however, climate change is an issue for sustainable development mainly as *one of many* sources of possible stress (e.g., O'Brien and Leichenko, 2000, 2003; Wilbanks, 2003b). Its significance lies primarily in its interactions with other stresses and stress-related thresholds, such as population growth and redistribution, social and political instability, and poverty and inequity. In the longer run, climate change is likely to affect sustainable development by reshaping the world map of comparative advantage which, in a globalising economy, will support sustainable development in some areas but endanger it in others, especially in areas with limited capacities to adapt. Underlying such questions, of course, are the magnitude and pace of climate change. Most human activities and societies can adapt given information, time and resources, which suggests that actions which moderate the rate of climate change are likely to reduce the negative effects of climate change on sustainable development (Wilbanks, 2003b).

At the same time, development paths may increase or decrease vulnerabilities to climate-change impacts. For instance, development that intensifies land use in areas vulnerable to extreme weather events or sea-level rise adds to risks of climate-change impacts. Another example is development that moves an economy and society toward specialisation in a single economic activity if that activity is climate-sensitive; development that is more diversified is likely to be less risky. In many cases, actions that increase resilience of industry, settlements and society to climate change will also contribute to development with or without climate change by reducing vulnerabilities to climate variation and increasing capacities to cope with other stresses and uncertainties (Wilbanks, 2003b).

Impacts of climate change on development paths also include impacts of climate-change <u>response</u> policies, which can affect a wide range of development-related choices, from energy sources and costs to industrial competitiveness to patterns of tourism. Areas and sectors most heavily dependent on fossil fuels are especially likely to be affected economically, often calling for adaptation strategies that may in some cases require assistance with capacity building, technological development and transition financing.

7.8 Key uncertainties and research priorities

Because research on vulnerabilities and adaptation potentials of human systems has lagged behind research on physical environmental systems, ecological impacts and mitigation, uncertainties dominate the subject matter of this chapter. Key issues include (a) uncertainties about climate-change impacts at a relatively fine-grained geographic and sectoral scale, both harmful and beneficial, which undermine efforts to assess potential benefits from investments in adaptation; (b) improved understanding of indirect second and third order impacts: i.e., the trickle down of primary effects, such as temperature or precipitation change, storm behaviour change and sea-level rise, through interrelationships among human systems; (c) relationships between specific effects in one location and the well-being of other locations, through linkages in inflows/outflows and inter-regional trade and migration flows; (d) uncertainties about potentials, costs and limits of adaptation in keeping stressful impacts within acceptable limits, especially in developing countries and regions (see Parson et al., 2003); and (e) uncertainties about possible trends in societal, economic and technological change with or without climate change. A particular challenge is improving the capacity to provide more quantitative estimates of impacts and adaptation potentials under the sets of assumptions included in SRES and other climate-change scenarios and scenarios of greenhouse gas emissions stabilisation, especially for time horizons of interest to decision makers, such as 2020, 2050 and 2080.

All of these issues are very high priorities for research in both developed and developing countries, with certain differences in emphasis related to the different development contexts. As a broad generalisation, the primary impact issue for developed countries is the possibility of abrupt climate change, which could cause changes too rapid and disruptive even for a relatively developed country to absorb, at least over a period of several decades. High priorities include reducing uncertainty about the potential for adaptation to cope with climate-change impacts in the absence of abrupt climate change, considering possible responses to threats from low-probability/high consequence contingencies, and considering interactions between climate change and other stresses. The primary impact issue for developing countries is the possibility that climate change, combined with other stresses affecting sustainable development, could jeopardise livelihoods and societies in many regions. High priorities include improving the understanding of multiple-stress contexts for sustainable development and improving the understanding of climate-sensitive thresholds for components of sustainable development paths.

Some of these uncertainties call for careful location- and sector-specific research, including better information about the geographic distribution of vulnerabilities of settlements and societies at a relatively localised scale, emphasising especially vulnerable areas, such as coastal areas in lower-income developing countries, and especially vulnerable sectors, such as tourism, and possible financial thresholds regarding the insurability of climate-change impact risks. Others call for attention to cross-sectoral and multi-locational relationships between climate change, adaptation and mitigation (Chapter 18), including both complementarities and trade-offs in policy and investment strategies. Underlying all of these issues for industry, settlement and society are relationships between possible climate-change impact vulnerabilities and adaptation responses and broader processes of sustainable economic and social development, which suggest a need for a much greater emphasis on research that investigates such linkages. In some cases, because of the necessarily speculative nature of research about future contingencies, it is likely to be useful to consider past experiences with climate variability and analogues drawn from other experiences with managing risks and adapting to environmental changes and stresses (e.g., Abler, 2003). In many others, an important step will be to establish mechanisms for monitoring interactions between emerging climate changes and other processes and stresses in order both to learn from the observations and to provide early alerts regarding potential problems or opportunities.

Underlying all of these research needs are often very serious limitations on available data to support valid analysis, especially data on nature-society linkages and data on relatively detailed-scale contexts in both developed and developing countries (e.g., Wilbanks et al., 2003). If information about possible impacts, vulnerabilities and adaptation potentials for industry, settlement and society is to be substantially improved, serious attention is needed towards establishing improved data sources on human-environmental relationships in both developing and developed countries, improving the integration of physical and earth science data from space-based and *in situ* observation systems with socioeconomic data, and improving the ability to associate data systems with high-priority questions.

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