IPCC WGII Fourth Assessment Report – Draft for Expert Review

Chapter 7 – Industry, Settlement, and Society

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Executive Summary

Industry, settlement, and society could be affected by climate change in a wide variety of ways, although it is difficult to generalize about vulnerabilities and adaptation potentials worldwide. The central issues for industry, settlement, and society are whether the costs of 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.

The ability to project possible magnitudes, thresholds, and damages or benefits from climate change as it affects industry, settlement, and society is limited not only by uncertainties about climate change itself at the relatively fine-grained geographical and sectoral scale appropriate to the topic but also by uncertainties about trends in human systems over the next century *regardless of climate change* (Chapter 2). In some cases, uncertainties about such socioeconomic variables as possible technological and institutional change over a period of many decades tend to undermine the feasibility of comparing future prospects involving *considerable* climate change with prospects involving *relatively little* climate change. In many cases, therefore, research focuses on <u>vulnerabilities</u> to impacts of 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*. 2003; also see Clark *et al*. 2000) rather than on <u>projections of impacts</u> of change.

More specifically, key vulnerabilities are most often 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, and (b) limited access to resources (financial, human, institutional) to cope, rooted in issues of development context. Most key vulnerabilities are relatively localized, in terms of geographic location, sectoral focus, and segments of the population, although literatures to support such detailed findings about potential impacts are very limited. Based on available information, key vulnerabilities of industry, settlement, and society include the following, each characterized by a level of confidence:

1 Interactions between climate change and global urbanization, especially in developing countries, which is often focused in vulnerable areas (e.g., coastal) – especially the growing phenomenon of mega-cities and rapidly growing mid-sized cities and possible thresholds of sustainability (VERY HIGH CONFIDENCE).

2 Interactions between climate change and global economic growth: demands on resource bases and associated environmental impacts resulting from economic and social development – 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).

3 Interactions with increasingly strong and complex global linkages, which cause climate change to cascade through expanding series of interactions to produce a variety of indirect effects, some of which may be unanticipated, especially as the globalised economy becomes more locally specialized, less resilient, and more interdependent – vulnerabilities include interregional trade patterns and migration patterns (VERY HIGH CONFIDENCE).

4 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).

5 Interactions with governmental and social/cultural structures that are already stressed in some places by other kinds of change, such as population pressure and limited economic resources, and which 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, while vulnerabilities in less developed areas are often focused on human populations and institutions, which need different numeraires.

Costs of climate change-related impacts are clearly diverse and not in many cases well-documented. The existing literatures are in some cases useful in considering possible costs of climate change for industry, settlement, and society; but they are not sufficient to estimate costs globally or regionally associated with any specific scenario of climate change. All that can be said at the present time is that economic costs of climate change impacts at a large national or regional scale are unlikely to represent more than several percent of the value of the total economy, except for possible abrupt changes (HIGH CONFIDENCE), while economic and other human costs of climate change impacts for some economic sectors in some smaller locations, especially in developing countries, could in the short run exceed 25 percent (HIGH CONFIDENCE).

Challenges to adapt to observed and expected 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). Adaptation strategies vary widely by 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).

The central issues for adaptation to climate change by industry, settlements, and society are 1) impact types and magnitudes and their associated adaptation requirements, 2) potential contributions by adaptation strategies to reducing stresses and impacts, 3) costs of adaptation strategies, and 4) 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 organization: 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 industrialized countries. More specifically, the chapter finds that;

1 In many cases, prospects for adaptation depend on the magnitude and rate of climate change: adaptation is often more feasible when climate change is moderate and gradual than when it is massive and/or abrupt (VERY HIGH CONFIDENCE).

2 Climate change adaptation strategies are inseparable from increasingly strong and complex global linkages, which mean that no system is isolated from what is happening in other systems. Urban and rural are interconnected, as are industrialized and developing societies.

This issue is becoming more salient as the globalised economy becomes more locally specialized, less resilient, and more interdependent (VERY HIGH CONFIDENCE).

3 Adaptation depends fundamentally on such linkages, which shape potentials for human agency. For instance, adaptation decisions for local activities owned or controlled by external systems involve distinctly different processes from adaptation decisions for local activities that are under local control (VERY HIGH CONFIDENCE).

4 Climate change is one of many challenges to human institutions to manage risks. In any society, institutions have evolved 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 potentials to be foundations for a number of kinds of adaptations (HIGH CONFIDENCE).

5 The relatively long time horizon of climate change and its impacts makes the potential for technological change a critical issue in evaluating adaptation prospects. Anticipated vulnerabilities and possible impacts in the mid to long range can in many cases be addressed, at least in part, by research and development agendas. Targeting R&D on critical needs can add significantly to adaptability; on the other hand, failing to do so can leave gaps in coping capacities that are difficult to fill through institutional and policy response (HIGH CONFIDENCE).

6 Adaptation actions in one context can be effective in achieving their goals, narrowly interpreted, but at the same time they may have more complex effects of other types, such as reducing support for mitigation efforts or reducing resources available to address vulnerabilities elsewhere (MEDIUM CONFIDENCE).

7.1 Introduction

7.1.1 Key issues

Climate change and sustainable development are linked with industries, human settlements, and society for a number of reasons. Many of the forces shaping carbon emissions – such as economic growth, technological transformations, demographic shifts, and governance structures -- are similar to those underlying diverse pathways of development, explaining in part why industrialized countries account for the highest share of carbon emissions. Meanwhile, 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 (O’Brien and Leichenko 2003). Urban areas and industry are often key focal points for linkages between mitigation and adaptation; for instance, warming can increase energy use and greenhouse gas emissions associated with air conditioning in urban buildings, while building design and technologies could contribute to adaptations to changing climates.

Industries, settlements, and human society are accustomed to variability in environmental conditions, and in ways that vary according to history and circumstance they have become resilient to the kinds of variability that are 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 (e.g., Figure 1).

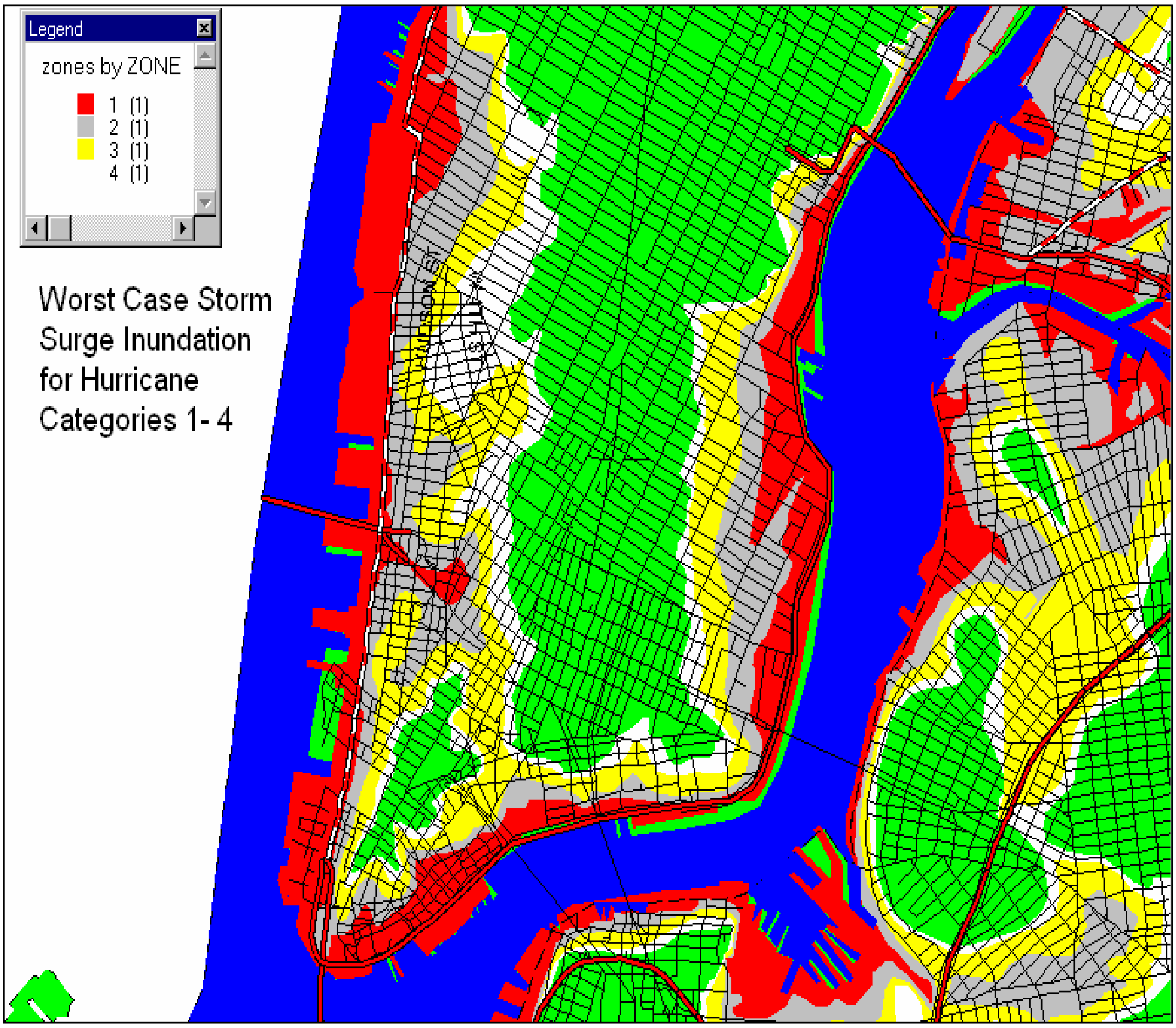

Figure 7.1: *Worst-case storm inundation of a part of New York City, illustrating effects of severe storms with differing intensities. Source: Rosenzweig and Solecki, 2001*

The central issues for industry, settlement, and society are whether the costs of 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.

For some scholars, the vulnerability of human settlements to climate change relates to the characteristics of the locality (arid, polar, coastal, forest, agricultural: IPCC 2001a). Other scholars tend to emphasize the weight of social factors such as the level of social organization or institutional capacity (Adger, Kelly, and Ninh 2001). Another school of thought suggests that vulnerability depends on a specific interplay of both physical and developmental features of human settlements. Studies show, for instance, that the growth in reported losses from weather-related natural disasters is due not only to socioeconomic factors (e.g. population growth and growth in per capita real wealth) but also to weather variables such as precipitation and the number of extreme events per period (Choi and Fischer 2003).

Scale matters in at least three ways when assessing the impacts of climate change on human settlements, industry and energy. 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 and the distribution of climate sensitive settlements and industrial and energy sectors vary greatly across 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 industrialized countries such as England and Norway can cope with most kinds of gradual climate change, but focusing on more localized 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, Sygna and Haugen 2004). Third, temporal scale is a critical determinant of the capacity of human systems to adapt to climate change: for instance, rapid changes are more difficult to absorb without painful costs than gradual change (Chapter 16).

7.1.2 Scope of the chapter

This chapter's topic of "industry, settlements, and society" is clearly very broad, and many of the components of the chapter (i.e. industry and services, settlements, financial issues, and social issues) are so heterogeneous that each could be the subject of a separate chapter. Notwithstanding the extent of this challenge, the chapter will summarize and assess very briefly the literature relevant to the impacts of climate change on the structure, functioning and relationships of all those topics.

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

7.1.3 Human systems in context

Human systems related to industry, settlement, and society are diverse and dynamic. They are constantly evolving as such forces as population growth, economic globalization, changes in governance structures, changes in non-governmental institutions, and technological change reshape how the systems work, what their most immediate objectives are, and the stresses that preoccupy them. Industrialized countries and developing countries often differ in the mix of stresses, in considerable part due to differences in economic and human resources available to respond the most salient stresses.

Notable examples of current stresses include continued urbanization, especially in developing countries, due substantially to rural to urban migration; competing demands for scarce management and financial resources, especially demands on governments in developing countries; institutional limitations and instabilities, also most serious in less-developed areas (Thomas and Twyman 2005); a frequent lack of equity in access to benefits of economic and social development (ECLAC/CEPAL 2002; Wade, Eakin, and Lemos forthcoming); and potentials for conflict related to equity concerns, pressures for changes in governance, and other roots of political instability (Ocampo and Ocampo 2003).

In most cases, climate affects human systems in three principal ways. First, it provides a context for the operation of 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 artificial built climates for human life and activity; clearly, higher temperatures increase costs of cooling and lower temperatures increase costs of heating. Third, it interacts with other types of stresses on human systems, in some cases reducing stress but in many cases exacerbating stresses. For example, drought can contribute to rural-urban migration which, combined with population growth, increases stress on urban infrastructures. In all of these connections, extreme climate events and other abrupt changes affect human systems more severely, because they offer less time for adaptation.

Stress is caused not only by the severity of individual impacts, but perhaps even more by their frequency. An isolated extreme event might not have lasting economic consequences, in contrast to more frequent events.

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 (IPCC 2001a) and also a separate chapter on Insurance and Other Financial Services (IPCC 2001c). The first of these chapters 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 (with 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 urbanization in relatively high-risk areas is a special concern, because it 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.

Regarding financial services, TAR concluded that climate change will increase actuarial uncertainty in risk assessment, placing upward pressure on insurance premiums and possibly leading to changes in risk coverage. One effect could be to increase demands for government roles in risk management. In general, the financial services sector has shown considerable sensitivity and adaptability with respect to rising costs of weather events in recent years; but either low-probability/high-impact events or multiple closely spaced events could represent threats to the viability of some parts of the sector.

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 seacoasts. Recent experience with climate variability, however, reminds us that -- at least at conceivable levels of investment and technological development -- human control over climate-related aspects of nature is in some cases limited.

One example is environmental quality, where weather and climate can affect air and water pollution and, in cases of extreme events, exposures to wastes that are risks to human and ecological health. A familiar example is the interaction between the ambient air temperature of an urban area and its concentration of ozone, which can have adverse health implications (Chapter 8). Linkage systems, such as transportation and transmission systems for inputs to and outputs from industry and settlements (e.g., water, food supply, energy, information systems, and waste disposal), can also be subject to climate-related extreme events such as floods, landslides, fire, and severe storm damage. Such exposed infrastructures as bridges and electricity transmission networks are especially vulnerable. Consider, for instance, the experience of Caribbean islands over the past two decades, where Hurricane Georges in 1998 threatened port and oil storage facilities in the Dominican Republic (REC, 2004). Other types of physical infrastructures can be affected by weather and climate as well. For instance, the rate of deterioration of external shells of building structures is weather-related, depending on the materials used, and buildings are affected by drainage and water-logging where these factors are related to precipitation patterns. Another kind of impact is on demands for physical infrastructures, where (for instance) demands for water supply systems and energy supply systems can be related to temperature.

Box 7.1: Drought in The Sahel

One of the most tragic encounters between climate and society in the 20th century was the drought in the Sahel region of West Africa during the 1970s, dramatically illustrating how a combination of (a) human livelihoods at the margin of sustainability and (b) climatic variability beyond the bounds of experience can lead to disastrous impacts on societies and the environment. Although most of the focus of the international response was on agricultural and pastoral livelihoods disrupted by the drought (Chapter 4), responses were rooted in immensely complex traditional social systems, and a long history of urban settlement was impacted by population migration into urban squatter areas, with burdens on already limited social services and some resulting political instability. In this way and others, even in a region where local social and economic systems were adapted to an unusual degree of climatic variability, the challenges associated with this drought were often beyond local adaptive capacities, and efforts continue today to extract lessons from this painful experience with the climate-human interface in marginal environments pressured by population growth where coping capacities are limited.

Social infrastructures are also vulnerable in some cases, especially to extreme events (e.g., Box 7.1). For example, storms and floods can damage homes and other shelters; and risks of such impacts shape structures for emergency preparedness, especially where impacted populations have disproportionate 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). 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 box 7.2; and see Arsenault 1984). In some cases, the 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 suburban areas in industrialized urban areas. Another example is the sensitivity of energy production to heat waves; in the summer of 2003, the level of many French rivers dropped so low that the cooling of nuclear power plants was endangered and some cases came close to a mandatory shutdown (see box 7.4).

Finally, weather and 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 supplies (Chapter 5) to tourist attractions. Climate also affects costs of business operation, for example costs of climate control in office, production, and storage buildings. One issue for any area is not only how climate affects its own economic patterns but also how climate is related to the competitive position of its markets and competitors.

Impacts of climate on industry, settlements, and society can be either direct or indirect. For instance, as indicated above, temperature increases can lead to increases in ozone concentrations in urban areas, which in turn increase certain kinds of respiratory problems in the population, which then impact public health care infrastructures. One of the challenges in assessing aggregate impacts is tracing out such second, third, and higher-order cascading indirect impacts.

Box 7.2: 2003 Heat wave in Europe

In the summer of 2003, a heat wave hit Western Europe that was the warmest period ever recorded. The situation reached a crisis in mid-August, as temperatures reached 40 degrees C. in a region where air-conditioning is not widespread. Most seriously affected was France, where nearly 15,000 people died. During the heat wave in France, electricity became scarce, construction activities had to be modified, and 25-30 percent of food-related establishments found their cooling systems to be inadequate (Sénat, 2003). Some research has suggested that such heat waves are likely to become more intense, more frequent, and longer-lasting in this century (Meehl and Tebaldi 2004). The impact issues 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. In addition, it illustrated how government infrastructures can be unable to deal with complex, relatively sudden environmental challenges (Lagadec 2004).

A further issue is that impacts are not equally experienced by every segment of an industrial structure or a population. Some segments -- often smaller and more traditional industry 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. Some of these differences are not only sectoral; they are also regional, more problematic in developing regions and intricately related to development processes (ISDR 2004).

Tourism is an example of an economic sector whose sensitivity to climate has been analyzed in particular depth. For example, sun, sand, and sea travel decisions are often based on perceptions of warm and sunny environments, while winter tourism builds on expectations of snow and snow-covered landscapes. Tourism is thus sensitive to a range of climate variables such as temperature, precipitation, humidity, and storm intensity and frequency (Matzarakis *et al*. 2001; Matzarakis *et al*. 2004; Besancenot 1989). Scientific publications have sought to assess the consequences of climate change for the tourist industries of nations (e.g. Agnew and Viner 2001; Scott, D. W., G., McBoyle, G. 2005), destinations (e.g. Staple and Wall 1996); specific attractions, such as national parks, and particular tourism activities (Holmes *et al*. 2000) or sectors of tourism such as ski-tourism (e.g.; Breiling and Charamza 1999; Harrison 2005; Scott, D., G. McBoyle, B. Mills, and A. Minogue, 2004). Most of these studies have warned that tourist destinations might lose part of their attractiveness due to climate change, for example as a result of a loss of snow in ski resorts, even though there might also be ‘gains’ in terms of less rain or extended summer seasons. A second set of studies has sought to express the behaviour of tourists as a function of weather, climate and other factors such as travel costs, length of coastline, economic wealth, etc. In particular, the effects of increasing temperatures and related parameters (such as rain) on the choice of a destination and time of departure have been examined. For example, in an attempt to identify ‘optimal’ temperatures, Maddison (2001) analysed travel patterns of British tourists and found that the maximum daytime temperature was 30.7°C, with even small increases above this level leading to decreasing numbers of visits. Maddison also found that greater rainfall would deter tourists. In another study, Lise and Tol (2002) analysed a cross-section of destinations of Organization of Economic Co-operation and Development (OECD) tourists, finding that OECD tourists preferred an average temperature of 21°C at the hottest month of the year at their destinations. Both studies come to the conclusion that tourists may shift to other destinations or travel during other periods of the year under a scenario of climate change. These models, however, do not capture a wide range of aspects that are likely to influence results. For instance, databases used for modelling do not differentiate between business and leisure tourists, and there is uncertainty about the role of other weather parameters such as rain, storms, air pollution or humidity, the effects of weather extremes, the information process in decision-making, perceptions of other non-climatic parameters (e.g. perceived travel risks), and the complexity of travel behaviour in general. Furthermore, the future costs of transport and their effects on travel are uncertain (Gössling and Hall 2005a, 2005b).

Secondly, tourism is sensitive to resources which themselves depend on climate. For instance, the availability of freshwater can be a costly challenge for tourism (Gössling 2005a, b; Wall 1998; Chapters 6 and 16), particularly if managed through water imports or desalination. Tourism is in competition with other uses of water (such as agriculture) and is based on high quality water supplies, while it simultaneously threatens water quality through discharges of untreated sewage, introducing increasing nutrient loads and toxic substances in adjacent water bodies. In addition, higher water temperatures might be associated with algae blooms which reduce water clarity and reduce the attractiveness of visitation experiences.

Snow is an essential resource for winter sports, and has (like water in lakes, streams and oceans) a high amenity value. Numerous studies in the past decade have dealt with the climatic sensitivity of winter destinations (Scott *et al*. 2004) considering, even in the absence of climate change, to annual variations.

Biodiversity might attract tourists for reasons of exoticism; often, as in the case of rainforests or coral reefs, it might be the precondition for special interest tourism (Chapter 4; box 7.3).

Tourist activities are also often considered to be associated with aesthetic values of the landscape of the destination. The history of tourism shows that, over the long term, the type of landscape valued by tourists varies considerably, and the sensitivity of tourism-landscape interrelationships varies according to locality and tourist population.

Box 7.3: Coral reefs

Coral reefs are an important tourist destination in many parts of the world, from Australia to the Caribbean. If climate change were to threaten the viability of these reefs, the economic consequences for some localities could be substantial. *(more to come)*

7.3 Assumptions about future trends

Obviously, diverse processes underlie current structures and future tendencies of human systems, and projections of future trends for human systems are not generally offered with confidence for the century-long time scale of climate change projections. Moreover, literatures referenced by this chapter often arise from a variety of assumptions (or unclear assumptions) about underlying social and economic trends. As a result, at the current state of knowledge it is not possible to be specific about assumed future trends that are used as the basis of statements about possible vulnerabilities and adaptation potentials. This fact limits statements in this chapter about vulnerabilities, impacts, and adaptation potentials to robust qualitative points that are judged to valid under a range of possible trends. General assumptions, however, are as follows.

The world's population reached 6 billion at the end of the last century. The global rate of population growth has declined over the last twenty years, but in absolute terms the world is still within an era of remarkable demographic increase. According to the latest United Nations projections, 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 and a net addition of between 2.7 and 3.3 billion persons to the 2000 population (UN, 2005).

A considerable proportion of this growth will occur in poorer countries and regions of the world, whose economies and governments are usually ill equipped to deal not only with demographic growth and the associated demands on development processes, but also with the impacts of climate change on human settlements, industries and energy systems. Rates of growth, however, vary considerably between regions.

Most of the population growth will take place in cities, even in developing regions where overall growth rates are declining; but there will be differences between developed and other nations, accompanied by differences in economic growth and income distribution (UN 2005**;** Montgomery *et al*. 2004**).** The most dramatic population growth will occur in urban areas of developing countries, where populations are expected to double during the next 50 years. This means that features of development relevant to adaptation by settlements (e.g. poverty, opportunity, institutional capacity, migration) are likely to be predominantly urban, with the greatest stresses likely to be in areas with the most limited capacities for responding.

Economic globalization shapes the impacts that changes in population, affluence, technology, markets, policies, and other drivers have on the ability of human settlements to adapt (Chase-Dunn, Kawano *et al*. 2000). One consequence is the flow of goods, services, capital, information, ideas, people and other processes embodied by the notion of globalization has generally reduced the collective diversity of human systems (Schaeffer 2003, Mitchell and Romero Lankao 2004, IGBP 2004). An unsettled question is whether a tendency toward homogenization reduces the ability of human systems to develop diverse strategies to cope with climate change and other sources of stress.

At the same time, globalization, together with trade liberalization and other institutional reforms, is associated with quite varied patterns of participation in global trade, development, and environmental impacts of climate change (World Bank 2005), which means that socio-cultural homogenization is accompanied by growing economic contrasts. These trends will continue to produce economic benefits for some sectors and people but to provide fewer benefits to, and often imposed economic and environmental costs on, many others. Industrialized country shares of manufacturing exports, for instance, have declined recently while their shares of technology-intensive, high-value added exports have increased, allowing these countries to promote technological and institutional innovations and to have greater potential to adapt to climate change. The most affluent of the industrialized countries typically have low poverty rates and average incomes almost 40 times those of the poorest countries (World Bank 2000). In many developing countries, by contrast, the increase in manufacturing exports has entailed products that involve intensive exploitation of environmental and natural resources, the use of unskilled labour, and low-skill assembly stages of transnational production chains (Fischer and Amann 2001; UNCTAD 2002). In these countries, the number of people in poverty rose from 1.2 to 2.8 billion from 1987 to 1998 (World Bank 2003). Growing gaps between industrialized and less developed nations may limit the current and future ability of human settlements, industrial and energy sectors in less developed areas to adapt to climate change, and they may add stresses associated with political and social conflict, as growing disparities motivate actions to reduce those disparities.

Finally, the globalization of ideas and paradigms for governance structures is changing how political and administrative systems at scales from local to global address societal stresses and policy alternatives, including adaptive capacity building. Within this context, the dominant public-sector influences on development have been institutions and organizations focused primarily on economic issues (World Trade Organization (WTO), the Organization for Economic Co-operation and Development (OECD), the World Bank, and the International Monetary Fund (IMF). GATT and WTO efforts have sought to reduce or eliminate tariffs, commodity cartels, subsidies, and regulatory standards and expand bilateral, regional, and global trade agreements to promote international trade and protect patents, copyrights, and trademarks (Schaefer 2003). Pressures from the World Bank, IMF, and developed or core countries have led many industrializing and less-developed countries to adopt a broad range of structural reforms which have resulted in reduced expenditures on environmental protection, social welfare, and institutional capacity (Gwynne and Kay 2000; Harris 2000; Schaefer 2003), although some studies have argued for the need to emphasize environmental protection as an aspect of poverty alleviation (e.g., McGranahan *et al*. 2002). All of these factors may have an influence on the ability to adapt to climate change without serious impacts and transition costs.

7.4 Key future impacts and vulnerabilities

The ability to project possible magnitudes, thresholds, and damages or benefits from climate change as it affects industry, settlement, and society is limited not only by uncertainties about climate change itself at the relatively fine-grained geographical and sectoral scale appropriate to the topic but also by uncertainties about trends in human systems over the next century *regardless of climate change* (Chapter 2). In some cases, uncertainties about such socioeconomic variables as possible technological and institutional change over a period of many decades tend to undermine the feasibility of comparing future prospects involving *considerable* climate change with prospects involving *relatively little* climate change. In many cases, therefore, research focuses on vulnerabilities to impacts of 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*. 2003; also see Clark *et al*. 2000) rather than on projections of impacts of change.

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 (Kolsky 1999). Sea-level rise affects land uses and physical infrastructures in coastal areas. Moreover, such 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: see box below). Effects can either be cumulative, as in losses of property, or systematic, as damages to institutions or systems of production.

Besides gradual changes in climate, along with climatic extremes, human systems are affected by a change in the magnitude, frequency, and/or intensity of storms and other extreme weather events. In fact, some assessments suggest that many impact issues are more directly associated with climatic *extremes* than with *averages* (NACC, 2000). Of special concern is the possibility of abrupt climate changes not anticipated by normal response planning (Chapter 19), which can be associated with locally or regionally catastrophic impacts if they were to occur.

Although localities differ in almost every conceivable way, interactions between climate change and human systems are often substantively different for relatively developed, industrialized countries vs. less developed countries and regions. As a broad generalization, possible negative impacts of climate change pose risks of higher *economic* damages in industrialized areas but higher *human* damages in less-developed areas.

Not all implications of possible climate change are negative (see Chapter 5). For instance, along with possible carbon fertilization effects, many mid-latitude areas see quality-of-life benefits from winter warming, and some areas welcome changes in precipitation patterns. The greater proportion of the research literature, however, is related to possible adverse impacts. Categories of climate impact concerns include environmental quality (e.g., more or less ozone, water logging, or salinization), linkage systems (e.g., threats to water supply or storm effects on power supply, including increased competition for critical inputs), social infrastructure (e.g., changed energy/water/health requirements, heat island effects, disruptive severe weather events, reductions in resources for other social needs, environmental migration, 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 such infrastructures as water supply), and economic infrastructures and comparative advantages (e.g., costs and/or risks increased, markets or competitors affected).

Along with climate change itself, economic sectors, settlements, and social groups can be affected by climate change response policies. For instance, certain greenhouse gas stabilization strategies can affect developing economies dependent on abundant local fossil fuel resources, including economic sectors involved in mining and fuel supply as well as fuel use.

In many cases, the importance of climate change effects on human systems seems to depend on the scale of attention (Association of American Geographers, 2003; Wilbanks, 2003b). At the scale of a large nation or a large region, at least in most industrialized 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

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.

7.4.2.1 Industry

Industry is defined for this chapter as including manufacturing, electricity and gas supply, mining and quarrying, construction, and related informal production activities in developing economies, often very localized. Other sectors sometimes included in industrial classifications, such as wholesale and retail trade, transport and communication, and real estate and business activities, are included in the categories of services and infrastructure (below). Together, industry and economic services account for 50-60 percent of most industrialized economies and between 25 and 50 percent of developing economies.

Although economically significant, industrial and service sectors are generally thought to be less vulnerable to the impacts of climate change than other sectors. This is in part because their sensitivity to climatic variability and change is viewed as being relatively low compared with other sectors that are more obviously climate-related, such as agriculture and water, and because industry is seen as having a high capacity to adapt in response to changes in climate. The major exceptions noted in the literature are sectors with long-lived capital assets, principally the infrastructure industries, along with others, such as food processing, that are linked to high-sensitivity sectors and/or regions (Ruth *et al*, 2004). These assumptions are borne out in recent aggregate assessments of the impacts and costs of climate change. For instance, of the sectors listed above, in identifying vulnerable sectors Tol (2002a and b) includes only energy consumption, Jorgensen *et al* (2004) include energy services related to space heating and cooling, and Smith (2004) and Easterling *et al* (2004) include none. Regarding the energy sector, see Box 7.1.

In assessing the economic impacts of the hot summer of 1995 in the UK, Subak *et al* (2000) include in their analysis changes in gas and electricity consumption, changes in demand for food, drink and clothing and footwear, and impacts on retailing. Parry *et al* (2000: 204-205), in an overall assessment of climate change impacts in Europe, cast the net a little wider still, including impacts on transport, general manufacturing, construction and energy use. Both Jorgenson and Smith argue that caution is needed in interpreting the results of these analyses since they are partial and incomplete: not all potentially climate-sensitive industrial and service activities may have been included in available surveys (Jorgenson, 2004: viii and Smith, 2004: 8).

Besides impacts on primary inputs to industry, a range of more indirect effects also needs to be considered. While many industrial activities may be insensitive to temperature and precipitation changes, industrial facilities across a range of sectors are often located in areas vulnerable to extreme weather events (flooding, drought, high winds etc). Transportation infrastructures on which industries are dependent for input and output streams may also be vulnerable to such events. Where extreme events threaten linkage infrastructures such as bridges, roads, pipelines, or transmission networks, industry can be affected regionally. Beyond this, given the deepening connectedness of global economic activities, there may be more widespread effects on industrial supply chains as a result of climate change. For instance, sectors dependent on forest products for inputs, such as paper production, may be affected by changes in the location and productivity of forests. In the longer term there could be impacts on regional patterns of comparative advantage, leading to regional shifts in the distribution of industrial production, especially combined with other driving forces for global economic restructuring. Economically, these indirect impacts of climate change over the short and longer term may be more significant than the direct impacts. Table 7.1 summarises direct and indirect impacts on the built environment and network- and resource-intensive industries.

In developing countries, industry is often small-scale and informally organized. Impacts of climate change 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.

Table 7.1: *Direct and indirect climate change impacts on industry*

Sector	Direct impacts	Indirect impacts	References
Built Environment: Construction, Civil Engineering	-Internal environment (higher temperatures) -External fabric (extreme events) -Structural integrity (greater variability) -Construction process (extreme events) -Service infrastructure (extreme events and variability)	- climate-driven standards and regulations (changing average conditions and extreme events) - changing consumer preferences linked to climate risk perceptions	Camillieri, 2000; Graves and Philipson, 2000; Consodine, 2000; Spence *et al*., 2004; Brewer, 2005;
Network Industries: Energy, Water, Telecommunications, Transport	- Structural integrity (extreme events and greater variability) - Throughput	- Changing patterns of demand (changing average conditions and	UKWIR, 2004; Fowler, 2005

	capacity (extreme events) - Control systems (extreme events)	extreme events)	
Resource Intensive Industries: Pulp and paper, Food processing etc	- Damage to input resources (extreme events)	- Supply chain shifts and disruption (changing average conditions and extreme events)	Broadmeadow *et al*, 2005; Whitney and Upmeyer, 2005; Anon, 2004

Box 7.4: Impacts on Energy Demand and Supply

Energy demand is shaped in part by weather conditions; and this is where, most likely, temperature effects of climate change would have direct impacts on energy systems. Changed regional climatic patterns would affect future energy consumption behaviour in different parts of the world. The net effect would depend on whether the region presently has a relatively ‘cold’ or ‘warm’ climate, with the effect varying seasonally.

In the residential and building sector, the major change is expected to be in energy demand for space cooling and heating. The air-conditioning and refrigeration load is closely related to ambient air temperature and thus would have a direct relation to a temperature increase. Temperature increases in the regions where space heating is required in winter might, in turn see some savings in heating energy. In warmer regions, an increased energy requirement for space cooling is expected to increase net energy requirements. Net energy requirement estimates at a national scale, however, can mask differences in energy sources (Hadley *et al*., 2004). The main source of energy for cooling is electricity, while sources of energy for space heating include coal, oil, gas, biomass, and electricity. 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.

Various approaches have been used by different researchers in calculating future energy demand, but the concept of heating and cooling degree days is most common. Hadley *et al*. (2004) estimate that there would be large regional differences in impacts of warming on energy demand in USA, with a total of 40 GW per year required by 2025 to meet additional electricity requirements. Tol (2002) has 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%. Thus he estimates a net energy demand decrease. Hitz and Smith (2004) have presented an analysis of the discussions related to the increase or decrease in global energy demand by suggesting that a curve relating energy demand to mean global temperature might be ‘‘U’’ shaped. An important question is whether the world is already to the right of the low point of such a curve, in which case global energy consumption will rise with higher GMT, or whether we are still on the portion of the curve that foretells decreasing demand (left of the low point). They conclude that, based on the limited literature, it is not possible to determine the effective shape of the damage relationship we are facing.

In addition to the total global energy demand, a discussion of seasonal variation in the demand is also important. During summers, most of the tropical countries experience increase in demand of electricity for cooling because of intense heat. In some cases, due to infrastructure limitations, this demand goes beyond the maximum capacity of the transmission system. For instance, in July 2002, a heat surge followed several months of intense drought that had affected many regions of India. The transmission system could not cope up with the load increase and resulted in a blackout spread over five states of Western India. The interruption of the western grid took long hours to restore. One of the victims was the Indian railway system where service was interrupted for several hours and it took about a week to return to normality. This shows that different sectors may face indirect impacts of demand and supply imbalances arising from increased demands for energy due to climate change.

Many sectors affected by climate change would have indirect impacts on the energy sector, e.g., agriculture. Climate change is expected to affect agriculture through temperature rise and changing precipitation patterns (Chapter 4). For instance, the evaporation rate is expected to rise because of temperature increase. In addition, water consumption by society at large will increase with higher temperatures, resulting in higher water requirement in settlements. Combined, these changes will result in a higher demand for energy for pumping and irrigation, although this may be countered by increase in rainfall and humidity in some regions.
In addition to direct and indirect *demand*-side impacts discussed above, the *supply* side of the energy sector is also likely to be affected by climate change. TAR concluded that hydropower generation is the energy source 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 jeopardize hydropower production in some areas, whereas greater stream flows, depending on their timing, might help hydroelectric production. Even here, though, it may be necessary to operate hydropower stations at less than full capacity so that dams can absorb larger and more frequent peak flows and prevent downstream flooding (Bolton, 1983). In addition, regional water scarcity might affect requirements for energy facilities dependent on inexpensive water to control process temperatures, especially nuclear power plants. Breslow and Sailor (2002) have investigated potential impacts of climate change on wind speeds and hence on wind power across the continental US. General Circulation Model output from the Canadian Climate Center and the Hadley Center were used to provide a range of possible variations in seasonal mean wind magnitude to assess the vulnerability of current and potential wind power generation regions. According to their analysis, although a large degree of uncertainty remains there is a need to consider climate variability and long term climate change in citing wind power facilities by including estimates of vulnerabilities in the wind power site selection decision process.

Other supply-side vulnerabilities include possible impacts of precipitation changes on potentials for biomass energy and impacts of severe weather events on windpower stations, electricity transmission and distribution networks, oil product storage facilities, and off-shore oil production Policies for reducing GHG emissions are expected to affect both energy demand and the energy supply fuel mix. Various research teams have tried to analyse the effect of mitigation scenarios on energy demand and fuel mix. For instance, Kainuma *et al*. (2004) have compared a reference scenario with six different GHG reduction scenarios. In the reference scenario, the use of coal increases from 18% in 2000 to 48% in 2100. In contrast, the world's final energy demand in strong mitigation scenarios decreases to nearly half that in the reference scenario in 2100. This reduction comes about mainly from cutting coal use, whereas the share of electricity increases. Kuik (2003) has assessed two long-term alternative climate change policy scenarios for Europe. The results show that there is a trade-off between economic efficiency, energy security and carbon dependency for the EU.

7.4.2.2 Services

Services include retail and wholesale commerce and trade, real estate and business activities, financial services, and such sectors of the economy as recreation and tourism. Transportation and communication are included in the section on infrastructure, and government services are included in the sections on human settlement and social issues.

Some impacts of climate change on services are quite obvious, such as changes in requirements for heating and cooling commercial and governmental space (including schools and hospitals). In a larger sense, however, impact vulnerabilities tend to be focused on certain climate-sensitive sectors such as tourism and finance; changes in regional economic advantage due to climate change are likely to affect patterns of trade; and services located in areas especially vulnerable to such climate impacts as extreme stores and sea level rise.

Possible impacts of climate change on interregional trade are still rather speculative, because of a lack of literature on this specific issue; but several dimensions can be discussed with a relatively high level of confidence. Climate change could affect trade by reshaping regional comparative advantage related to either general climate-related influences (Figure 7.2), such as on agricultural production, or exposure to extreme events combined with a lack of capacity to cope with such events, or by effects of climate change mitigation policies that create markets for emission-reduction alternatives. In an era of increased globalization, small changes in price structures could have amplified effects on regional economies. Beyond actual climate change impacts, of course, a prediction or perception of future impacts may affect investment and trade, as well as perceptions of future regulatory initiatives. A further possibility is that certain parties impacted by climate change might try to hold parties they believe contributory to those impacts liable to damages.

Climate change may also disrupt transport activities that are important to national supplies as well as international trade. For instance, extreme events may temporarily close ports or transport routes and damage infrastructure critical to trade. Considering Norway as an example, increases in the frequency or magnitude of extreme weather events could amplify the costs to transport companies and state authorities of closed mountain passes, train delays and cancellations, road detours, and other interruptions of activities (O'Brien *et al*. 2005).

It appears that there are linkages between climate change scenarios and trade growth and trade liberalization scenarios (namely the re-launched Doha "Development" round: Oxley 2002) and also effects of the ongoing partial liberalization in the form of regional and subregional free trade agreements ranging from the expansion of the European Union to NAFTA, CAFTA, transatlantic trade negotiations, Pacific Basin cooperation and trade negotiations, etc. An example of a possibly relevant question is whether price variations of goods and services might in the longer run be linked to climate change (as in the case of falling coffee prices in the world market and the conversion of coffee plantations that provide forest cover as in Central America to other uses, namely urbanization and tourism).

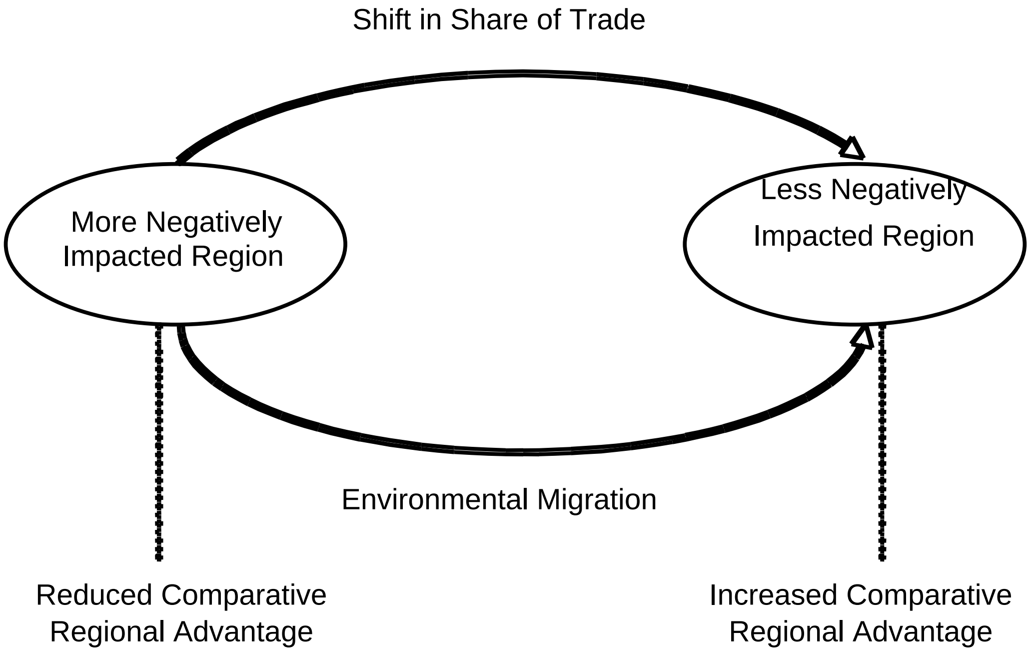

Figure 7.2: *General Effects of Climate Change on International Trade*

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 northern countries seems to mean a northward shift in conditions favourable to many forms of tourism (Chapter 15), other than conditions related to snow. This might, for instance, lead to more domestic tourism in NW Europe (Chapter 12; Agnew, Viner, 2001; Maddison, 2001) and in the middle latitudes of North America (Chapter 14). 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 (Chapters 11, l2, and 14), although artificial snow-making may be a technical solution in the short-term (Scott, Mc Boyle, Mills 2003). However, minimum temperatures are needed to make snow; lower elevation ski areas may not be able to make use of this technology (O'Brien *et al*. 2004), and other externalities could reduce the sustainability of snow-making as an option. In summer, destinations already hot could become too hot for affordable comfort (Chapter 12); but 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 (Gossling and Hall 2005b). Regarding low-lying islands, sea-level rise and increasingly frequent and intense weather extremes might become of great importance in the future (Chapter 16). 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 (Sasidharan, Yarnal, Yarnal, Godbey, 2001; see Ch 14). 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. 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) are 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 (Becken, Simmons, Frampton 2001) and the cost of travelling to them (Becken, Simmons, Frampton 2003). 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, 2003b).

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 (Chapter 14) or other scenarios (Chapter 11). In these scenarios, tourist reactions to climate change are assumed to be constant, notwithstanding the fact that these responses are currently not satisfactorily understood. Climate change is likely to directly and indirectly influence human activities in the Arctic region, including tourism, oil and gas exploration, and transport (ACIA 2004). Climate modelling results indicate that there will be substantial changes in the Barents Sea Ecoregion over the next 50 years, including a decrease in sea ice concentration and a thinning of sea ice that may open new transport routes (Furevik *et al*. 2002). A projected increase in maritime activities in the Barents Sea Ecoregion due to increased transport of oil and gas from Northwest Russia, combined with increased interest in petroleum reserves in the region, will contribute to an increase in the potential risks involved (PAME 2000). Climate change will interact both cumulatively and synergistically with transport changes to create new challenges for the region's biodiversity (O'Brien *et al*. 2004b).

Possible impacts of climate change on financial institutions and risk financing were the focus of a separate chapter in TAR. Impact concerns involve complex functions of risks associated with various climate and weather variables, along with alternative institutions for risk financing, from private insurance to government catastrophe protection. The chapter identified a significant inflation of losses from meteorological disasters since 1986, which were considered to reflect an increase in catastrophe occurrence over and above the rise in values, exposures, and vulnerabilities.

Because the insurance market acts as an integrator of the effects on other sectors, it has the potential to focus many of the sudden onset economic consequences of climate change. However even in developed countries it is important to consider the whole scope of the risk-bearing sector, which also includes banks, government-backed insurance systems and disaster funds, and individuals, while in developing countries (as highlighted by the Dec 26th 2004 Indian Ocean tsunami) individuals bear the majority of the risk and manage it through the solidarity of family and other networks, if at all. The risk financing systems in place today have been shaped by past events: especially for flood. For this reason, in predicting the potential impacts of future increases in catastrophe occurrence, it is important to consider how the allocation of risk-bearing is likely to change.

Different climate change scenarios imply different development paths for the role of insurance, considering such factors as the inter-relation between projected expansions in insurance coverage and economic growth, implications of where (by region and situation) increases in the direct or indirect consequence of catastrophe occurrence are predicted to have principal impacts on current insurance coverage, implications of reduced availability of insurance on local and regional economic activity, implications of increased government participation in risk mitigation and risk financing, responses in the developed world (e.g., increased funding of flood defences until such time as cost benefits of risk protection are exceeded and land and property is abandoned), responses in the developing world (e.g., expansion of microfinance initiatives and implications of retreat from locations at highest risk of flooding) and the range of risks and time-scale of investment decisions within the financial markets. Specific areas in which climate change could prove a significant risk factor in investment decisions: include hydroelectric projects, irrigation and agriculture, tourist facilities, ski-resorts etc. (UNEP, 2002), and financial markets and catastrophe risk: through conventional or alternative risk transfer products. Box 7.2 summarizes relationships between climate change and the insurance industry.

Box 7.5: Insurance Industry and Climate Change

The Global Insurance Industry comprises a series of commercial entities that contract to fund future losses in exchange for a premium (a process known as risk transfer). These entities include private (individual and shareholder owned) and state (government backed) insurers, mutuals (that distribute all profits to policy holders), captives (that hold the risk on behalf of their parent corporation or organization) and reinsurers (most privately owned, but some state backed), who insure insurers, in particular against the largest catastrophic losses. It is better to consider the ‘collective of all insurers’ as a ‘market’ rather than an ‘industry’, as in all risk purchase and transfer there will be different perspectives on what is the true risk cost. In the purchase of reinsurance, for example, reinsurers will be more pessimistic about catastrophe risk-costs than the insurers who are ceding the risk and this perspective is highlighted in concerns about the potential impact of climate c(Swiss Re, 2004; Munich Re, 2005). For global reinsurers the dominant traded catastrophe risks are those arising from US and Caribbean hurricanes, US earthquakes, windstorms in Europe and typhoons and earthquakes in Japan, but their portfolios also contain many other regions and perils as well as ‘tail’ insurance losses from other sectors.

The central principle of insurance concerns diversification: the amount (and hence the cost) of capital required to provide protection can be reduced when uncorrelated risks are pooled. Any process or phenomenon that changes the frequency, severity, or geography of climate related losses and in particular catastrophic losses (involving losses to many policyholders within the same event or period) will inevitably have an impact on the property insurance industry, with the magnitude of the impact dependent on the industry’s participation in that country/sector and peril. Different insurance policies protect against damage to physical property (such as houses, crops, factories, cars, ships) and commercial activity (business interruption), to life (including costs of medical intervention, compensation for injury and death), as well as liability compensation (for harm caused by one party to another). While a number of lines of insurance have some potential to be affected by climate change, the principal impacts will be to property lines. Directors and officers liability policies could also be affected where one party could prove that another was negligent in failing to prevent or mitigate climate change related consequences, and life policies could be affected where changes in mortality resulted from some alteration in disease vectors (Swiss Re, 2004).

Whereas wind related insurance coverages are generally available as part of standard fire insurance policies, flood insurance is in many countries either unavailable, or significantly restricted (Swiss Re, 2002). In some countries, as in the US, Spain or France, flood insurance is provided by a government run insurance system, in others such as Germany, Japan and Australia and many regions of the developing world, it may be purchased as an additional protection,

although may be unavailable in locations of highest risk, while in Sweden, Portugal, the UK (and in countries that have inherited the UK insurance systems) flood insurance is a general coverage. Because of the magnitude of the flood risk in the Netherlands and the belief that it is the government's responsibility to provide protection, flood insurance is not available.
As the actuarial analysis of recent loss experience will typically be an inadequate guide to catastrophe risk, since the 1990s probabilistic 'Catastrophe' modelling software has become universally employed for pricing and managing portfolios of catastrophe risk, in particular in the principal catastrophe risk insurance markets of the US, Western Europe and Japan (Grossi and Kunreuther, 2004). Such models cover earthquake, tropical (and extra-tropical) cyclone, windstorm, and some flood perils. The output of a probabilistic catastrophe model is a loss exceedence probability (EP) curve; the integral under which is the average annualized loss, or 'risk cost'. For example in the US, Catastrophe models indicate 1% annual probability (i.e. '100 year return period') losses of around $60 billion being slightly higher for aggregate losses within a season. Frequency can also be important, as in the 2004 Hurricane season, when four medium sized hurricane losses combined to create an insurance industry loss larger than that of the previous record: 1992 Hurricane Andrew **(**Insurance Journal, 2004). In an environment of changing risk the challenge is to calibrate such models to reflect the current risk, rather than that sampled over a historic baseline.

Insurance organizations also manage very large portfolios of investments (the funds by which claims are paid) and are therefore concerned with all those factors that affect the value of these investments, among which, for certain sectors such as agriculture, tourism, and the construction sector will be both gradual and catastrophic meteorological impacts (both destructive and beneficial) potentially associated with climate change (UNEP, 2002**).**

The take-up of insurance is far lower in developing and newly developed countries than in the US, Western Europe, Japan and Australasia (Enz, 2000) as insurance reflects wealth protection that typically lags a generation behind wealth generation. However once development is underway insurance typically expands faster than GDP growth. For developing countries it is recognized (Gurenko, 2004) that among the two ways of funding catastrophic damage the ex-ante mechanism (before the fact) in the form of insurance is far more beneficial for the affected community and the whole country's economy than the ex-post mechanism (after the fact) by means of credit, government subsidies or private donations. Only the ex ante approach offers 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 & economic growth (Gurenko, 2004). 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).

The $15.5 billion insurance loss of Hurricane Andrew in 1992 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 big increases in insurance and reinsurance prices, the retreat of private insurance from locations at highest risk, the creation of new state backed insurance and reinsurance organizations, the universal adoption of catastrophe models and ten years of low claims, the private insurance market re-expanded its role, so that in the four hurricanes of 2004 (with a Florida loss totalling $21.5 billion) only one small insurance company failed, and there was little impact on reinsurance rates. Hurricane Andrew also triggered improvements to the Florida building code, which proved itself in the 2004 hurricanes (International Code Council, 2005). However questions remain as to how the balance between private and government backed insurance systems in Florida will be forced to change faced with ongoing losses (Hartwig, 2005) as well as anticipated rising levels of hurricane risk (see Climate Risk Management, 2005**).**

Insofar as premiums for contracts are collected and renewed annually, the insurance industry is highly adaptive to changes in catastrophe risk. Trends towards 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 potentially contribute to this robustness (European Environment Agency, 2004). The size of the insurance industry is a compound of the overall size of the economy and of the amount of insurable risk within that economy, so that, if risk increases under climate change, overall the insurance industry can be expected to expand in the volume of premium collected, claims paid and income (where insurers overcome consumer, regulatory and cyclical pressures to restrict increases in insurance rates). As reinsures sit outside any regulatory system of price controls they have been free to raise prices and reduce coverages after major catastrophe losses and have generally been more profitable than insurers (US Insurer, 2005), although rate rises that followed the 9/11 attacks, meant that while the 2004 year both the worst for US catastrophe losses it was also the most profitable year ever for US Insurers (Dyson, 2005). The rise in reinsurance prices after major catastrophe losses (as in 1994-5 and again in 2002-2) meant that significant new capital entered the reinsurance market (in particular in Bermuda) in search of higher returns.

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. 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, threatening to withdraw flood insurance from locations at greatest risk (Association of British Insurers, 2004). 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. In the northern Bahaman islands of Abaco and Grand Bahama (hit by three major hurricanes between 1999 and 2004), flood insurance became withdrawn for some areas, and without any state-backed alternative houses were becoming abandoned as their value collapsed **(**Woon and Rose, 2004**).** Meanwhile builders had begun to construct new houses on concrete stilts, bringing properties back into the domain of insurability. Similar outcomes can be expected in other coastal regions affected by increasing flood risk.

7.4.2.2 Utilities/infrastructure

Infrastructures for industry, settlements, and society include both “hard” (i.e., physical, such as water, sanitation, energy, transportation, and communication systems) and “soft” (i.e., institutions, such as shelter, health care, food supply, security, and fire and other forms of emergency protection). In many instances, such “hard” and “soft” infrastructures are linked. For example, in New York City adaptations of hard water supply systems to possible water supply variability are dependent on changes within the soft institutions that manage them; conversely, soft institutions such as health care are dependent to some degree on adjustments in hard infrastructures to maintain effective service delivery (Rosenzweig and Solecki, 2001).

These infrastructures are vulnerable in different ways and to different degrees to climate change, depending on their state of development, their resilience, and their adaptability. In general, “wet” and "dry" conditions have different effects; the former (e.g., floods) induce more physical damage, while the latter (e.g., heat waves) tend to have impacts on systems and users that are more indirect.

Often, the soft infrastructure is less vulnerable as it embodies less fixed investment and is more readily adapted within the time scale of climate change. Moreover, the impact of climate change on institutional infrastructure can be small or even an improvement in their resilience; for example, it could lead to increased investment in emergency services.

7.4.2.2.1 Water supply

Climate change, either annual or seasonal, could affect water supply systems in a number of ways. It could affect water <u>demand</u>. 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 migration, this may also cause increased demand on other systems. It could affect water <u>availability</u>. Changes in precipitation patterns may lead to reductions in river flows, falling ground water tables and, in coastal areas, to saline intrusion. And climate change could <u>damage the system</u> itself, including erosion of pipelines by unusually heavy rainfall or river flows, although the main category is the damage caused by flooding.

Water supplies are designed for a life of many years. It is generally not economic to expand a water supply system piecemeal; so in principle, they are designed with extra capacity in reserve to respond to future growth in demand, although in practice systems in large urban areas tend to expand in a series of discrete stages reflecting perceptions of near-term needs. Allowance is also made in the design for anticipated variations in demand, such as those occurring with the seasons and with the time of day (Chapter 3). From the point of view of the impacts of climate change therefore, water supply systems are quite resilient with respect to the relatively small changes in mean values of parameters such as temperature and precipitation which are anticipated in the next century, except at the margin where a change in the mean requires a significant change in the design or technology of the water supply system. In practice, such marginal phenomena can take three forms:

1. One occurs at the point where cheap shallow well hand pumps need to be replaced by the more costly deepwell pumps because the groundwater table has fallen. It is typically a problem of rural areas where groundwater is shallow, such as the alluvial plains of China and Bangladesh. However, the drawdown of the water table is usually occasioned by excessive abstraction for agriculture, rather than from climate change alone.
2. A more expensive change arises when groundwater extraction must be abandoned altogether because of the subsidence it is causing in the ground above. A decision restricting groundwater withdrawals can be motivated by the need to protect buildings from differential settlement, as in London, by drainage problems, as in Bangkok, or by both, as in Mexico City. Where sea level rise is a contributory factor, the change in water supply is likely to be only one part of the necessary flood prevention strategy, and the other components are likely to cost more.
3. The third occurs when saline intrusion, into an aquifer or into the lower reaches of a river, makes it necessary to move the abstraction works. Sea level rise can contribute to this, but a greater impact is likely to stem from reduced base flow in the dry season. This is expected in several regions, including Southern Africa (Ruosteenoja *et al.*, 2003), where the city of Beira in Mozambique is already extending its 50 km pumping main a further 13 km inland to be sure of

fresh water.

The problem can arise even where total mean precipitation remains constant or shows a modest increase, if extreme precipitation events become more frequent or more intense. An increase in flood flows implies a reduced base flow if total mean discharge is unchanged. In a similar way and in addition to this, an increase in the seasonal variation of flow could imply a reduced dry season base flow under conditions of constant mean discharge. Where water supply systems assume constant water supply, changes in seasonal patterns can have important implications (Chapter 3).

More dramatic impacts on water supplies are liable to be felt under extremes of weather that are likely to arise as a result of climate change, particularly drought and flooding. Drought does not normally cause substantial damage to water supply systems, but it can prevent them temporarily from functioning. This is likely to make its impact less costly than the damage caused by flooding, which puts water supplies out of action until expensive repairs can be carried out. An estimated one third of urban water supplies in Africa, Latin America and the Caribbean, and more than half those in Asia, are operating intermittently (WHO/Unicef, 2000). At first glance, therefore, they might appear to be operating on the margin where water resource constraints would be crucial. However, statistical analysis of data from over 100 countries, comparing the water-stressed countries with the others and controlling for confounding by per capita income, found no difference in the proportion of the urban population with access to improved water supplies (McGranahan, 2002). Clearly other factors are at work, not least the extent and efficacy of investment in expanding water supply capacity and extending service to those who lack it.

Even where water resource constraints, rather than system capacity, affect water supply functioning during droughts, this often results from inappropriate allocation of the resource 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, whereas under Integrated Water Resource Management they would receive priority in allocation as the value of municipal water use is so much greater than agricultural use that they can pay a premium price for the water (Dinar *et al*. 1997).

Nevertheless, in some industrialized countries with low agricultural but high municipal water demand, additional investment will 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 (Environmental Agency 2004).

Moreover, there is cause for concern in the trends discernible during the last century, by which mean precipitation in all four seasons of the year has tended to fall in all the main arid and semi-arid regions of the world: e.g., northern Chile and the Brazilian Northeast, 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.

In addition, 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 a fortnight. In severe riverine floods with high flow velocities, pipelines may also be damaged requiring more extensive repair work. Note also that salt water intrusion can be associated with corrosion and other compromises of drinking water supply systems.

Some of the considerations applying to water supply also apply to sewered sanitation systems, but in general the effect of climate change on sanitation is likely to be less than that of water supply. When water supplies cease to function, sewered sanitation also becomes unusable. Sewer outfalls are usually into rivers, 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 resilient. Sea level rise will affect the functioning of sea outfalls, but the rise is slow enough for the outfalls to be adapted, by pumping if necessary, to the changed conditions at modest expense. 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.

Box 7.6: Water Management

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7.4.2.2.2 Sanitation

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7.4.2.2.3 Transport infrastructure

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, with their attendant 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 adaptation 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 re-surfacing. Transport infrastructure is more vulnerable to effects of extreme local climatic events. For instance, Parry *et al* (2000: 207) provide an assessment of the impacts of severe local storms on road transportation, much of which also applies to rail: Table 7.2.

Table 7.2: *Effects and Response Strategies Associated with Storm Interactions with Surface Transportation*

Storm attribute	**Impact**	**Possible adaptation**
Tornadic wind	Structure and vehicle damage/displacement of power loss	Evasion, diversion, closure
Strong winds	Structure damage, debris damage, vehicle instability, visibility reduction, power loss	Design, advisories, caution
Heavy rain	Flooding, visibility reduction	Design, advisories, caution, diversion, closure,

		flood control
Heavy snow/sleet	Closure, impedance, entrapment, visibility reduction	Advisories, caution, diversion, closure, ploughing
Hail	Vehicle damage, impedance	Seek shelter, advisories, caution
Lightning	Structure and circuit damage, power loss, distraction	Design, back-up, caution, advisories

Of all the impacts in this table, the greatest in terms of cost is that of flooding. An example is the flooding of one point on the rail link between Oxford and London, UK, between 13th and 18th December 2000. The financial loss to the railway company due to time delay penalties as a result of this one disruption has been estimated to be at least £1.2 m. (ref: London's warming). This does not include the value of lost time suffered by train passengers and the cost of repair to the rail infrastructure. A single and local rainfall event can have far-reaching impacts on transport infrastructure, as on 7th August 2002, when a rainfall of over 25 mm in a half hour period led to the closure of five of London's mainline train stations due to local flooding, and the inundation and closure of a number of stations of the underground rail system (London Climate Change Partnership 2004).

7.4.2.2.4 Communications infrastructure

Infrastructure for communications is subject to much the same considerations; it is vulnerable to high winds when in the form of suspended overhead cables, but 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. However, such infrastructure can often be repaired at a fraction of the cost of repairing roads, bridges and railway lines, and in much less time.

7.4.2.3 Human settlement

One of the most important questions about climate change impacts is their implications for the places where the world's people live: their settlements, large and small. Beyond the general perspectives of TAR (see section 7.1.4 above), the research literature is still limited, but a number of case studies are emerging. Larger settlements, or urban areas, are of course important not only in terms of their vulnerabilities to <u>impacts</u> of climate change but also as <u>determinants</u> of climate change (WG III).

Several recent assessments have shown rather serious vulnerabilities of settlements, or at least large urban areas, to climate change. Examples include cities in the developed and developing world such as London (London Climate Change Partnership 2004**),** New York (Rosenzweig and Solecki (a and b), 2001), Boston (Ruth and Kirshen, 2001), Mexico City (Aguilar 2004), and São Paulo. Especially vulnerable are informal settlements within urban areas of developing countries, which tend to be built on hazardous sites and to be susceptible to floods, landslides, and other climate-related disasters (Cross, 2002).

Possible climate change impacts for London have been assessed (e.g. increased summer heat stress, more heavy precipitation days in winter) (London Climate Change Partnership, 2004). In the case of New York City, projections are that climate change will bring higher temperatures all year long and more heat waves in the summer, rising sea levels, shorter coastal flooding recurrence periods, and increased frequencies of drought and riverine flooding for inland locations. These climate stresses, in turn, are likely to inundate coastal wetlands, threaten vital infrastructure and water supplies, augment summertime energy demand, and affect public health, all at the same time (Rosenzweig and Solecki,(a) 2001). These concurrent impacts could have further impacts on the local quality of life and economic activity. Given the city's leading position in the global urban economic hierarchy, the effects could be felt at the national and international scales via disruptions of business activities in the region (Solecki and Rosenzweig 2005).

Globally, approximately 400 million people live within 20m of sea level and within 20 km of a coast (Small *et al*, 2000), and there is increasing trend toward settlement in coastal areas, especially in developing countries (Box 7.7). Moreover, in some coastal areas, such as the Gulf Coast of the United States, land subsidence is expected to add to apparent sea level rise. Studies in the New York City metropolitan area have projected that climate change impact scenarios associated with expectations that sea level will rise could reduce the return period of 100-year storm flooding to 19-68 years, on average, by the 2050s, and to 4-60 years by the 2080s (Rosenzweig and Solecki, 2001a), jeopardizing low-lying buildings and transportation systems. Due to a long coastline and extensive low-lying coastal areas, projected sea-level rise in Estonia could endanger natural ecosystems and cover beach areas high in recreational value. The greatest threat to the environment of the Gulf of Finland and the whole Baltic Sea is the dumping site of the former uranium enrichment plant in Sillamäe which is situated very close to the coastline and can be disturbed during storms, which may increase in their intensity (Kont *et al*, 2003). Similarly, a study on the climate change impacts on coastal infrastructure in the eastern Caribbean found that the area is vulnerable to sea level rise (Lewsey *et al*, 2004).

Another body of evidence suggests that human settlements, coastal and otherwise, are also affected by precipitation and related climate parameters. In particular, larger urban areas are increasingly vulnerable to flooding due to pavement of the land surface, spreading impacts downstream to other areas as increased streamflow. On the other hand, decreases in precipitation in certain season and arid and semi-arid areas threaten reductions in crop yields in rural areas, and hence (together with other stressors) encourage rural settlers to migrate to urban areas whose infrastructures are already stressed (Tacoli, 2002).

Water availability affects human settlement differently according to scale and site. Particularly in arid and semi arid places, fresh water supply is a key to the viability of human settlement. In the Souss-Massa region of Morocco, where economic growth and educational opportunities are limited and women in rural settlements spend an average of 90 minutes per day hauling water (Rhode 1999), both urbanization and irrigation are dependent on water supply. In arid central Asia, water is also a key issue for sustainable development (Smith 1999), and the limited supply of water is already being challenged by rapid population increases in the urban areas that are exceeding traditional demands. In such cases, any change in climate that further reduces precipitation would be a very serious concern. In many cases, since water supplies are drawn from regional watersheds, settlements can be affected by reductions in snowpacks and retreats of glaciers far away; and competition for scarce water between settlements and agriculture can create social, economic, political, and environmental pressures.

Box 7.7: Industry, Settlement, and Society in Mega-Deltas

Not all of the world's mega-deltas are densely populated, but those which contain major concentrations of population – such as the Huanghe (Yellow), the Changjiang (Yangtze), the Ganges-Brahmaputra, the Nile, the Mississippi, and the Rhine – represent special concerns about possible vulnerabilities to climate change, related to sea level rise, intensified severe storms, intense rainfall events, and especially combinations of these possibilities. It is possible to say with a high level of confidence that sustainable development in some densely populated mega-deltas of the world will be challenged by climate change by the end of the current century. Concerns are particularly acute where the coastal area is gently sloping; where coastal lands are subject to subsidence, as in the case of New Orleans, USA; where mega-deltas coincide with mega-urban concentrations, putting very large numbers of people at risk, along with their infrastructures; where fragmented coastlines make protective coastal adaptations prohibitively expensive; and where local financial and human resources limit both the ability to protect against impacts and the ability to cope with them.

With growing urbanization and development of modern industry, air quality has become a more salient issue in many urban areas. Many cities in the world are experiencing air pollution problems, such as London, Chongqing, Lanzhou and Mexico City. The problems of London and Chongqing are mainly due to the air pollutants and fog, while Lanzhou and Mexico City are mainly due to air pollution that cannot be dispersed because they are surrounded by mountains. 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 *et al*., 2005).

Settlements can also be affected by a wider range of health implications of climate change. For example, besides heat stress and respiratory distress from air pollution, changes in temperature, precipitation, and/or humidity affect environments for water-borne and vector-related diseases. Projections of climate change impacts in New York City show significant increases in respiratory-related health attacks and hospitalization (Rosenzweig and Solecki, 2001a).

Another issue is urban heat island effects: higher temperatures occur in urban areas because their physical structures generate heat and reflect the sun's rays. The intensity of this effect may be important for secondary reactions in the urban atmosphere, leading to elevated levels of some pollutants (Jonsson *et al*., 2004; Junk *et al*., 2003; Morris and Simmonds, 2000), which can be prejudicial to health. The urban heat island effect can also influence the climatic comfort of the urban population, affecting their health, their labour productivity, and their leisure-time 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 cities as Aveiro in Portugal have been shown to create a heat island, the intensity (the difference between night-time minimum temperatures in urban vs. rural areas) of which can reach 7.5 degrees C. (Pinho and Orgaz, 2000). Rosenzweig *et al*. found that climate change would exacerbate the heat island condition by increasing the baseline temperatures and reducing the local wind speeds (Rosenzweig *et al* 2005).

In these ways and others, in their vulnerabilities to climate change impacts, settlements are sensitive to such direct impacts as climate extremes (e.g., severe storms and associated coastal and riverine flooding, especially when combined with sea level rise, snow storms and freezes, and fire). They are also vulnerable to a wide variety of indirect effects, many of them discussed above and below. For example, settlements are affected by the viability of the local economy, pressures on local infrastructures, and pressures on social cohesion (Rosenzweig and Solecki 2001).

Generally, however, except for abrupt extreme events, climate change impacts are not dominant issues for human settlements on their own (Solecki and Rosenzweig 2005). Their importance lies in interactions with *other* stresses on settlements, such as water supply infrastructures or governance structures that are inadequate even in the absence of climate change. Such stresses as unmet resource requirements, congestion, poverty, economic inequity, social tensions, and insecurity can be serious enough in some settlements that any significant additional stress could be the trigger for serious disruptive events and impacts in those particular areas. Other stresses may include institutional and jurisdictional fragmentation, limited revenue streams for public-sector roles, and fixed and inflexible patterns of land use. These types of stress do not take the same form in every city and community, nor are they equally severe everywhere, but 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/or aging infrastructure.

7.4.2.4 Social issues

Climate change and variability have the potential to interact with social stresses in many ways. These impacts will vary from place to place and among different social groups, of course, but in summary the greatest concerns at this point are:

a Extreme weather events. If such extreme events as severe storms, floods, and fires become more frequent and/or more intense, cities and communities will be severely impacted: lives will be lost, property will be destroyed, activities will be disrupted, and economic and managerial resources will be strained (references). Recent examples from experience include El Niño-related fires in Indonesia, heavy rainfall in western coastal areas of USA, and floods in the Mississippi and Red River valleys of the USA.

b Sea level rise/storm surges. A rise in sea level of any significant extent, especially if it is combined with more severe storms, threatens massive damage and disruption for cities and communities in coastal areas, especially on gently-sloping coastal plains (Nicholls, 2004). The first impacts to be experienced will probably be increased storm-related flooding. Later, sea-front and other low-lying property and activities would eventually be threatened even without storms.

c Second and third order impacts. Human habitations and activities are unique among climate change impact concerns in the importance of indirect impacts. For instance, a primary impact of warming can lead to a secondary impact of increased urban air pollution, which can in turn lead to a third-order impact on human health, which then affects public service requirements, which affects social harmony. Another example is climate change which influences the economic competitiveness of other regions of the country and the world, which affects local job creation and population migration into or out of the area. One indirect impact of particular concern in some areas is the effects on city life, local economies, and family budgets of climate change mitigation initiatives (e.g., Rose and Zhang 2004; Rose and Oladosu 2002).

d Especially impacted segments of the population. Impacts of climate change are likely to be felt most acutely by certain segments of the population, especially the poor, the elderly, the young, the least skilled, the powerless, and recent immigrants, particularly if they are linguistically isolated -- those most dependent on public support. Another impact issue is differences in impacts according to gender (e.g., Cannon 2002).

e Especially impacted locations. Impacts of climate change are of greatest concern in certain areas that are more exposed to climate change, more sensitive to such change, or less adaptable in coping with such change. Examples include small island states, especially low-lying islands; polar areas where warming is more pronounced; coastal areas affected by sea level rise and storm behaviour; and areas with limited human and financial resources.

f Increased vulnerability of governance systems. The vulnerability of governance systems —or the means through which public and private actors make decisions and implement them—may increase dramatically as climate changes. Governance includes not only organizations and social actors but also the mechanisms and processes through which interests are articulated, rights are exercised and conflicts mediated. 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 of the world. Already we see how poverty, violence, environmental stress, and authoritarianism threaten the survival of governance systems in many areas. Among possible casualties of governance breakdown could be democratic institutions, advances in human and social standards, improved livelihood conditions and traditional cultures. To avoid such outcomes, governance systems are likely to react to perceptions of growing stresses through regulation and other policy interventions, which themselves can represent significant impacts of climate change.

g Increased uncertainty/interruptions and opportunity costs. These concerns add up to increased demands on local institutions and infrastructures that in many cases are already strained, especially in developing countries. Increased uncertainty is itself an impact, with the potential to undermine decisiveness and public support, and increased frequency or severity of climate-related crises will present serious opportunity costs: i.e., other things that cities need to do that are excluded by having to pay the costs of climate change/variability impacts.

These potential impacts are serious indeed for the places where people live, directly related to human well-being, social harmony, and the quality of life. The probability of specific impacts on particular places remains highly uncertain, but it seems increasingly clear that the likelihood is greater of some disruptive impacts on most cities and communities than of no impacts whatsoever; and it is likely that if things go wrong people will blame “the government.”

The vulnerability of human societies to climate change varies not only with environmental features of the location, with gender, or with time, but also with economic, social and institutional conditions. This is where socioeconomic diversity within cities, rural settlements, and their productive sectors, linkage systems, and infrastructure comes to the fore. Neighbourhoods within cities 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 (e.g. heat outbreaks, floods) than poor and informal settlement areas, and their actions can affect the poor as well (Reiter *et al*., 2004). Relatively wealthy market-oriented farmers can afford more expensive deep well pumps. Large-scale fishing entrepreneurs can afford to relocate or diversify, while local fishing populations affected by weather and/or oceanographic changes tend to have few alternatives.

For instance, impact issues related to poverty include the following:

a Poor dwellers in cities or subsistence peasants and fishers cannot always afford adaptation mechanisms such as air conditioning, heating, or climate-risk financing from insurance;

instead, they base their responses on diversification of their livelihoods or on remittances and other social assets. (Climate risk financing is generally either unavailable or significantly restricted in developing countries). Under many recent institutional reforms, associated with reductions in services and support from central governments, local governments have even more limited resources to develop local public-sector alternatives to the private insurance market, or to provide adequate preparedness and protection. This does not necessarily mean that "the poor are lost;" In many cases, they are historically resilient in developing other coping mechanisms (see adaptation below); the question is whether climate change might go beyond what traditional coping mechanisms can handle.

b The poor tend to live in dilapidated housing and lack adequate water, drainage and other public services, especially in developing countries. Often located in marginal areas, they can be especially vulnerable to climate-related events such as floods that threaten life and homes, droughts that affect the already intermittent functioning of their water supply, and supply shortages which can either deny or increase the cost of meeting critical needs (Wood and Salway, 2000).

c Especially in developing countries, poor and informal dwellers (i.e. with irregular land tenure, and self-help construction of houses) are often situated in risk-prone areas (OECD 2004 , Romero Lankao *et al* 2005).

d For these reasons, low-income people living in traditional, informal settlements are those most likely to be killed or harmed by weather-related disasters. Over the past decade, disasters in countries of high human development killed an average of 44 people per event, while disasters in countries of low human development killed an average of 300 people each (reference).

Of course, vulnerabilities to impacts of climate variability and change are not only related to poverty independent of location. Some consequences relate to geographical location. For instance, indigenous societies in polar regions are already experiencing threats to their traditional livelihoods (Chapter 15; ACIA, 2005), and such other locations as low-lying island nations are also threatened (Chapter 16). Increased temperatures in mountain areas and in temperate zones needing space-heating during the winter may result in energy cost savings for their poor settlers, reducing pressures on household budgets as average temperatures rise. On the other hand, societies in areas relying on fans or air conditioning may see increased pressures on household budgets as average temperatures rise.

7.4.3 Key vulnerabilities

As a general statement about such a diverse assemblage of circumstances, the major climate change vulnerabilities of industries, settlements, and societies are:

1 vulnerabilities to particular exposures to climate change: especially extreme weather and climate events, particularly if abrupt major climate change should occur
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 (e.g., Box 7.8)
3 vulnerabilities of particular geographical areas: coastal and riverine areas vulnerable to flooding and continental locations where changes have particular impacts on human livelihoods; the 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 the Sahel

4 vulnerabilities of particular populations: those 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.

More specifically, key vulnerabilities are most often 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, and (b) limited access to resources (financial, human, institutional) to cope, rooted in issues of development context. Most key vulnerabilities are relatively localized, in terms of geographic location, sectoral focus, and segments of the population, although literatures to support such detailed findings about potential impacts are very limited. Based on the information summarized in the sections above, key vulnerabilities of industry, settlement, and society include the following, each characterized by a level of confidence:

1 Interactions between climate change and global urbanization, especially in developing countries, which is often focused in vulnerable areas (e.g., coastal) – especially the growing phenomenon of mega-cities and rapidly growing mid-sized cities and possible thresholds of sustainability (VERY HIGH CONFIDENCE).

2 Interactions between climate change and global economic growth: demands on resource bases and associated environmental impacts resulting from economic and social development – 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 <u>response</u> policies, which could affect development paths by requiring higher cost fuel choices (HIGH CONFIDENCE).

3 Interactions with increasingly strong and complex global linkages, which cause climate change to cascade through expanding series of interactions to produce a variety of indirect effects, some of which may be unanticipated, especially as the globalised economy becomes more locally specialized, less resilient, and more interdependent – vulnerabilities include interregional trade patterns and migration patterns (VERY HIGH CONFIDENCE).

4 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).

5 Interactions with governmental and social/cultural structures that are already stressed in some places by other kinds of change, such as population pressure and limited economic resources, and which 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, while vulnerabilities in less developed areas are often focused on human populations and institutions, which need different

numeraires.
Although it would be very 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.

Box 7.8: Environmental Migration

Estimates of the impact of climate change on human population displacement are fraught with difficulty. One problem is that while migration may represent a coping strategy used to adapt to interannual variability of climate, it is also in many cases a longstanding response to *seasonal* variability in environmental conditions, while for others it represents a strategy to *accumulate* wealth or to seek a route out of poverty. 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 megacity of Dhaka, the encouragement of migration by some politicians in India, 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).

Under some sets of assumptions, the numbers of environmental refugees associated with climate change could be alarmingly large, although such analyses are only preliminary (Myers, 1995): as many as tens of millions from Bangladesh, China, India, and Egypt, along with refugees from small island states and areas where agricultural production is impacted.
An argument is also 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 – oil, diamonds, cobalt, and gold for example, than with scarcity (Fairhead, 2004). This allows little confidence in the prediction of such conflicts as a result of climate change.

7.5 Costs and other socioeconomic issues

Costs of climate change-related impacts are clearly diverse and not in many cases well-documented. For instance, a number of estimates exist of economic costs of sea-level rise (CPSL 2001**,** Bosello *et al* 2004), and isolated analyses have estimated costs from increased storm frequency and/or intensity (Munich Re 2005). Generalizing from scattered cases that are not necessarily representative of the global portfolio of situations is risky, and there is no truly comprehensive global or large-regional bottom line for costs of impacts on industry, settlements, and society based on published research to date. Increasing the challenge is the fact that 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.

The best current data exist on costs of climate-related extreme events in recent years. As the best-documented example, a number of sources indicate that disasters, or at least estimates of their economic damages, have been increasing in past decades (Chapter 1). Evidence from recent and current sensitivities shows that impacts vary enormously according to the level of human development achieved in the area where disaster strikes. Over the past decade, disasters in countries of high human development inflicted an average of US$ 318 million worth of damage per event - over 11 times higher than the US$ 28 million recorded per disaster in countries of low human development (reference). However, these statistics fail to capture the far more devastating impact which disasters have on GDP in poorer countries, as well as their impact on people and their communities and societies. For example, though the Mozambique floods of 2000 caused only 7000 deaths directly, it has been estimated that between 200 and 4200 additional deaths resulted from the ensuing outbreaks of diarrhoeal disease. The floods also caused a drop of between 4 and 6% in the country's GDP, and it is estimated that between 400 and 1700 further deaths would have been associated with the economic damage and hardship caused by the floods (Cairncross and Alvarinho 2005).

A few examples exist of efforts to estimate costs of climate change for certain sectors of interest, based on experience with climate variation rather than with climate change. One example is related to the possible impact of climate change on urban water supplies. In many cases, if climate change were to result in an interruption of urban water supplies (for instance because shifts in precipitation patterns reduce surface water availability), the cost of such interruptions might be far greater than the median water production cost of US$ 0.30 / m^3 reported by WHO/Unicef (2000), as the missing water is often impossible to replace, so that many industries are obliged to close down when the water supply is not functioning. The consumer surplus on a minimum volume of water is worth as much as half the income of a poor family (Cairncross and Kinnear, 1992). Moreover, there are important distributional aspects to the costs, particularly in developing countries. When water from the piped urban water systems of developing countries is in short supply, the poorest in the population usually pay most, and the increased cost of water is met mainly by sacrificing from families' budgets for food and health care (Mehotra and Brocklehurst 2005).

The cost of extending pipelines is considerable, especially if it means that the 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. Bearing in mind that a city water utility, obliged to move the abstraction point upstream to avoid saline intrusion, will usually choose to do so at a time when capacity needs to be expanded anyway, the marginal cost of the longer pipeline can more reasonably be assumed to be of the order of 10% of the total. The average total construction costs of urban water supplies in the developing countries of Africa, Asia and Latin America are respectively US$102, $92 and $144 per person served (WHO/Unicef, 2000). It follows that the cost of relocating abstraction works upstream amounts to about $10 per person for the urban population affected. Assuming that half the developing world's urban population of 2 billion people live coastal cities likely to be affected, the additional investment required is of the order of US$ 10 billion. This compares with the grand total of US$8 billion invested annually – from external and domestic sources and the public and private sectors – in urban water supplies in those countries.

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 according to the Government cost $27 million to repair, although in Gaza Province, where the vast majority of this damage was done, only some 300,000 people were directly affected by the floods (Christie and

Hanlon, 2001). The Government may have overestimated the cost; the World Bank estimated it at $13.4 million (World Bank, 2000). However, even this lower estimate puts the damage at roughly $50 per person, of the same order as the cost of providing them with water supplies in the first place. 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. The number exposed could then diminish or continue to increase, depending upon the extent to which flood defences improve with economic growth. The additional population affected due to sea level rise is not apparent until the 2080s, when it varies between 2 and 50 million, depending upon the scenario. The cost of repairing flood damaged water supplies for the 10 million people estimated using the Mozambican figure, is $500 million/year; it would be far higher in an industrialized country.

Data on costs of other aspects of climate variability appear in ECLAC's assessments of the "El Niño" phenomenon in the Andean region (CAF, *"Las lecciones del Niño").* In terms of GDP growth in the case of the 1997-98 episode, the negative impact on GDP varied from zero (Bolivia, a landlocked country) to nearly 3% in Peru, a country with extensive coastlines.

According to ECLAC assessments (reference), the negative impacts of the El Niño in 1998-99 were focused on productive activities (with agriculture the most affected) and infrastructure (mainly transport). Housing and education were also affected. Adaptive changes in productive activities since a similar event in 1982-83 sharply reduced impacts on industry, extractive industries, and fishing.

Extreme events, such as cyclones and hurricanes cause similar economic downturns. An example was Hurricane Mitch (1989) in Central America, where the impact on GDP ranged from 0.3% to 9% (reference; Figure 7.3)

In socioeconomic and environmental terms, the economic impact of droughts associated with recent climate variability has been assessed by ECLAC (2002**),** where damage and losses for the five Central American countries was estimated as ranging from negligible to 2.15% of GDP, totalling $189 million US in losses to national economies.

Losses caused by the 2001 drought in Central America are of an indirect nature in that no major damage was suffered by economic assets, except for the small food stocks that the peasant population had, that were not lost but consumed without the possibility of replenishment during the emergency. More significant losses in economic terms were energy production losses and increased cost in providing basic services such as energy and water and sanitation. Even though overall their macroeconomic impact was relatively minor, countries facing the emergency had to incur increased public spending and obtain significant support from the international donor community in order to provide food to the affected population. Fiscal balances and current account external deficits increased, particularly in the cases of Honduras and Nicaragua.

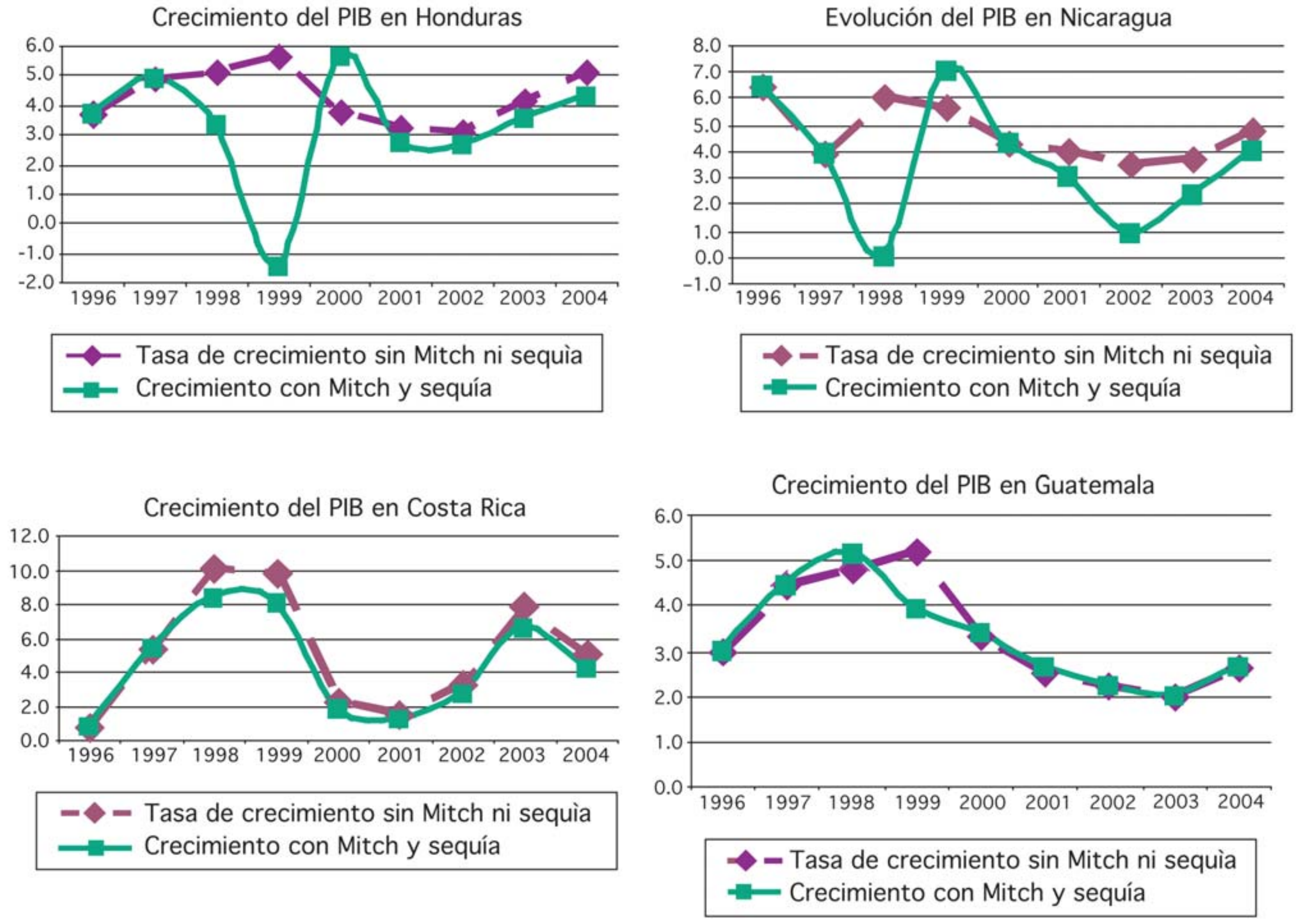

Figure 7.3: *Economic impacts of hurricanes and droughts in Central America, showing significant impacts on some countries but not others (reference)*

Drought caused a reduction of production and lower yields, particularly in basic food and grains. This situation, coming on top of the crisis caused by the fall in the international coffee prices, worsened problems that agriculture was facing, particularly those lower income groups producing for self-consumption. Since the 1997 climate variability, and with a sequel of extreme natural phenomena in this region, these low income groups have seen their assets –namely their “backyard economy” shrink, creating problems of food security and malnutrition and increasing their vulnerability. To compensate for these losses and in order to generate necessary income peasants find employment in the coffee sector not only at crop season but thereafter on the maintenance of the plantations in order to subsist till their seasonal food crops mature. The international price drop led to reduced investment by coffee producers, curtailing their maintenance investment so these jobs were not available for peasants, and thus they could not generate income to buy food. As a consequence, the population’s access to food situation was made worse, with observable consequences for the nutrition of women, children and older folk.

This led to a pre-famine situation in mid 2001 and increased migration –mainly to urban areas in the country but also among other countries in the region and beyond the region’s border, looking for employment, food and medical attention. Governments and the international community intervened during the emergency providing food and supplies purchased in the local markets.

One of the perverse effects of such phenomena is that, due to insufficient resources to rebuild lost assets and the diversion of investments to reconstruction and rehabilitation, full recovery is not achieved or, worse, improved and more resilient structures are not put in place. Thus vulnerability is increased and there is a higher exposure to increased damage and losses in future events. In this sense, climate change scenarios require additional investment and utilize resources to repair negative impacts and increase the cost of development projects if adaptation measures are taken.

In a similar line of research and analysis, the International Institute for Applied Systems Analysis (IIASA) is considering future impacts of climate change. Studying data on damages due to natural disasters expressed as percent of world GDP, an upward trend in the climate-related damages can be discerned while the damages due to other events such as earthquakes and volcanic eruptions are characterized by large spikes, but not a substantial increase over time. Losses due to climate related events seem to be increasing, whereas the losses due to other events stay approximately constant in relation to world GDP (CRED 2004; Madison 1995).

Economic costs of sea-level rise have been estimated for the Wadden Sea ecosystem (bathing German, Dutch and Danish shores), where "for the most realistic scenario (25 cm of sea-level rise in 50 years): (i) Changes in the Wadden Sea ecosystem (morphology and biology) are expected not to be substantial, (ii) costs for coastal defence might increase by 5 to 15%; and for the "worst-case" scenario (50 cm of sea-level rise in 50 years): (i) the capacity of the system to balance changes might become exhausted, (ii) the Wadden Sea tidal basins might start to evolve into tidal lagoons, (iii) these morphological changes will substantially influence the biology, (iv) and the costs for coastal defence might double (CPSL 2001).

The existing literatures are, in these ways, useful in considering possible costs of climate change for industry, settlement, and society; but they are not sufficient to estimate costs globally or regionally associated with any specific scenario of climate change. All that can be said at the present time is that economic costs of climate change impacts at a large national or regional scale are unlikely to represent more than several percent of the value of the total economy, except for possible abrupt changes (HIGH CONFIDENCE), while economic and other human costs of climate change impacts for some economic sectors in some smaller locations, especially in developing countries, could in the short run exceed 25 percent (HIGH CONFIDENCE).

7.6 Adaptation: practices, options, and constraints

Challenges to adapt to observed and expected 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 decentralized or dependent on centrally initiated policy changes and social collaboration, gradual and evolutionary or rooted in abrupt changes in settlement patterns or economic activity. Adaptations are probably most notable in seacoast 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 virtually unlimited

Adaptation strategies vary widely by 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 multisectoral, such as improving climate forecasting at a local scale, emergency preparedness, and public education. One example of cross-cutting adaptation is improving information and institutions for emergency preparedness. In a number of cases, systematic disaster preparedness at community level has helped reduce death tolls; for instance, one study (Winchester, 2000) reports that new warning systems and evacuation procedures in Andhra Pradesh, India, reduced deaths from coastal tropical cyclones by 90 percent, comparing 1979 with 1977. The effectiveness of such systems in reaching marginal populations and their responses to such warnings, however, is uneven.

Other strategies are focused on a sector, such as water, agriculture, forests, and health (see Chapters 3, 4, 5, and 8). Some are geographically focused, such as coastal area and floodplain adaptation, which can involve such initiatives as changing land uses in highly vulnerable areas and protecting critical areas; in fact, adaptation tends very often to be context-specific, working within larger market and policy structures (Adger, *et al*. 2005).

There is a considerable literature on adaptations to climate *variation* and vulnerabilities to *extreme events*, but research on potentials and costs of adaptation to *climate change* is still in an early stage. 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. More generally, there is little scientific basis as yet for assessing possible limits of adaptation, especially differences among locations and systems, which has obvious implications for mitigation policies aimed at greenhouse gas stabilization levels that avoid dangerous impacts; and the knowledge base about costs of adaptation is less well-developed than the knowledge base about possible potentials.

7.6.1. Industry

The extent to which potential vulnerabilities of industry are significant economically 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 (energy and other network industries), fixed or weather-dependent resources (mining and quarrying, food and agriculture) and extended supply chains (an increasing proportion of manufacturing 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), and to adapt to become more climate-proof over the longer term. It is also clear that many other economic and social factors will play a more important in influencing industrial development 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.

There is now considerable evidence emerging in Europe, North America and Japan that the construction and transportation sectors are paying more attention to climate change impacts and the need for adaptation (Liso *et al* 2003, Shimoda, 2003, Salagnac, 2004). To give one example, the $1 billion 12.9 kilometre Confederation Bridge between New Brunswick and Prince Edward Island, 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 whole range of technical advice is now available to planners, architects and engineers on climate impacts risk assessment (UKCIP, 2002, Willows and Connell, 2003) and specialised advice on options for responding to these risks (Lancaster *et al*., 2004, Vivien *et al*., 2005). Early estimates of possible costs of adaptation measures are also available. O'Connell and Hargreaves (2004) show that measures to reduce wind damage, flood risk and indoor heat would add about 5 percent to the cost of a typical new house in New Zealand.

What is apparent is that business adaptations can take a wide variety of forms. They may include changes in business processes, technologies or business models (Hertin *et al*, 2003). Also apparent is that many of these adaptations represent incremental adjustments to current business activities (Berkhout *et al*., forthcoming). For instance, many techniques already exist for adapting buildings in response to greater risks of ground movement, higher temperatures and driving rain. For more structural adaptations, such as choice of location for industrial facilities, planning guidance and risk management by insurers will play a major role.

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 areas vulnerable to flooding, coastal erosion and land slips, and is more likely to be tied to natural resources that may be affected by changing climates.

Potentials for adaptation to climate change in informal industry 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 productive activities, and reducing stresses associated with other operating conditions to add general resiliency. But most adaptations that are substantial rather than marginal may call for an awareness of threats and alternatives 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.

7.6.2 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 likely also be associated with changes in costs/prices, applications of technology, and attention to risk financing. For instance, wholesale and retail trade 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 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.

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 ch 14), beach enhancement (see Ch 6), or additional air-conditioning. 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 two categories of adaptation processes: technological and behavioural. While tourism providers tend to focus on the former (preserving tourism assets), 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). Adaptive capacities and strategies are likely to vary among 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. Very small businesses might also prove resilient to some degree, as they often have returning guests and can survive economically on smaller guest numbers, at least until some thresholds are reached and the entire destination collapses.

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, it is likely that air transport, now the means of transport of 42% of all international tourists, will become more expensive (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 (Peeters 2003, 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 (Gossling 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 (see Chapter 16), 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.

Insofar as premiums for contracts are collected and renewed annually, the insurance industry is highly adaptive to changes in catastrophe risk. Trends towards 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 potentially contribute to this robustness (European Environment Agency, 2004). Increased use of seasonal hurricane forecasts and real-time loss modelling for slow-onset weather hazards (such as hurricanes) offers the potential for the insurance industry to better manage risks, including taking out short-term hedges, and will influence the trading of catastrophe bonds and other capital market products (Malmquist and Michaels, 1999)

7.6.3 Utilities/infrastructure

The most general form of adaptation by infrastructures vulnerable to impacts of climate change is investment in increased resiliency, for instance new sources of water supply for urban areas or designing infrastructure additions or changes to withstand a wider range of stresses. 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 practices. Resilience may be defined as the ability of a system to respond to external pressures without losing actual or potential functions (Klein *et al*., 1998), the probability of recovery from a failure once a failure has occurred (Vogel *et al*., 1999), the ability of a system to return to its normal status after external changes exceed the norm of natural fluctuations (Vilcheck, 1998), or how quickly a system is able to recover from a disturbance (Maier, 2001).

In a situation where climate change -- observed or projected -- indicates needs 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 selection of physical structure designs that can handle more extreme conditions for operation.

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, and 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 (see Chapter 11, box 11.1).

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 is anticipated to decline to its original design standard of 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 £4 billion will be required within the next 40 years (London Climate Change Partnership 2004).

7.6.4 Human settlement

For settlements, adaptation strategies include assuring effective governance, increasing resilience of urban physical infrastructures, increasing resilience of linkage infrastructures, changing urban form, reducing heat-island effects, reducing emissions and improving waste handling, providing financial mechanisms for increasing resiliency, targeting assistance programs for especially impacted segments of the population, and adopting sustainable community development practices, incorporating possible climate-change impacts (Wilbanks and others, 2005). The choice of strategies from among the options depends in part on their relationships with other processes of social and ecological transformations (O’Brien and Leichenko, 2000).

The recent case study of London demonstrates that climate change could bring opportunities as well as impacts, depending on socioeconomic conditions, institutional settings, and cultural and consumer values. These might include (for settlements sharing London’s physical and social features): an increase in outdoor lifestyles such as increased use of open spaces for “open air festivals” and an increase in cycling and walking which would reduce pressures on transport system; an opportunity to develop sustainable houses and neighbourhoods; climate change as a driver for greater environmental awareness and action; increased demand for “green products and services” including renewable energy; increase in inbound tourism and leisure markets; and new opportunities for carbon trading services (London Climate Change Partnership 2004).

One of the opportunities, especially where settlements are growing in size, is to work toward constructing a more sustainable city, in many ways improving the quality of the urban environment for most of its citizens. Urban planning can take into account the construction density, the distribution and impact of the heat emissions, and the importance of green spaces in order to reduce heat island effects that add to climate warming, and promote decreased air conditioning demands. Currently, several cities in the Arizona, USA region are incorporating concerns regarding urban warming into planning codes and practices (Baker *et al*, 2002). Particular considerations include site and building design, urban microclimates (e.g., Assis and Frota, 1999; Capeluto *et al*, 2003), the use of vegetation (e.g., Gómez *et al*, 2004; Lindsey, 1999;

Shashua-Bar and Hoffman, 2000), and stakeholder participation.

Models have been established to predict 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 quantified in Tel-Aviv, Israel (Shashua-Bar and Hoffman, 2002, 2004). Research in that city also showed that the cooling effect of small green areas was significant. The cooling effect was perceptible at a range up to 100m; so that gardens 0.1ha in area were suggested to be sited 200m apart. The cooling effect of trees along a street reached about 1km, and was effective in reducing traffic-generated heating effects (Shashua-Bar and Hoffman, 2000).

Other adaptive responses by settlements to concerns about climate change tend to focus on institutional development, often including improved structures for coordination between individual settlements and other parties, such as enhanced regional water supply planning and infrastructure development (Rosenweig and Solecki 2001a). Often, settlements exist in a splintered political landscape that makes coherent collaborative adaptation strategies difficult to contemplate. Policy responses are also hampered by the reactive nature of much policymaking, 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 "analogs" circumstances in recent history when those settlements have confronted other environmental management challenges (AAG, 2003). In many cases, settlements have acted under the pressure of immediate crises to seek solutions by going beyond their own borders (e.g., Rees, 1992; Tarr, 1996).

7.6.5 Social issues

Most forms of adaptation are social processes aimed at reducing the sensitivity of human settlements, industry and services to climate change, to alter their exposure to climate change, and to increase their resilience. One of the central issues for climate change responses concerns the adaptability of human societies and their institutions, precisely because "adapting to climate change involves cascading decisions across a landscape made up of agents from individuals, firms and civil society, to public bodies and government" operating at different scales (Adger *et al*. 2005: 481).

As the need to design policies to respond to the negative impacts of climate change increases, more attention has been paid to specific ways to improve adaptive capacity—that is, the "potential and capability to change to a more desirable state in the face of the impacts or risks of climate change." (Brooks and Adger, 2005). Whereas there is growing consensus around the factors believed to build adaptive capacity–such as free flow of ideas, knowledge and technology, more flexible and efficient institutions and governance schemes, policies that enhance human, social and political capital and more equitable flow of resources—the identification of specific ways through which capacity can be effectively built in the context of policy systems has been more difficult.

Considering that climate is one of many sources of stress affecting socio-economic and political structures, the complexity of building adaptive capacity can overwhelm already overtaxed policy systems especially in less developed countries (Eakin and Lemos, in review). For example, the globalization of ideas may provide policy systems with new tools for policy design and implementation that in principle should build conditions for adaptive capacity. These include efficient use of technology, free flow of information, democratic decentralization, construction of social capital, and synergistic public-private partnerships. Conversely, globalization has introduced new and diverse challenges by simultaneously encouraging decentralized decision-making and broadening the range of problems governments are called upon to address. Globalization and market-oriented policies may also have further strained the resource basis of nation-states and contributed to growing inequalities (Huber and Solt 2004, Wade 2004), that, in turn, will shape levels of vulnerability and resilience to climate change. Processes such as market-oriented policy reform and the proliferation multilateral trade agreements have in some cases complicated national government action by transferring power both to lower scales of decision-making (decentralization) as well as to the private sector.

While decentralization theoretically allows for better decision-making at the local level, it may also significantly constrain the state's ability to regulate and distribute resources that may be critical to facilitate adaptation (Eakin and Lemos, in review). For example, on the one hand, the attempt to reform water management to promote efficient and sustainable water use in countries such as Chile, Bolivia, Argentina, Mexico and South Africa have met with a myriad of constraining factors including lacklustre and faulty markets, lack of institutional capacity, flawed societal participation, opposition from users, and insufficient political support (Wester *et al*. 2003, Bauer 1997, Nickson and Vargas 2002, Loftus and McDonald 2001). On the other hand, the design of participatory, integrated, and decentralized water management institutions such as in Brazil's recent water reform is likely to build adaptive capacity to climate change by improving availability and access to technology, involving stakeholders, and encouraging sustainable use (Lemos and Oliveira 2004).

Certain criteria for assessing the success of adaptation actions (effectiveness, efficiency, equity and legitimacy: Adger *et al*. 2005) are useful in characterizing the social and institutional dimensions of adaptation by industries, services and human settlements. Adaptation actions such as coastal planning, flood embankment, or air conditioning following heat-waves in Western Europe may be effective in achieving one goal (protection against coastal erosion or flooding, comfort against high temperatures), but they may: a) inflict externalities on neighbouring coastal areas, other countries, or to the globe (via increased GHG emissions) and be therefore non sustainable; or b) reduce the abilities of others to adapt to climate change (see Box 7-1, Adger *et al*. 2005).

The effectiveness of adaptation actions relates not only to their ability to achieve certain goals, but also to issues of equity and perceived legitimacy (Adger, Huq. and Mace 2005). The former refers to the distribution of benefits and negative effects of climate change across society and to procedural questions (i.e., "how and by whom decisions on adaptive responses are made" (Thomas and Twyman 2005: 468). Adaptive capacity is highly uneven across human societies, and high national levels of adaptive capacity mask the barriers and constraints to adaptation among those who are most vulnerable to climate change (O'Brien *et al*. forthcoming). It has been shown that usually responses to floods (waste clearance or aid flows) only provide benefits to some sectors (Pelling 1999). Adaptation practices by natural-resource-reliant communities may enhance the differentiation of well-being in rural communities (Thomas and Twyman 2005). Public programs such as the Financial Assistance Programme in Botswana (Thomas and Twyman 2005) may contribute to increase inequality, induce unsustainable natural-resource use and inhibit local creativity in adaptation. Procedural justice is closely related with legitimacy, defined as the "extent to which decisions are acceptable to participants and non-participants that are affected by those decisions. Legitimacy can be gained as well as compromised through the evolution of adaptation strategies" (Adger *et al*. 2005: 481).

Two more issues need attention when considering the social and institutional dimensions of adaptation: livelihood strategies and resilience (sustainability). Rural communities in Africa and Latin America have developed the capacity to adapt and build a key element of resilience: the diversification of their livelihood strategies, which may happen within their households, but also within agriculture and beyond activities reliant on the environment (Thomas and Twyman 2005). One consequence of this process, the movements of rural population to urban centres, may put stress on urban services and environments and by this increase farmers' vulnerability to climate-related urban hazards (Tacoli 2002). As of resilience, measures and actions focusing on development i.e. on reducing poverty and/or increasing the access to resources (e.g. mangrove planting to reduce the vulnerability of coastal communities in Vietnam) may enhance the resilience of affected communities or economic activities. They may in other words result in win-win situations (reduction of both present-day vulnerability, and vulnerability to climate variability and change). One way to achieve these goals is through "adaptive management"—management schemes that "learn" from previous practical experiences based on assessment, monitoring, and adjustment—although knowledge of the ways to promote it is incomplete. In addition, policy focusing on adaptation has the potential to create positive synergies between outcomes (better managed natural and social systems) and processes (adoption of good governance structures that promote democratic decision making, participatory and stakeholder-driven management strategies, equity, transparency, and accountability) which in turn will yield more resilient systems.

In general, the capacity to adapt to climate change tends to be related to levels of economic development, including economic productivity and access to investment resources. However, other social, economic, political, institutional, environmental, and cultural factors can either promote or constrain adaptation; thus the link between adaptive capacity and economic development is not straightforward. In addition, temporal scale is a critical determinant of the capacity of human systems to adapt to climate change in several ways: past adaptations exert an influence on current coping capacity, and current capacities provide a basis from which future coping capacity may evolve. Nevertheless, the features of future climate changes may be very different than in the past, and rapid changes are more difficult to absorb without painful costs than gradual change (see chapter 16).

The kinds of social and economic effects described above also suggest cultural impacts: i.e., impacts on patterns of behaviour, including ideas, beliefs, customs, and codes -- especially in traditional cultures where livelihoods are deeply imbedded in tradition. An indication of what could be ahead for other traditional cultures is the current experience of indigenous groups in the Arctic such as the Inuit (Fenge 2001; Kruse *et al*., 2004; ACIA).

Box 7.9: Indigenous Knowledge For Adaptation

Most adaptations to reduce vulnerabilities to climate change are place-based, focused on realities in local areas as they are viewed by local people (ARW 2003; AIACC, undated). In almost every case, a part of the essential knowledge base for determining what kinds of adaptive behaviours and actions make sense for risks to industry, settlement, and society is <u>local</u> knowledge, whether the context is an isolated rural area in a developing country or an urban neighbourhood in an industrialized country (e.g., Kruse *et al*., 2004; Nichols *et al*., 2004). This is particularly the case when adaptations are concerned with social structures and norms, with settlement characteristics and patterns, and with informal industry and other economic activity (Reid *et al*., 2005).

The central issues for adaptation to climate change by industry, settlements, and society are 1) impact types and magnitudes and their associated adaptation requirements, 2) potential contributions by adaptation strategies to reducing stresses and impacts, 3) costs of adaptation strategies, and 4) 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 organization: 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 industrialized countries.

In industries, communities, and societies at large, the most common approach is likely to be decentralized and autonomous, using information to make adjustments appropriate to each context and in many cases cooperating with others facing similar challenges. If such "autonomous" approaches are unlikely to be adequate in keeping impacts within a bearable range, the knowledge base on disaster response suggests that a number of other 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; economic systems that offer access to alternatives; increased attention to adaptive structures that are locally appropriate, geographically and/or sectorally; contingency planning, which may include strategic stockpiles; incorporating climate change vulnerability into land use planning for the long term; and in some cases physical facility investment, such as flood walls, beach restoration, or emergency shelters.

Adaptations, however, are not necessarily optimal. For example, recent stakeholder evaluations of scenarios of extreme sea level rise in three regions of Europe showed a variety of responses, including cases of a failure of public action resulting in social and economic impacts (Londsdale *et al*. 2005; Poumadère *et al*. 2005; and Olsthoorn 2005).

Somewhat more specifically:

1 In many cases, prospects for adaptation depend on the magnitude and rate of climate change: adaptation is often more feasible when climate change is moderate and gradual than when it is massive and/or abrupt (VERY HIGH CONFIDENCE).

2 Climate change adaptation strategies are inseparable from increasingly strong and complex global linkages, which mean that no system is isolated from what is happening in other systems. Urban and rural are interconnected, as are industrialized and developing societies. This issue is becoming more salient as the globalised economy becomes more locally specialized, less resilient, and more interdependent (VERY HIGH CONFIDENCE).

3 Adaptation depends fundamentally on such linkages, which shape potentials for human agency. For instance, adaptation decisions for local activities owned or controlled by external systems involve distinctly different processes from adaptation decisions for local activities that are under local control (VERY HIGH CONFIDENCE).

4 Climate change is one of many challenges to human institutions to manage risks. In any society, institutions have evolved 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 potentials to be foundations for a number of kinds of adaptations (HIGH CONFIDENCE).

5 The relatively long time horizon of climate change and its impacts makes the potential for technological change a critical issue in evaluating adaptation prospects. Anticipated vulnerabilities and possible impacts in the mid to long range can in many cases be addressed, at least in part, by research and development agendas. Targeting R&D on critical needs can add significantly to adaptability; on the other hand, failing to do so can leave gaps in coping capacities that are difficult to fill through institutional and policy response (HIGH CONFIDENCE).

6 Adaptation actions in one context can be effective in achieving their goals, narrowly interpreted, but at the same time they may have more complex effects of other types, such as reducing support for mitigation efforts or reducing resources available to address vulnerabilities elsewhere (MEDIUM CONFIDENCE).

7.7 Implications for sustainable development

Sustainable development is largely about people and their well-being, in a context where nature-society imbalances can threaten economic and social stability. Possible impacts of climate change on economic production and services, human settlements, and human societies are likely to be important dimensions of this over the next century, because climate is a significant factor in the sustainable development of human communities, activities, and societies (e.g., Downing 2002).. Simply stated, climate change has the potential to affect many aspects of human development, in some cases positively but in some cases 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)..

The most serious sustainable development issues associated with climate change impacts on the subjects of this chapter are: 1) threats to vulnerable regions and localities in developing countries from ecological changes 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, semi-arid regions, and low-lying islands and 2) prospects of low-probability but high-consequence abrupt climate changes that would exceed the coping 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 changes in temperature, precipitation, and other implications of climate change are less than in less developed economies; but effects of crossing thresholds of sustainability can be especially large in "brittle" industrialized economies: i.e., economies whose foundations are both rigid and frail.

In general, however, climate change is an issue for sustainable development mainly as *one of many* sources of possible stress (e.g., Wilbanks, 2003c; O'Brien and Leichenko, 2000 and 2003). Its significance lies primarily in its interactions with stresses and stress-related thresholds of a variety of other kinds, 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 globalizing 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 negative effects of climate change on sustainable development (Wilbanks, 2003c).

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 specialization in a single economic activity if that activity is climate-sensitive; development that is more diversified is likely to be less risky.

In addition, 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 vulnerable, 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 1) 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; 2) improving the 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; 3) relationships between specific effects in one location and the well-being of other locations, through linkages in inflows/outflows and interregional trade and migration flows; and 4) 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).

All of these issues are very high priorities for research in both industrialized and developing countries, with certain differences in emphasis related to the different development contexts. As a broad generalization, the primary impact issue for industrialized 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 and considering possible responses to threats from low-probability/high consequence contingencies. The primary impact issue for developing countries is the possibility that climate change, combined with other stresses affecting sustainable development, could jeopardize 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, emphasizing especially vulnerable areas such as coastal areas in lower-income developing countries and especially vulnerable sectors such as tourism. Others call for attention to cross-sectoral and multi-locational relationships between climate change adaptation and mitigation (Chapter 18), including both complementarities and tradeoffs 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 analogs drawn from other experiences with environmental changes and stresses (e.g., Association of American Geographers 2003).

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