18

Adaptation to Climate Change in the Context of Sustainable Development and Equity

BARRY SMIT (CANADA) AND OLGA PILIFOSOVA (KAZAKHSTAN)

Lead Authors:
I. Burton (Canada), B. Challenger (Antigua and Barbuda), S. Huq (Bangladesh), R.J.T. Klein (Germany/The Netherlands), G. Yohe (USA)

Contributing Authors:
N. Adger (UK), T. Downing (UK), E. Harvey (Canada), S. Kane (USA), M. Parry (UK), M. Skinner (Canada), J. Smith (USA), J. Wandel (Canada)

Review Editors:
A. Patwardhan (India) and J.-F. Soussana (France)

CONTENTS

EXECUTIVE SUMMARY

Adaptation refers to adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change.

Estimates of likely future adaptations are an essential ingredient in *impact and vulnerability assessments*. The extent to which ecosystems, food supplies, and sustainable development are vulnerable or "in danger" depends both on exposure to changes in climate and on the ability of the impacted system to adapt. In addition, adaptation is an important policy *response* option, along with mitigation. There is a need for the development and assessment of planned adaptation initiatives to help manage the risks of climate change.

Adaptations vary according to the system in which they occur, who undertakes them, the climatic stimuli that prompts them, and their timing, functions, forms, and effects. In unmanaged natural systems, adaptation is autonomous and reactive; it is the process by which species and ecosystems respond to changed conditions. This chapter focuses on adaptations consciously undertaken by humans, including those in economic sectors, managed ecosystems, resource use systems, settlements, communities, and regions. In human systems, adaptation is undertaken by private decisionmakers and by public agencies or governments.

Adaptation depends greatly on the *adaptive capacity* or adaptability of an affected system, region, or community to cope with the impacts and risks of climate change. The adaptive capacity of communities is determined by their socioeconomic characteristics. Enhancement of adaptive capacity represents a practical means of coping with changes and uncertainties in climate, including variability and extremes. In this way, enhancement of adaptive capacity reduces vulnerabilities and promotes sustainable development.

Adaptation to climate change has the potential to substantially reduce many of the adverse impacts of climate change and enhance beneficial impacts—though neither without cost nor without leaving residual damage.

The key features of climate change for vulnerability and adaptation are those related to variability and extremes, not simply changed average conditions. Most sectors and regions and communities are reasonably adaptable to changes in average conditions, particularly if they are gradual. However, these communities are more vulnerable and less adaptable to changes in the frequency and/or magnitude of conditions other than average, especially extremes.

Sectors and regions will tend to adapt autonomously to changes in climate conditions. Human systems have evolved a wide range of strategies to cope with climatic risks; these strategies have potential applications to climate change vulnerabilities. However, losses from climatic variations and extremes are substantial and, in some sectors, increasing. These losses indicate that autonomous adaptation has not been sufficient to offset damages associated with temporal variations in climatic conditions.The ecological, social, and economic costs of relying on reactive, autonomous adaptation to the cumulative effects of climate change are substantial.

Planned anticipatory adaptation has the potential to reduce vulnerability and realize opportunities associated with climate change, regardless of autonomous adaptation. Implementation of adaptation policies, programs, and measures usually will have immediate benefits, as well as future benefits. Adaptation measures are likely to be implemented only if they are consistent with or integrated with decisions or programs that address nonclimatic stresses. The costs of adaptation often are marginal to other management or development costs.

The capacity to adapt varies considerably among regions, countries, and socioeconomic groups and will vary over time. The most vulnerable regions and communities are those that are highly exposed to hazardous climate change effects and have limited adaptive capacity. Countries with limited economic resources, low levels of technology, poor information and skills, poor infrastructure, unstable or weak institutions, and inequitable empowerment and access to resources have little capacity to adapt and are highly vulnerable.

Enhancement of adaptive capacity is a necessary condition for reducing vulnerability, particularly for the most vulnerable regions, nations, and socioeconomic groups. Activities required for the enhancement of adaptive capacity are essentially equivalent to those promoting sustainable development. Climate adaptation and equity goals can be jointly pursued by initiatives that promote the welfare of the poorest members of society—for example, by improving food security, facilitating access to safe water and health care, and providing shelter and access to other resources. Development decisions, activities, and programs play important roles in modifying the adaptive capacity of communities and regions, yet they tend not to take into account risks associated with climate variability and change. Inclusion of climatic risks in the design and implementation of

development initiatives is necessary to reduce vulnerability and enhance sustainability.

Current knowledge of adaptation and adaptive capacity is insufficient for reliable prediction of adaptations; it also is insufficient for rigorous evaluation of planned adaptation options, measures, and policies of governments. Climate change vulnerability studies now usually consider adaptation, but they rarely go beyond identifying adaptation options that might be possible; there is little research on the dynamics of adaptation in human systems, the processes of adaptation decisionmaking, conditions that stimulate or constrain adaptation, and the role of nonclimatic factors. There are serious limitations in existing evaluations of adaptation options: Economic benefits and costs are important criteria but are not sufficient to adequately determine the appropriateness of adaptation measures; there also has been little research to date on the roles and responsibilities in adaptation of individuals, communities, corporations, private and public institutions, governments, and international organizations. Given the scope and variety of specific adaptation options across sectors, individuals, communities, and locations, as well as the variety of participants—private and public—involved in most adaptation initiatives, it is probably infeasible to systematically evaluate lists of particular adaptation measures; improving and applying knowledge on the constraints and opportunities for enhancing adaptive capacity is necessary to reduce vulnerabilities associated with climate change.

18.1. Introduction: Adaptation and Adaptive Capacity

Adaptation is adjustment in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. This term refers to changes in processes, practices, or structures to moderate or offset potential damages or to take advantage of opportunities associated with changes in climate. It involves adjustments to reduce the vulnerability of communities, regions, or activities to climatic change and variability. Adaptation is important in the climate change issue in two ways—one relating to the assessment of impacts and vulnerabilities, the other to the development and evaluation of response options.

Understanding expected adaptations is essential to *impact and vulnerability assessment* and hence is fundamental to estimating the costs or risks of climate change (Fankhauser, 1996; Yohe *et al*., 1996; Tol *et al*., 1998; UNEP, 1998; Smit *et al*., 1999; Pittock and Jones, 2000). Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC) refers to "dangerous" human influences on climate in terms of whether they would "allow ecosystems to adapt, ensure food production is not threatened, and enable economic development to proceed in a sustainable manner." The extent to which ecosystems, food supplies, and sustainable development are vulnerable or "in danger" depends on their exposure to climate change effects and on the ability of impacted systems to adapt. Thus, to assess the dangerousness of climate change, impact and vulnerability assessments must address the likelihood of autonomous adaptations (see Figure 18-1).

Adaptation also is considered an important *response option or strategy*, along with mitigation (Fankhauser, 1996; Smith, 1996; Pielke, 1998; Kane and Shogren, 2000). Even with reductions in greenhouse gas (GHG) emissions, global temperatures are expected to increase, other changes in climate—including extremes—are likely, and sea level will continue to rise (Raper *et al.*, 1996; White and Etkin, 1997; Wigley, 1999). Hence, development of planned adaptation strategies to deal with these risks is regarded as a necessary complement to mitigation actions (Burton, 1996; Smith *et al*., 1996; Parry *et al*., 1998; Smit *et al*., 1999) (see Figure 18-1). Article 4.1 of the UNFCCC commits parties to formulating, cooperating on, and implementing "measures to facilitate adequate adaptation to climate change." The Kyoto Protocol (Article 10) also commits parties to promote and facilitate adaptation and deploy adaptation technologies to address climate change.

Adaptive capacity is the potential or ability of a system, region, or community to adapt to the effects or impacts of climate change. Enhancement of adaptive capacity represents a practical means of coping with changes and uncertainties in climate, including variability and extremes. In this way, enhancement of adaptive capacity reduces vulnerabilities and promotes

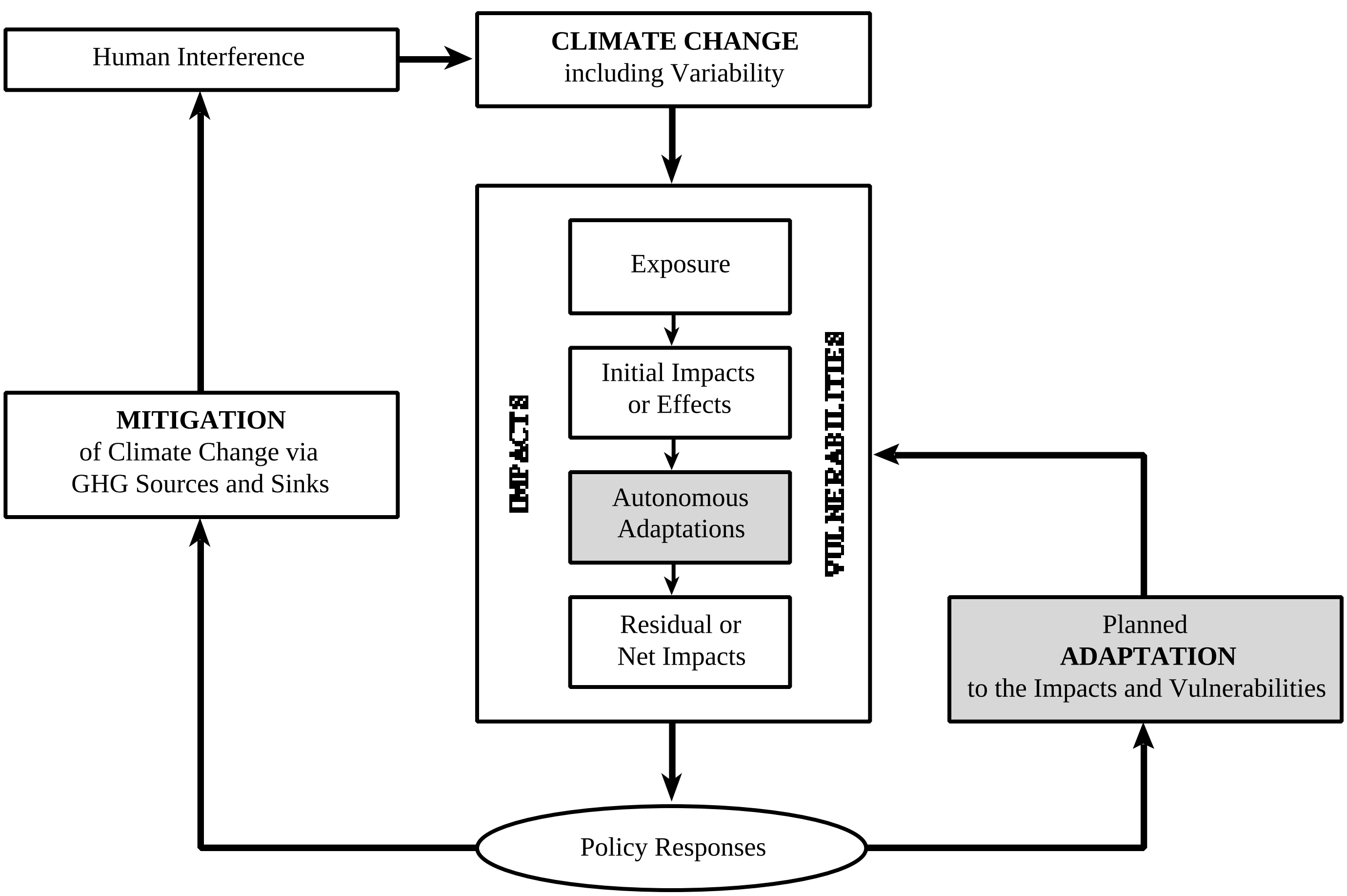

Figure 18-1: Places of adapatation in the climate change issue (Smit *et al*., 1999).

sustainable development (Goklany, 1995; Burton, 1997; Cohen *et al.*, 1998; Klein, 1998; Rayner and Malone, 1998; Munasinghe, 2000; Smit *et al.*, 2000).

Considerable attention has been devoted to the characteristics of communities, countries, and regions that influence their propensity or ability to adapt and hence their vulnerability to risks associated with climate change. These *determinants of adaptive capacity* relate to the economic, social, institutional, and technological conditions that facilitate or constrain the development and deployment of adaptive measures (e.g., Bohle *et al.*, 1994; Rayner and Malone, 1998; Kelly and Adger, 1999).

18.2. Adaptation Characteristics and Processes

Adaptation refers both to the *process* of adapting and to the *condition* of being adapted. The term has specific interpretations in particular disciplines. In ecology, for example, adaptation refers to changes by which an organism or species becomes fitted to its environment (Lawrence, 1995; Abercrombie *et al.*, 1997); whereas in the social sciences, adaptation refers to adjustments by individuals and the collective behavior of socioeconomic systems (Denevan, 1983; Hardesty, 1983). This chapter follows Carter *et al.* (1994), IPCC (1996), UNEP (1998),

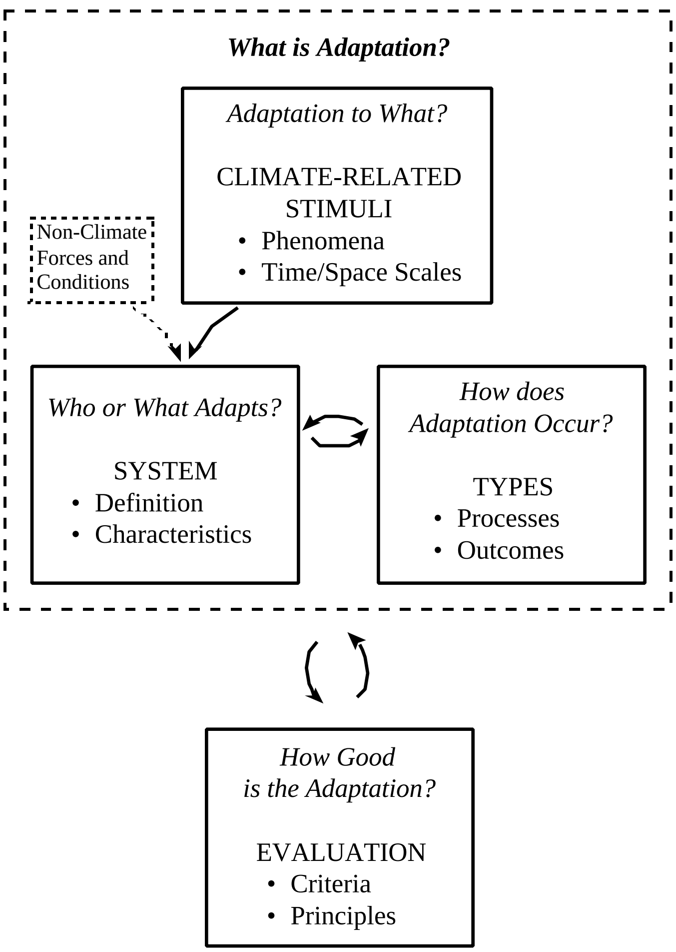

Figure 18-2: Adaptation to climate change and variability (from Smit *et al*., 2000).

and Smit *et al.* (2000) in a broad interpretation of adaptation to include adjustment in natural or human systems in response to experienced or future climatic conditions or their effects or impacts—which may be beneficial or adverse.

18.2.1. Components and Forms of Adaptation

As both a process and a condition, adaptation is a relative term: It involves an alteration in something (the system of interest, activity, sector, community, or region) to something (the climate-related stress or stimulus). Description of an adaptation requires specification of who or what adapts, the stimulus for which the adaptation is undertaken, and the process and form it takes (Downing *et al.*, 1997; Krankina *et al.*, 1997; UNEP, 1998; Pittock *et al*., 1999; Risbey *et al*., 1999; Reilly and Schimmelpfennig, 2000). These elements are summarized in Figure 18-2 and addressed in turn in subsequent subsections.

18.2.2. Climate Stimuli for Adaptation

Most impact and adaptation studies to date have been based on climate change scenarios that provide a limited set of possible future climates—invariably specified as average annual conditions, such as temperature and moisture. Yet the climate change-related stimuli for which adaptations are undertaken (i.e., adaptation to what?) are not limited to changes in average annual conditions; they include variability and associated extremes. Climatic conditions are inherently variable, from year to year and decade to decade. Variability goes along with, and is an integral part of, climate change (Mearns *et al*., 1997; Karl and Knight, 1998; Berz, 1999; Hulme *et al*., 1999): A change in mean conditions actually is experienced through changes in the nature and frequency of particular yearly conditions, including extremes (see Figure 18-3). Thus, adaptation to climate change necessarily includes adaptation to variability (Hewitt and Burton, 1971; Parry, 1986; Kane *et al.*, 1992b; Katz and Brown, 1992; Downing, 1996; Yohe *et al.*, 1996; Smithers and Smit, 1997; Smit *et al.*, 1999). Downing *et al.* (1996), Etkin (1998), Mileti (1999), and others use the term "climate hazards" to capture those climate stimuli, in addition to changes in annual averages, to which the system of interest is vulnerable. Climate change stimuli are described in terms of "changes in mean climate and climatic hazards," and adaptation may be warranted when either of these changes has significant consequences (Downing *et al.*, 1997). In water resource management, changes in the recurrence interval of extreme conditions, which are associated with changes in means, are the key stimuli (Beran and Arnell, 1995; Kundzewicz and Takeuchi, 1999).

Furthermore, for most systems and communities, changes in the mean condition commonly fall within the coping range (see Figure 18-3), whereas many systems are particularly vulnerable to changes in the frequency and magnitude of extreme events or conditions outside the coping range (Baethgen, 1997; Schneider, 1997; Rayner and Malone, 1998; Kelly and Adger,

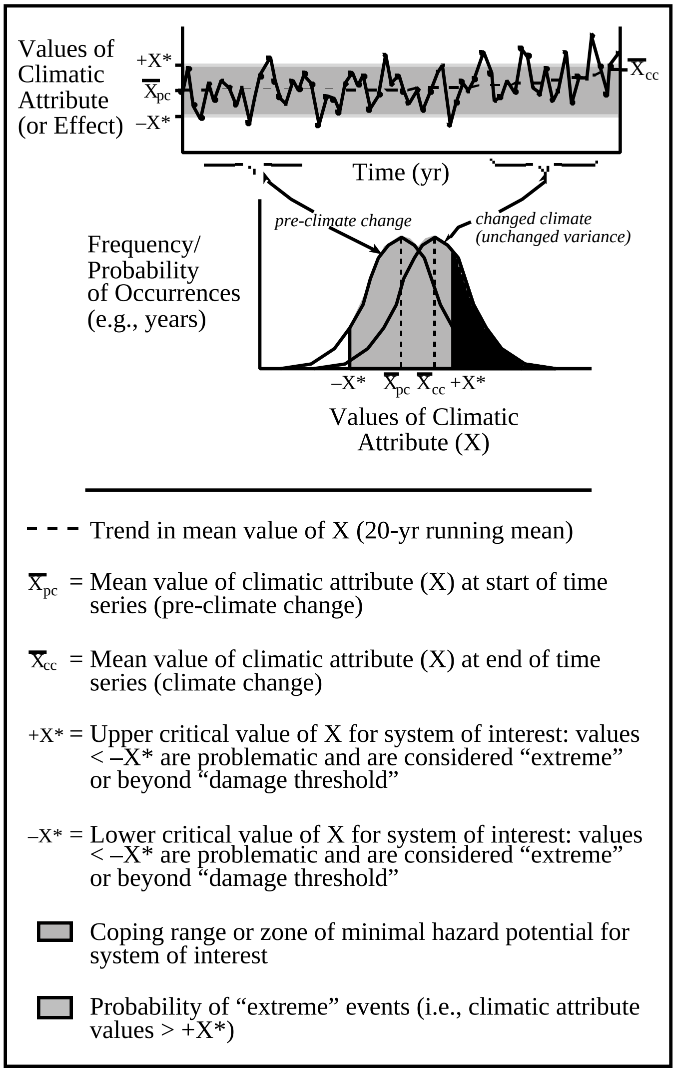

Figure 18-3: Climate change, variability, extremes, and coping range (after Hewitt and Burton, 1971; Fukui, 1979; Smit *et al*., 1999; and others).

1999). Interannual variations are key stimuli in many sectors (Rosenzweig, 1994; Adams *et al*., 1995; Mearns *et al*., 1997; Bryant *et al*., 2000).

Natural and human systems have adapted to spatial differences in climate. There also are examples of adaptation (with varying degrees of success) to temporal variations—notably, deviations from the annual average conditions on which climate change scenarios focus. Many social and economic systems—including agriculture, forestry, settlements, industry, transportation, human health, and water resource management—have evolved to accommodate some deviations from "normal" conditions, but rarely the extremes. This capacity of systems to accommodate variations in climatic conditions from year to year is captured in Figure 18-3 in the shaded "coping range." This capacity also is referred to as the vulnerability or damage threshold (Pittock and Jones, 2000). The coping range, which varies among systems and regions, need not remain static, as depicted in Figure 18-3. The coping range itself may change (move up or down, expand or contract), reflecting new adaptations in the system (De Vries, 1985; de Freitas, 1989; Smit *et al.*, 2000). The coping range indicated in Figure 18-3 can be regarded as the adaptive capacity of a system to deal with current variability. Adaptive capacity to climate change would refer to both the ability inherent in the coping range and the ability to move or expand the coping range with new or modified adaptations. Initiatives to enhance adaptive capacity (Section 18.6) would expand the coping range.

18.2.3. Adaptation Types and Forms

Adaptations come in a huge variety of forms. Adaptation *types* (i.e., how adaptation occurs) have been differentiated according to numerous attributes (Carter *et al.*, 1994; Stakhiv, 1994; Bijlsma *et al.*, 1996; Smithers and Smit, 1997; UNEP, 1998; Leary, 1999; Bryant *et al.*, 2000; Reilly and Schimmelpfennig, 2000). Commonly used distinctions are purposefulness and timing. Autonomous or spontaneous adaptations are considered to be those that take place—invariably in reactive response (after initial impacts are manifest) to climatic stimuli—as a matter of course, without the directed intervention of a public agency. Estimates of these autonomous adaptations are now used in impact and vulnerability assessment. Planned adaptations can be either reactive or anticipatory (undertaken before impacts are apparent). In addition, adaptations can be short or long term, localized or widespread, and they can serve various functions and take numerous forms (see Table 18-1).

Adaptations have been distinguished according to individuals' choice options as well, including "bear losses," "share losses," "modify threats," "prevent effects," "change use," and "change location" (Burton *et al*., 1993; Rayner and Malone, 1998). The choice typology has been extended to include the role of community structures, institutional arrangements, and public policies (Downing *et al*., 1997; UNEP, 1998; see Figure 18-4).

18.2.4. Systems, Scales, and Actors

Adaptations occur in something (i.e., who or what adapts?), which is called the "system of interest," "unit of analysis," "exposure unit," "activity of interest," or "sensitive system" (Carter *et al.*, 1994; Smithers and Smit, 1997; UNEP, 1998; Reilly and Schimmelpfennig, 2000). In *unmanaged natural systems*, adaptation is autonomous and reactive and is the means by which species and communities respond to changed conditions. In these situations, adaptation assessment is essentially equivalent to natural system impact assessment (addressed in other WGII chapters). This chapter focuses on adaptations consciously undertaken by *humans*, including those in economic sectors, settlements, communities, regions, and managed ecosystems.

Human system adaptation can be motivated by private or public interest (i.e., who adapts?). *Private* decisionmakers include individuals, households, businesses, and corporations; *public* interests are served by governments at all levels. The roles of

Table 18-1*: Bases for characterizing and differentiating adaptation to climate change (Smit et al., 1999).*

General Differentiating Concept orAttribute	**Examples of Terms Used**		
Purposefulness	Autonomous Spontaneous Automatic Natural Passive	←→ ←→ ←→ ←→ ←→	Planned Purposeful Intentional Policy Active Strategic
Timing	Anticipatory Proactive *Ex ante*	←→ ←→ ←→	Responsive Reactive *Ex post*
Temporal Scope	Short term Tactical Instantaneous Contingency Routine	←→ ←→ ←→	Long term Strategic Cumulative
Spatial Scope	Localized	←→	Widespread
Function/Effects	Retreat - Accommodate - Protect Prevent - Tolerate - Spread - Change - Restore		
Form	Structural - Legal - Institutional - Regulatory - Financial - Technological		
Performance	Cost - Effectiveness - Efficiency - Implementability - Equity		

public and private participants are distinct but not unrelated. Figure 18-5 shows examples of types of adaptation differentiated according to timing, natural or human systems, and public or private decisionmakers.

Planned adaptation often is interpreted as the result of a deliberate policy decision on the part of a public agency, based on an awareness that conditions are about to change or have changed and that action is required to minimize losses or benefit from opportunities (Pittock and Jones, 2000). Autonomous adaptations are widely interpreted as initiatives by private actors rather than by governments, usually triggered by market or welfare changes induced by actual or anticipated climate change (Leary, 1999). Smith *et al.* (1996) describe autonomous adaptations as those that occur "naturally," without interventions by public agencies, whereas planned adaptations are called "intervention strategies." Thus defined, autonomous and planned adaptation largely correspond with private and public adaptation, respectively (see Figure 18-5).

The extent to which society can rely on autonomous, private, or market adaptation to reduce the costs of climate change impacts to an acceptable or nondangerous level is an issue of great interest. Autonomous adaptation forms a baseline against which the need for planned anticipatory adaptation can be evaluated.

Distinguishing among the various decisionmakers involved in adaptation is important. The case of African agriculture and water resources illustrates that stakeholders and potential adapters range from vulnerable consumers to international organizations charged with relief and research (Eele, 1996; Magadza, 1996; Downing *et al*., 1997). Poor and landless households have limited resources, yet failure to adapt can lead to significant deprivation, displacement, morbidity, and mortality. Subsistence farmers do not have the same adaptation options as commercial producers. Water supply adaptations may involve landowners, private traders, local authorities, water-dependent businesses, national governments, and international organizations. Each stakeholder has distinct interests, information, risks, and resources and hence would consider distinct types of adaptive responses (Downing *et al*., 1997).

18.2.5. Processes and Evaluation of Adaptations

In order to predict autonomous adaptations and provide input to adaptation policies, there is a need for improved knowledge about processes involved in adaptation decisions. This knowledge includes information on steps in the process, decision rationales, handling of uncertainties, choices of adaptation types and timing, conditions that stimulate or dampen adaptation, and the consequences or performance of adaptation strategies or

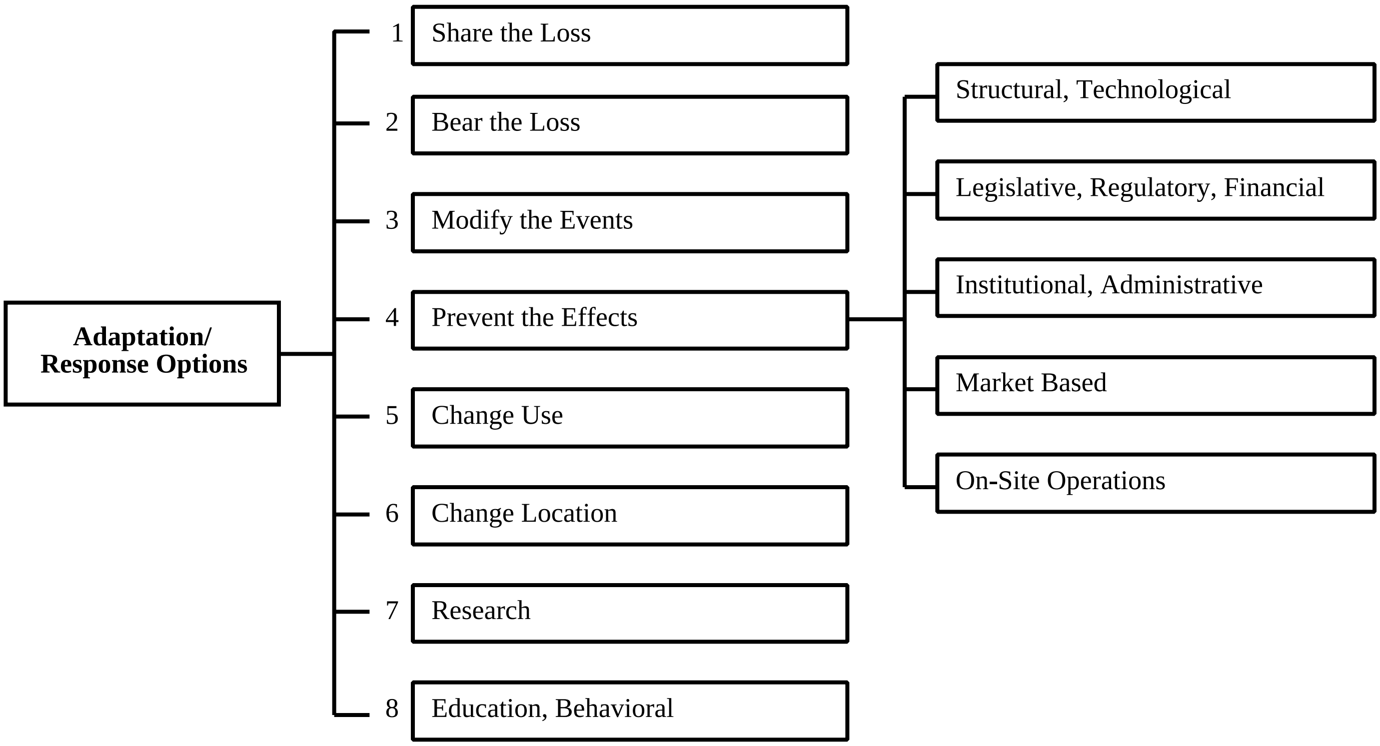

Figure 18-4: Classification of adaptation options (Burton, 1996).

measures (Burton, 1997; Rayner and Malone, 1998; Tol *et al.*, 1998; Basher, 1999; Klein *et al*., 1999; Pittock, 1999; Smit *et al.*, 1999).

Decisions regarding adaptations can be undertaken at any of several scales, by private individuals, local communities or institutions, national governments, and international organizations. Where these adaptations are consciously planned activities, whether by public agencies or individuals, there is an interest in assessing the performance or relative merits of alternative measures and strategies (see Figure 18-4). This *evaluation* (i.e., how good is the adaptation?) can be based on criteria such as costs, benefits, equity, efficiency, and implementability (see Sections 18.3.5 and 18.4.3).

		Anticipatory	Reactive
Natural Systems			• Changes in length of growing season • Changes in ecosystem composition • Wetland migration
Human Systems	Private	• Purchase of insurance • Construction of house on stilts • Redesign of oil-rigs	• Changes in farm practices • Changes in insurance premiums • Purchase of air-conditioning
	Public	• Early-warning systems • New building codes, design standards • Incentives for relocation	• Compensatory payments, subsidies • Enforcement of building codes • Beach nourishment

Figure 18-5: Types of adaptation to climate change, including examples (from Klein, 1999).

18.3. Future Adaptations

Predictions or estimates of likely future adaptations are an essential element of climate change impact and vulnerability assessment. The degree to which a future climate change risk is dangerous depends greatly on the likelihood and effectiveness of adaptations in that system. Studies that ignore or assume no adaptation are likely to overestimate residual or net impacts and vulnerabilities, whereas those that assume full and effective adaptation are likely to underestimate residual impacts and vulnerabilities (Reilly, 1999; Reilly and Schimmelpfennig, 1999; Risbey *et al.*, 1999; Smit *et al.*, 2000). Hence, it is important to have an improved understanding of the process of adaptation and better information on the conditions under which adaptations of various types are expected to occur. Such scholarship on the "how, when, and why" of adaptation is necessary to make informed judgments on the vulnerabilities of sectors, regions, and communities (Ausubel, 1991a; Kane *et al.*, 1992a; Reilly, 1995; Burton, 1997; Smithers and Smit, 1997; Tol *et al.*, 1998; Klein *et al.*, 1999). Insights into processes of adaptation have been gained from several types of analysis, including listing of possible adaptation measures, impact assessment models, adaptation process models, historical and spatial analogs, and empirical analysis of contemporary adaptation processes.

18.3.1. Possible Adaptation Measures

There are many arbitrary lists of possible adaptation measures, initiatives, or strategies that have a potential to moderate impacts,

***Table 18-2**: Examples of multilevel adaptive measures for some anticipated health outcomes of global climate change (Patz, 1996).*

Adaptive Measure	Heat-Related Illness	Vector-Borne Diseases	Health and Extreme Weather Events
Administrative/legal	– Implement weather watch/warning systems – Plant trees in urban areas – Implement education campaigns	– Implement vaccination programs – Enforce vaccination laws – Implement education campaigns to eliminate breeding sites	– Create disaster preparedness programs – Employ land-use planning to reduce flash floods – Ban precarious residential placements
Engineering	– Insulate buildings – Install high-albedo materials for roads	– Install window screens – Release sterile male vectors	– Construct strong seawalls – Fortify sanitation systems
Personal behavior	– Maintain hydration – Schedule work breaks during peak daytime temperatures	– Use topical insect repellents – Use pyrethroid-impregnated bed nets	– Heed weather advisories

if they were implemented (e.g., Benioff *et al*., 1996; Smith *et al*., 1996; Mimura, 1999b). Such *possible* adaptations are based on experience, observation, and speculation about alternatives that might be created (Carter, 1996); they cover a wide range of types and take numerous forms (UNEP, 1998). For example, possible adaptive measures for health risks associated with climate change listed by Patz (1996) appear in Table 18-2.

Similarly, in coastal zone studies, comprehensive lists of potential adaptation measures are presented; these adaptations include a wide array of engineering measures, improvements, or changes, including agricultural practices that are more flood-resistant; negotiating regional water-sharing agreements; providing efficient mechanisms for disaster management; developing desalination techniques; planting mangrove belts to provide flood protection; planting salt-tolerant varieties of vegetation; improving drainage facilities; establishing setback policies for new developments; developing food insurance schemes; devising flood early warning systems; and so forth (Al-Farouq and Huq, 1996; Jallow, 1996; Rijsberman and van Velzen, 1996; Teves *et al*., 1996; Mimura and Harasawa, 2000). In many other sectors and regions, arbitrary lists of possible adaptations are common (Erda, 1996; Iglesias *et al*., 1996). In the Canadian agricultural sector alone, 96 different adaptation measures have been identified, as summarized in Table 18-3.

Such lists indicate the range of strategies and measures that represent possible adaptations to climate change risks in particular sectors and regions. They show that there is a large variety and number of possible adaptations, including many with the potential to reduce adverse climatic change impacts. Many of these adaptations—especially in agriculture, water resources, and coastal zone applications—essentially represent improved resource management, and many would have benefits in dealing with current climatic hazards as well as with future climatic risks (El Shaer *et al*., 1996; Harrington, 1996; Huang, 1996; Stakhiv, 1996; Frederick, 1997; Hartig *et al*., 1997; Mendelsohn and Bennett, 1997; Major, 1998). In only a few cases are such lists of possible adaptations considered according to who might undertake them, under what conditions might they be implemented, and how effective might they be (Easterling, 1996; Harrington, 1996; Frederick, 1997; Major, 1998; Moss, 1998).

18.3.2. Impact Assessment Models

Estimates of likely future adaptations are essential parts of climate change impact models. Integrated assessment models also include assumptions about adaptations in the impact

***Table 18-3**: Adaptation strategies for the agricultural sector (adapted from Smit, 1993; Carter, 1996).*

Adaptation Strategy	Number of Measures
Change topography of land	11
Use artificial systems to improve water use/ availability and protect against soil erosion	29
Change farming practices	21
Change timing of farm operations	2
Use different crop varieties	7
Governmental and institutional policies and programs	16
Research into new technologies	10

components (Leemans, 1992; Rotmans *et al*., 1994; Dowlatabadi, 1995; Hulme and Raper, 1995; West and Dowlatabadi, 1999). Some early studies of impacts assumed no adaptation (Tol *et al.,* 1998), invoking the so-called "naive" or "dumb farmer" assumption. The "dumb farmer" assumption—which is not unique to agriculture—is a metaphor for any impacted agent that is assumed not to anticipate or respond to changed climate conditions but continues to act as if nothing has changed (Rosenberg, 1992; Easterling *et al.*, 1993; Smit *et al.*, 1996). By ignoring autonomous and planned adaptations, such studies do not distinguish between potential and residual net impacts and are of limited utility in assessing vulnerability.

An alternative approach that is common in more recent impact modeling has been to assume levels of adaptation. Applications include Nicholls and Leatherman (1995) for coastal zones, Mendelsohn *et al*. (1994) and Rosenzweig and Parry (1994) for agriculture, Sohngen and Mendelsohn (1998) for timber, and Rosenthal *et al.* (1995) for space conditioning in buildings. These studies demonstrate that adaptive measures have the potential to significantly alleviate adverse impacts of climate change and to benefit from opportunities associated with changed climatic conditions (Helms *et al.*, 1996; Schimmelpfennig, 1996; Mendelsohn and Neumann, 1999). The models of Rosenzweig and Parry (1994) show that, with adaptations assumed, food production could be increased under climate change in many regions of the world. Stuczyinski *et al.* (2000) conclude that climate change would reduce Polish agriculture production by 5–25% without adaptation; with adaptation assumed, production is estimated to change by –5 to +5% of current levels. Downing (1991) demonstrates the potential of adaptations to reduce food deficits in Africa from 50 to 20%. Mendelsohn and Dinar (1999) estimate that private adaptation could reduce potential climate damages in India's agriculture from 25 to 15–23%. Reilly *et al.* (1994) estimate global "welfare" losses in the agri-food sector of between US$0.1 billion and 61.2 billion without adaptation, compared to +US$70 to –37 billion with adaptation assumed. These studies indicate *potential* rather than the *likelihood* of adaptation to alleviate damages (or benefit from opportunities) associated with changes in climatic mean conditions (rather than changing conditions that include variability and extremes of climate).

Impact models invariably are based on climate scenarios that focus on adaptation to changed average conditions, with little attention given to interannual variations and extremes. Limited research suggests that the potential of adaptation to cope with changes in average conditions is greater than its potential to cope with climate change-related variability. For example, Mendelsohn *et al*. (1999) show that, assuming adaptation, increases in average temperature would be beneficial for U.S. agriculture, but increases in interannual variation would be harmful. West and Dowlatabadi (1999) demonstrate that considering variability and extremes can lead to estimates of "optimal" adaptation and damages that differ considerably from those based on gradual changes in mean climatic conditions. The importance of considering variability, not just mean climate, when estimating adaptation is widely recognized (Robock *et al*., 1993; Mearns *et al*., 1997; Alderwish and Al-Eryani, 1999; Alexandrov, 1999; Luo and Lin, 1999; Murdiyarso, 2000).

In numerical impact models, assumptions about perception and adaptation are more commonly arbitrary or based on principles of efficiency and rationality and assume full information (Yohe *et al.*, 1996; Hurd *et al.*, 1997; Mendelsohn *et al.*, 1999). As Tol *et al.* (1998), Schneider *et al*. (2000), and others have noted, however, actual and assumed behavior do not necessarily match. In an analysis of global food production, Parry *et al*. (1999) assume farm-level and economic system adaptations but recognize that the "adoption of efficient adaptation techniques is far from certain." In addition to questions relating to rationality principles, adaptation behavior is known to vary according to the amount and type of information available, as well as the ability to act. Hence, rational behavior that is based on assumed perfect information differs from rational behavior under uncertainty (Yohe *et al*., 1996; Yohe and Neumann, 1997; West and Dowlatabadi, 1999). Replacing the "no adaptation" model with one that assumes rational, unconstrained actors with full information replaces the "dumb farmer" assumption with the "clairvoyant farmer" assumption (Smit *et al.*, 1996; Risbey *et al*., 1999). Reilly (1998) questions the ability and hence the likelihood of agents to detect and respond efficiently to the manifestations of climate change. Tol (1998b) also questions whether perfect foresight and rational behavior are realistic assumptions for predictive models. Schneider (1997) explores further the assumptions that underlie equilibrium approaches (ergodic economics), including the equivalence of temporal and spatial variations.

Numerical impact assessment models tend to *use*, rather than *generate*, information on adaptations to estimate future impacts of climate stimuli, after the effects of adaptation have been factored in. They indicate the potential of human systems to adapt autonomously and thus to moderate climate change damages.

18.3.3. Models, Analogs, and Empirical Analysis of Autonomous Adaptation

Adaptation to rapid anthropogenic climate change may be a new challenge, but individuals, societies, and economies have adapted—in various ways and with various degrees of success—to changed and variable environmental conditions throughout history. These experiences in adaptive behavior provide information on the processes, constraints, and consequences of adaptations.

Knowledge of the processes by which individuals or communities actually adapt to changes in conditions over time comes largely from analog and other empirical analyses (Wigley *et al*., 1981; Glantz, 1996; Meyer *et al*., 1998; Tol *et al*., 1998; Smit *et al*., 1999; Yohe and Dowlatabadi, 1999; Bryant *et al*., 2000). These studies indicate that autonomous adaptations tend to be incremental and ad hoc, to take multiple forms, to be in response to multiple stimuli (usually involving a particular catalyst and rarely climate alone), and to be constrained by economic, social, technological, institutional, and political conditions.

Conceptual models of adaptation processes describe sequential relationships and feedback involving climatic and nonclimatic stimuli, system sensitivities and impacts, tactical and strategic adaptations, and net or residual impacts. They also indicate conditions that constrain or facilitate various kinds of adaptation (e.g., Carter, 1996; Smit *et al*., 1996; UNEP, 1998; Schneider *et al*., 2000). Spatial analogs have been used to gain insight into adaptation, by transferring experience from existing climatic regions to places where such climate may be found in the future. The contributions and limits of spatial analogs are known (Schneider, 1997; Rayner and Malone, 1998). Some ecological and paleoecological studies reconstruct species or community dynamics over hundreds and thousands of years (e.g., MacDonald *et al.*, 1993).

Temporal analog or case studies document adaptive responses to climatic stimuli in resource-based economic sectors and communities over periods of several decades (e.g., Glantz, 1988; Olsthoorn *et al.*, 1996; Changnon *et al*., 1997). Other empirical analyses have examined adaptive behavior in key sectors such as agriculture in light of climatic variability and extremes over even shorter time periods (e.g., Appendi and Liverman, 1996; Smit *et al.*, 1997; Bryant *et al*., 2000).

These direct empirical analyses of adaptation processes tend to start with the system of interest, then assess its sensitivity and adaptability to climate and other stimuli. This analytical strategy is consistent with vulnerability assessment (Downing *et al*., 1996; Adger, 1999; Handmer *et al*., 1999; Kelly and Adger, 1999), the "adjoint approach" (Parry, 1986), and "shift-in-risk" perspectives (Warrick *et al.*, 1986). These studies have yielded some important insights about adaptation.

For systems such as agriculture, forestry, water resources, and coastal zone settlements, the key climatic stimuli are not average conditions but variability and extremes. Adirect climatic condition prompts adaptation less often than the economic and social effects or implications of the climatic stimuli that are fundamental in triggering adaptive responses. Nonclimatic conditions are important in moderating and sometimes overwhelming the influence of climate stimuli in the decisionmaking of resource users. Decisions on adaptation are rarely made in response to climate stimuli alone. These findings are important for predicting autonomous adaptations and for improving adaptation assumptions in impact models.

In estimating future adaptations and developing adaptation policies (see Section 18.4), it is helpful to understand factors and circumstances that hinder or promote adaptation. As Rayner and Malone (1998) conclude, the consequences of a climate event are not direct functions of its physical characteristics; they also are functions of "the ways in which a society has organized its relation to its resource base, its relations with other societies, and the relations among its members." To understand vulnerability in archeological, historical, and contemporary contexts, Rayner and Malone (1998) identify the most promising research strategy:

> "…explicitly to focus attention on the process of adaptation—or, on the other hand, of failure to adapt—that partly condition the impact of the climatic stress in particular societies…cases in which societies appear to have been seriously damaged by, or even totally succumbed to, climatic stress should not be taken to demonstrate the determining influence of climate. It is essential to consider ways in which these societies might have coped better, and to focus on the political, cultural, and socioeconomic factors which inhibited them from doing so" (Ingram *et al.*, 1981).

Following this approach, McGovern's (1991) reexamination of the extinction of Greenland settlements found that the stress imposed by climate shifts was indeed severe but was within the theoretical ability of the colonies to have coped, by means that were available to them. Why they failed to employ those adaptive means emerges as the key question, still incompletely answered, in explaining the collapse: "It did get cold and they did die out, but why?" (McGovern, 1991). Intervening between the physical events and the social consequences is the adaptive capacity and hence vulnerability of the society and its different groups and individual members.

18.3.4. Costs of Autonomous Adaptation

As assessments of climate impacts (commonly measured as "costs" that include damages and benefits) increasingly have incorporated expected adaptations, and particularly as impact models and "integrated assessment" models have shown the potential of adaptation to offset initial impact costs, interest has grown in calculating the costs of autonomous adaptations. Whether climate change or another climate stimulus is expected to have problematic or "dangerous" impacts depends on the adaptations and their costs (Leary, 1999). Climate change impact cost studies that assume adaptation also should include the "adjustment of costs" of these adaptations (Reilly, 1998).

Tol and Fankhauser (1997) provide a comprehensive summary of analyses of the costs of autonomous, mainly (but not exclusively) reactive adaptations, undertaken privately (i.e., not adaptation policies of government). A common basis for evaluating impact costs is to sum adaptation costs and residual damage costs (Fankhauser, 1996; Rothman *et al*., 1998). Procedures for defining and calculating such adaptation costs are subject to ongoing debate. Tol and Fankhauser (1997) note that most approaches consider equilibrium adaptation costs but ignore transition costs. Hurd *et al.* (1997) include market and nonmarket adaptation in their assessment of impact costs. Most research to date on adaptation "costs" is limited to particular economic measures of well-being (Brown, 1998). Any comprehensive assessment of adaptation costs (including benefits) would consider not only economic criteria but also social welfare and equity.

Cost estimation for autonomous adaptations is not only important for impact assessment; it also is a necessary ingredient in the "base case," "reference scenario," or "do-nothing option" for evaluations of policy initiatives, with respect to both adaptation and mitigation (Rayner and Malone, 1998; Leary, 1999; Smit *et al.*, 2000).

18.3.5. Lessons from Adaptation Experiences

Research in many sectors and regions indicates an impressive human capacity to adapt to long-term mean climate conditions but less success in adapting to extremes and to year-to-year variations in climatic conditions. Climate change will be experienced via conditions that vary from year to year, as well as for ecosystems (Sprengers *et al.*, 1994) and human systems (Downing *et al*., 1996); these variations are important for adaptation. Thus, although human settlements and agricultural systems, for example, have adapted to be viable in a huge variety of climatic zones around the world, those settlements and systems often are vulnerable (with limited adaptive capacity) to temporal deviations from normal conditions (particularly extremes). As a result, adaptations designed to address changed mean conditions may or may not be helpful in coping with the variability that is inherent in climate change.

All socioeconomic systems (especially climate-dependent systems such as agriculture, pastoralism, forestry, water resources, and human health) are continually in a state of flux in response to changing circumstances, including climatic conditions. The evidence shows that there is considerable potential for adaptation to reduce the impacts of climate change and to realize new opportunities. In China's Yantze Valley, 18th-century regional expansions and contractions on the double-cropping system for rice represented adaptive responses to the frequency of production successes and failures associated with climatic variations (Smit and Cai, 1996). Adaptation options occur generally in socioeconomic sectors and systems in which the turnover of capital investment and operating costs is shorter and less often where long-term investment is required (Yohe *et al*., 1996; Sohngen and Mendelsohn, 1998).

Although an impressive variety of adaptation initiatives have been undertaken across sectors and regions, the responses are not universally or equally available (Rayner and Malone, 1998). For example, the viability of crop insurance depends heavily on the degree of information, organization, and subsidy available to support it. Similarly, the option of changing location in the face of hazard depends on the resources and mobility of the affected part and on the availability and conditions in potential destination areas (McGregor, 1993). Many response strategies have become less available; many others have become more available. Individual cultivator response to climate risk in India has long relied on a diverse mix of strategies, from land use to outside employment (sometimes requiring temporary migration) to reciprocal obligations for support; many of these strategies have been undermined by changes such as population pressure and government policy, without being fully replaced by others—illustrating the oft-remarked vulnerability of regions and populations in transition (Gadgil *et al.*, 1988; Johda, 1989). In areas of China, many historical adaptations in agriculture (e.g., relocating production or employing irrigation) are no longer available as population pressures increase on limited land and water resources (Fang and Liu, 1992; Cai and Smit, 1996). In Kenya, effective smallholder response to drought has shifted from traditional planting strategies to employment diversification (Downing *et al.*, 1989).

Not only is there rarely only one adaptation option available to decisionmakers (Burton and Cohen, 1993) but also "rarely do people choose the best responses—the ones among those available that would most effectively reduce losses—often because of an established preference for, or aversion to, certain options" (Rayner and Malone, 1998). In some cases there is limited knowledge of risks or alternative adaptation strategies. In other cases, adoption of adaptive measures is constrained by other priorities, limited resources, or economic or institutional barriers (Eele, 1996; Bryant *et al.*, 2000; de Loë and Kreutzwiser, 2000). Recurrent vulnerabilities, in many cases with increasing damages, illustrate less-than-perfect adaptation of systems to climatic variations and risks. There is some evidence that the costs of adaptations to climate conditions are growing (Burton, 1997; Etkin, 1998). There is strong evidence of a sharp increase in damage costs of extreme climatic or weather events (Berz, 1999; Bruce, 1999). Growing adaptation costs reflect, at least in part, increases in populations and/or improvements in standards of living, with more disposable income being used to improve levels of comfort, health, and safety in the short run. It is not clear whether the expansion in adaptations is likely to be effective and sustainable in the long run. In any event, although adaptations to changed and variable climatic conditions are undertaken, they are not necessarily effective or without costs.

Many adaptations to reduce vulnerability to climate change risks also reduce vulnerability to current climate variability, extremes, and hazards (El Shaer *et al*., 1996; Rayner and Malone, 1998). Measures that are likely to reduce current sensitivity of climate variations in Africa also are likely to reduce the threat of adverse impacts of climate change (Ominde and Juna, 1991):

> "Most analysts in the less-developed countries believe that the urgent need, in the face of both climate variation and prospective climate change, is to identify policies which reduce recurrent vulnerability and increase resilience. Prescriptions for reducing vulnerability span drought-proofing the economy, stimulating economic diversification, adjusting land and water uses, providing social support for dependent populations, and providing financial instruments that spread the risk of adverse consequences form individual to society and over longer periods. For the near term, development strategies should ensure that livelihoods are resilient to a wide range of perturbations." (Rayner and Malone, 1998)

Examples of current adaptation strategies in agriculture with clear applications to climate change are given by Easterling (1996) and Smit *et al.* (1997), including moisture-conserving practices, hybrid selection, and crop substitution. In the water resources sector, Stakhiv (1996) shows how current management practices represent useful adaptive strategies for climate change. Some analysts go further to point out that certain adaptations to climate change not only address current hazards but may be additionally beneficial for other reasons (e.g., "no regrets" or "win-win" strategies) (Carter, 1996).

Societal responses to large environmental challenges tend to be incremental and ad hoc rather than fundamental (Rayner and Malone, 1998). In all of the climate analog cases examined by Glantz (1988), "Ad hoc responses were favored over long term planned responses. As a result, there has been a tendency to 'muddle through.' This has not necessarily been an inappropriate response, but it is probably more costly in the long term than putting a long-term strategy together in order to cope with climate-related environmental change." In each case, moreover, action was not taken without a catalyst or trigger that dramatically indicated the seriousness of a threat (Glantz, 1988). Other studies also indicate the ad hoc nature of adaptations and the importance of a catalyst (Wilhite *et al.*, 1986; Glantz, 1992; Kasperson *et al.*, 1995). These findings suggest that problems that demand early or long-term attention often fail to receive it, and the most efficient responses are not taken. That the earlier action would have been more efficacious, however, presupposes that the best strategy was evident to the decisionmakers and that premature responses closing off useful options would not have been taken instead (Rayner and Malone, 1998). There is little evidence that efficient and effective adaptations to climate change risks will be undertaken autonomously.

A consistent lesson from adaptation research is that climate is not the singular driving force of human affairs that is sometimes assumed—but neither is it a trivial factor. Climate is an important resource for human activities and an important hazard. Climate change is a source of significant stresses (and perhaps significant opportunities) for societies, yet it has always been only one factor among many. The consequences of a shift in climate are not calculable from the physical dimensions of the shift alone; they require attention to human dimensions through which they are experienced (Rayner and Malone, 1998; Bryant *et al.*, 2000). The significance of climate change for regions depends fundamentally on the ability and likelihood of those regions to adapt.

To what degree are societies likely to adapt autonomously to avoid climate change damages? Some studies show faith in market mechanisms and suggest considerable capacity of human systems to adapt autonomously (Ausabel, 1991b; Mendelsohn *et al.*, 1996; Yohe *et al.*, 1996; Mendelsohn, 1998; Mendelsohn and Neumann, 1999). Other studies highlight the constraints on "optimal" autonomous adaptation, such as limited information and access to resources, adaptation costs, and residual damages; these studies emphasize the need for planned, especially anticipatory, adaptations undertaken or facilitated by public agencies (Smith *et al.*, 1996; Reilly, 1998; Tol, 1998a; Fankhauser *et al.*, 1999; Bryant *et al.*, 2000; Schneider *et al.*, 2000)

18.4. Planned Adaptations and Evaluation of Policy Options

This section considers *planned*, mainly (but not exclusively) *anticipatory* adaptations, undertaken or directly influenced by *governments* or collectives as a public policy initiative. These adaptations represent conscious policy options or response strategies to concerns about climate change (Benioff *et al.*, 1996; Fankhauser, 1996; Smith, 1997; Pielke, 1998; UNEP, 1998). Public adaptation initiatives may be direct or indirect, such as when they encourage or facilitate private actions (Leary, 1999). Planned adaptation by public agencies represents an alternative or complementary response strategy to mitigation (of net GHG emissions). Analyses of such planned adaptations are essentially normative exercises involving identification of possible policy strategies and evaluation of the relative merit of alternatives, as an aid to policy development.

18.4.1. Rationale and Objectives for Planned Adaptations

Numerous reasons have been given for pursuing planned adaptations at this time (see Table 18-4). Public adaptation initiatives are regarded not as a substitute for reducing GHG emissions but as a necessary strategy to manage the impacts of climate change (Burton, 1996; Pielke, 1998). Adaptation can yield benefits regardless of the uncertainty and nature of climate change (Ali, 1999). Fankhauser *et al*. (1998) and Leary (1999) outline rationales for public adaptation policies or projects relative to relying on private actions. Leary concludes that "we

***Table 18-4**: Six reasons to adapt to climate change now (Burton, 1996).*

1) Climate change cannot be totally avoided.
2) Anticipatory and precautionary adaptation is more effective and less costly than forced, last-minute, emergency adaptation or retrofitting.
3) Climate change may be more rapid and more pronounced than current estimates suggest. Unexpected events are possible.
4) Immediate benefits can be gained from better adaptation to climate variability and extreme atmospheric events.
5) Immediate benefits also can be gained by removing maladaptive policies and practices.
6) Climate change brings opportunities as well as threats. Future benefits can result from climate change.

cannot rely solely or heavily on autonomous adjustments of private agents to protect public goods and should examine public policy responses to do so." Planned anticipatory adaptation, as recognized in the UNFCCC (Article 3.3), is aimed at reducing a system's vulnerability by diminishing risk or improving adaptive capacity.

There has been work on the process by which public agencies might or should undertake planned adaptation strategies, particularly noting the steps to be followed, relationships with other policy and management objectives, and the criteria with which options might be evaluated (Louisse and Van der Meulen, 1991; Carter *et al.*, 1994; Smith and Lenhart, 1996; Stakhiv, 1996; Major and Frederick, 1997; Smith, 1997). Klein and Tol (1997) identify five generic objectives of adaptation:

1) Increasing robustness of infrastructural designs and long-term investments—for example, by extending the range of temperature or precipitation a system can withstand without failure and changing the tolerance of loss or failure (e.g., by increasing economic reserves or by insurance)
2) Increasing the flexibility of vulnerable managed systems—for example, by allowing mid-term adjustments (including change of activities or location) and reducing economic lifetimes (including increasing depreciation)
3) Enhancing the adaptability of vulnerable natural systems—for example, by reducing other (nonclimatic) stresses and removing barriers to migration (including establishing eco-corridors)
4) Reversing trends that increase vulnerability (also termed "maladaptation")—for example, by introducing setbacks for development in vulnerable areas such as floodplains and coastal zones
5) Improving societal awareness and preparedness—for example, by informing the public of the risks and possible consequences of climate change and setting up early-warning systems.

18.4.2. Identification of Adaptation Policy Options

Research addressing future adaptations to climate change tends to be normative, suggesting anticipatory adaptive strategies to be implemented through public policy. Generally, such adaptation recommendations are based on forecasts of expected (though still largely unpredictable) climate change. Recommended adaptations:

- Tend to be in response to changes in *long-term mean climate*, though more specific elements of climate change (e.g., sea-level change) gain focus when sector-specific adaptations are proposed (e.g., integrated coastal zone management) (Al-Farouq and Huq, 1996; Smith *et al.*, 1996), and some studies specifically examine potential adaptations to variability and extreme events (e.g., Appendi and Liverman, 1996; Yang, 1996; Yim, 1996).
- *Range in scope* from very broad strategies for adaptation (e.g., enhancing decisionmakers'awareness of climatic change and variability) to recommendations of sector-specific policy. Sectors receiving particular attention include water resources, coastal resources, agriculture, and forest resources (Smith and Lenhart, 1996; Smith *et al.*, 1996; Hartig et al., 1997; Mendelsohn and Bennett, 1997).
- Tend to be *regionally focused* (Smith and Lenhart, 1996), in recognition of the fact that vulnerability to the impacts of climate change is highly spatially variable. There is interest in developing countries and nations with economies in transition, given their greater reliance on natural systems-based economic activity (such as agriculture) (e.g., Magalhães, 1996; Smith *et al.*, 1996; Kelly and Adger, 1999).

Because no single set of adaptive policy recommendations can be universally appropriate, several studies suggest means by which proposed adaptations may be selected and evaluated. At a very basic level, the success of potential adaptations is seen to depend on the *flexibility* or effectiveness of the measures, such as their ability to meet stated objectives given a range of future climate scenarios (through either robustness or resilience), and their potential to produce *benefits that outweigh costs* (financial, physical, human, or otherwise) (Smith and Lenhart, 1996). Clearly, these are difficult criteria to assess, given the complexity of adaptation measures, the variable sensitivities and capacities of regions, and uncertainties associated with climate change and variability. Some research (e.g., Carter, 1996; Smith and Lenhart, 1996; Smith *et al.*, 1996; de Loë and Kreutzwiser, 2000) offers supplementary characteristics of, or criteria for, the identification of adaptations:

- The measure generates benefits to the economy, environment, or society under current conditions (i.e., independent of climate change).
- The measure addresses high-priority adaptation issues such as irreversible or catastrophic impacts of climate change (e.g., species extinction), long-term planning for adaptation (e.g., infrastructure), and unfavorable trends (e.g., deforestation, which may inhibit future adaptive flexibility).
- The measure targets current areas of opportunity (e.g., land purchases, revision of national environmental action or development plans, research and development).
- The measure is feasible—that is, its adoption is not significantly constrained by institutional, social/cultural, financial, or technological barriers.
- The measure is consistent with, or even complementary to, adaptation or mitigation efforts in other sectors.

18.4.3. Evaluation of Adaptation Options and Adaptation Costs

Some very general steps for identifying and evaluating planned adaptations are given in Carter *et al.* (1994) and UNEP(1998).

Somewhat more detailed procedures for evaluating anticipatory adaptation policies in the climate change context are outlined in Smith and Lenhart (1996) and Smith (1997). This approach addresses management of institutional processes and players and proposes net benefits and implementability as central evaluative criteria. Numerous other considerations are noted, including flexibility, benefits independent of climate change ("no regrets"), local priorities, levels of risk, and time frames of decisions. From a disaster management perspective, Tol *et al.* (1996) argue that policies must be evaluated with respect to economic viability, environmental sustainability, public acceptability, and behavioral flexibility. Tol *et al*. (1999) apply these observations in an examination of adaptation to increased risk of river floods in The Netherlands. They note several possible adaptations, but none could be accomplished without creating significant distributional and/or ecological impacts. None, therefore, would be feasible without enormous political will and institutional reform. Klein and Tol (1997) and UNEP (1998) describe methodologies for evaluation, including cost-benefit, cost-effectiveness, risk-benefit, and multi-criteria methods. Multi-criteria methods to evaluate possible adaptation options have been demonstrated for coastal zones (El-Raey *et al*., 1999) and agriculture (Mizina *et al*., 1999).

Fankhauser (1996) provides an economic efficiency framework in which adaptation actions are considered justified as long as the additional costs of adaptation are lower than the additional benefits from the associated reduced damages. Optimal levels of adaptation (in an economic efficiency sense) are based on minimizing the sum of adaptation costs and residual damage costs. Such studies require the definition of a base case that involves estimation of autonomous adaptations. These and other normative studies (e.g., Titus, 1990; Goklany, 1995) illustrate the range of principles and methods that have been proposed for identifying, evaluating, and recommending (planned) adaptation measures.

There are, however, few comprehensive estimates of the costs of adaptation. Mimura and Harasawa (2000) report estimates of 11.5–20 trillion Yen as the cost of maintaining the functions of Japanese infrastructure against a 1-m rise in sea level. Yohe and Schlesinger (1998) applied a cost-benefit rule to adaptation decisions across a sample of the developed coastline of the United States. With a 3% discount rate, their national estimates of the expected discounted cost of protecting or abandoning developed coastal property in response to sea-level rise that is based on a mean greenhouse emissions scenario is US$1.3 billion with foresight and US$1.8 billion without. Their estimates climb to more than US$4 billion and 5 billion, respectively, along the 1-m sea-level rise scenario that matches the Mimura and Harasawa study. Between 55 and 70% of these costs were attributed to planned adaptation. The remainder reflect estimates of residual damage associated with abandoning property with and without completely efficient autonomous adaptation. Indeed, the differences between the foresight and non-foresight estimates can be regarded as estimates of the incremental cost of incomplete autonomous adaptation in advance of planned responses.

On a more local scale, Smith *et al*. (1998) report cost estimates that are clearly sensitive to design and evaluation criteria. For example, none of the five flood protection strategies for the southernmost part of the Dutch Meuse (assuming 10% more winter precipitation and a warming of 2°C) would achieve economic benefits that exceed their costs of DGL 243–1,505 million, given a 5% discount rate. Moreover, only building quays would meet the benefit-cost standard with a 5% discount rate. Nonetheless, the government chose a wildlife renovation strategy on the basis of additional benefits for nature and recreation. Smith *et al.* (1998) also report that the cost of raising the Northumberland Bridge between Prince Edward Island and New Brunswick to accommodate a 1-m sea-level rise would be US$1 billion or 250,000, depending on whether the entire bridge or only the portion that spanned the shipping lanes were raised.

Klein *et al.* (1999) develop a conceptual framework of the process of planned adaptations, aimed at changing existing

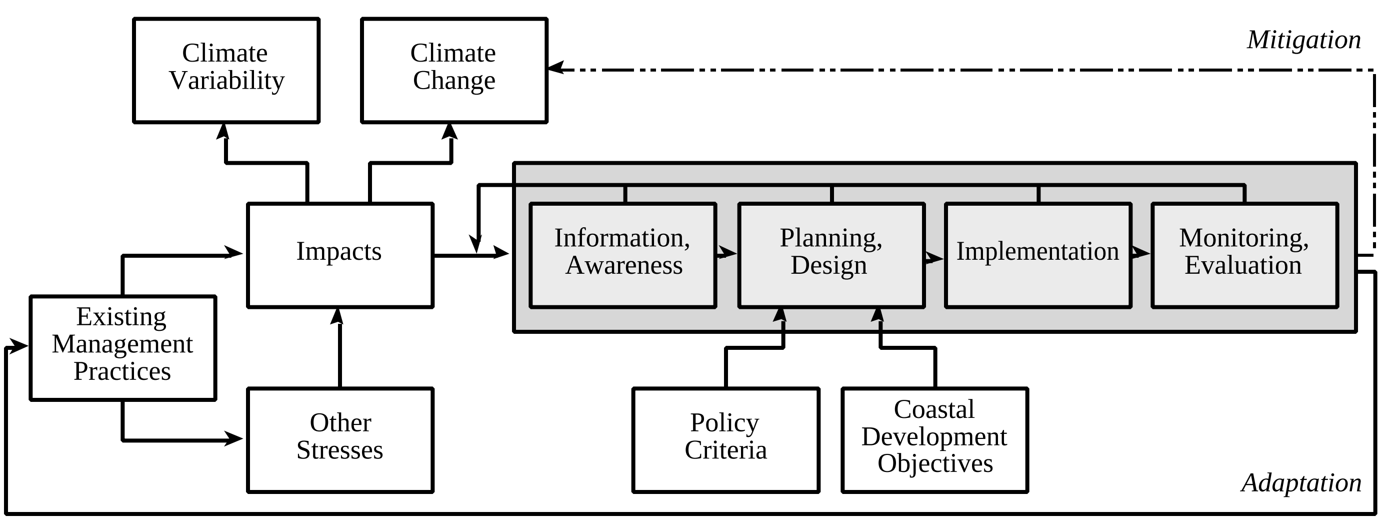

Figure 18-6: Conceptual framework showing, in shaded area, iterative steps involved in planned coastal adaptation to climate variability and change (Klein *et al*., 1999).

management practices in coastal zones. In this model, adaptation is a continuous and iterative cycle, involving several steps: information collection and awareness raising, planning and design (incorporating policy criteria and development objectives), implementation, monitoring, and evaluation (see Figure 18-6).

18.4.4. Public Adaptation Decisions, Uncertainty, and Risk Management

Research increasingly addresses how adaptation is considered in actual policy decisionmaking. Stakhiv (1996) and Frederick (1997), dealing with the U.S. water resources sector, conclude that existing institutions and planning processes can deal with climate change; such processes essentially represent adaptive management. As in many other sectors and circumstances, adaptation to climate change hazards in the coastal zone is part of ongoing coastal zone management. Adaptation to sea-level rise and extreme climate events is being included in Japanese coastal policies (Mimura and Kawaguchi, 1997), British shoreline management (Leafe *et al*., 1998), and Dutch law and coastal zone management (Koster and Hillen, 1995; Helmer *et al*., 1996; Klein *et al*., 1998).

Planning of adaptation invariably is complicated by multiple policy criteria and interests that may be in conflict (Hareau *et al*., 1999). For example, the economically most efficient path to implement an adaptation option might not be the most effective or equitable one. Moreover, decisions have to be made in the face of uncertainty (Lempert *et al*., 2000). Uncertainties that are pertinent to adaptation are associated with climate change itself, its associated extremes, their effects, the vulnerability of systems and regions, conditions that influence vulnerability, and many attributes of adaptations, including their costs, implementability, consequences, and effectiveness (Campos *et al*., 1996; Lansigan *et al.*, 1997; Handmer *et al*., 1999; Murdiyarso, 2000).

Given these uncertainties, it is not surprising that adaptation strategies frequently are described as forms of risk management. For example, adaptations to deal with climate change impacts or risks to human health can be biological (acquired immunity), individual (risk-aversion options), or social (McMichael *et al*., 1996). Most social adaptation strategies are measures to reduce health risks via public health programs (Patz, 1996; McMichael and Kovats, 2000). Similarly, public adaptations via "disaster loss mitigation" (Bruce, 1999) are mainly risk management initiatives such as improved warning and preparedness systems, less vulnerable buildings and infrastructure, risk-averse land-use planning, and more resilient water supply systems. Nguyen *et al.* (1998), Hisschemöller and Olsthoorn (1999), and Perez *et al*. (1999) also describe adaptations to climate change and extremes as modifications to existing risk management programs. As de Loë and Kreutzwiser (2000) and others point out, it remains unclear whether practices designed for historical climatic variability will be able to cope with future variability.

To recognize these uncertainties, decision tools to help evaluate adaptation options include risk-benefit and multi-criteria analyses (Klein and Tol, 1997). Such evaluations are further complicated by the existence of secondary impacts related to the adaptation itself. For example, water development projects (adaptations to water supply risks) can have significant effects on local transmission of parasitic diseases, including malaria, lymphatic filasiasis, and schistosomiasis (Hunter *et al*., 1993; McMichael and Kovats, 2000). Improved water supply in some rural areas of Asia has resulted in a dramatic increase in Aedes mosquito breeding sites and, consequently, outbreaks of dengue (WHO, 1997). Langen and Tol (1999) provide examples of technical response options to climate hazards that are counterproductive in the longer term. Existing resource management programs do not necessarily consider changed risks or recognize local interests and inequities (Primo, 1996). Wilhite's (1996) analysis of programs in the United States, Australia, and Brazil shows the ineffectiveness of reactive crisis management approaches and the need for proactive and cooperative planning.

Nonetheless, it is widely accepted that planned adaptations to climate risks are most likely to be implemented when they are developed as components of (or as modifications to) existing resource management programs or as part of national or regional strategies for sustainable development (Campos *et al.*, 1996; Magalhães, 1996; Theu *et al.*, 1996; Mimura, 1999a; Apuuli *et al*., 2000; Munasinghe, 2000; Osokova *et al*., 2000).

18.5. Adaptive Capacity and its Determinants

18.5.1. Vulnerability and Adaptive Capacity

Considerable attention has been devoted to the characteristics of systems (communities or regions) that influence their propensity or ability to adapt (as part of impact and vulnerability assessment) and/or their priority for adaptation measures (as a basis for policy development). These characteristics have been called *determinants of adaptation*. Generic concepts such as sensitivity, vulnerability, susceptibility, coping range, critical levels, adaptive capacity, stability, robustness, resilience, and flexibility have been used to differentiate systems according to their likelihood, need, or ability for adaptation (Sprengers *et al.*, 1994; De Ruig, 1997; Klein and Tol, 1997; Smithers and Smit, 1997; Adger and Kelly, 1999; Kelly and Adger, 1999). These characteristics influence (promote, inhibit, stimulate, dampen, or exaggerate) the occurrence and nature of adaptations and thereby circumscribe the vulnerability of systems and their residual impacts. In the hazards literature, these characteristics are reflected in socially constructed or endogenous risks (Blaikie *et al.*, 1994; Hewitt, 1997). Together (in whole or part), they represent the adaptive capacity of a system.

Table 18-5 lists terms that are commonly used to characterize the adaptive propensity of systems to climate stimuli. There is considerable overlap in the basic concepts captured in these terms. Particular terms have been employed to distinguish natural from socioeconomic systems or to differentiate the condition of a system before adaptation from its condition after adaptation (Klein and Nicholls, 1998). These distinctions are important and can be captured without narrowing the meaning of widely used terms. Thus, ecosystem vulnerability is different from socioeconomic vulnerability.

Adaptive capacity refers to the potential, capability, or ability of a system to adapt to climate change stimuli or their effects or impacts. Adaptive capacity greatly influences the vulnerability of communities and regions to climate change effects and hazards (Bohle *et al*., 1994; Downing *et al*., 1999; Kelly and Adger, 1999; Mileti, 1999; Kates, 2000). Vulnerability has been described as the "capacity to be wounded" (Kates *et al*., 1985). Human activities and groups are considered sensitive to climate to the degree that they can be affected by it and vulnerable to the degree that they can be harmed (Rayner and Malone, 1998). Because vulnerability and its causes play essential roles in determining impacts, understanding the dynamics of vulnerability is as important as understanding climate itself (Liverman, 1990; Handmer *et al*., 1999).

With regard to climate change, the vulnerability of a given system or society is a function of its physical exposure to climate change effects and its ability to adapt to these conditions. Chambers (1989) distinguishes between these two aspects of differential vulnerability: physical exposure to the hazardous agent and the ability to cope with its impacts. Thus, vulnerability recognizes the role of socioeconomic systems in amplifying or moderating the impacts of climate change and "emphasizes the degree to which the risks of climate catastrophe can be cushioned or ameliorated by adaptive actions that or can be brought within the reach of populations at risk" (Downing, 1991).

The significance of climate variation or change depends on the change itself and the characteristics of the society exposed to it

Table 18-5*: Terms to describe characteristics of systems that are pertinent to adaptation[a] (from Smit et al., 1999).*

Sensitivity	Degree to which a system is affected by or responsive to climate stimuli (note that sensitivity includes responsiveness to both problematic stimuli and beneficial stimuli)
Susceptibility	Degree to which a system is open, liable, or sensitive to climate stimuli (similar to sensitivity, with some connotations toward damage)
Vulnerability	Degree to which a system is susceptible to injury, damage, or harm (one part—the problematic or detrimental part—of sensitivity)
Impact Potential	Degree to which a system is sensitive or susceptible to climate stimuli (essentially synonymous with *sensitivity*)
Stability	Degree to which a system is not easily moved or modified
Robustness	Strength; degree to which a system is not given to influence
Resilience	Degree to which a system rebounds, recoups, or recovers from a stimulus
Resistance	Degree to which a system opposes or prevents an effect of a stimulus
Flexibility	Degree to which a system is pliable or compliant (similar to *adaptability*, but more absolute than relative)
Coping Ability	Degree to which a system can successfully grapple with a stimulus (similar to *adaptability*, but includes more than adaptive means of "grappling")
Responsiveness	Degree to which a system reacts to stimuli (broader than *coping ability* and *adaptability* because responses need not be "successful")
Adaptive Capacity	The potential or capability of a system to adapt to (to alter to better suit) climatic stimuli or their effects or impacts
Adaptability	The ability, competency, or capacity of a system to adapt to (to alter to better suit) climatic stimuli (essentially synonymous with *adaptive capacity*)

[a] These definitions of systems characteristics are based on widely (but not unanimously) held conventions. They focus on distinguishing generic properties and do not include factors that might influence the state of a property or the forms it might take. The terms "climate stimulus" and "system" are used as established earlier.

(Ausubel, 1991a; Rayner and Malone, 1998; Munasinghe, 2000). These characteristics of society determine its adaptive capacity and its adaptability. Adaptive capacity refers to the ability to prepare for hazards and opportunities in advance (as in anticipatory adaptation) and to respond or cope with the effects (as in reactive adaptation).

Studies of similar hazardous events recurring at different times in a given region show vastly different consequences because of societal transformations that occurred between the events. For example, rainfall and temperature fluctuations in western Europe have far milder effects on human well-being today (society generally is less vulnerable) than they did in the medieval and early modern periods, essentially as a result of enhanced adaptive capacity that reflects changes in practices, economics, and government programs (Abel, 1976; De Vries, 1977; Rayner and Malone, 1998). Similarly, particular climate events or hazards can have "vastly different consequences for those on whom they infringe because of differences in coping ability" (Rayner and Malone, 1998). An extreme climatic event will result in higher losses of life in a developing country than in a developed country because of differential adaptive capacity (Burton, *et al.,* 1993; Blaikie *et al.*, 1994; Kundzewicz and Takeuchi, 1999). Martens *et al*. (1999) describe potential adaptations to deal with increases in disease incidence associated with climate change but note that in most poor developing countries, socioeconomic, technical, and political barriers will mean that the changed health risks will not be addressed.

> "In developing countries overall social, environmental, and economic vulnerability enhances the effects of droughts and other climatic events. Overpopulation (relative to current productivity, income, and natural resources), poverty, and land degradation translate into a poor capacity to face any kind of crisis. Poor people have no insurance against loss of income. Weak economic structures mean difficulties in maintaining jobs during an economic failure. Degraded marginal lands become totally unproductive when precipitation decreases. As a result, these regions have difficulty in facing climatic crises, although such crises are recurrent. Any extreme climatic event can become a social catastrophe when combined with the social-political characteristics of the region. For example, the droughts and internecine wars in Ethiopia interact to increase the adverse effects of both. Although developing regions are more vulnerable to climate changes than are developed countries, the degree of vulnerability varies in each specific region." (Magalhães, 1996)

Research on comparative adaptive capacity and vulnerability is evolving, and its difficulties are well recognized (Bohle *et al*., 1994; Downing, 1996; Handmer *et al*., 1999; Kelly and Adger, 1999). Estimates of adaptive capacity tend to be based on premises such as the position that highly managed systems (such as agriculture), given sufficient resources, are likely to be more adaptable (and at a lower cost) than less managed ecosystems (Strzepek and Smith, 1995; Burton, 1996; Toman and Bierbaum, 1996). It is also widely accepted that systems with high levels of capacity to cope with historical and/or existing stresses can be expected to have high adaptive capacity for stresses associated with climatic change (Ausubel, 1991a). Such premises have formed the basis for broad assessments of sensitivity and adaptability (USNAS, 1992). Of course, sensitivity and adaptive capacity vary according to the climate change-related stress being considered. Thus, adaptive capacity to gradual changes in mean temperature may be high (or not much needed), but adaptive capacity to changes in the magnitude or frequency of extreme climatic conditions may not be so high (Appendi and Liverman, 1996).

18.5.2. Determinants of Adaptive Capacity

Adaptation to climate change and risks takes place in a dynamic social, economic, technological, biophysical, and political context that varies over time, location, and sector. This complex mix of conditions determines the capacity of systems to adapt. Although scholarship on adaptive capacity is extremely limited in the climate change field, there is considerable understanding of the conditions that influence the adaptability of societies to climate stimuli in the fields of hazards, resource management, and sustainable development. From this literature, it is possible to identify the main features of communities or regions that seem to determine their adaptive capacity: economic wealth, technology, information and skills, infrastructure, institutions, and equity.

18.5.2.1. Economic Resources

Whether it is expressed as the economic assets, capital resources, financial means, wealth, or poverty, the economic condition of nations and groups clearly is a determinant of adaptive capacity (Burton *et al*., 1998; Kates, 2000). It is widely accepted that wealthy nations are better prepared to bear the costs of adaptation to climate change impacts and risks than poorer nations (Goklany, 1995; Burton, 1996). It is also recognized that poverty is directly related to vulnerability (Chan and Parker, 1996; Fankhauser and Tol, 1997; Rayner and Malone, 1998). Although poverty should not be considered synonymous with vulnerability, it is "a rough indicator of the ability to cope" (Dow, 1992). Holmes (1996) recognizes that Hong Kong's financial strength has contributed in the past to its ability to better manage environmental hazards through conservation and pollution control. Bohle *et al.* (1994) state that, by definition, it usually is the poor who are among the most vulnerable to famine, malnutrition, and hunger. Deschingkar (1998) describes a situation in India in which pastoralist communities are "locked into" a vulnerable situation in part because of a lack of financial power that would allow them to diversify and engage in other sources of income. At a local level, Pelling (1998) concludes that the highest levels of household vulnerability in coastal Guyana also are characterized by low household incomes in conjunction with poor housing quality and little community organization. Neighborhoods with higher levels of household income are better able to manage vulnerability through the transfer of flood impacts from health to economic investment and loss. Kelly and Adger (1999) demonstrate the influence of poverty on a region's coping capacity; poor regions tend to have less diverse and more restricted entitlements and a lack of empowerment to adapt. There is ample evidence that poorer nations and disadvantaged groups within nations are especially vulnerable to disasters (Banuri, 1998; Munasinghe, 2000).

18.5.2.2. Technology

Lack of technology has the potential to seriously impede a nation's ability to implement adaptation options by limiting the range of possible responses (Scheraga and Grambsch, 1998). Adaptive capacity is likely to vary, depending on availability and access to technology at various levels (i.e., from local to national) and in all sectors (Burton, 1996). Many of the adaptive strategies identified as possible in the management of climate change directly or indirectly involve technology (e.g., warning systems, protective structures, crop breeding and irrigation, settlement and relocation or redesign, flood control measures). Hence, a community's current level of technology and its ability to develop technologies are important determinants of adaptive capacity. Moreover, openness to the development and utilization of new technologies for sustainable extraction, use, and development of natural resources is key to strengthening adaptive capacity (Goklany, 1995). For example, in the context of Asian agriculture and the impact of future climate change, Iglesias e*t al*. (1996) note that the development of heat-resistant rice cultivars will be especially crucial. Regions with the ability to develop technology have enhanced adaptive capacity.

18.5.2.3. Information and Skills

"Successful adaptation requires a recognition of the necessity to adapt, knowledge about available options, the capacity to assess them, and the ability to implement the most suitable ones" (Fankhauser and Tol, 1997). In the context of climate variability and change, this idea may be better understood through the example of the insurance industry: As information on weather hazards becomes more available and understood, it is possible to study, discuss, and implement adaptation measures (Downing, 1996). Building adaptive capacity requires a strong, unifying vision; scientific understanding of the problems; an openness to face challenges; pragmatism in developing solutions; community involvement; and commitment at the highest political level (Holmes, 1996). Lack of trained and skilled personnel can limit a nation's ability to implement adaptation options (Scheraga and Grambsch, 1998). In general, countries with higher levels of stores of human knowledge are considered to have greater adaptive capacity than developing nations and those in transition (Smith and Lenhart, 1996). Magalhães (1996) includes illiteracy along with poverty as a key determinant of low adaptive capacity in northeast Brazil. Such findings have prompted Gupta and Hisschemöller (1997) to conclude that it is important, therefore, to ensure that systems are in place for the dissemination of climate change and adaptation information nationally and regionally and that there are forums for discussion and innovation of adaptation strategies at various levels.

18.5.2.4. Infrastructure

Adaptive capacity is likely to vary with social infrastructure (Toman and Bierbaum, 1996). Some researchers regard the adaptive capacity of a system as a function of *availability of* and *access to* resources by decisionmakers, as well as vulnerable subsectors of a population (Kelly and Adger, 1999). For example, the Philippine island of Mindanao uses hydroelectric power to generate more than 90% of its electricity, which in turn supports local development and industry. During El Niño, drought conditions resulted in suspension of production by the hydroelectric plant and severely increased the economic vulnerability of the region (Tiglao, 1992). In the coastal area of Hong Kong, the capacity to adapt to the risk of typhoons differs for existing urban areas and for new coastal land reclamation. For existing urban areas, there is no possibility of retreat or accommodation, although during urban renewal the formation level of the ground could be raised, thereby decreasing the vulnerability of settlements (Yim, 1996). At the community level, Pelling (1997) notes that the lack of flexibility "in formal housing areas where dwelling form and drainage infrastructure were more fixed" reduced the capacity to respond to contemporary environmental conditions.

18.5.2.5. Institutions

O'Riordan and Jordan (1999) describe the role of institutions "as a means for holding society together, giving it sense and purpose and enabling it to adapt." In general, countries with well-developed social institutions are considered to have greater adaptive capacity than those with less effective institutional arrangements—commonly, developing nations and those in transition (Smith and Lenhart, 1996). The role of inadequate institutional support is frequently cited in the literature as a hindrance to adaptation. Kelly and Adger (1999) show how institutional constraints limit entitlements and access to resources for communities in coastal Vietnam and thereby increase vulnerability. Huq *et al.* (1999) demonstrate that Bangladesh is particularly vulnerable to climate change—especially in the areas of food production, settlements, and human life—reflecting serious constraints on adaptive capacity in the "existing institutional arrangements (which) is not conducive to ease the hardship of the people. Due to inherent institutional deficiencies and weaknesses in managerial capacities to cope with the anticipated natural event, it would be extremely difficult for the country to reduce vulnerability to climate change" (Ahmed *et al.*, 1999). Baethgen (1997) discusses an example in which the presence of inconsistent and unstable agricultural policies has increased the vulnerability of the food production sector in Latin America. Drastic changes in economic and policy conditions are expected to make agricultural systems more vulnerable to changes in climate. Parrish and Funnell (1999) note that although the local agro-ecosystem in the Moroccon High Atlas region may prove resilient to climate change initially, it is possible that the need to change tenure conditions and other arrangements may create conflicts that are beyond the capacity of local institutions to resolve. Magadza (2000) shows how adaptation options in southern Africa are precluded by political and institutional inefficiencies and resulting resource inequities.

It is generally held that established institutions in developed countries not only facilitate management of contemporary climate-related risks but also provide an institutional capacity to help deal with risks associated with future climate change. Stakhiv (1994) states that in the water resource sector, present-day strategies, demand management tools, and measures (i.e., institutions) have evolved over the past 25 years and are capable of serving as a basis for adaptive response strategies to climate change: "[T]he accumulation of numerous small changes in the present range of water resources management practices and procedures increases the flexibility for adaptation to current climate uncertainty and serves as a precursor to future possible responses with an ill-defined, changing climatic regime." However, some analyses are less sanguine about the ability of existing institutions to efficiently deal with climate change hazards. For example, Miller *et al.* (1997) note that "the time has come for innovative thinking on the question of how our water allocation institutions should function to improve our capacity to adapt to the uncertain but potentially large impacts of global climate change on regional water supplies. Given the climatic uncertainties and the very different institutional settings that have developed in this country, there is no simple prescription for adaptation."

18.5.2.6. Equity

It is frequently argued that adaptive capacity will be greater if social institutions and arrangements governing the allocation of power and access to resources within a community, nation, or the globe assure that access to resources is equitably distributed (Ribot *et al*., 1996; Mustafa, 1998; Adger, 1999; Handmer *et al*., 1999; Kelly and Adger, 1999; Rayner and Malone, 1999; Toth, 1999). The extent to which nations or communities are "entitled" to draw on resources greatly influences their adaptive capacity and their ability to cope (Adger and Kelly, 1999). Some people regard the adaptive capacity of a system as a function not only of the *availability* of resources but of *access* to those resources by decisionmakers and vulnerable subsectors of a population (Kelly and Adger, 1999). In the case of technological innovation, Cyert and Kumar (1996) show that differential distribution of information within an organization can impose constraints on adaptation strategies. Differentiation in demographic variables such as age, gender, ethnicity, educational attainment, and health often are cited in the literature as being related to the ability to cope with risk (Chan and Parker, 1996; Burton *et al.*, 1998; Scheraga and Grambsch, 1998). Wisner's (1998) study of homeless people in Tokyo provides an example of a situation in which inequality in access to resources results in a diminished capacity to adapt to environmental risk. Homeless people generally occupy marginal areas that are more vulnerable to environmental hazards. An associated lack of financial resources and infrastructure restricts the availability of adaptation options. A study by Bolin and Stanford (1991) draws parallel conclusions about the marginalization of minority groups.

These determinants of adaptive capacity are not independent of each other, nor are they mutually exclusive. Adaptive capacity is the outcome of a combination of determinants and varies widely between countries and groups, as well as over time. "Vulnerability varies spatially because national environments, housing and social structure vary spatially. It varies temporally because people move through different life stages with varying mixes of resources and liabilities" (Uitto, 1998). Bohle *et al*. (1994) document variable vulnerability to climatic variations of groups in Zimbabwe and its association with poverty, the macro-political economy, and inequitable land distribution. Not only are conditions for adaptive capacity diverse, they also behave differently in different countries and regions, particularly depending on the level of development. These determinants represent conditions that constrain or enhance the adaptive capacity and hence the vulnerability of regions, nations, and communities.

18.5.3. Adaptive Capacity of Regions

At the global scale, there is considerable variation among countries with regard to their capacity to adapt to climate change. Given their economic affluence and stability; their institutions and infrastructures; and their access to capital, information, and technology, developed nations are broadly considered to have greater capacity to adapt than developing regions or countries in economic transition (Goklany, 1995; Burton, 1996; Magalhães, 1996; Toman and Bierbaum, 1996). In general, countries with well-developed social institutions supported by higher levels of capital and stores of human knowledge are considered to have greater adaptive capacity (Smith and Lenhart, 1996). Adaptation options—including traditional coping strategies—often are available in developing countries and countries in transition; in practice, however, those countries' capacity to effect timely response actions may be beyond their infrastructure and economic means (IPCC, 1997). For those countries, the main barriers are (Smith, 1996; IPCC, 1998; Mizina *et al.*, 1999):

- Financial/market (uncertain pricing, availability of capital, lack of credit)
- Institutional/legal (weak institutional structure, institutional instability)
- Social/cultural (rigidity in land-use practices, social conflicts)
- Technological (existence, access)
- Informational/educational (lack of information, trained personnel).

A study by Rosenzweig and Parry (1994) found considerable disparity between developed and developing countries in terms of potential adverse effects of climate change on agricultural systems; developing countries suffer the greatest losses. In addition, poorer, developing regions presumably will face stricter constraints on technology and institutions (Fankhauser and Tol, 1997) and that measures taken in response to climate change may be very demanding financially (Dvorak *et al.*, 1997; Deschingkar, 1998). Researchers also believe that compared to industrialized countries, developing countries possess a lower adaptive capacity as a result of greater reliance on climatic resources (Schelling, 1992; Fankhauser and Tol, 1997).

There is some suggestion, however, that the complex, multi-species, low- to middle-intensity farming systems that characterize agricultural endeavors in the developing world may have greater adaptive capacity under conditions of global climate change than western monocultures (Ramakrishnan, 1998). An example is found in the village of Maatisar (India), where local institutions in the past have operated on the principle of "moral economy," or guaranteed subsistence to all households in the village. These institutions have eroded over time, however, giving way to competitive market relations that do not guarantee subsistence during times of drought. As a result, the capacity of individual households to withstand seasonal fluctuations has decreased over time (Chen, 1991). Magalhães (1996) describes how northeast Brazil has become more vulnerable to droughts as inappropriate land use overstresses natural land and water resources and as the capacity to cope is limited by poverty.

Acceptance of western economic ideals coupled with increasing and rapid development may reduce the capacity of traditional societies to adapt (Watts, 1983; Chan and Parker, 1996). In the case of traditional or indigenous societies, the pursuit of western/European-style development trajectories may modify the nature of adaptive capacity (some improved, some diminished) by introducing greater technology dependence and higher density settlement and by devaluing traditional ecological knowledge and cultural values (Newton, 1995). For example, notwithstanding remarkable adaptations to a harsh climate, the North American Inuit continue to be vulnerable to climate change as a result of their dependence on wildlife (which are climate-sensitive). This vulnerability has been reduced by technological enhancement of adaptive capacity through the acquisition of snowmobiles, motorized boats, and even sonar. Such technological advances have allowed Inuit communities to become far more "fixed" than before. Many of the most densely populated areas lie at least partially within a few meters of sea level. This lack of "semi-permanence" may actually increase the Inuits' vulnerability to potential climate-induced sea-level rise by decreasing their capacity to adapt through retreat or migration (Rayner and Malone, 1998).

Although there is considerable literature on the determinants of adaptive capacity and examples of how they influence the adaptability of particular communities, there is little scholarship (and even less agreement) on criteria or variables by which adaptive capacity can be measured and by which the adaptive capacity of global regions can be quantitatively compared. Various studies have attempted to identify overall trends that cause increased or decreased vulnerability to environmental hazards (Torry, 1979; Lamb, 1982; Warrick and Reibsame, 1983; Ausubel, 1991b; Blaikie *et al.*, 1994); unfortunately, however, the concept of vulnerability "does not rest well on a developed theory, nor is it associated with widely accepted indicators or methods of measurement" (Bohle *et al.*, 1994).

Even less progress has been made in measuring adaptive capacity. In the context of African agriculture, Downing *et al.* (1997) attempt to quantitatively measure relative adaptive capacity of regions by using crude surrogates such as gross national product (GNP). Empirical local-level studies of vulnerability are so complex, however, that attempts to describe patterns or estimate trends at global or regional scales are extremely difficult (Liverman, 1990; Downing, 1991; Dow, 1992). These "difficulties in generalizing about levels of vulnerability even in a relatively small community" are demonstrated by Adger and Kelly's (1999) study of vulnerability to climate change in Vietnam. Because vulnerability is a composite concept, social change has the potential to make individuals or activities more vulnerable in some ways and less vulnerable in others (Rayner and Malone, 1998). The influence of changes in the determinants of adaptive capacity are not necessarily direct or clear, rendering the attempt to develop systematic indices for measurement and comparison a difficult task.

18.6. Enhancing Adaptive Capacity

The adaptive capacity of a system or nation is likely to be greater when the following requirements are met:

1) The nation has a stable and prosperous economy. Regardless of biophysical vulnerability to the impacts of climate change, developed and wealthy nations are better prepared to bear the costs of adaptation than developing countries (Goklany, 1995; Burton, 1996).
2) There is a high degree of access to technology at various levels (i.e., from local to national) and in all sectors (Burton, 1996). Moreover, openness to development and utilization of new technologies for sustainable extraction, use, and development of natural resources is key to strengthening adaptive capacity (Goklany, 1995).
3) The roles and responsibilities for implementation of adaptation strategies are well delineated by central governments and are clearly understood at national, regional, and local levels (Burton, 1996).
4) Systems are in place for the dissemination of climate change and adaptation information, nationally and regionally, and there are forums for the discussion and innovation of adaptation strategies at various levels (Gupta and Hisschemöller, 1997).
5) Social institutions and arrangements governing the allocation of power and access to resources within a nation, region, or community assure that access to

resources is equitably distributed because the presence of power differentials can contribute to reduced adaptive capacity (Mustafa, 1998; Handmer *et al*., 1999; Kelly and Adger, 1999).

6) Existing systems with high adaptive capacity are not compromised. For example, in the case of traditional or indigenous societies, pursuit of western/European-style development trajectories may reduce adaptive capacity by introducing greater technology dependence and higher density settlement and by devaluing traditional ecological knowledge and cultural values.

18.6.1. Adaptive Capacity and Sustainable Development

Ability to adapt clearly depends on the state of development (Berke, 1995; Munasinghe, 1998). As Ribot *et al*. (1996) illustrate, underdevelopment fundamentally constrains adaptive capacity, especially because of a lack of resources to hedge against extreme but expected events. The events are not surprises: "It is not that the risk is unknown, not that the methods for coping do not exist…rather inability to cope is due to lack of—or systematic alienation from—resources needed to guard against these events" (Ribot *et al*., 1996).

The process of enhancing adaptive capacity is not simple; it involves "spurts of growth inter-dispersed with periods of consolidation, refocusing and redirection" (Holmes, 1996). Enhancement of adaptive capacity involves similar requirements as promotion of sustainable development, including:

- Improved access to resources (Ribot *et al*., 1996; Kelly and Adger, 1999; Kates, 2000)
- Reduction of poverty (Berke, 1995; Eele, 1996; Karim, 1996; Kates, 2000)
- Lowering of inequities in resources and wealth among groups (Berke, 1995; Torvanger, 1998)
- Improved education and information (Zhao, 1996)
- Improved infrastructure (Magalhães and Glantz, 1992; Ribot *et al*., 1996)
- Diminished intergenerational inequities (Berke, 1995; Munasinghe, 2000)
- Respect for accumulated local experience (Primo, 1996)
- Moderate long-standing structural inequities (Magadza, 2000)
- Assurance that responses are comprehensive and integrative, not just technical (Ribot *et al*., 1996; Cohen *et al*., 1998; Rayner and Malone, 1998; Munasinghe and Swart, 2000)
- Active participation by concerned parties, especially to ensure that actions match local needs and resources (Berke, 1995; Ribot *et al*., 1996; Rayner and Malone, 1998; Ramakrishnan, 1999)
- Improved institutional capacity and efficiency (Handmer *et al*., 1999; Magadza, 2000).

Because actions taken without reference to climate have the potential to affect vulnerability to it, enhancement of adaptive capacity to climate change can be regarded as one component of broader sustainable development initiatives (Ahmad and Ahmed, 2000; Munasinghe, 2000; Robinson and Herbert, 2000). Hazards associated with climate change have the potential to undermine progress with sustainable development (Berke, 1995; Wang'ati, 1996). Therefore, it is important for sustainable development initiatives to explicitly consider hazards and risks associated with climate change (Apuuli *et al*., 2000).

Clearly, adaptive capacity to deal with climate risks is closely related to sustainable development and equity. Enhancement of adaptive capacity is fundamental to sustainable development. For example, in the drought-stricken region of northeastern Brazil, an assessment of past successes and failures has indicated that a comprehensive sustainable development strategy is needed to increase regional and societal capacity to face present and future climate variability (Magalhães, 1996). By assessing differences in vulnerability among regions and groups and by working to improve the adaptive capacity of those regions and groups, planned adaptation can contribute to equity considerations of sustainable development. In the context of African agriculture, Downing *et al.* (1997) conclude that enhancement of present resource management activities is necessary to prepare for potential impacts of climate change. In Malawi, as in many other places, the UNFCCC's objectives to "ensure food production is not threatened, and to enable economic development to proceed in a sustainable manner" also are central to the nation's development policies (Theu *et al.*, 1996). Thus, progress to reducing vulnerability to climate risks is consistent with Malawi's planning and development initiatives.

Notwithstanding the considerable literature on the impacts of climate change as described throughout this volume, very little attention has been devoted to the interaction of adaptation to climate change with ongoing development projects and programs. Because vulnerability to climate depends on the adaptive capacity of a wide range of attributes, it may be unrealistic to focus on development programs that deal with adaptation to climate alone (Cohen, *et al*., 1998; Rayner and Malone, 1998). Yet there is surprisingly little recognition of climate hazards and risks associated with climate change in established development projects and programs (Berke, 1995; Burton and Van Aalst, 1999). O'Brian and Liverman (1996) show how climate change can have serious implications for development projects planned or underway in Mexico, including hydroelectric and irrigation initiatives. Torvanger (1998) shows how climate flexibility considerations that can be built into development investments at modest incremental costs are applicable regardless of the uncertainties of climate change and with immediate value because of existing risks.

18.6.2. Capacity Enhancement by Scale

The vulnerabilities and anticipated impacts of climate change will be observed at different scales and levels of society—and enhancement of adaptive capacity can be initiated at different

***Table 18-6**: Adaptation and adaptive capacity in sectors (key findings from Chapters 4 through 9).*

Sector	Key Findings
Water Resources	– Water managers have experience adapting to change. Many techniques exist to assess and implement adaptive options. However, the pervasiveness of climate change may preclude some traditional adaptive strategies, and available adaptations often are not used. – Adaptation can involve management on the supply side (e.g., altering infrastructure or institutional arrangements) and on the demand side (changing demand or risk reduction). Numerous no-regret policies exist that will generate net social benefits regardless of climate change. – Climate change is just one of numerous pressures facing water managers. Nowhere are water management decisions taken solely to cope with climate change, although it is increasingly considered for future resource management. Some vulnerabilities are outside the conventional responsibility of water managers. – Estimates of the economic costs of climate change impacts on water resources depend strongly on assumptions made about adaptation. Economically optimum adaptation may be prevented by constraints associated with uncertainty, institutions, and equity. – Extreme events often are catalysts for changes in water management, by exposing vulnerabilities and raising awareness of climate risks. Climate change modifies indicators of extremes and variability, complicating adaptation decisions. – Ability to adapt is affected by institutional capacity, wealth, management philosophy, planning time scale, organizational and legal framework, technology, and population mobility. – Water managers need research and management tools aimed at adapting to uncertainty and change, rather than improving climate scenarios.
Ecosystems and Their Services	– Adaptation to loss of some ecosystem services may be possible, especially in managed ecosystems. However, adaptation to losses in wild ecosystems and biodiversity may be difficult or impossible. – There is considerable capacity for adaptation in agriculture, including crop changes and resource substitutions, but adaptation to evolving climate change and interannual variability is uncertain. – Adaptations in agriculture are possible, but they will not happen without considerable transition costs and equilibrium (or residual) costs. – Greater adverse impacts are expected in areas where resource endowments are poorest and the ability of farmers to adapt is most limited. – In many countries where rangelands are important, lack of infrastructure and investment in resource management limit options for adaptation. – Commercial forestry is adaptable, reflecting a history of long-term management decisions under uncertainty. Adaptations are expected in both land-use management (species-selection silviculture) and product management (processing-marketing). – Adaptation in developed countries will fare better, while developing countries and countries in transition, especially in the tropics and subtropics, will fare worse.
Coastal Zones	– Without adaptations, the consequences of global warming and sea-level rise would be disastrous. – Coastal adaptation entails more than just selecting one of the technical options to respond to sea-level rise (strategies can aim to protect, accommodate, or retreat). It is a complex and iterative process rather than a simple choice. – Adaptation options are more acceptable and effective when they are incorporated into coastal zone management, disaster mitigation programs, land-use planning, and sustainable development strategies. – Adaptation choices will be conditioned by existing policies and development objectives, requiring researchers and policymakers to work toward a commonly acceptable framework for adaptation. – The adaptive capacity of coastal systems to perturbations is related to coastal resilience, which has morphological, ecological, and socioeconomic components. Enhancing resilience—including the technical, institutional, economic, and cultural capability to cope with impacts—is a particularly appropriate adaptive strategy given future uncertainties and the desire to maintain development opportunities. – Coastal communities and marine-based economic sectors with either low exposure or high adaptive capacity will be least affected. Communities with less economic resources, poorer infrastructure, less developed communications and transportation systems, and weak social support systems have less access to adaptation options and are more vulnerable.

Table 18-6 (continued)

Sector	Key Findings
Human Settlements, Energy, and Industry	– The larger and more costly impacts of climate change occur through changed probability of extreme weather events that overwhelm the design resiliency of human systems. – There are many adaptation options available to reduce the vulnerability of settlements. However, urban managers, especially in developing countries, have so little capacity to deal with current problems (housing, sanitation, water, and power) that dealing with climate change risks is beyond their means. – Lack of financial resources, weak institutions, and inadequate or inappropriate planning are major barriers to adaptation in human settlements. – Successful environmental adaptation cannot occur without locally based, technically competent, and politically supported leadership. – Uncertainty with respect to capacity and the will to respond hinder the assessment of adaptations and vulnerability.
Insurance and Other Financial Services	– Adaptation in financial and insurance services in the short term is likely to be to changing frequencies and intensities of extreme weather events. – Increasing risk could lead to a greater volume of traditional business and the development of new financial risk management products, but increased variability of loss events would heighten actuarial uncertainty. – Financial services firms have adaptability to external shocks, but there is little evidence that climate change has been incorporated into investment decisions. – The adaptive capacity of the financial sector is influenced by regulatory involvement, the ability of firms to withdraw from at-risk markets, and fiscal policy regarding catastrophe reserves. – Adaptation will involve changes in the roles of private and public insurance. Changes in the timing, intensity, frequency, and/or spatial distribution of climate-related losses will generate increased demand on already overburdened government insurance and disaster assistance programs. – Developing countries seeking to adapt in a timely manner face particular difficulties, including limited availability of capital, poor access to technology, and absence of government programs. – Insurers'adaptations include raising prices, nonrenewal of policies, cessation of new policies, limiting maximum claims, and raising deductibles—actions that can seriously affect investment in developing countries. – Developed countries generally have greater adaptive capacity, including technology and economic means to bear the costs.
Human Health	– Adaptation involves changes in society, institutions, technology, or behavior to reduce potential negative impacts or to increase positive ones. There are numerous adaptation options, which may occur at the population, community, or personal levels. – The most important and cost-effective adaptation measure is to rebuild public health infrastructure—which, in much of the world, has declined in recent years. Many diseases and health problems that may be exacerbated by climate change can be effectively prevented with adequate financial and human public health resources, including training, surveillance and emergency response, and prevention and control programs. – Adaptation effectiveness will depend on timing. “Primary” prevention aims to reduce risks before cases occur, whereas “secondary” interventions are designed to prevent further cases. – Determinants of adaptive capacity to climate-related threats to health include the level of material resources, the effectiveness of governance and civil institutions, the quality of public health infrastructure, and the preexisting burden of disease. – Capacity to adapt also will depend on research to understand associations between climate, weather, extreme events, and vector-borne diseases.

social scales (Ribot *et al*., 1996; Handmer *et al*., 1999). In Bangladesh, Ahmed *et al.* (1999) distinguish between four scales: mega, macro, meso, and micro. Using the example of sea-level rise as a climate change impact, the authors describe adaptation options at each scale. The process of sea-level rise occurs at the mega-scale and is global in its effect. At the macro-scale, an associated increase in surface water and groundwater has the potential to similarly effect neighboring rivers and flood plains in China, Nepal, India, Bhutan, and Pakistan. Adaptive capacity at this scale is a function of international economic and political structures, with implications for the nations'capital and technological resources and institutions. At the meso-scale, different communities within Bangladesh are differentially vulnerable, depending on adaptive capacity and physiographic characteristics. At this scale, location-specific adaptation options would need to be considered. Finally, at a micro-scale, family units and individuals would experience vulnerabilities irrespective of the origin of the processes and would employ adaptations within their particular economic and sociocultural constraints.

Because the vulnerabilities of climate change occur at various scales, successful adaptation will depend on actions taken at a number of levels. Examples of initiatives to enhance adaptive capacity at various scales follow:

- At a *global* scale
  - Greater cooperation between industrialized and developing countries to align global and local priorities by improving policy/science interactions and working toward greater public awareness of climate change and adaptation issues (Wang'ati, 1996; Gupta and Hisschemöller, 1997)
  - Inclusion of global institutions for global-level adaptation, which would include research and facilitation of policy, funding, and monitoring at all levels (Ahmed *et al*., 1999)
  - Removal of barriers to international trade; it is argued that improving market conditions, reducing the exploitation of marginal land, accelerating the transfer of technology, and contributing to overall economic growth will promote both sustainability and adaptive capacity (Goklany, 1995)
  - Effective global economic participation. Benefits go beyond direct financial gain and include technology transfers, technical and managerial skills transfers, and other skills transfers associated with the "learning and doing" process (Ebohon *et al*., 1997)
- At a *national* level
  - Development of climate change policy that is specifically geared toward more vulnerable sectors in the country (Mustafa, 1998), with an emphasis on poverty reduction (Kelly and Adger, 1999)
  - Establishment of broadly based monitoring and communication systems (e.g., integrated drought monitoring and information system, as suggested in Wilhite, 1997)
  - Establishment of public policy that encourages and supports adaptation at local or community levels and in the private sector (Burton, 1996)
  - Pursuit of sustainable economic growth—which, in turn, allows for greater dedication of resources to development of adaptive technologies and innovations (Goklany, 1995)
- Via *local* means
  - Establishment of social institutions and arrangements that discourage concentration of power in a few hands and prevent marginalization of sections of the local population (Mustafa, 1998); arrangements need to consider representativeness of decision-making bodies and maintenance of flexibility in the functioning of local institutions (Ramakrishnan, 1998)
  - Encouragement of diversification of income sources (and therefore risk-spreading), particularly for poorer sectors of society (Wang'ati, 1996; Adger and Kelly, 1999)
  - Encouragement of formal or informal arrangements for collective security (Kelly and Adger, 1999)
  - Identification and prioritization of local adaptation measures and provision of feedback to higher levels of government. These efforts would have to be reinforced by the adequate provision of knowledge, technology, policy, and financial support (Ahmed *et al*., 1999).

18.7. Sectoral and Regional Findings

Insights gained about adaptation and adaptive capacity from the sector chapters and the regional chapters are summarized in Tables 18-6 and 18-7, respectively.

Increasingly, adaptation and adaptive capacity are explicitly considered in impact and vulnerability assessments, and there are some consistent findings across sectors and regions (see Section 18.8). However, there is insufficient basis to rank systematically countries according to their adaptive capacity or to list the "most vulnerable" overall. Analyses to date indicate that adaptive capacity and vulnerability are multidimensional, so that one country (or, more often, a group within a country) may be extremely vulnerable economically whereas another country (or community) is extremely vulnerable in terms of life and livelihood. These different types of vulnerability reflect different types of exposures and adaptive capacities.

18.8. Conclusions

Adaptation can significantly reduce adverse impacts of climate change. Adaptation is an important part of societal response to global climate change. Planned, anticipatory adaptation has the potential to reduce vulnerability and realize opportunities associated with climate change effects and hazards. There are numerous examples of successful adaptations that would apply to climate change risks and opportunities. Substantial reductions in climate change damages can be achieved, especially in the most vulnerable regions, through timely deployment of adaptation measures.

In the absence of planned adaptation, communities will adapt autonomously to changing climatic conditions, but not without costs and residual damages. Societies and economies have been making adaptations to climate for centuries. However, losses from climate-related extreme events are substantial and, in some sectors, increasing—indicating patterns of development that remain vulnerable to temporal variations in climatic

Table 18-7*: Adaptation and capacity in regions (key findings from Chapters 10 through 17).*

Sector	Key Findings
Africa	– Adaptive measures would enhance flexibility and have net benefits in water resources (irrigation and water reuse, aquifer and groundwater management, desalinization), agriculture (crop changes, technology, irrigation, husbandry), and forestry (regeneration of local species, energy-efficient cook stoves, sustainable community management). – Without adaptation, climate change will reduce the wildlife reserve network significantly by altering ecosystems and causing species emigration and extinctions. This represents an important ecological and economic vulnerability in Africa. – A risk-sharing approach between countries will strengthen adaptation strategies, including disaster management, risk communication, emergency evacuation, and cooperative water resource management. – Most countries in Africa are particularly vulnerable to climate change because of limited adaptive capacity, as a result of widespread poverty, recurrent droughts, inequitable land distribution, and dependence on rainfed agriculture. – Enhancement of adaptive capacity requires local empowerment in decisionmaking and incorporation of climate adaptation within broader sustainable development strategies.
Asia	– Priority areas for adaptation are land and water resources, food productivity, and disaster preparedness and planning—particularly for poorer, resource-dependent countries. – Adaptations already are required to deal with vulnerabilities associated with climate variability, in human health, coastal settlements, infrastructure, and food security. The resilience of most sectors in Asia to climate change is very poor. Expansion of irrigation will be difficult and costly in many countries. – For many developing countries in Asia, climate change is only one of a host of problems to deal with, including nearer term needs such as hunger, water supply and pollution, and energy. Resources available for adaptation to climate are limited. Adaptation responses are closely linked to development activities, which should be considered in evaluating adaptation options. – Early signs of climate change already are observed and may become more prominent over 1 or 2 decades. If this time is not used to design and implement adaptations, it may be too late to avoid upheavals. Long-term adaptation requires anticipatory actions. – A wide range of precautionary measures are available at the regional and national level to reduce economic and social impacts of disasters. These measures include awareness building and expansion of the insurance industry. – Development of effective adaptation strategies requires local involvement, inclusion of community perceptions, and recognition of multiple stresses on sustainable management of resources. – Adaptive capacities vary between countries, depending on social structure, culture, economic capacity, and level of environmental disruptions. Limiting factors include poor resource and infrastructure bases, poverty and disparities in income, weak institutions, and limited technology. – The challenge in Asia lies in identifying opportunities to facilitate sustainable development with strategies that make climate-sensitive sectors resilient to climate variability. – Adaptation strategies would benefit from taking a more systems-oriented approach, emphasizing multiple interactive stresses, with less dependence on climate scenarios.
Australia and New Zealand	– Adaptations are needed to manage risks from climatic variability and extremes. Pastoral economies and communities have considerable adaptability but are vulnerable to any increase in the frequency or duration of droughts. – Adaptation options include water management, land-use practices and policies, engineering standards for infrastructure, and health services. – Adaptations will be viable only if they are compatible with the broader ecological and socioeconomic environment, have net social and economic benefits, and are taken up by stakeholders. – Adaptation responses may be constrained by conflicting short- and long-term planning horizons. – Poorer communities, including many indigenous settlements, are particularly vulnerable to climate-related hazards and stresses on health because they often are in exposed areas and have less adequate housing, health care, and other resources for adaptation.

Table 18-7 (continued)

Sector	Key Findings
Europe	– Adaptation potential in socioeconomic systems is relatively high as a result of strong economic conditions; stable population (with capacity to migrate); and well-developed political, institutional, and technological support systems. – The response of human activities and the natural environment to current weather perturbations provides a guide to critical sensitivities under future climate change. – Adaptation in forests requires long-term planning; it is unlikely that adaptation measures will be put in place in a timely manner. – Farm-level analyses show that if adaptation is fully implemented large reductions in adverse impacts are possible. – Adaptation for natural systems generally is low. – More marginal and less wealthy areas will be less able to adapt, so without appropriate policies of response climate change may lead to greater inequities.
Latin America	– Adaptation measures have potential to reduce climate-related losses in agriculture and forestry. – There are opportunities for adapting to water shortages and flooding through water resource management. – Adaptation measures in the fishery sector include changing species captured and increasing prices to reduce losses.
North America	– Strain on social and economic systems from rapid climate and sea-level changes will increase the need for explicit adaptation strategies. In some cases, adaptation may yield net benefits, especially if climate change is slow. – Stakeholders in most sectors believe that technology is available to adapt, although at some social and economic cost. – Adaptation is expected to be more successful in agriculture and forestry. However, adaptations for the water, health, food, and energy sectors and the cities are likely to require substantial institutional and infrastructure changes. – In the water sector, adaptations to seasonal runoff changes include storage, conjunctive supply management, and transfer. It may not be possible to continue current high levels of reliability of water supply, especially with transfers to high-valued uses. Adaptive measures such as "water markets" may lead to concerns about accessibility and conflicts over allocation priorities. – Adaptations such as levees and dams often are successful in managing most variations in the weather but can increase vulnerability to the most extreme events. – There is moderate potential for adaptation through conservation programs that protect particularly threatened ecosystems, such as high alpines and wetlands. It may be difficult or impossible to offset adverse impacts on aquatic systems.

conditions and to climate change. The ecological, social, and economic costs of relying on reactive, autonomous adaptation to the cumulative effects of climate change are substantial and largely avoidable through planned, anticipatory adaptation.

The key features of climate change for vulnerability and adaptation are those that relate to variability and extremes, not simply changed average conditions. In addition, the speed of changes in event frequency is important. Most communities, sectors, and regions are reasonably adaptable to changes in average conditions, unless those changes are particularly sudden or not smooth. However, these communities are more vulnerable and less adaptable to changes in the frequency and/or magnitude of conditions other than average, especially extremes. Changes in the frequency and magnitude of extremes underlie changes in mean conditions and thus are inherent in climate change; adaptation initiatives to these hazards are of particular need.

Implementation of adaptation policies, programs, and measures usually will have immediate as well as future benefits. Adaptations to current climate and climate-related risks (recurring droughts, storms, floods, and other extremes) generally are consistent with adaptation to changing and changed climatic conditions.

Adaptations to changing climatic conditions are more likely to be implemented if they are consistent with or integrated with decisions or programs that address nonclimatic stresses. Vulnerabilities associated with climate change rarely are experienced independent of nonclimatic conditions. Impacts of climatic stimuli are felt via economic or social stresses, and adaptations to climate (by individuals, communities, and governments) are evaluated and undertaken in light of these conditions. The costs of adaptation often are marginal to other management or development costs. To be effective, climate change adaptation must consider nonclimatic stresses and be

Table 18-7 (continued)

Sector	Key Findings
Polar Regions	– Adaptation will occur in natural polar ecosystems through migration and changing mixes of species. Species such as walrus, seals, and polar bears will be threatened, although others (such as fish) may flourish. – Potential for adaptation is limited in indigenous communities that follow traditional lifestyles. – Technologically developed communities are likely to adapt quite readily, although the high capital investment required may result in costs in maintaining lifestyles. – Adaptation depends on technological advances, institutional arrangements, availability of financing, and information exchange.
Small Island States	– The need for adaptation has become increasingly urgent, even if swift implementation of global agreements to reduce future emissions occurs. – Most adaptation will be carried out by people and communities who inhabit island countries; support from governments is essential for implementing adaptive measures. – Progress will require integration of appropriate risk-reduction strategies with other sectoral policy initiatives in areas such as sustainable development planning, disaster prevention and management, integrated coastal zone management, and health care planning. – Strategies for adaptation to sea-level rise are retreat, accommodate, and protect. Measures such as retreat to higher ground, raising of the land, and use of building set-backs appear to have little practical utility, especially when hindered by limited physical size. – Measures for reducing the severity of health threats include health education programs, improved health care facilities, sewerage and solid waste management, and disaster preparedness plans. – Islanders have developed some capacity to adapt by application of traditional knowledge, locally appropriate technology, and customary practice. Overall, however, adaptive capacity is low because of the physical size of nations, limited access to capital and technology, shortage of human resource skills, lack of tenure security, overcrowding, and limited access to resources for construction. – Many small islands require external financial, technical, and other assistance to adapt. Adaptive capacity may be enhanced by regional cooperation and pooling of limited resources.

consistent with existing policy criteria, development objectives, and management structures.

Adaptive capacity varies considerably among regions, countries, and socioeconomic groups. The ability to adapt and cope with climate change impacts is a function of wealth, technology, information, skills, infrastructure, institutions, and equity. Groups and regions with limited adaptive capacity are more vulnerable to climate change damages.

Development decisions, activities, and programs play important roles in modifying the adaptive capacity of communities and regions, yet they tend not to take into account risks associated with climate variability and change. This omission in the design and implementation of many recent and current development initiatives results in unnecessary additional losses to life, well-being, and investments in the short and longer terms.

Enhancement of adaptive capacity is necessary to reduce vulnerability, particularly for the most vulnerable regions, nations, and socioeconomic groups. Activities required for the enhancement of adaptive capacity are essentially equivalent to those that promote sustainable development and equity.

Current knowledge about adaptation and adaptive capacity is insufficient for reliable prediction of adaptations and for rigorous evaluation of planned adaptation options, measures, and policies of governments:

- Although climate change vulnerability studies now usually consider adaptation, they rarely go beyond identifying adaptation options that might be possible. There is little research on the dynamics of adaptation in human systems, the processes of adaptation decisionmaking, the conditions that stimulate or constrain adaptation, and the role of nonclimatic factors.
- There are serious limitations in existing evaluations of adaptation options. Economic benefits and costs are key criteria, but they are not sufficient to adequately determine the appropriateness of adaptation measures. There also has been little research to date on the roles and responsibilities of individuals, communities, corporations, private and public institutions, governments, and international organizations in adaptation.
- Given the scope and variety of specific adaptation options across sectors, individuals, communities, and locations and the variety of participants—private and public—involved in most adaptation initiatives, it is probably infeasible to systematically evaluate lists of particular adaptation measures. Improving and applying knowledge on the constraints and opportunities for enhancing adaptive capacity is necessary to reduce vulnerabilities.

References

Abel, W., 1976: *Massenarmut und Hungerkrisen im Vorindustriellen Europa.* Rev. ed., Paul Parey, Hamburg, Germany, 233 pp.

Abercrombie, M., C.J. Hickman, and M.L. Johnson, 1997: *A Dictionary of Biology*. Penguin Books, Harmondsworth, United Kingdom, 309 pp.

Adams, R.M., K.J. Bryant, D.M. Legler, B.A. McCarl, J. O'Brian, A. Solow, and R. Weiher, 1995: Value of improved long-range weather information. *Contemporary Economic Policy*, **13,** 10–19.

Adger, W.N., 1999: Exploring income inequality in rural, coastal Vietnam. *Journal of Development Studies*, **35,** 96–119.

Adger, W.N. and P.M. Kelly, 1999: Social vulnerability to climate change and the architecture of entitlements. *Mitigation and Adaptation Strategies for Global Change*, **4(3–4),** 253–266.

Ahmad, Q.K. and A.U. Ahmed, 2000: Social sustainability, indicators and climate change. In: *Climate Change and Its Linkages with Development, Equity and Sustainability: Proceedings of the IPCC Expert Meeting held in Colombo, Sri Lanka, 27–29 April, 1999* [Munasinghe, M. and R. Swart (eds.)]. LIFE, Colombo, Sri Lanka; RIVM, Bilthoven, The Netherlands; and World Bank, Washington, DC, USA, pp. 95–108.

Ahmed, A.U., M. Alam, and A.A. Rahman, 1999: Adaptation to climate change in Bangladesh: future outlook. In: *Vulnerability and Adaptation to Climate Change for Bangladesh* [Huq, S., M. Asaduzzaman, Z. Karim, and F. Mahtab (eds.)]. J. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 125–143.

Alderwish, A. and M. Al-Eryani, 1999: An approach for assessing the vulnerability of the water resources of Yemen to climate change. In: *National Assessment Results of Climate Change: Impacts and Responses: CR Special 6* [Mimura, N. (ed.)]. Inter-research, Oldendorf, Germany, pp. 85–89.

Alexandrov, V., 1999: Vulnerability and adaptation of agronomic systems in Bulgaria. In: *National Assessment Results of Climate Change: Impacts and Responses: CR Special 6* [Mimura, N. (ed.)]. Inter-research, Oldendorf, Germany, pp. 161–173.

Al-Farouq, A. and S. Huq, 1996: Adaptation to climate change in the coastal resources sector of Bangladesh: some issues and problems. In: *Adapting to Climate Change: An International Perspective* [Smith, J., N. Bhatti, G. Menzhulin, R. Benioff, M.I. Budyko, M. Campos, B. Jallow, and F. Rijsberman (eds.)]. Springer-Verlag, New York, NY, USA, pp. 335–344.

Ali, A., 1999: Climate change impacts and adaptation assessment in Bangladesh. In: *National Assessment Results of Climate Change: Impacts and Responses: CR Special 6* [Mimura, N. (ed.)]. Inter-research, Oldendorf, Germany, pp. 109–116.

Appendi, K. and D. Liverman, 1996: Agricultural policy and climate change in Mexico. In: *Climate Change and World Food Security* [Downing, T.E. (ed.)]. Springer-Verlag, Berlin, Germany, pp. 525–550.

Apuuli, B., J. Wright, C. Elias, and I. Burton, 2000: Reconciling national and global priorities in adaptation to climate change: with an illustration from Uganda. *Environmental Monitoring and Assessment*, **61(1),** pp. 145–159.

Ausubel, J., 1991a: A second look at the impacts of climate change. *American Scientist*, **79,** 211–221.

Ausubel, J.H., 1991b: Does climate still matter? *Nature*, **350,** 649–652.

Baethgen, W., 1997: Vulnerability of the agricultural sector of Latin America to climate change. *Climate Research*, **9,** 1–7.

Banuri, T., 1998: Human and environmental security. *Policy Matters*, **3,** 196–205.

Basher, R.E., 1999: Data requirements for developing adaptations to climate variability and change. *Mitigation and Adaptation Strategies for Global Change*, **4(3–4),** 227–225.

Benioff, F., S. Guill, and J. Lee, 1996: *Vulnerability and Adaptation Assessments: An International Handbook*. J. Kluwer Academic Publishers, Boston, MA, USA, 177 pp.

Beran, M. and N. Arnell, 1995: Climate change and hydrological disasters. In: *Hydrology of Disasters* [Singh, V.P. (ed.)]. J. Kluwer Academic Publishers, Dordrecht, The Netherlands, 53–77.

Berke, P.R., 1995: Natural-hazard reduction and sustainable development: a global assessment. *Journal of Planning Literature*, **9(4),** 370–382.

Berke, P.R., J. Kartez, and D. Wenger, 1993: Recovery after disaster: achieving sustainable development, mitigation and equity. *Disasters: The Journal of Disaster Studies and Management*, **17(2),** 93–109.

Berz, G.A., 1999: Catastrophes and climate change: concerns and possible countermeasures of the insurance industry. *Mitigation and Adaptation Strategies for Global Change*, **4(3–4),** 283–293.

Bijlsma, L., C.N. Ehler, R.J.T. Klein, S.M. Kulshrestha, R.F. McLean, N. Mimura, R.J. Nicholls, L.A. Nurse, H. Pérez Nieto, E.Z. Stakhiv, R.K. Turner, and R.A. Warrick, 1996: Coastal zones and small islands. In: *Climate Change 1995: Impacts, Adaptations, and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change* [Watson, R.T., M.C. Zinyowera, and R.H. Moss (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 289–324.

Blaikie, P., T. Cannon, I. Davies, and B. Wisner, 1994: *At Risk: Natural Hazards, People's Vulnerability, and Disasters*. Routledge, New York, NY, USA, 284 pp.

Bohle, H.G., T.E. Downing, and M.J. Watts, 1994: Climate change and social vulnerability: toward a sociology and geography of food insecurity. *Global Environmental Change*, **4(1),** 37–48.

Bolin, R. and L. Stanford, 1991: Shelter, housing and recovery: a comparison of U.S. disasters. *Disasters*, **15(1),** 24–34.

Brown, P.G., 1998: Toward and economics of stewardship: the case of climate. *Ecological Economics*, **26,** 11–21.

Bruce, J.P., 1999: Disaster loss mitigation as an adaptation to climate variability and change. *Mitigation and Adaptation Strategies for Global Change*, **4(3–4),** 295–306.

Bryant, C.R., B. Smit, M. Brklacich, T.R. Johnston, J. Smithers, Q. Chiotti, and B. Singh, 2000: Adaptation in Canadian agriculture to climatic variability and change. *Climatic Change*, **45(1),** 181–201.

Burton, I., 1997: Vulnerability and adaptive response in the context of climate and climate change. *Climatic Change*, **36**, 185–196.

Burton, I., 1996: The growth of adaptation capacity: practice and policy. In: *Adapting to Climate Change: An International Perspective* [Smith, J., N. Bhatti, G. Menzhulin, R. Benioff, M.I. Budyko, M. Campos, B. Jallow, and F. Rijsberman (eds.)]. Springer-Verlag, New York, NY, USA, pp. 55–67.

Burton, I. and M. van Aalst, 1999: *Come Hell or High Water: Integrating Climate Change Vulnerability and Adaptation into Bank Work*. World Bank Environment Department Paper No. 72, Climate Change Series, Washington D.C., USA, 60 pp.

Burton, I. and S.J. Cohen, 1993: Adapting to global warming: regional options. In: *Proceedings of the International Conference on the Impacts of Climatic Variations and Sustainable Development in the Semi-Arid Regions, A Contribution to UNCED* [Magelhães, A.R. and A.F. Bezerra (eds.)]. Esquel Brazil Foundation, Brasilia, Brazil, pp. 871–886.

Burton, I., R.W. Kates, and G.F. White, 1993: *The Environment As Hazard*. The Guilford Press, New York, NY, USA, 290 pp.

Burton, I., J.B. Smith, and S. Lenhart, 1998: Adaptation to climate change: theory and assessment. In: *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies* [Feenstra, J.F., I. Burton, J.B. Smith, and R.S.J. Tol (eds.)]. United Nations Environment Programme and Institute for Environmental Studies, Free University of Amsterdam, Amsterdam, pp. 5.1–5.20.

Cai, Y. and B. Smit, 1996: Sensitivity and adaptation of Chinese agriculture under global climate change. *Acta Geographica Sinica*, **51(3),** 202–212.

Campos, M., A. Sánchez, and D. Espinosa, 1996: Adaptation of hydropower generation in Costa Rica and Panama to climate change. In: *Adapting to Climate Change: An International Perspective* [Smith, J., N. Bhatti, G. Menzhulin, R. Benioff, M.I. Budyko, M. Campos, B. Jallow, and F. Rijsberman (eds.)]. Springer-Verlag, New York, NY, USA, pp. 232–242.

Carter, T.R., 1996: Assessing climate change adaptations: the IPCC guidelines. In: *Adapting to Climate Change: An International Perspective* [Smith, J., N. Bhatti, G. Menzhulin, R. Benioff, M.I. Budyko, M. Campos, B. Jallow, and F. Rijsberman (eds.)]. Springer-Verlag, New York, NY, USA, pp. 27–43.

Carter, T.R., M.L. Parry, H. Harasawa, and S. Nishioka, 1994: *IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations*. University College, London, United Kingdom, and Centre for Global Environmental Research, Tsukuba, Japan, 59 pp.

Chambers, R., 1989: Editorial introduction: vulnerability, coping and policy. *IDS Bulletin*, **21,** 1–7.

Chan, N. and D. Parker, 1996: Response to dynamic flood hazard factors in peninsular Malaysia. *The Geographic Journal*, **162(3),** 313–325.

Changnon, S.A., D. Changnon, E.R. Fosse, D.C. Hoganson, R.J. Roth, and J.M. Totsch, 1997: Effects of recent weather extremes on the insurance industry: major implications for the atmospheric science. *Bulletin of the American Meteorological Society,* **78(3),** 425–435.

Chen, M., 1991: *Coping with Seasonality and Drought*. Sage Publications, New Delhi, India, 254 pp.

Cohen, S., D. Demeritt, J. Robinson, and D. Rothman, 1998: Climate change and sustainable development: towards dialogue. *Global Environmental Change*, **8(4),** 341–371.

Cyert, R. and P. Kumar, 1996: Strategies for technological innovation with learning and adaptation costs. *Journal of Economics and Management Strategy,* **5(1),** 25–67.

De Loë, R.C. and R. Kreutzwiser, 2000: Climate variability, climate change and water resource management in the Great Lakes. *Climatic Change*, **45(1),** 163–179.

De Freitas, C.R., 1989: The hazard potential of drought for the population of the Sahel. In: *Population and Disaster* [Clarke, J.I., P. Curson, S.L. Kayastha, and P. Nag (eds.)]. Blackwell, Oxford, United Kingdom, pp. 98–113.

De Ruig, J.H.M., 1997: Resilience in ditch coastline management. *Coastline*, **6(2),** 4–8.

Denevan, W.M., 1983: Adaptation, variation, and cultural geography. *Professional Geographer*, **35,** 399–407.

Deschingkar, P., 1998: Climate change adaptation in India: a case study of forest systems in Himachal Pradesh. *International Journal of Environment and Pollutio*n, **9(2/3),** 186–197.

De Vries, J., 1985: Analysis of historical climate-society interaction. In: *Climate Impact Assessment* [Kates, R.W., J.H. Ausubel, and M. Berberian (eds.)]. John Wiley and Sons, New York, NY, USA, pp. 273–291.

De Vries, J., 1977: Histoire du climat et économie: des faits nouveaux, une interprétation différente. *Annales: Economies, Sociétés, Civilisations*, **32,** 198–227.

Dow, K., 1992: Exploring the differences in our common future(s): the meaning of vulnerability to global environmental change. *Geoforum*, **23(3),** 417–436.

Dowlatabadi, H., 1995: Integrated assessment models of climate change. *Energy Policy*, **23(4/5),** 289–296.

Downing, T.E. (ed.), 1996: *Climate Change and World Food Security.* Springer-Verlag, Berlin, Germany, pp. 662.

Downing, T.E., 1991: Vulnerability to hunger in Africa. *Global Environmental Change*, **1,** 365–380.

Downing, T.E., K.W. Gitu, and C.M. Kaman (eds.), 1989: *Coping with Drought in Kenya: National and Local Strategies*. Lynne Rienner, Boulder, CO, USA, 411 pp.

Downing, T.E., A.A. Olsthoorn, and R.S.J. Tol, 1996: *Climate Change and Extreme Events: Altered Risks, Socio-Economic Impacts and Policy Responses.* Vrije Universiteit, Amsterdam, The Netherlands, 411 pp.

Downing, T.E., L. Ringius, M. Hulme, and D. Waughray, 1997: Adapting to climate change in Africa. *Mitigation and Adaptation Strategies for Global Chang*e, **2(1),** 19–44.

Downing, T.E., M.J. Gawaith, A.A. Olsthoorn, R.S.J. Tol, and P. Vellinga, 1999: Introduction. In: *Climate Change and Risk* [Downing, T.E., A.A. Olsthoorn, and R.S.J. Tol (eds.)]. Routledge, London, United Kingdom, pp. 1–19.

Dvorak, V., J. Hladmy, and L. Kasparek, 1997: Climate change, hydrology and water resources impact and adaptation for selected river basins in the Czeck Republic. *Climatic Change*, **36,** 93–106.

Easterling, W.E., 1996: Adapting North American agriculture to climate change in review. *Agricultural and Forest Meteorology,* **80(1),** 1–54.

Easterling, W.E., P.R. Crosson, N.J. Rosenberg, M.S. McKenney, L.A. Katz, and K.M. Lemon, 1993: Agricultural impacts of and responses to climate change in the Missouri-Iowa-Nebraska-Kansas (MINK) Region. *Climatic Chang*e, **24,** 23–61.

Ebohon, O.J., B.G. Field, and R. Ford, 1997: Institutional deficiencies and capacity building constraints: the dilemma for environmentally sustainable development in Africa. *International Journal of Sustainable Development and World Ecology,* **4(3),** 204–213.

Eele, G., 1996: Policy lessons from communities under pressure. In: *Climate Change and World Food Security* [Downing, T.E. (ed.)]. Springer-Verlag, Berlin, Germany, pp. 611–624.

El-Raey, M., K. Dewidar, and M. El-Hattab, 1999: Adaptation to the impacts of sea level rise in Egypt. *Mitigation and Adaptation Strategies for Global Change*, **4(3–4),** 343–361.

El-Shaer, M.H., H.M. Eid, C. Rosenzweig, A. Iglesias, and D. Hillel, 1996: Agricultural adaptation to climate change in Egypt. In: *Adapting to Climate Change: An International Perspective* [Smith, J., N. Bhatti, G. Menzhulin, R. Benioff, M.I. Budyko, M. Campos, B. Jallow, and F. Rijsberman (eds.)]. Springer-Verlag, New York, NY, USA, pp. 109–127.

Erda, L., 1996: Agricultural vulnerability and adaptation to global warming in China. *Water, Air and Soil Pollution*, **92,** 63–75.

Etkin, D., 1998: Climate change and extreme events: Canada. *Canada Country Study: Climate Impacts and Adaptation*, **8,** 31–80.

Fang, J-Q. and G. Liu, 1992: Relationship between climatic change and the nomadic southward migration in eastern Asia during historical times. *Climatic Change*, **22,** 151–169.

Fankhauser, S., 1996: The potential costs of climate change adaptation. In: *Adapting to Climate Change: An International Perspective* [Smith, J., N. Bhatti, G. Menzhulin, R. Benioff, M.I. Budyko, M. Campos, B. Jallow, and F. Rijsberman (eds.)]. Springer-Verlag, New York, NY, USA, pp. 80–96.

Fankhauser, S. and R.S.J. Tol, 1997: The social costs of climate change: the IPCC second assessment report and beyond. *Mitigation and Adaptation Strategies for Global Change*, **1,** 385–403.

Fankhauser, S., J.B. Smith, and R.S.J. Tol, 1999: Weathering climate change: some simple rules to guide adaptation decisions. *Ecological Economics*, **30(1),** 67–78.

Fankhauser, S., J.B. Smith, and R.S.J. Tol, 1998: *Weathering Climate Change: Some Simple Rules to Guide Adaptation Decisions*. Institute for Environmental Studies, Amsterdam, The Netherlands, 12 pp.

Frederick, K.D., 1997: Adapting to climate impacts in the supply and demand for water. *Climatic Change*, **37,** 141–156.

Fukui, H., 1979: Climate variability and agriculture in tropical moist regions. In: *Proceedings of the World Climate Conference*. World Meteorological Association Report No. 537, Geneva, Switzerland, pp 407–426.

Gadgil, S., A.K.S. Huda, N.S. Johda, R.P. Singh, and S.M. Virmani, 1988: The effects of climatic variations on agriculture in dry tropical regions of India. In: *The Impact of Climatic Variations on Agriculture: Assessments in Semi-Arid Regions* [Parry, M.L., T.R. Carter, and N.T. Konjin (eds.)]. J. Kluwer Academic Publishers, Dordrecht, The Netherlands, 764 pp.

Glantz, M.H., 1996: Forecasting by analogy: local responses to global climate change. In: *Adapting to Climate Change: An International Perspective* [Smith, J., N. Bhatti, G. Menzhulin, R. Benioff, M.I. Budyko, M. Campos, B. Jallow, and F. Rijsberman (eds.)]. Springer-Verlag, New York, NY, USA, pp. 407–426.

Glantz, M.H. (ed.), 1992: *Climate variability, climate change, and fisheries*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 450 pp.

Glantz, M.H., 1988: *Societal Responses to Climate Change: Forecasting by Analogy*. Westview Press, Boulder, CO, USA, 428 pp.

Goklany, I.M., 1995: Strategies to enhance adaptability: technological change, sustainable growth and free trade. *Climatic Chang*e, **30,** 427–449.

Gupta, J. and M. Hisschemöller, 1997: Issue linkage as a global strategy toward sustainable development: a comparative case study of climate change. *International Environmental Affairs*, **9(4),** 289–308.

Handmer, J., S. Dovers, and T.E. Downing, 1999: Societal vulnerability to climate change and variability. *Mitigation and Adaptation Strategies for Global Change*, **4(3–4),** 267–281.

Hardesty, D.L., 1983: Rethinking cultural adaptation. *Professional Geographer*, **35,** 399–406.

Hareau, A., R. Hofstadter, and A. Saizar, 1999: Vulnerability to climate change in Uruguay: potential impacts on the agricultural and coastal resource sectors and response capabilities. In: *National Assessment Results of Climate Change: Impacts and Responses: CR Special 6* [Mimura, N. (ed.)]. Inter-research, Oldendorf, Germany, pp. 185–193.

Harrington, K., 1996: The risk management dilemma of climate change. *Water Resources Update*, **103,** 35–45.

Hartig, E.K., O. Grosev, and C. Rosenzweig, 1997: Climate change, agriculture and wetlands in eastern europe: vulnerability adaptation and policy. *Climatic Change*, **36,** 101–121.

Helmer, W.P., P. Vellinga, G. Litjens, H. Goosen, E. Ruijgrok, and W. Overmars, 1996: *Growing with the Sea—Creating a Resilient Coastline*. World Wildlife Fund for Nature, Zeist, The Netherlands, 39 pp.

Helms, S., R. Mendelsohn, and J. Neumann, 1996: The impact of climate change on agriculture: editorial essay. *Climatic Change*, **33,** 1–6.

Hewitt, K., 1997: *Regions of Risk: A Geographical Introduction to Disasters*. Addison-Wesley Longman, Essex, United Kingdom, 389 pp.

Hewitt, K.and I. Burton, 1971: *The Hazardousness of a Place: A Regional Ecology of Damaging Events*. University of Toronto, Toronto, ON, Canada, 154 pp.

Hisschemöller, M. and A.A. Olsthoorn, 1999: Identifying barriers and opportunities for policy responses to changing climatic risks. In: *Climate, Change and Risk* [Downing, T.E., A.A. Olsthoorn, and R.S.J. Tol (eds.)]. Routledge, London, United Kingdom, pp. 365–390.

Holmes, P., 1996: Building capacity for environmental management in Hong Kong. *Water Resources Development*, **12(4),** 461–472.

Huang, J.C.K., 1996: Climate change adaptation strategies: a challenge for small island nations. In: *Adapting to Climate Change: An International Perspective* [Smith, J., N. Bhatti, G. Menzhulin, R. Benioff, M.I. Budyko, M. Campos, B. Jallow, and F. Rijsberman (eds.)]. Springer-Verlag, New York, NY, USA, pp. 311–321.

Hulme, M. and S. Raper, 1995: An integrated framework to address climate change (ESCAPE) and further developments of the global and regional climate modules (MAGICC). *Energy Policy*, **23(4/5),** 347–355.

Hulme, M., E.M. Barrow, N.W. Arnell, P.A. Harrison, T.C. Johns, and T.E. Downing, 1999: Relative impacts of human-induced climate change and natural climate variability. *Nature*, **397,** 688–691.

Hunter, J.M., L. Rey, K.Y. Chu, E.O. Adekolu-John, and K.E. Mott, 1993: *Parasitic Diseases in Water Resource Development: The Need for Intersectoral Negotiation*. World Health organization, Geneva, Switzerland, 152 pp.

Huq, S., Z. Karim, M. Asaduzzaman, and F. Mahtab (eds.), 1999: *Vulnerability and Adaptation to Climate Change in Bangladesh*. J. Kluwer Academic Publishers, Dordrecht, The Netherlands, 147 pp.

Hurd, B., J. Callaway, P. Kirshen, and J. Smith, 1997: Economic effects of climate change on U.S. water resources. In: *The Impacts of Climate Change on the U.S. Economy* [Mendelsohn, R. and J. Newmann (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 331 pp.

Iglesias, A., L. Erda, and C. Rosenzweig, 1996: Climate change in Asia: a review of the vulnerability and adaptation of crop production. *Water, Air, and Soil Pollution*, **92,** 13–27.

Ingram, M.J., G. Farmer, and T.M.L. Wigley, 1981: Past climates and their impacts on man: a review. In: *Climate and History* [Wigley, T.M.L., M.J. Ingram, and G. Farmer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 530 pp.

IPCC, 1998: *The Regional Impacts of Climate Change: An Assessment of Vulnerability. Special Report of IPCC Working Group II* [Watson, R.T., M.C. Zinyowera, and R.H. Moss (eds.)]. Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 517 pp.

IPCC, 1997: *Technologies, Policies, and Measures for Mitigating Climate Change: IPCC Technical Paper I. Intergovernmental Panel on Climate Change, Working Group II* [Watson, R.T., M.C. Zinyowera, and R.H. Moss (eds.)]. World Meteorological Organization, Geneva, Switzerland, 84 pp.

IPCC, 1996: *Climate Change 1995: Impacts, Adaptations, and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change* [Watson, R.T., M.C. Zinyowera, and R.H. Moss (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1–18.

Jallow, B.P., 1996: Response strategies and adaptive measures to potential sea-level rise in the Gambia. In: *Adapting to Climate Change: An International Perspective* [Smith, J., N. Bhatti, G. Menzhulin, R. Benioff, M.I. Budyko, M. Campos, B. Jallow, and F. Rijsberman (eds.)]. Springer-Verlag, New York, NY, USA, pp. 299–310.

Johda, N.S., 1989: Potential strategies for adapting to greenhouse warming: perspectives from the developing world. In: *Greenhouse Warming: Abatement and Adaptation, Resources for the Future* [Rosenberg, N.J., W.E. Easterling, P.R. Crosson, and J. Darmstadter (eds.)]. Resources for the Future, Washington, DC, USA, pp. 147–158.

Kane, S.M., J. Reilly, and J. Tobey, 1992a: An empirical study of the economic effects of climate change on world agriculture. *Climatic Change*, **21,** 17–35.

Kane, S.M., J. Reilly, and J. Tobey, 1992b: A sensitivity analysis of the implications of climate change for world agriculture. In: *Economic Issues in Global Climate Change* [Reilly, J.M. and M. Anderson (eds.)]. Westview Press, Boulder, CO, USA, pp. 117–131.

Kane, S.M. and J.F. Shogren, 2000: Linking adaptation and mitigation in climate change policy. *Climatic Change*, **45(1),** 75–102.

Karim, Z., 1996: Agricultural vulnerability and poverty alleviation in Bangladesh. In: *Climate Change and World Food Security* [Downing, T.E. (ed.)]. Springer-Verlag, Berlin, Germany, pp. 307–346.

Karl, T.R. and R.W. Knight, 1998: Secular trends of precipitation amount, frequency, and intensity in the United States. *Bulletin of the American Meteorological Society*, **79(2),** 231–241.

Kasperson, J.X., R.E. Kasperson, and B.L. Turner II (eds.), 1995: *Regions at Risk: Comparisons of Threatened Environments*. United Nations University Press, Tokyo, Japan, 588 pp.

Kates, R.W., 2000: Cautionary tales: adaptation and the global poor. *Climatic Change*, **45(1),** 5–17.

Kates, R.W., J.H. Ausubel, and M. Berberian (eds.), 1985: *Climate Impact Assessment: Studies of the Impact of Climate and Society*. John Wiley and Sons, Chichester, United Kingdom, 625 pp.

Katz, R. and B. Brown, 1992: Extreme events in a changing climate: variability is more important than averages. *Climatic Change*, **21,** 289–302.

Kelly, P. and W.N. Adger, 1999: *Assessing Vulnerability to Climate Change and Facilitating Adaptation*. Working Paper GEC 99–07, Centre for Social and Economic Research on the Global Environment, University of East Anglia, Norwich, United Kingdom, 32 pp.

Klein, R.J.T., 1998: Towards better understanding, assessment and funding of climate adaptation. *Change*, **44,** 15–19.

Klein, R.J.T. and R.J. Nicholls, 1998: Coastal zones. In: *UNEP Handbook on Methods for Climate Change Impact Assessment and Adaptation Studies* [Burton, I., J.F. Feenstra, J.B. Smith, and R.S.J. Tol (eds.)]. Version 2.0, United Nations Environment Programme and Institute for Environmental Studies, Vrije Universiteit, Nairobi, Kenya and Amsterdam, The Netherlands, Chapter 7, pp. 1–36. Available online at http://www.vu.nl/english/o_o/instituten/IVM/research/climatechange/Handbook.htm.

Klein, R.J.T. and R.S.J. Tol, 1997: *Adaptation to Climate Change: Options and Technologies, An Overview Paper*. Technical Paper FCCC/TP/1997/3, United Nations Framework Convention on Climate Change Secretariat, Bonn, Germany, 33 pp. Available online at http://www.unfccc.int/resource/docs/tp/tp3.pdf.

Klein, R.J.T., R.J. Nicholls, and N. Mimura, 1999: Coastal adaptation to climate change: Can the IPCC Technical Guidelines be applied? *Mitigation and Adaptation Strategies for Global Change*, **4(3-4),** 239–252.

Klein, R.J.T., M.J. Smit, H. Goosen, and C.H. Hulsbergen, 1998: Resilience and vulnerability: coastal dynamics or Dutch dikes? *The Geographical Journal*, **164(3),** 259–268.

Koster, M.J. and R. Hillen, 1995: Combat erosion by law coastal defence policy for the Netherlands. *Journal of Coastal Research*, **11(4),** 1221–1228.

Krankina, O.N., R.K. Dixon, A.P. Kirilenko, and K.I. Kobak, 1997: Global climate change adaptation: examples from Russian boreal forests. *Climatic Change*, **36,** 197–215.

Kundzewicz, Z. and K. Takeuchi, 1999: Flood protection and management: quo vadimus? *Hydrological Sciences*, **44(3),** 417–432.

Lamb, H.H., 1982: *Climate, History and the Modern World*. Routledge, London, United Kingdom, 387 pp.

Langen, A. and R.S.J. Tol, 1999: A concise history of riverine floods and flood management in the Dutch Rhine delta. In: *Climate, Change and Risk* [Downing, T.E., A.A. Olsthoorn, and R.S.J. Tol (eds.)]. Routledge, London, United Kingdom, pp. 162–172.

Lansigan, F.P., S. Pandey, and M.A.M. Bouman, 1997: Combining crop modeling with economic risk-analysis for the evaluation of crop management. *Journal of Field Crop Research*, **51,** 133–145.

Lawrence, E., 1995: *Henderson's Dictionary of Biological Terms*. Longman Scientific and Technical, Harlow, United Kingdom, 693 pp.

Leafe, R., J. Pethick, and I. Townsend, 1998: Realizing the benefits of shoreline management. *The Geographical Journal*, **164(3),** 282–290.

Leary, N.A., 1999: Aframework for benefit-cost analysis of adaptation to climate change and climate variability. *Mitigation and Adaptation Strategies for Global Change*, **4(3–4),** 307–318.

Leemans, R., 1992: Modelling ecological and agricultural impacts of global change on a global scale. *Journal of Scientific and Industrial Research*, **51,** 709–724.

Lempert, R.J., M.E. Schesinger, S.C. Bankes, and N.G. Andronova, 2000: The impacts of climate variability on near-term policy choices and the value of information. *Climatic Change*, **45(1),** 129–161.

Liverman, D.M., 1990: Vulnerability to global environmental change. In: *Environmental Risks and Hazards* [Cutter, S. (ed.)]. Prentice-Hall, Englewood Cliffs, NJ, USA, pp. 326–342.

Louisse, C.J. and F. Van der Meulen, 1991: Future coastal defence in The Netherlands: strategies for protection and sustainable development. *Journal of Coastal Research*, **7(4),** 1027–1041.

Luo, Q. and E. Lin, 1999: Agricultural vulnerability and adaptation in developing countires: the Asia-Pacific region. *Climatic Change*, **43,** 729–743.

MacDonald, G.M., T.W.D. Edwards, K.A. Moser, R. Pienitz, and J.P. Smol, 1993: Rapid response of treeline vegetation and lakes to past climate warming. *Nature*, **361,** 243–246.

Magadza, C.H.D., 2000: Climate change impacts and human settlements in Africa: prospects for adaptation. *Environmental Monitoring and Assesment*, **61(1),** 193–205.

Magadza, C.H.D, 1996: Climate change: some likely multiple impacts in southern Africa. In: *Climate Change and World Food Security* [Downing, T.E. (ed.)]. Springer-Verlag, Berlin, Germany, pp. 449–484.

Magalhães, A.R., 1996: Adapting to climate variations in developing regions: a planning framework. In: *Adapting to Climate Change: An International Perspective* [Smith, J., N. Bhatti, G. Menzhulin, R. Benioff, M.I. Budyko, M. Campos, B. Jallow, and F. Rijsberman (eds.)]. Springer-Verlag, New York, NY, USA, pp. 44–54.

Magalhães, A.R. and M.H. Glantz, 1992: *Socio-Economic Impacts of Climate Variations and Policy Responses in Brazil*. United Nations Environment Program, Esquel, Brasilia, Brazil, 155 pp.

Major, D.D. and K.D. Frederick, 1997: Water resources planning and climate change assessment methods. *Climatic Change*, **37(1),** 25–40.

Major, D.C., 1998: Climate change and water resources: the role of risk management methods. *Water Resources Update*, **112,** 47–50.

Martens, P., R.S. Kovats, S. Nijhof, P. de Vries, M.T.J. Livermore, D.J. Bradley, J. Cox, and A.J. McMichael, 1999: Climate change and future populations at risk of malaria. *Global Environmental Change*, **9,** S89–S107.

McGovern, T.H., 1991: Climate, correlation, and causation in Norse Greenland. *Arctic Anthroplogy*, **28(2),** 77–100.

McGregor, J., 1993: Refugees and the environment. In: *Geography and Refugees: Patterns and Processes of Change* [Black, R. and V. Robinson (eds.)]. Belhaven, Chichester, United Kingdom, 220 pp.

McMichael, A.J. and R.S. Kovats, 2000: Climate change and climate variability: adaptations to reduce adverse health impacts. *Environmental Monitoring and Assessment*, **61,** 49–64.

McMichael, A.J., A. Haines, R. Slooff, and S. Kovats (eds.), 1996: *Climate Change and Human Health*. WHO/EHG/96.7, an assessment prepared by a Task Group on behalf of the World Health Organization, the World Meteorological Organization, and the United Nations Environment Programme, Geneva, Switzerland, 270 pp.

Mearns, L.O., C. Rosenzweig, and R. Goldberg, 1997: Mean and variance change in climate scenarios: methods, agricultural applications, and measures of uncertainty. *Climatic Change*, **34(4),** 367–396.

Mendelsohn, R., 1998: Climate-change damages. In: *Economics and Policy Issues in Climate Change* [Nordhaus, W.D. (ed.)]. Resources for the Future, Washington, DC, USA, pp. 219–236.

Mendelsohn, R. and L.L. Bennett, 1997: Global warming and water management: water allocation and project evaluation. *Climatic Change*, **37(1),** 271–290.

Mendelsohn, R. and A. Dinar, 1999: Climate change, agriculture, and developing countries: does adaptation matter? *The World Bank Research Observer*, **14(2),** 277–293.

Mendelsohn, R. and J. Neumann, 1999: *The Impact of Climate Change on the United States Economy*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 344 pp.

Mendelsohn, R., W. Nordhaus, and D. Shaw, 1999: The impact of climate variation on U.S. agriculture. In: *The Impact of Climate Change on the United States Economy* [Mendelsohn, R. and J. Neumann (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, pp. 55–74.

Mendelsohn, R., W. Nordhaus, and D. Shaw, 1996: Climate impacts on aggregate farm value: accounting for adaptation. *Agricultural and Forest Meteorology*, **80(1),** 55–66.

Mendelsohn, R., W. Nordhaus, and D. Shaw, 1994: The impact of global warming on agriculture: a Ricardian analysis. *The American Economic Review*, **84(4),** 753–771.

Meyer, W.B., K.W. Butzer, T.E. Downing, B.L. Turner II, G.W. Wenzel, and J.L. Wescoat, 1998: Reasoning by analogy. In: *Human Choice and Climate Change, Volume 3: Tools for Analysis* [Rayner, S. and E.L. Malone (eds.)]. Battelle Press, Columbus, OH, USA, pp. 217–289.

Mileti, D.S., 1999: *Disasters by Design: A Reassessment of Natural Hazards in the United States*. Joseph Henry Press, Washington, DC, USA, 351 pp.

Miller, K.A., S.L. Rhodes, and L.J. MacDonnell, 1997: Water allocation in a changing climate: institutions and adaptation. *Climatic Change*, **35,** 157–177.

Mimura, N., 1999a: Vulnerability of island countries in the South Pacific to sea level rise in climate change. In: *National Assessment Results of Climate Change: Impacts and Responses: CR Special 6* [Mimura, N. (ed.)]. Inter-research, Oldendorf, Germany, pp. 137–143.

Mimura, N. (ed.), 1999b: *National Assessment Results of Climate Change: Impacts and Responses: CR Special 6*. Inter-research, Oldendorf, Germany, 230 pp.

Mimura, N. and H. Harasawa, 2000: *Data Book of Sea-Level Rise 2000*. Centre for Global Environmetal Research, National Institute for Enviromental Studies, Environmetal Agency of Japan, Ibaraki, Japan, 280 pp.

Mimura, N. and E. Kawaguchi, 1997: Responses of coastal topography to sea-level rise. In: *Coastal Engineering. 1996 Proceedings of the Twenty-Fifth International Conference, Orlando, FL, USA, September 1996* [Edge, B.L. (ed.)]. American Society of Civil Engineers, New York, NY, USA, pp. 1349–1360.

Mizina, S.V., J. Smith, E. Gossen, K. Spiecker, and S. Witkowski, 1999: An evaluation of adaptation options for climate change impacts on agriculture in Kazakhstan. *Mitigation and Adaptation Strategies for Global Change*, **4,** 25–41.

Moss, R.H., 1998: Water and the challenge of linked environmental changes. *Water Resources Update*, **112,** 6–9.

Munasinghe, M., 2000: Development, equity and sustainabillity (DES) in the context of climate change. In: *Climate Change and Its Linkages with Development, Equity and Sustainability: Proceedings of the IPCC Expert Meeting held in Colombo, Sri Lanka, 27–29 April, 1999* [Munasinghe, M. and R. Swart (eds.)]. LIFE, Colombo, Sri Lanka; RIVM, Bilthoven, The Netherlands; and World Bank, Washington, DC, USA, pp. 13–66.

Munasinghe, M., 1998: Climate change decision-making: science, policy and economics. *International Journal of Environment and Pollution*, **10(2),** 188–239.

Munasinghe, M. and R. Swart (eds.), 2000: *Climate Change and Its Linkages with Development, Equity, and Sustainability. Proceedings of the IPCC Expert Meeting held in Columbo, Sri Lanka, April 1999*. LIFE, Colombo, Sri Lanka; RIVM, Bilthoven, The Netherlands; and World Bank, Washington, DC, USA, 319 pp.

Murdiyarso, D., 2000: Adaptation to climatic variability and change: Asian perspectives on agriculture and food security. *Environmental Monitoring and Assessment*, **61(1),** 123–131.

Mustafa, D., 1998: Structural causes of vulnerability to flood hazard in Pakistan. *Economic Geography*, **74(3),** 289–305.

Newton, J., 1995: An assessment of coping with environmental hazards in northern aboriginal communities. *The Canadian Geographer*, **39(2),** 112–120.

Nguyen, H.T., W.N. Adger, and P.M. Kelly, 1998: Natural resource management in mitigating impacts: the example of mangrove restoration in Vietnam. *Global Environmental Change*, **8(1),** 49–61.

Nicholls, N. and S.P. Leatherman, 1995: The implications of accelerated sea-level rise for developing countries: a discussion. *Journal of Coastal Research*, **14,** 303–323.

O'Brian, K. and D. Liverman, 1996: Climate change and variability in Mexico. In: *Climate Variability, Climate Change and Social Vulnerability in the Semi-Arid Tropics* [Ribot, J.C., A.R. Magalhães, and S.S. Panagides (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 55–70.

Ominde, S.H. and C. Juma, 1991: Stemming the tide: an action agenda. In: *A Change in the Weather: African Perpectives on Climate Change* [Ominde, S.H. and C. Juma (eds.)]. ACTS Press, Nairobi, Kenya, pp. 125–153.

O'Riordan, T. and A. Jordan, 1999: Institutions, climate change and cultural theory: towards a common analytical framework. *Global Environmental Change*, **9,** 81–93.

Olsthoorn, A.A., W.J. Maunder, and R.S.J. Tol, 1996: Tropical cyclones in the southwest Pacific: Impacts on Pacific island countries with particular reference to Fiji. In: *Climate Change and Extreme Events: Altered Risks, Socio-Economic Impacts and Policy Responses* [Downing, T.E., A.A. Olsthoorn, and R.S.J. Tol (eds.)]. Institute for Environmental Management, Vrije Universiteit, Amsterdam, The Netherlands, pp. 185–208.

Osokova, T., N. Gorelkin, and V. Chub, 2000: Water resources of central Asia and adaptation measures for climate change. *Environmental Monitoring and Assessment*, **61(1),** 161–166.

Parrish, R. and D.C. Funnell, 1999: Climate change in mountain regions: some possible consequences in the Moroccan High Atlas. *Global Environmental Change*, **9,** 45–58.

Parry, M.L., 1986: Some implications of climatic change for human development. In: *Sustainable Development of the Biosphere* [Clark, W.C. and R.E. Munn (eds.)]. International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 378–406.

Parry, M., C. Rosenzweig, A. Iglesias, G. Fischer, and M. Livermore, 1999: Climate change and world food security: a new assessment. *Global Environmental Change*, **9,** S51–S68.

Parry, M., N. Arnell, M. Hulme, R. Nicholls, and M. Livermore, 1998: Adapting to the inevitable. *Nature*, **395,** 741–742.

Patz, J.A., 1996: Health adaptation to climate change: need for far-sighted, integrated approaches. In: *Adapting to Climate Change: An International Perspective* [Smith, J., N. Bhatti, G. Menzhulin, R. Benioff, M.I. Budyko, M. Campos, B. Jallow, and F. Rijsberman (eds.)]. Springer-Verlag, New York, NY, USA, pp. 450–464.

Pelling, M., 1998: Participation, social capital and vulnerability to urban flooding in Guyana. *Journal of International Development*, **10,** 469–486.

Pelling, M., 1997: What determines vulnerability to floods; a case study in Georgetown, Guyana. *Environment and Urbanization*, **9(1),** 203–226.

Perez, R.T., L.A. Amadore, and R.B. Feir, 1999: Climate change impacts and responses in the Philippines coastal sector. In: *National Assessment Results of Climate Change: Impacts and Responses: CR Special 6* [Mimura, N. (ed.)]. Inter-research, Oldendorf, Germany, pp. 97–107.

Pielke, R.A., 1998: Rethinking the role of adaptation in climate policy. *Global Environmental Change*, **8(2),** 159–170.

Pittock, B., 1999: The question of significance. *Nature*, **397,** 657–658.

Pittock, B. and R.N. Jones, 2000: Adaptation to what and why? *Environmental Monitoring and Assessment*, **61(1),** 9–35.

Pittock, B., R.J. Allan, K.J. Hennessy, K.L. McInnes, R. Suppia, K.J. Walsh, P.H. Whetton, H. McMaster, and R. Taplin, 1999: Climate change, climatic hazards and policy responses in Australia. In: *Climate, Change and Risk* [Downing, T.E., A.A. Olsthoorn, and R.S.J. Tol (eds.)]. Routledge, London, United Kingdom, pp. 19–59.

Primo, L.H., 1996: Anticipated effects of climate change on commercial pelagic and artisanal coastal fisheries in the Federated States of Micronesia. In: *Adapting to Climate Change: An International Perspective* [Smith, J.B. (ed.).]. Springer-Verlag, New York, NY, USA, pp. 427–436.

Ramakrishnan, P.S., 1999: Lessons from the Earth Summit: protecting and managing biodiversity in the Tropics. In: *Global Environmental Economics* [Dore, M.H.I. and T.D. Mount (eds.)]. Blackwell Publishers, Oxford, United Kingdom, pp. 240–264.

Ramakrishnan, P.S., 1998: Sustainable development, climate change, and the tropical rain forest landscape. *Climatic Change*, **39,** 583–600.

Raper, S.C.B., T.M.L. Wigley, and R.A. Warrick, 1996: Global sea level rise: past and future. In: *Sea Level Rise and Coastal Subsidence: Causes, Consequences and Strategies* [Milliman, J.D. and B.U. Haq (eds.)]. J. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 11–45.

Rayner, S. and E.L. Malone, 1999: Climate change, poverty and intragenerational equity: the national level. In: *Climate Change and Its Linkages with Development, Equity and Sustainability: Proceedings of the IPCC Expert Meeting held in Colombo, Sri Lanka, 27–29 April, 1999* [Munasinghe, M. and R. Swart (eds.)]. LIFE, Colombo, Sri Lanka; RIVM, Bilthoven, The Netherlands; and World Bank, Washington, DC, USA, pp. 215–242.

Rayner, S. and E.L. Malone (eds.), 1998: *Human Choice and Climate Change Volume 3: The Tools for Policy Analysis*. Battelle Press, Columbus, OH, USA, 429 pp.

Reilly, J., 1999: What does climate change mean for agriculture in developing countries? A comment on Mendelsohn and Dinar. *The World Bank Research Observer*, **14(2),** 295–305.

Reilly, J., 1998: Comments: climate-change damages. In: *Economics and Policy Issues in Climate Change* [Nordhaus, W.D. (ed.)]. Resources for the Future, Washington, DC, USA, pp. 243–256.

Reilly, J., 1995: Climate change and global agriculture: recent findings and issues. *American Journal of Agricultural Economics*, **77,** 727–733.

Reilly, J. and D. Schimmelpfennig, 2000: Irreversibility, uncertainty, and learning: portraits of adaptation to long-term climate change. *Climatic Change*, **45(1),** 253–278.

Reilly, J. and D. Schimmelpfennig, 1999: Agricultural impact assessment, vulnerability, and the scope for adaptation. *Climatic Change*, **43,** 745–788.

Reilly, J., N. Hohmann, and S. Kane, 1994: Climate change and agricultural trade: who benefits, who loses? *Global Environmental Change*, **4(1),** 24–36.

Ribot, J.C., A. Najam, and G. Watson, 1996: Climate variation, vulnerability and sustainable development in the semi-arid tropics. In: *Climate Variability, Climate Change and Social Vulnerability in the Semi-Arid Tropics* [Ribot, J.C., A.R. Magalhães, and S.S. Panagides (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 13–54.

Rijsberman, F.R. and A. van Velzen, 1996: Vulnerability and adaptation assessment of climate change and sea-level rise in the coastal zone: perspective from the Netherlands and Bangladesh. In: *Adapting to Climate Change: An International Perspective* [Smith, J., N. Bhatti, G. Menzhulin, R. Benioff, M.I. Budyko, M. Campos, B. Jallow, and F. Rijsberman (eds.)]. Springer-Verlag, New York, NY, USA, pp. 322–334.

Risbey, J., M. Kandlikar, H. Dowlatabadi, and D. Graetz, 1999: Scale, context, and decision making in agricultural adaptation to climate variability and change. *Mitigation and Adaptation Strategies for Global Change*, **4,** 137–165.

Robinson, J.B. and D. Herbert, 2000: Integrating climate change and sustainable development. In: *Climate Change and Its Linkages with Development, Equity and Sustainability: Proceedings of the IPCC Expert Meeting held in Colombo, Sri Lanka, 27–29 April, 1999* [Munasinghe, M. and R. Swart (eds.)]. LIFE, Colombo, Sri Lanka; RIVM, Bilthoven, The Netherlands; and World Bank, Washington, DC, USA, pp. 143–162.

Robock, A., R.P. Turco, M.A. Harwell, T.P. Ackerman, R. Andressen, H.-S. Chang, and M.V.K. Sivakumar, 1993: Use of general circulation model output in the creation of climate change scenarios for impact analysis. *Climatic Change*, **23,** 293–355.

Rosenberg, N.J., 1992: Adaptation of agriculture to climate change. *Climatic Change*, **21,** 385–405.

Rosenthal, D.H., H.G. Gruenspecht, and E.A. Moran, 1995: Effects of global warming on energy use for space heating and cooling in the United States. *Energy Journal*, **16(2),** 77–96.

Rosenzweig, C., 1994: Maize suffers a sea change. *Nature*, **370,** 175–176.

Rosenzweig, C. and M.L. Parry, 1994: Potential impacts of climate change on world food supply. *Nature*, **367,** 133–139.

Rothman, D.S., D. Demeritt, Q. Chiotti, and I. Burton, 1998: Costing climate change: the economics of adaptations and residual impacts for Canada. *Canada Country Study: Climate Impacts and Adaptation*, **8,** 1–29.

Rotmans, J., M. Hulme, and T.E. Downing, 1994: Climate change implications for Europe: an application of the ESCAPE model. *Global Environmental Change*, **4(2),** 97–124.

Schelling, T.C., 1992: Some economics of global warming. *The American Economic Review*, **82(1),** 1–14.

Scheraga, J. and A. Grambsch, 1998: Risks, opportunities, and adaptation to climate change. *Climate Research*, **10**, 85–95.

Schimmelpfennig, D., J. Lewandrowski, J.Reilly, M. Stigas, and I. Parry, 1996: *Agricultural Adaptation to Climate Change: Issues of Long Run Sustainability*. Agricultural Economic Report Number 740, U.S. Department of Agriculture, Washington, DC, USA, 53 pp.

Schneider, S.H., 1997: Integrated assessment modeling of global climate change: transparent rational tool for policymaking or opaque screen hiding value-laden assumptions? *Environmental Modeling and Assessment,* **2(4),** 229–248.

Schneider, S.H., W.E. Easterling, and L.O. Mearns, 2000: Adaptation: sensitivity to natural variability, agent assumptions and dynamic climate changes. *Climatic Change*, **45(1),** 203–221.

Smit, B. (ed.), 1993: *Adaptation to Climatic Variability and Change: Report of the Task Force on Climate Adaptation*. Guelph, Environment Canada, 53 pp.

Smit, B. and Y. Cai, 1996: Climate change and agriculture in China. *Global Environmental Change*, **6(3),** 205–214.

Smit, B., R. Blain, and P. Keddie, 1997: Corn hybrid selection and climatic variability: gambling with nature? *The Canadian Geographer,* **42(1),** 429–438.

Smit, B., D. McNabb, and J. Smithers, 1996: Agricultural adaptation to climate change. *Climatic Change*, **33,** 7–29.

Smit, B., I. Burton, R.J.T. Klein, and R. Street, 1999: The science of adaptation: a framework for assessment. *Mitigation and Adaptation Strategies for Global Change*, **4,** 199–213.

Smit, B., I. Burton, R.J.T. Klein, and J. Wandel, 2000: An anatomy of adaptation to climate change and variability. *Climatic Change*, **45,** 223–251.

Smith, J.B., 1997: Setting priorities for adaptation to climate change. *Global Environmental Change*, **7(3),** 251–264.

Smith, J.B. and S.S. Lenhart, 1996: Climate change adaptation policy options. *Climate Research*, **6(2),** 193–201.

Smith, J.B., R.S.J. Tol, S. Ragland, and S. Fankhauser, 1998: *Proactive Adaptations to Climate Change: Three Case Studies on Infrastructure Investments*. IVM Discussion Paper D98/03, Institute for Environmental Studies, Vrije Universiteit, Amsterdam, The Netherlands, 14 pp.

Smith, J.B., N. Bhatti, G. Menzhulin, R. Benioff, M.I. Budyko, M. Campos, B. Jallow, and F. Rijsberman (eds.), 1996: *Adapting to Climate Change: An International Perspective*. Springer-Verlag, New York, NY, USA, 475 pp.

Smith, K., 1996: *Environmental Hazards: Assessing Risk and Reducing Disaster*. Routledge, London, United Kingdom, 389 pp.

Smith, K.R., 1990: Risk transition and global warming. *Journal of Energy Engineering*, **116(3),** 178–188.

Smithers, J. and B. Smit, 1997: Human adaptation to climatic variability and change. *Global Environmental Change*, **7(2),** 129–146.

Sohngen, B. and R. Mendelsohn, 1998: Valuing the impact of large-scale ecological change in a market: the effect of climate change on U.S. timber. *The American Economic Review*, **88(4),** 686–710.

Sprengers, S.A., L.K. Slager, and H. Aiking, 1994: *Biodiversity and Climate Change Part 1: Establishment of Ecological Goals for the Climate Convention.* Vrije Universiteit, Amsterdam, The Netherlands, 172 pp.

Stakhiv, E.Z., 1996: Managing water resources for climate change adaptation. In: *Adapting to Climate Change: An International Perspective* [Smith, J., N. Bhatti, G. Menzhulin, R. Benioff, M.I. Budyko, M. Campos, B. Jallow, and F. Rijsberman (eds.)]. Springer-Verlag, New York, NY, USA, pp. 243–264.

Stakhiv, E.Z., 1994: Managing water resources for adaptation to climate change. *Engineering Risk in Natural Resources Management,* **275,** 379–393.

Strzepek, K.M. and J.B. Smith (eds.), 1995: *As Climate Changes, International Impacts and Implications*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 213 pp.

Stuczyinski, T., G. Demidowicz, T. Deputat, T. Górski, S. Krazowicz, and J. Kus, 2000: Adaptation scenarios of agriculture in Poland to future climate changes. *Environmental Monitoring and Assessment*, **61(1),** 133–144.

Teves, N., G. Laos, S. Carrasco, C. San Roman, L. Pizarro, G. Cardenas, and A. Romero, 1996: Sea-level rise along the Lima Coastal Zone, Peru, as a result of global warming: environmental impacts and mitigation measures. In: *Adapting to Climate Change: An International Perspective* [Smith, J., N. Bhatti, G. Menzhulin, R. Benioff, M.I. Budyko, M. Campos, B. Jallow, and F. Rijsberman (eds.)]. Springer-Verlag, New York, NY, USA, pp. 283–298.

Theu, J., G. Chavula, and C. Elias Malawi, 1996: How climate change adaptation options fit within the UNFCCC national communication and national development plans. In: *Adapting to Climate Change: An International Perspective* [Smith, J., N. Bhatti, G. Menzhulin, R. Benioff, M.I. Budyko, M. Campos, B. Jallow, and F. Rijsberman (eds.)]. Springer-Verlag, New York, NY, USA, pp. 97–104.

Tiglao, R., 1992: Grinding to a halt. *Far East Economic Review*, **16,** 50.

Titus, J.G., 1990: Strategies for adapting to the greenhouse effect. *APA Journal*, **56(3),** 311–323.

Tol, R.S.J., 1998a: Comment: climate-change damages. In: *Economics and Policy Issues in Climate Change* [Nordhaus, W.D. (ed.)]. Resources for the Future, Washington, DC, USA, pp. 237–242.

Tol, R.S.J., 1998b: Short-term decisions under long-term uncertainty. *Energy Economics*, **20,** 557–569.

Tol, R.S.J. and S. Fankhauser, 1997: On the representation of impact in integrated assessment models of climate change. *Environmental Modeling and Assessment*, **3,** 63–74.

Tol, R.S.J., S. Fankhauser, and J.B. Smith, 1998: The scope for adaptation to climate change: what can we learn from the impact literature? *Global Environmental Change*, **8(2),** 109–123.

Tol, R.S.J., H.M.A. Jansen, R.J.T. Klein, and H. Verbruggen, 1996: Some economic considerations on the importance of proactive integrated coastal zone management. *Ocean and Coastal Management*, **32(1),** 39–55.

Tol, R.S.J., N.M. van der Grijp, A.A. Olsthoorn, and P.E. van der Werff, 1999: *Adapting to Climate Change: A Case Study on Riverine Flood Risks in the Netherlands*. Societal and Institutional Response to Climate Change and Climate Hazards (SIRCH) Working Paper 5, Institute for Environmental Studies, Vrije Universiteit, Amsterdam, The Netherlands, 9 pp.

Toman, M. and R. Bierbaum, 1996: An overview of adaptation to climate change. In: *Adapting to Climate Change: An International Perspective* [Smith, J., N. Bhatti, G. Menzhulin, R. Benioff, M.I. Budyko, M. Campos, B. Jallow, and F. Rijsberman (eds.)]. Springer-Verlag, New York, NY, USA, pp. 5–15.

Torry, W.I., 1979: Anthropological studies in hazardous environments: past trends and new horizons. *Current Anthropology*, **20,** 517–540.

Torvanger, A., 1998: Burden sharing and adaptation beyond Kyoto: a more systematic approach essential for global climate success. *Environment and Development Economics*, **3(406),** 406–409.

Toth, F., 1999: Development, equity and sustainability concerns in climate change decisions. In: *Climate Change and Its Linkages with Development, Equity and Sustainability: Proceedings of the IPCC Expert Meeting held in Colombo, Sri Lanka, 27–29 April, 1999* [Munasinghe, M. and R. Swart (eds.)]. LIFE, Colombo, Sri Lanka; RIVM, Bilthoven, The Netherlands; and World Bank, Washington, DC, USA, pp. 263–288.

Uitto, J., 1998: The geography of disaster vulnerability in megacities: a theoretical framework. *Applied Geography*, **18,** 7–16.

UNEP, 1998: *Handbook on Methods for Climate Impact Assessment and Adaptation Strategies, 2* [Feenstra, J., I. Burton, J. Smith, and R. Tol (eds.)]. United Nations Environment Program, Institute for Environmental Studies, Amsterdam, The Netherlands, 359 pp.

USNAS, 1992: *Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base*. U.S. National Academies of Science and Engineering, Institute of Medicine, National Academy Press, Washington, DC, 944 pp.

Wang'ati, F.J., 1996: The impact of climate variation and sustainable development in the Sudano-Sahelian region. In: *Climate Variability, Climate Change and Social Vulnerability in the Semi-Arid Tropics* [Ribot, J.C., A.R. Magalhães, and S.S. Panagides (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 71–91.

Warrick, R.A. and W.E. Riebsame, 1983: Societal response to CO_2-induced climate change: opportunities. In: *Societal Research and Climate Change: An Interdisciplinary Appraisal* [Chen, R.S., E. Boulding, and S.H. Schneider (eds.)]. D. Reidel, Dordrecht, The Netherlands, pp. 20–60.

Warrick, R.A, R.M. Gifford, and M.L. Parry, 1986: CO_2 , climatic change and agriculture. In: *The Greenhouse Effect, Climatic Change and Ecosystems* [Bolin, B., B.R. Döös, J. Jager, and R.A. Warrick (eds.)]. John Wiley and Sons, New York, NY, USA, pp. 393–473.

Watts, M., 1983: On the poverty theory: natural hazards research in context. In: *Interpretations of Calamity from the Viewpoint of Human Ecology* [Hewitt, K. (ed.)]. Allen & Unwin, Boston, MA, USA, pp. 231–260.

West, J.J. and H. Dowlatabadi, 1999: On assessing the economic impacts of sea-level rise on developed coasts. In: *Climate, Change and Risk* [Downing, T.E., A.A. Olsthoorn, and R.S.J. Tol (eds.)]. Routledge, London, United Kingdom, pp. 205–220.

White, R. and D. Etkin, 1997: Climate change, extreme events and the Canadian insurance industry. *Natural Hazards*, **16,** 135–163.

WHO, 1997: *Division of Control of Tropical Diseases (CTD) Progress Report 1996*. CTD/PR/97.1, World Health Organization, Geneva, Switzerland, 147 pp.

Wigley, T.M.L., 1999: *The Science of Climate Change: Global and U.S. Perspectives*. Pew Center for Climate Change, Washington, DC, USA, 48 pp.

Wigley, T., M. Ingram, and G. Farmer, 1981: Past climates and their impact on man: a review. In: *Climate and History* [Ingram, M., G. Farmer, and T. Wigley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3–50.

Wilhite, D.A., 1997: Responding to drought: common threads from the past, visions for the future. *Journal of the American Water Resources Association*, **33(5),** 951–959.

Wilhite, D.A., 1996: A methodology for drought preparedness. *Natural Hazards*, **13,** 229–252.

Wilhite, D.A., N.J. Rosenberg, and M.H. Glantz, 1986: Improving federal response to drought. *Journal of Climate and Applied Meteorology*, **25,** 332–342.

Wisner, B., 1998: Marginality and vulnerability: why the homeless in Tokyo don't count in disaster preparations. *Applied Geography*, **18(1),** 25–33.

Yang, H., 1996: Potential effects of sea-level rise in the Pearl River delta area: preliminary study results and a comprehensive adaptation strategy. In: *Adapting to Climate Change: An International Perspective* [Smith, J., N. Bhatti, G. Menzhulin, R. Benioff, M.I. Budyko, M. Campos, B. Jallow, and F. Rijsberman (eds.)]. Springer-Verlag, New York, NY, USA, 475 pp.

Yim, W.W.S., 1996: Vulnerability and adaptation of Hong Kong to hazards under climatic change conditions. *Water, Air, and Soil Pollution*, **92,** 181–190.

Yohe, G. and H. Dowlatabadi, 1999. Risk and uncertainties, analysis and evaluation: lessons for adaptation and integration. *Mitigation and Adaptation Strategies for Global Change*, **4(3-4),** 319–330.

Yohe, G.W. and J. Neumann, 1997: Planning for sea-level rise and shore protection under climate uncertainty. *Climatic Change*, **37(1),** 243–270.

Yohe, G.W. and M.E. Schlesinger, 1998: Sea level change: the expected economic cost of protection or abandonment in the United States. *Climatic Change*, **38,** 447–472.

Yohe, G., J. Neumann, P. Marshall, and A. Ameden, 1996: The economic costs of sea-level rise on developed property in the United States. *Climate Change*, **32,** 387–410.

Zhao, Z.C., 1996: Climate change and sustainable development in China's semi-arid regions. In: *Climate Variability, Climate Change and Social Vulnerability in the Semi-arid Tropics* [Ribot, J.C., A.R. Magalhães, and S.S. Panagides (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 92–108.

@inproceedings{Smit2001AdaptationTC, title={Adaptation to climate change in the context of sustainable development and equity}, author={Barry Smit and Olga Pilifosova and Ian Burton and B Challenger and Saleemul Huq and Richard J. T. Klein and Gary W. Yohe and W. Neil Adger and Thomas E. Downing and Ed Harvey}, year={2001} }.Â Exploring the process of adaptation to climate change in the coastal regions of Bangladesh. Shameem, M. Mujtahid Iqbal. Geography.Â Natural-Hazard Reduction and Sustainable Development: A Global Assessment. Philip Berke. Economics. Climate change adaptation (CCA) is a response to global warming (also known as "climate change" or "anthropogenic climate change"). The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as: 'the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects'. This adjustment Climate change is the burning issue of the current world because it is considered to be one of the most serious threats to sustainable development, with adverse impacts expected on the environment, human health, food security, economic activity, natural resources and physical infrastructure. Climate change, biodiversity and forest loss are issues inextricably interlinked and need to be addressed simultaneously.