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Climate Change: New Dimensions in Disaster Risk, Exposure, Vulnerability, and Resilience

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This chapter should be cited as:

Lavell, A., M. Oppenheimer, C. Diop, J. Hess, R. Lempert, J. Li, R. Muir-Wood, and S. Myeong, 2012: Climate change: new dimensions in disaster risk, exposure, vulnerability, and resilience. In: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 25-64.

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Executive Summary

Disaster signifies extreme impacts suffered when hazardous physical events interact with vulnerable social conditions to severely alter the normal functioning of a community or a society (*high confidence)*. Social vulnerability and exposure are key determinants of disaster risk and help explain why non-extreme physical events and chronic hazards can also lead to extreme impacts and disasters, while some extreme events do not. Extreme impacts on human, ecological, or physical systems derive from individual extreme or non-extreme events, or a compounding of events or their impacts (for example, drought creating the conditions for wildfire, followed by heavy rain leading to landslides and soil erosion). [1.1.2.1, 1.1.2.3, 1.2.3.1, 1.3]

Management strategies based on the reduction of everyday or chronic risk factors and on the reduction of risk associated with non-extreme events, as opposed to strategies based solely on the exceptional or extreme, provide a mechanism that facilitates the reduction of disaster risk and the preparation for and response to extremes and disasters (*high confidence)*. Effective adaptation to climate change requires an understanding of the diverse ways in which social processes and development pathways shape disaster risk. Disaster risk is often causally related to ongoing, chronic, or persistent environmental, economic, or social risk factors. [1.1.2.2, 1.1.3, 1.1.4.1, 1.3.2]

Development practice, policy, and outcomes are critical to shaping disaster risk (*high confidence*). Disaster risk may be increased by shortcomings in development. Reductions in the rate of depletion of ecosystem services, improvements in urban land use and territorial organization processes, the strengthening of rural livelihoods, and general and specific advances in urban and rural governance advance the composite agenda of poverty reduction, disaster risk reduction, and adaptation to climate change. [1.1.2.1, 1.1.2.2, 1.1.3, 1.3.2, 1.3.3]

Climate change will pose added challenges for the appropriate allocation of efforts to manage disaster risk (*high confidence*). The potential for changes in all characteristics of climate will complicate the evaluation, communication, and management of the resulting risk. [1.1.3.1, 1.1.3.2, 1.2.2.2, 1.3.1, 1.3.2, 1.4.3]

Risk assessment is one starting point, within the broader risk governance framework, for adaptation to climate change and disaster risk reduction and transfer (*high confidence*). The assessment and analysis process may employ a variety of tools according to management context, access to data and technology, and stakeholders involved. These tools will vary from formalized probabilistic risk analysis to local level, participatory risk and context analysis methodologies. [1.3, 1.3.1.2, 1.3.3, Box 1-2]

Risk assessment encounters difficulties in estimating the likelihood and magnitude of extreme events and their impacts (*high confidence*). Furthermore, among individual stakeholders and groups, perceptions of risk are driven by psychological and cultural factors, values, and beliefs. Effective risk communication requires exchanging, sharing, and integrating knowledge about climate-related risks among all stakeholder groups. [Box 1-1, 1.1.4.1, 1.2.2.1, 1.3.1.1, 1.3.1.2, Box 1-2, Box 1-3, 1.4.2]

Management of the risk associated with climate extremes, extreme impacts, and disasters benefits from an integrated systems approach, as opposed to separately managing individual types of risk or risk in particular locations (*high confidence*). Effective risk management generally involves a portfolio of actions to reduce and transfer risk and to respond to events and disasters, as opposed to a singular focus on any one action or type of action. [1.1.2.2, 1.1.4.1, 1.3, 1.3.3, 1.4.2]

Learning is central to adaptation to climate change. Furthermore, the concepts, goals, and processes of adaptation share much in common with disaster risk management, particularly its disaster risk reduction component (*high confidence*). Disaster risk management and adaptation to climate change offer frameworks for, and examples of, advanced learning processes that may help reduce or avoid barriers that undermine planned adaptation efforts or lead to implementation of maladaptive measures. Due to the deep uncertainty, dynamic complexity, and long timeframe associated with climate change, robust adaptation efforts would require iterative risk management strategies. [1.1.3, 1.3.2, 1.4.1.2, 1.4.2, 1.4.5, Box 1-4]

Projected trends and uncertainty in hazards, exposure, and vulnerability associated with climate change and development make return to the status quo, coping, or static resilience increasingly insufficient goals for disaster risk management and adaptation (*high confidence*). Recent approaches to resilience of social-ecological systems expand beyond these concepts to include the ability to self-organize, learn, and adapt over time. [1.1.2.1, 1.1.2.2, 1.4.1.2, 1.4.2, 1.4.4]

Given shortcomings of past disaster risk management and the new dimension of climate change, greatly improved and strengthened disaster risk management and adaptation will be needed, as part of development processes, in order to reduce future risk (*high confidence*). Efforts will be more effective when informed by the experience and success with disaster risk management in different regions during recent decades, and appropriate approaches for risk identification, reduction, transfer, and disaster management. In the future, the practices of disaster risk management and adaptation can each greatly benefit from far greater synergy and linkage in institutional, financial, policy, strategic, and practical terms. [1.1.1, 1.1.2.2, 1.1.3, 1.3.3, 1.4.2]

Community participation in planning, the determined use of local and community knowledge and capacities, and the decentralization of decisionmaking, supported by and in synergy with national and international policies and actions, are critical for disaster risk reduction (*high confidence*). The use of local level risk and context analysis methodologies, inspired by disaster risk management and now strongly accepted by many civil society and government agencies in work on adaptation at the local levels, would foster greater integration between, and greater effectiveness of, both adaptation to climate change and disaster risk management. [1.1.2.2, 1.1.4.2, 1.3.3, 1.4.2]

1.1. Introduction

1.1.1. Purpose and Scope of the Special Report

Climate change, an alteration in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer, is a fundamental reference point for framing the different management themes and challenges dealt with in this Special Report.

Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use (see Chapter 3 for greater detail). Anthropogenic climate change is projected to continue during this century and beyond. This conclusion is robust under a wide range of scenarios for future greenhouse gas emissions, including some that anticipate a reduction in emissions (IPCC, 2007a).

While specific, local outcomes of climate change are uncertain, recent assessments project alteration in the frequency, intensity, spatial extent, or duration of weather and climate extremes, including climate and hydrometeorological events such as heat waves, heavy precipitation events, drought, and tropical cyclones (see Chapter 3). Such change, in a context of increasing vulnerability, will lead to increased stress on human and natural systems and a propensity for serious adverse effects in many places around the world (UNISDR, 2009e, 2011). At the same time, climate change is also expected to bring benefits to certain places and communities at particular times.

New, improved or strengthened processes for anticipating and dealing with the adverse effects associated with weather and climate events will be needed in many areas. This conclusion is supported by the fact that despite increasing knowledge and understanding of the factors that lead to adverse effects, and despite important advances over recent decades in the reduction of loss of life with the occurrence of hydrometeorological events (mainly attributable to important advances with early warning systems, e.g., Section 9.2.11), social intervention in the face of historical climate variability has not kept pace with the rapid increases in other adverse economic and social effects suffered during this period (ICSU, 2008) *(high confidence)*. Instead, a rapid growth in real economic losses and livelihood disruption has occurred in many parts of the world (UNISDR, 2009e, 2011). In regard to losses associated with tropical cyclones, recent analysis has shown that, with the exception of the East Asian and Pacific and South Asian regions, "both exposure and the estimated risk of economic loss are growing faster than GDP per capita. Thus the risk of losing wealth in disasters associated with tropical cyclones is increasing faster than wealth itself is increasing" (UNISDR, 2011, p. 33).

The Hyogo Framework for Action (UNISDR, 2005), adopted by 168 governments, provides a point of reference for disaster risk management and its practical implementation (see Glossary and Section 1.1.2.2 for a definition of this practice). Subsequent United Nations statements suggest the need for closer integration of disaster risk management and adaptation with climate change concerns and goals, all in the context of development and development planning (UNISDR, 2008a, 2009a,b,c). Such a concern led to the agreement between the IPCC and the United Nations International Strategy for Disaster Reduction (UNISDR), with the support of the Norwegian government, to undertake this Special Report on "Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation" (IPCC, 2009).

This Special Report responds to that concern by considering climate change and its effects on extreme (weather and climate) events, disaster, and disaster risk management; how human responses to extreme events and disasters (based on historical experience and evolution in practice) could contribute to adaptation objectives and processes; and how adaptation to climate change could be more closely integrated with disaster risk management practice.

The report draws on current scientific knowledge to address three specific goals:

1) To assess the relevance and utility of the concepts, methods, strategies, instruments, and experience gained from the management of climate-associated disaster risk under conditions of historical climate patterns, in order to advance adaptation to climate change and the management of extreme events and disasters in the future.
2) To assess the new perspectives and challenges that climate change brings to the disaster risk management field.
3) To assess the mutual implications of the evolution of the disaster risk management and adaptation to climate change fields, particularly with respect to the desired increases in social resilience and sustainability that adaptation implies.

The principal audience for this Special Report comprises decisionmakers and professional and technical personnel from local through to national governments, international development agencies, nongovernmental organizations, and civil society organizations. The report also has relevance for the academic community and interested laypeople.

The first section of this chapter briefly introduces the more important concepts, definitions, contexts, and management concerns needed to frame the content of this report. Later sections of the chapter expand on the subjects of extreme events and extreme impacts; disaster risk management, reduction, and transfer and their integration with climate change and adaptation processes; and the notions of coping and adaptation. The level of detail and discussion presented in this chapter is commensurate with its status as a 'scene setting' initiative. The following eight chapters provide more detailed and specific analysis.

Chapter 2 assesses the key determinants of risk, namely exposure and vulnerability in the context of climate-related hazards. A particular focus is the connection between near-term experience and long-term adaptation. Key questions addressed include whether reducing vulnerability to current hazards improves adaptation to longer-term climate change, and how near-term risk management decisions and adjustments constrain future vulnerability and enable adaptation.

Chapter 3 focuses on changes in extremes of atmospheric weather and climate variables (e.g., temperature and precipitation), large-scale phenomena that are related to these extremes or are themselves extremes (e.g., tropical and extratropical cyclones, El Niño, and monsoons), and collateral effects on the physical environment (e.g., droughts, floods, coastal impacts, landslides). The chapter builds on and updates the Fourth Assessment Report, which in some instances, due to new literature, leads to revisions of that assessment.

Chapter 4 explores how changes in climate, particularly weather and climate extremes assessed in Chapter 3, translate into extreme impacts on human and ecological systems. A key issue is the nature of both observed and expected trends in impacts, the latter resulting from trends in both physical and social conditions. The chapter assesses these questions from both a regional and a sectoral perspective, and examines the direct and indirect economic costs of such changes and their relation to development.

Chapters 5, 6, and 7 assess approaches to disaster risk management and adaptation to climate change from the perspectives of local, national, and international governance institutions, taking into consideration the roles of government, individuals, nongovernmental organizations, the private sector, and other civil society institutions and arrangements. Each chapter reviews the efficacy of current disaster risk reduction, preparedness, and response and risk transfer strategies and previous approaches to extremes and disasters in order to extract lessons for the future. Impacts, adaptation, and the cost of risk management are assessed through the prism of diverse social aggregations and means for cooperation, as well as a variety of institutional arrangements.

Chapter 5 focuses on the highly variable local contexts resulting from differences in place, social groupings, experience, management, institutions, conditions, and sets of knowledge, highlighting risk management strategies involving housing, buildings, and land use. Chapter 6 explores similar issues at the national level, where mechanisms including national budgets, development goals, planning, warning systems, and building codes may be employed to manage, for example, food security and agriculture, water resources, forests, fisheries, building practice, and public health. Chapter 7 carries this analysis to the international level, where the emphasis is on institutions, organizations, knowledge generation and sharing, legal frameworks and practices, and funding arrangements that characterize international agencies and collaborative arrangements. This chapter also discusses integration of responsibilities across all governmental scales, emphasizing the linkages among disaster risk management, climate change adaptation, and development.

Chapter 8 assesses how disaster risk reduction strategies, ranging from incremental to transformational, can advance adaptation to climate change and promote a more sustainable and resilient future. Key questions include whether an improved alignment between climate change responses and sustainable development strategies may be achieved, and whether short- and long-term perspectives may be reconciled.

Chapter 9 closes this report by presenting case studies in order to identify lessons and best practices from past responses to extreme climate-related events and extreme impacts. Cases illustrate concrete and diverse examples of disaster types as well as risk management methodologies and responses discussed in the other chapters, providing a key reference point for the entire report.

1.1.2. Key Concepts and Definitions

The concepts and definitions presented in this chapter and employed throughout the Special Report take into account a number of existing sources (IPCC, 2007c; UNISDR, 2009d; ISO, 2009) but also reflect the fact that concepts and definitions evolve as knowledge, needs, and contexts vary. Disaster risk management and adaptation to climate change are dynamic fields, and have in the past exhibited and will necessarily continue in the future to exhibit such evolution.

This chapter presents 'skeleton' definitions that are generic rather than specific. In subsequent chapters, the definitions provided here are often expanded in more detail and variants among these definitions will be examined and explained where necessary.

A glossary of the fundamental definitions used in this assessment is provided at the end of this study. Figure 1-1 provides a schematic of the relationships among many of the key concepts defined here.

1.1.2.1. Definitions Related to General Concepts

In order to delimit the central concerns of this Special Report, a distinction is made between those concepts and definitions that relate to disaster risk and adaptation to climate change generally; and, on the other hand, those that relate in particular to the options and forms of social intervention relevant to these fields. In Section 1.1.2.1, consideration is given to general concepts. In Section 1.1.2.2, key concepts relating to social intervention through 'Disaster Risk Management' and 'Climate Change Adaptation' are considered.

Extreme (weather and climate) events and disasters comprise the two central risk management concerns of this Special Report.

Extreme events comprise a facet of climate variability under stable or changing climate conditions. They are defined as the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends ('tails') of the range of observed values of the variable. This definition is further discussed and amplified in Sections 1.2.2, 3.1.1, and 3.1.2.

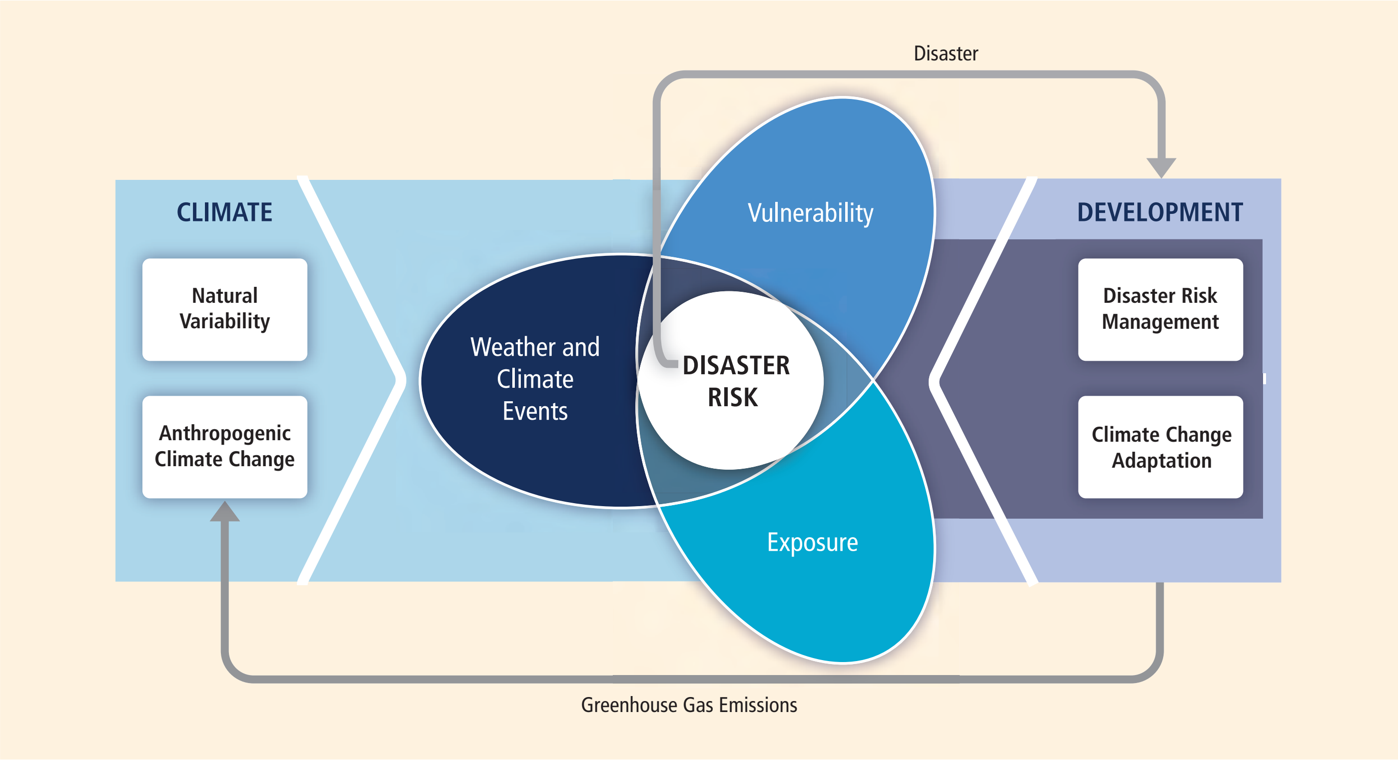

Figure 1-1 | The key concepts and scope of this report. The figure indicates schematically key concepts involved in disaster risk management and climate change adaptation, and the interaction of these with sustainable development.

Disasters are defined in this report as severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery.

The **hazardous physical events** referred to in the definition of disaster may be of natural, socio-natural (originating in the human degradation or transformation of the physical environment), or purely anthropogenic origins (see Lavell, 1996, 1999; Smith, 1996; Tobin and Montz, 1997; Wisner et al., 2004). This Special Report emphasizes hydrometeorological and oceanographic events; a subset of a broader spectrum of physical events that may acquire the characteristic of a hazard if conditions of exposure and vulnerability convert them into a threat. These include earthquakes, volcanoes, and tsunamis, among others. Any one geographic area may be affected by one, or a combination of, such events at the same or different times. Both in this report and in the wider literature, some events (e.g., floods and droughts) are at times referred to as physical impacts (see Section 3.1.1).

Extreme events are often but not always associated with disaster. This association will depend on the particular physical, geographic, and social conditions that prevail (see this section and Chapter 2 for discussion of the conditioning circumstances associated with so-called 'exposure' and 'vulnerability') (Ball, 1975; O'Keefe et al., 1976; Timmerman, 1981; Hewitt, 1983; Maskrey, 1989; Mileti, 1999; Wisner et al., 2004). Non-extreme physical events also can and do lead to disasters where physical or societal conditions foster such a result. In fact, a significant number of disasters registered annually in most disaster databases are associated with physical events that are not extreme as defined probabilistically, yet have important social and economic impacts on local communities and governments, both individually and in aggregate (UNISDR, 2009e, 2011) (*high confidence*).

For example, many of the 'disasters' registered in the widely consulted University of Louvaine EM-DAT database (CRED, 2010) are not initiated by statistically extreme events, but rather exhibit extreme properties expressed as severe interruptions in the functioning of local social and economic systems. This lack of connection is even more obvious in the DesInventar database (Corporación OSSO, 2010), developed first in Latin America in order to specifically register the occurrence of small- and medium-scale disasters, and which has registered tens and tens of thousands of these during the last 30 years in the 29 countries it covers to date. This database has been used by the UNISDR, the Inter-American Development Bank, and others to examine disaster occurrence, scale, and impacts in Latin America and Asia, in particular (Cardona 2005, 2008; IDEA, 2005; UNISDR, 2009e, 2011; ERN-AL, 2011). In any one place, the range of disaster-inducing events can increase if social conditions deteriorate (Wisner et al., 2004, 2011).

The occurrence of disaster is always preceded by the existence of specific physical and social conditions that are generally referred to as **disaster risk** (Hewitt, 1983; Lewis, 1999, 2009; Bankoff, 2001;

Wisner et al., 2004, 2011; ICSU, 2008; UNISDR, 2009e, 2011; ICSU-LAC, 2009).

Disaster risk is defined for the purposes of this study as the likelihood over a specified time period of severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery. Disaster risk derives from a combination of physical hazards and the vulnerabilities of exposed elements and will signify the potential for severe interruption of the normal functioning of the affected society once it materializes as disaster. This qualitative statement will be expressed formally later in this assessment (Section 1.3 and Chapter 2).

The definitions of disaster risk and disaster posited above do not include the potential or actual impacts of climate and hydrological events on ecosystems or the physical Earth system per se. In this assessment, such impacts are considered relevant to disaster if, as is often the case, they comprise one or more of the following, at times interrelated, situations: i) they impact livelihoods negatively by seriously affecting ecosystem services and the natural resource base of communities; ii) they have consequences for food security; and/or iii) they have impacts on human health.

Extreme impacts on the physical environment are addressed in Section 3.5 and extreme impacts on ecosystems are considered in detail in Chapter 4. In excluding such impacts from the definition of 'disaster' as employed here, this chapter is in no way underestimating their broader significance (e.g., in regard to existence value) or suggesting they should not be dealt with under the rubric of adaptation concerns and management needs. Rather, we are establishing their relative position within the conceptual framework of climate-related, socially-defined 'disaster' and 'disaster risk' and the management options that are available for promoting disaster risk reduction and adaptation to climate change (see Section 1.1.2.2 and the Glossary for definitions of these terms). Thus this report draws a distinction between 'social disaster,' where extreme impacts on the physical and ecological systems may or may not play a part, and so-called 'environmental disaster,' where direct physical impacts of human activity and natural physical processes on the environment are fundamental causes (with possible direct feedback impacts on social systems).

Disaster risk cannot exist without the threat of potentially damaging physical events. However, such events, once they occur, are not in and of themselves sufficient to explain disaster or its magnitude. In the search to better understand the concept of disaster risk (thus disaster) it is important to consider the notions of hazard, vulnerability, and exposure.

When extreme and non-extreme physical events, such as tropical cyclones, floods, and drought, can affect elements of human systems in an adverse manner, they assume the characteristic of a hazard. **Hazard** is defined here as the potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources. Physical events become hazards where social elements (or environmental resources that support human welfare and security) are exposed to their potentially adverse impacts and exist under conditions that could predispose them to such effects. Thus, hazard is used in this study to denote a threat or potential for adverse effects, not the physical event itself (Cardona, 1986, 1996, 2011; Smith, 1996; Tobin and Montz, 1997; Lavell, 2003; Hewitt, 2007; Wisner et al., 2004).

Exposure is employed to refer to the presence (location) of people, livelihoods, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected by physical events and which, thereby, are subject to potential future harm, loss, or damage. This definition subsumes physical and biological systems under the concept of 'environmental services and resources,' accepting that these are fundamental for human welfare and security (Crichton, 1999; Gasper, 2010).

Exposure may also be dictated by mediating social structures (e.g., economic and regulatory) and institutions (Sen, 1983). For example, food insecurity may result from global market changes driven by drought or flood impacts on crop production in another location. Other relevant and important interpretations and uses of exposure are discussed in Chapter 2.

Under exposed conditions, the levels and types of adverse impacts will be the result of a physical event (or events) interacting with socially constructed conditions denoted as vulnerability.

Vulnerability is defined generically in this report as the propensity or predisposition to be adversely affected. Such predisposition constitutes an internal characteristic of the affected element. In the field of disaster risk, this includes the characteristics of a person or group and their situation that influences their capacity to anticipate, cope with, resist, and recover from the adverse effects of physical events (Wisner et al., 2004).

Vulnerability is a result of diverse historical, social, economic, political, cultural, institutional, natural resource, and environmental conditions and processes.

The concept has been developed as a theme in disaster work since the 1970s (Baird et al., 1975; O'Keefe et al., 1976; Wisner et al., 1977; Lewis, 1979, 1984, 1999, 2009; Timmerman, 1981; Hewitt, 1983, 1997, 2007; Cutter, 1996; Weichselgartner, 2001; Cannon, 2006; Gaillard, 2010) and variously modified in different fields and applications in the interim (Adger, 2006; Eakin and Luers, 2006; Füssel, 2007). Vulnerability has been evaluated according to a variety of quantitative and qualitative metrics (Coburn and Spence, 2002; Schneider et al., 2007; Cardona, 2011). A detailed discussion of this notion and the drivers or root causes of vulnerability are provided in Chapter 2.

The importance of vulnerability to the disaster risk management community may be appreciated in the way it has helped to highlight the role of social factors in the constitution of risk, moving away from purely physical explanations and attributions of loss and damage (see Hewitt, 1983 for an early critique of what he denominated the 'physicalist' interpretation of disaster). Differential levels of vulnerability will lead to differential levels of damage and loss under similar conditions of exposure to physical events of a given magnitude (Dow, 1992; Wisner et al., 2011).

The fundamentally social connotation and 'predictive' value of vulnerability is emphasized in the definition used here. The earlier IPCC definition of vulnerability refers, however, to "the degree to which a system is susceptible to and unable to cope with adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity" (IPCC, 2007c, p. 883). This definition makes physical causes and their effects an explicit aspect of vulnerability while the social context is encompassed by the notions of sensitivity and adaptive capacity (these notions are defined later). In the definition used in this report, the social context is emphasized explicitly, and vulnerability is considered independent of physical events (Hewitt, 1983, 1997, 2007; Weichselgartner, 2001; Cannon, 2006; O'Brien et al., 2007).

Vulnerability has been contrasted and complimented with the notion of **capacity**.

Capacity refers to the combination of all the strengths, attributes, and resources available to an individual, community, society, or organization that can be used to achieve established goals. This includes the conditions and characteristics that permit society at large (institutions, local groups, individuals, etc.) access to and use of social, economic, psychological, cultural, and livelihood-related natural resources, as well as access to the information and the institutions of governance necessary to reduce vulnerability and deal with the consequences of disaster. This definition extends the definition of capabilities referred to in Sen's 'capabilities approach to development' (Sen, 1983).

The lack of capacity may be seen as being one dimension of overall vulnerability, while it is also seen as a separate notion that, although contributing to an increase in vulnerability, is not part of vulnerability per se. The existence of vulnerability does not mean an absolute, but rather a relative lack of capacity.

Promoted in disaster recovery work by Anderson and Woodrow (1989) as a means, among other objectives, to shift the analytical balance from the negative aspects of vulnerability to the positive actions by people, the notion of capacity is fundamental to imagining and designing a conceptual shift favoring disaster risk reduction and adaptation to climate change. Effective **capacity building**, the notion of stimulating and providing for growth in capacity**,** requires a clear image of the future with clearly established goals.

Adaptive capacity comprises a specific usage of the notion of capacity and is dealt with in detail in later sections of this chapter and Chapters 2 and 8 in particular.

The existence of vulnerability and capacity and their importance for understanding the nature and extent of the adverse effects that may occur with the impact of physical events can be complemented with a consideration of the characteristics or conditions that help ameliorate or mitigate negative impacts once disaster materializes. The notions of resilience and coping are fundamental in this sense.

Coping (elaborated upon in detail in Section 1.4 and Chapter 2) is defined here generically as the use of available skills, resources, and opportunities to address, manage, and overcome adverse conditions

FAQ 1.1 | Is there a one-to-one relationship between extreme events and disasters?

No. Disaster entails social, economic, or environmental impacts that severely disrupt the normal functioning of affected communities. Extreme weather and climate events will lead to disaster if: 1) communities are exposed to those events; and 2) exposure to potentially damaging extreme events is accompanied by a high level of vulnerability (a predisposition for loss and damage). On the other hand, disasters are also triggered by events that are not extreme in a statistical sense. High exposure and vulnerability levels will transform even some small-scale events into disasters for some affected communities. Recurrent small- or medium-scale events affecting the same communities may lead to serious erosion of its development base and livelihood options, thus increasing vulnerability. The timing (when they occur during the day, month, or year) and sequence (similar events in succession or different events contemporaneously) of such events is often critical to their human impact. The relative importance of the underlying physical and social determinants of disaster risk varies with the scale of the event and the levels of exposure and vulnerability. Because the impact of lesser events is exacerbated by physical, ecological, and social conditions that increase exposure and vulnerability, these events disproportionately affect resource-poor communities with little access to alternatives for reducing hazard, exposure, and vulnerability. The potential negative consequences of extreme events can be moderated in important ways (but rarely eliminated completely) by implementing corrective disaster risk management strategies that are reactive, adaptive, and anticipatory, and by sustainable development.

with the aim of achieving basic functioning in the short to medium terms.

Resilience is defined as the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a potentially hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions. As Gaillard (2010) points out, this term has been used in disaster studies since the 1970s (Torry, 1979) and has its origins in engineering (Gordon, 1978), ecology (Holling, 1973) and child psychology (Werner et al., 1971).

Although now widely employed in the fields of disaster risk management and adaptation, resilience has been subject to a wide range of interpretations and levels of acceptance as a concept (Timmerman, 1981; Adger, 2000; Klein et al., 2003; Berkes et al., 2004; Folke, 2006; Gallopín, 2006; Manyena, 2006; Brand and Jax, 2007; Gaillard 2007; Bosher, 2008; Cutter et al., 2008; Kelman, 2008; Lewis and Kelman, 2009; Bahadur et al., 2010; Aven, 2011). Thus, for example, the term is used by some in reference to situations at any point along the risk 'cycle' or 'continuum', that is, before, during, or after the impact of the physical event. And, in a different vein, some consider the notions of 'vulnerability' and 'capacity' as being sufficient for explaining the ranges of success or failure that are found in different recovery scenarios and are thus averse to the use of the term at all (Wisner et al., 2004, 2011). Under this latter formulation, vulnerability both potentiates original loss and damage and also impedes recovery, while capacity building can change this adverse balance and contribute to greater sustainability and reduced disaster risk.

Older conceptions of resilience, as 'bouncing back,' and its conceptual cousin, coping (see Section 1.4), have implicitly emphasized a return to a previous status quo or some other marginally acceptable level, such as 'surviving,' as opposed to generating a cyclical process that leads to continually improving conditions, as in 'bouncing forward' and/or eventually 'thriving' (Davies, 1993; Manyena, 2006). However, the dynamic and often uncertain consequences of climate change (as well as ongoing, now longstanding, development trends such as urbanization) for hazard and vulnerability profiles underscore the fact that 'bouncing back' is an increasingly insufficient goal for disaster risk management (Pelling, 2003; Vale and Campanella, 2005; Pendalla et al., 2010) (*high confidence*). Recent conceptions of resilience of social-ecological systems focus more on process than outcomes (e.g., Norris et al., 2008), including the ability to self-organize, learn, and adapt over time (see Chapter 8). Some definitions of resilience, such as that used in this report, now also include the idea of anticipation and 'improvement' of essential basic structures and functions. Section 1.4 examines the importance of learning that is emphasized within this more forward-looking application of resilience. Chapter 8 builds on the importance of learning by drawing also from literature that has explored the scope for innovation, leadership, and adaptive management. Together these strategies offer potential pathways for transforming existing development visions, goals, and practices into more sustainable and resilient futures. Chapters 2 and 8 address the notion of resilience and its importance in discussions on sustainability, disaster risk reduction, and adaptation in greater detail.

1.1.2.2. Concepts and Definitions Relating to Disaster Risk Management and Adaptation to Climate Change

Disaster risk management is defined in this report as the processes for designing, implementing, and evaluating strategies, policies, and measures to improve the understanding of disaster risk, foster disaster risk reduction and transfer, and promote continuous improvement in disaster preparedness, response, and recovery practices, with the explicit purpose of increasing human security, well-being, quality of life, and sustainable development.

Disaster risk management is concerned with both disaster and disaster risk of differing levels and intensities. In other words, it is not restricted to a 'manual' for the management of the risk or disasters associated with extreme events, but rather includes the conceptual framework that describes and anticipates intervention in the overall and diverse patterns, scales, and levels of interaction of exposure, hazard, and vulnerability that can lead to disaster. A major recent concern of disaster risk management has been that disasters are associated more and more with lesser-scale physical phenomena that are not extreme in a physical sense (see Section 1.1.1). This is principally attributed to increases in exposure and associated vulnerability (UNISDR, 2009e, 2011).

Where the term **risk management** is employed in this chapter and report, it should be interpreted as being a synonym for disaster risk management, unless otherwise made explicit.

Disaster Risk Management can be divided to comprise two related but discrete subareas or components: **disaster risk reduction** and **disaster management**.

Disaster risk reduction denotes both a policy goal or objective, and the strategic and instrumental measures employed for anticipating future disaster risk, reducing existing exposure, hazard, or vulnerability, and improving resilience. This includes lessening the vulnerability of people, livelihoods, and assets and ensuring the appropriate sustainable management of land, water, and other components of the environment. Emphasis is on universal concepts and strategies involved in the consideration of reducing disaster risks, including actions and activities enacted pre-impact, and when recovery and reconstruction call for the anticipation of new disaster risk scenarios or conditions. A strong relationship between disaster risk and disaster risk reduction, and development and development planning has been established and validated, particularly, but not exclusively, in developing country contexts (UNEP, 1972; Cuny, 1983; Sen, 1983; Hagman, 1984; Wijkman and Timberlake, 1988; Lavell, 1999, 2003, 2009; Wisner et al., 2004, 2011; UNDP, 2004; van Niekerk, 2007; Dulal et al., 2009; UNISDR, 2009e, 2011) (*high confidence*).

Disaster management refers to social processes for designing, implementing, and evaluating strategies, policies, and measures that promote and improve disaster preparedness, response, and recovery practices at different organizational and societal levels. Disaster management processes are enacted once the immediacy of the disaster event has become evident and resources and capacities are put in place with which to respond prior to and following impact. These include the activation of early warning systems, contingency planning, emergency response (immediate post-impact support to satisfy critical human needs under conditions of severe stress), and, eventually, recovery (Alexander, 2000; Wisner et al., 2011). Disaster management is required due to the existence of 'residual' disaster risk that ongoing disaster risk reduction processes have not mitigated or reduced sufficiently or eliminated or prevented completely (IDB, 2007).

Growing disaster losses have led to rapidly increasing concerns for post-impact financing of response and recovery (UNISDR, 2009e, 2011). In this context, the concept and practice of disaster risk transfer has received increased interest and achieved greater salience. **Risk transfer** refers to the process of formally or informally shifting the financial consequences of particular risks from one party to another, whereby a household, community, enterprise, or state authority will obtain resources from the other party after a disaster occurs, in exchange for ongoing or compensatory social or financial benefits provided to that other party. Disaster risk transfer mechanisms comprise a component of both disaster management and disaster risk reduction. In the former case, financial provision is made to face up to the impacts and consequences of disaster once this materializes. In the latter case, the adequate use of insurance premiums, for example, can promote and encourage the use of disaster risk reduction measures in the insured elements. Chapters 5, 6, 7, and 9 discuss risk transfer in some detail.

Over the last two decades, the more integral notion of disaster risk management and its risk reduction and disaster management components has tended to replace the unique conception and terminology of 'disaster and emergency management' that prevailed almost unilaterally up to the beginning of the 1990s and that emphasized disaster as opposed to disaster risk as the central issue to be confronted. Disaster as such ordered the thinking on required intervention processes, whereas with disaster risk management, disaster risk now tends to assume an increasingly dominant position in thought and action in this field (see Hewitt, 1983; Blaikie et al., 1994; Smith, 1996; Hewitt, 1997; Tobin and Montz, 1997; Lavell, 2003; Wisner et al., 2004, 2011; van Niekerk, 2007; Gaillard, 2010 for background and review of some of the historical changes in favor of disaster risk management).

The notion of **disaster or disaster management cycle** was introduced and popularized in the earlier context dominated by disaster or emergency management concerns and viewpoints. The cycle, and the later 'disaster continuum' notion, depicted the sequences and components of so-called disaster management. In addition to considering preparedness, emergency response, rehabilitation, and reconstruction, it also included disaster prevention and mitigation as stated components of 'disaster management' and utilized the temporal notions of before, during, and after disaster to classify the different types of action (Lavell and Franco, 1996; van Niekerk, 2007).

The cycle notion, criticized for its mechanistic depiction of the intervention process, for insufficient consideration of the ways different components and actions merge and can act synergistically with and influence each other, and for its incorporation of disaster risk reduction considerations under the rubric of 'disaster management' (Lavell and Franco, 1996; Lewis, 1999; Wisner et al., 2004; Balamir, 2005; van Niekerk, 2007), has tended to give way over time, in many parts of the world, to the more comprehensive approach and concept of disaster risk management with its consideration of distinct risk reduction and disaster intervention components. The move toward a conception oriented in terms of disaster risk and not disaster per se has led to initiatives to develop the notion of a '**disaster risk continuum**' whereby risk is seen to evolve and change constantly, requiring different modalities of intervention over time, from pre-impact risk reduction through response to new risk conditions following disaster impacts and the need for control of new risk factors in reconstruction (see Lavell, 2003).

With regard to the influence of actions taken at one stage of the 'cycle' on other stages, much has been written, for example, on how the form and method of response to disaster itself may affect future disaster risk reduction efforts. The fostering of active community involvement, the use of existing local and community capacities and resources, and the decentralization of decisionmaking to the local level in disaster preparedness and response, among other factors, have been considered critical for also improving understanding of disaster risk and the development of future disaster risk reduction efforts (Anderson and Woodrow, 1989; Alexander, 2000; Lavell, 2003; Wisner et al., 2004) (*high confidence*). And, the methods used for, and achievements with, reconstruction clearly have important impacts on future disaster risk and on the future needs for preparedness and response.

In the following subsection, some of the major reasons that explain the transition from disaster management, with its emphasis on disaster, to disaster risk management, with its emphasis on disaster risk, are presented as a background for an introduction to the links and options for closer integration of the adaptation and disaster risk management fields.

The gradual evolution of policies that favor disaster risk reduction objectives as a component of development planning procedures (as opposed to disaster management seen as a function of civil protection, civil defense, emergency services, and ministries of public works) has inevitably placed the preexisting emergency or disaster-response-oriented institutional and organizational arrangements for disaster management under scrutiny. The prior dominance of response-based and infrastructure organizations has been complemented with the increasing incorporation of economic and social sector and territorial development agencies or organizations, as well as planning and finance ministries. Systemic, as opposed to single agency, approaches are now evolving in many places.

Synergy, collaboration, coordination, and development of multidisciplinary and multiagency schemes are increasingly seen as positive attributes for guaranteeing implementation of disaster risk reduction and disaster risk management in a sustainable development framework (see Lavell and Franco, 1996; Ramírez and Cardona, 1996; Wisner et al., 2004, 2011). Under these circumstances the notion of **national disaster risk management systems** or **structures** has emerged strongly. Such notions are discussed in detail in Chapter 6.

Adaptation to climate change, the second policy, strategic, and instrumental aspect of importance for this Special Report, is a notion that refers to both human and natural systems. Adaptation in human systems is defined here as the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, it is defined as the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate.

These definitions modify the IPCC (2007c) definition that generically speaks of the "adjustment in natural and human systems in response to actual and expected climatic stimuli, such as to moderate harm or exploit beneficial opportunities." The objective of the redefinition used in this report is to avoid the implication present in the prior IPCC definition that natural systems can adjust to expected climate stimuli. At the same time, it accepts that some forms of human intervention may provide opportunities for supporting natural system adjustment to future climate stimuli that have been anticipated by humans.

Adaptation is a key aspect of the present report and is dealt with in greater detail in Sections 1.3 and 1.4 and later chapters. The more ample introduction to disaster risk management offered above derives from the particular perspective of the present report: that adaptation is a goal to be advanced and extreme event and disaster risk management are methods for supporting and advancing that goal.

The notion of adaptation is counterposed to the notion of **mitigation** in the climate change literature and practice. **Mitigation** there refers to the reduction of the rate of climate change via the management of its causal factors (the emission of greenhouse gases from fossil fuel combustion, agriculture, land use changes, cement production, etc.) (IPCC, 2007c). However, in disaster risk reduction practice, 'mitigation' refers to the amelioration of disaster risk through the reduction of existing hazards, exposure, or vulnerability, including the use of different **disaster preparedness** measures.

Disaster preparedness measures, including early warning and the development of contingency or emergency plans, may be considered a component of, and a bridge between, disaster risk reduction and disaster management. Preparedness accepts the existence of residual, unmitigated risk, and attempts to aid society in eliminating certain of the adverse effects that could be experienced once a physical event(s) occurs (for example, by the evacuation of persons and livestock from exposed and vulnerable circumstances). At the same time, it provides for better response to adverse effects that do materialize (for example, by planning for adequate shelter and potable water supplies for the affected or destitute persons or food supplies for affected animal populations).

In order to accommodate the two differing definitions of mitigation, this report presumes that **mitigation** is a substantive action that can be applied in different contexts where attenuation of existing specified conditions is required.

Disaster mitigation is used to refer to actions that attempt to limit further adverse conditions once disaster has materialized. This refers to the avoidance of what has sometimes been called the 'second disaster' following the initial physical impacts (Alexander, 2000; Wisner et al., 2011). The 'second disaster' may be characterized, among other things, by adverse effects on health (Noji, 1997; Wisner et al., 2011) and livelihoods due to inadequate disaster response and rehabilitation plans, inadequate enactment of existing plans, or unforeseen or unforeseeable circumstances.

Disaster risk **prevention** and disaster **prevention** refer, in a strict sense, to the elimination or avoidance of the underlying causes and conditions that lead to disaster, thus precluding the possibility of either disaster risk or disaster materializing. The notion serves to concentrate attention on the fact that disaster risk is manageable and its materialization is preventable to an extent (which varies depending on the context). **Prospective (proactive) disaster risk management** and adaptation can contribute in important ways to avoiding future, and not just reducing existing, risk and disaster once they have become manifest, as is the case with **corrective** or **reactive management** (Lavell, 2003; UNISDR, 2011).

1.1.2.3. The Social Construction of Disaster Risk

The notions of hazard, exposure, vulnerability, disaster risk, capacity, resilience, and coping, and their social origins and bases, as presented above, reflect an emerging understanding that disaster risk and disaster, while potentiated by an objective, physical condition, are fundamentally a 'social construction,' the result of social choice, social constraints, and societal action and inaction (*high confidence*). The notion of social construction of risk implies that management can take into account the social variables involved and to the best of its ability work toward risk reduction, disaster management, or risk transfer through socially sustainable decisions and concerted human action (ICSU-LAC, 2009). This of course does not mean that there are not risks that may be too great to reduce significantly through human intervention, or others that the very social construction process may in fact exacerbate (see Sections 1.3.1.2 and 1.4.3). But in contrast with, for example, many natural physical events and their contribution to disaster risk, the component of risk that is socially constructed is subject to intervention in favor of risk reduction.

The contribution of physical events to disaster risk is characterized by statistical distributions in order to elucidate the options for risk reduction and adaptation (Section 1.2 and Chapter 3). But, the explicit recognition of the political, economic, social, cultural, physical, and psychological elements or determinants of risk leads to a spectrum of potential outcomes of physical events, including those captured under the notion of **extreme impacts** (Section 1.2 and Chapter 4). Accordingly, risk assessment (see Section 1.3) using both quantitative and qualitative (social and psychological) measures is required to render a more complete description of risk and risk causation processes (Section 1.3; Douglas and Wildavsky, 1982; Cardona, 2004; Wisner et al., 2004; Weber, 2006). Climate change may introduce a break with past environmental system functioning so that forecasting physical events becomes less determined by past trends. Under these conditions, the processes that cause, and the established indicators of, human vulnerability need to be reconsidered in order for risk assessment to remain an effective tool. The essential nature and structure of the characteristics that typify vulnerability can of course change without climate changing.

1.1.3. Framing the Relation between Adaptation to Climate Change and Disaster Risk Management

Adaptation to climate change and disaster risk management both seek to reduce factors and modify environmental and human contexts that contribute to climate-related risk, thus supporting and promoting sustainability in social and economic development. The promotion of adequate preparedness for disaster is also a function of disaster risk management and adaptation to climate change. And, both practices are seen to involve learning (see Section 1.4), having a corrective and prospective component dealing with existing and projected future risk.

However, the two practices have tended to follow independent paths of advance and development and have on many occasions employed different interpretations of concepts, methods, strategies, and institutional frameworks to achieve their ends. These differences should clearly be taken into account in the search for achieving greater synergy between them and will be examined in an introductory fashion in Section 1.3 and in greater detail in following chapters of this report.

Public policy and professional concepts of disaster and their approaches to disaster and disaster risk management have undergone very significant changes over the last 30 years, so that challenges that are now an explicit focus of the adaptation field are very much part of current disaster risk reduction as opposed to mainstream historical disaster management concerns (Lavell, 2010; Mercer, 2010).These changes have occurred under the stimuli of changing concepts, multidisciplinary involvement, social and economic demands, and impacts of disasters, as well as institutional changes reflected in international accords and policies such as the UN Declaration of the International Decade for Natural Disaster Reduction in the 1990s, the 2005 Hyogo Framework for Action, as well as the work of the International Strategy for Disaster Reduction since 2000.

Particularly in developing countries, this transition has been stimulated by the documented relationship between disaster risk and 'skewed' development processes (UNEP, 1972; Cuny, 1983; Sen, 1983; Hagman, 1984; Wijkman and Timberlake, 1988; Lavell, 1999, 2003; UNDP, 2004; Wisner et al., 2004, 2011; Dulal et al., 2009; UNISDR, 2009e, 2011). Significant differentiation in the distribution or allocation of gains from development and thus in the incidence of chronic or everyday risk, which disproportionately affect poorer persons and families, is a major contributor to the more specific existence of disaster risk (Hewitt, 1983, 1997; Wisner et al., 2004). Reductions in the rate of ecosystem services depletion, improvements in urban land use and territorial organization processes, the strengthening of rural livelihoods, and general and specific advances in urban and rural governance are viewed as indispensable to achieving the composite agenda of poverty reduction, disaster risk reduction, and adaptation to climate change (UNISDR, 2009e, 2011) (*high confidence*).

Climate change is at once a problem of development and also a symptom of 'skewed' development. In this context, pathways toward resilience include both incremental and transformational approaches to development (Chapter 8). Transformational strategies place emphasis on addressing risk that stems from social structures as well as social behavior and have a broader scope extending from disaster risk management into development goals, policy, and practice (Nelson et al., 2007). In this way transformation builds on a legacy of progressive, socially informed disaster risk research that has applied critical methods, including that of Hewitt (1983), Watts (1983), Maskrey (1989, 2011), Blaikie et al. (1994), and Wisner et al. (2004).

However, while there is a longstanding awareness of the role of development policy and practice in shaping disaster risk, advances in the reduction of the underlying causes – the social, political, economic, and environmental drivers of disaster risk – remain insufficient to reduce hazard, exposure, and vulnerability in many regions (UNISDR, 2009e, 2011) (*high confidence*).

The difficult transition to more comprehensive disaster risk management raises challenges for the proper allocation of efforts among disaster risk reduction, risk transfer, and disaster management efforts. Countries exhibit a wide range of acceptance or resistance to the various challenges of risk management as seen from a development perspective, due to differential access to information and education, varying levels of debate and discussion, as well as contextual, ideological, institutional, and other related factors. The introduction of disaster risk reduction concerns in established disaster response agencies may in some cases have led to a downgrading of efforts to improve disaster response, diverting scarce resources in favor of risk reduction aspects (Alexander, 2000; DFID, 2004, 2005; Twigg, 2004).

The increasing emphasis placed on considering disaster risk management as a dimension of development, and thus of development planning, as opposed to strict post-impact disaster response efforts, has been accompanied by increasing emphasis and calls for proactive, prospective disaster risk prevention as opposed to reactive, corrective disaster risk mitigation (Lavell, 2003, 2010; UNISDR, 2009e, 2011).

The more recent emergence of integrated disaster risk management reflects a shift from the notion of disaster to the notion of disaster risk as a central concept and planning concern. Disaster risk management places increased emphasis on comprehensive disaster risk reduction. This shifting emphasis to risk reduction can be seen in the increasing importance placed on developing **resistance** to the potential impacts of physical events at various social or territorial scales, and in different temporal dimensions (such as those required for corrective or prospective risk management), and to increasing the resilience of affected communities. **Resistance** refers to the ability to avoid suffering significant adverse effects.

Within this context, disaster risk reduction and adaptation to climate change are undoubtedly far closer practically than when emergency or disaster management objectives dominated the discourse and practice. The fact that many in the climate change and disaster fields have associated disaster risk management principally with disaster preparedness and response, and not with disaster risk reduction per se, contributed to the view that the two practices are essentially different, if complementary (Lavell, 2010; Mercer, 2010). Once the developmental basis of adaptation to climate change and disaster risk management are considered, along with the role of vulnerability in the constitution of risk, the temporal scale of concerns, and the corrective as well as prospective nature of disaster risk reduction, the similarities between and options for merging of concerns and practices increases commensurately.

Section 1.3 examines the current status of adaptation to climate change, as a prelude to examining in more detail the barriers and options for greater integration of the two practices. The historical frame offered in this subsection comprises an introduction to that discussion.

1.1.4. Framing the Processes of Disaster Risk Management and Adaptation to Climate Change

In this section, we explore two of the key issues that should be considered in attempting to establish the overlap or distinction between the phenomena and social processes that concern disaster risk management on the one hand, and adaptation to climate change on the other, and that influence their successful practice: 1) the degree to which the focus is on extreme events (instead of a more inclusive approach that considers the full continuum of physical events with potential for damage, the social contexts in which they occur, and the potential for such events to generate 'extreme impacts' or disasters); and 2) consideration of the appropriate social-territorial scale that should be examined (i.e., aggregations, see Schneider et al., 2007) in order to foster a deeper understanding of the causes and effects of the different actors and processes at work.

1.1.4.1. Exceptionality, Routine, and Everyday Life

Explanations of loss and damage resulting from extreme events that focus primarily or exclusively on the physical event have been referred to as 'physicalist' (Hewitt, 1983). By contrast, notions developed around the continuum of normal, everyday-life risk factors through to a linked consideration of physical and social extremes have been defined as 'comprehensive,' 'integral,' or 'holistic' insofar as they embrace the social as well as physical aspects of disaster risk and take into consideration the evolution of experience over time (Cardona, 2001; ICSU-LAC, 2009). The latter perspective has been a major contributing factor in the development of the so-called 'vulnerability paradigm' as a basis for understanding disaster (Timmerman, 1981; Hewitt, 1983, 1997; Wisner et al., 2004; Eakin and Luers, 2006; NRC, 2006).

Additionally, attention to the role of small- and medium-scale disasters (UNISDR, 2009e, 2011) highlights the need to deal integrally with the problem of cumulative disaster loss and damage, looking across the different scales of experience both in human and physical worlds, in order to advance the efficacy of disaster risk management and adaptation. The design of mechanisms and strategies based on the reduction and elimination of everyday or chronic risk factors (Sen, 1983; World Bank, 2001), as opposed to actions based solely on the 'exceptional' or 'extreme' events, is one obvious corollary of this approach. The ability to deal with risk, crisis, and change is closely related to an individual's life experience with smaller-scale, more regular physical and social occurrences (Maskrey, 1989, 2011; Lavell, 2003; Wisner et al., 2004) (*high confidence*). These concepts point toward the possibility of reducing vulnerability and increasing resilience to climate-related disaster by broadly focusing on exposure, vulnerability, and socially-determined propensity or predisposition to adverse effects across a range of risks.

As illustrated in Box 1-1, many of the extreme impacts associated with climate change, and their attendant additional risks and opportunities, will inevitably need to be understood and responded to principally at the scale of the individual, the individual household, and the community, in the framework of localities and nations and their organizational and management options, and in the context of the many other day-to-day changes, including those of an economic, political, technological, and cultural nature. As this real example illustrates, everyday life, history, and a sequence of crises can affect attitudes and ways of approaching more extreme or complex problems. In contrast, many agents and institutions of disaster risk management and climate change adaptation activities necessarily operate from a different perspective, given the still highly centralized and hierarchical authority approaches found in many parts of the world today.

Whereas disaster risk management has been modified based on the experiences of the past 30 years or more, adaptation to anthropogenic climate change is a more recent issue on most decisionmakers' policy agendas and is not informed by such a long tradition of immediate experience. However, human adaptation to prevailing climate variability and change, and climate and weather extremes in past centuries and millennia, provides a wealth of experience from which the field of adaptation to climate change, and individuals and governments, can draw.

Box 1-1 | One Person's Experience with Climate Variability in the Context of Other Changes

Joseph is 80 years old. He and his father and his grandfather have witnessed many changes. Their homes have shifted back and forth from the steep slopes of the South Pare Mountains at 1,500 m to the plains 20 km away, near the Pangani River at 600 m, in Tanzania. What do 'changes' (mabadiliko) mean to someone whose father saw the Germans and British fight during the First World War and whose grandfather defended against Maasai cattle raids when Victoria was still Queen?

Joseph outlived the British time. He saw African Socialism come and go after Independence. A road was constructed parallel to the old German rail line. Successions of commercial crops were dominant during his long life, some grown in the lowlands on plantations (sisal, kapok, and sugar), and some in the mountains (coffee, cardamom, ginger). He has seen staple foods change as maize became more popular than cassava and bananas. Land cover has also changed. Forest retreated, but new trees were grown on farms. Pasture grasses changed as the government banned seasonal burning. The Pangani River was dammed, and the electricity company decides how much water people can take for irrigation. Hospitals and schools have been built. Insecticide-treated bed nets recently arrived for the children and pregnant mothers.

Joseph has nine plots of land at different altitudes spanning the distance from mountain to plain, and he keeps in touch with his children who work them by mobile phone. What is 'climate change' (mabadiliko ya tabia nchi) to Joseph? He has suffered and benefited from many changes. He has lived through many droughts with periods of hunger, witnessed floods, and also seen landslides in the mountains. He is skilled at seizing opportunities from changes – small and large: "Mabadiliko bora kuliko mapumziko" (Change is better than resting).

The provenance of this story is an original field work interview undertaken by Ben Wisner in November 2009 in Same District, Kilimanjaro Region, Tanzania in the context of the U.S. National Science Foundation-funded research project "Linking Local Knowledge and Local Institutions for the Study of Adaptive Capacity to Climate Change: Participatory GIS in Northern Tanzania."

The ethnographic vignette in Box 1-1 suggests the way some individuals may respond to climate change in the context of previous experience, illustrating both the possibility of drawing successfully on past experience in adapting to climate variability, or, on the other hand, failing to comprehend the nature of novel risks.

1.1.4.2. Territorial Scale, Disaster Risk, and Adaptation

Climate-related disaster risk is most adequately depicted, measured, and monitored at the local or micro level (families, communities, individual buildings or production units, etc.) where the actual interaction of hazard and vulnerability are worked out *in situ* (Hewitt, 1983, 1997; Lavell, 2003; Wisner et al., 2004; Cannon, 2006; Maskrey, 2011). At the same time, it is accepted that disaster risk construction processes are not limited to specifically local or micro processes but, rather, to diverse environmental, economic, social, and ideological influences whose sources are to be found at scales from the international through to the national, sub-national and local, each potentially in constant flux (Lavell, 2002, 2003; Wisner et al., 2004, 2011).

Changing commodity prices in international trading markets and their impacts on food security and the welfare of agricultural workers, decisions on location and cessation of agricultural production by international corporations, deforestation in the upper reaches of river basins, and land use changes in urban hinterlands are but a few of these 'extra-territorial' influences on local risk. Moreover, disasters, once materialized, have ripple effects that many times go well beyond the directly affected zones (Wisner et al., 2004; Chapter 5) Disaster risk management and adaptation policy, strategies, and institutions will only be successful where understanding and intervention is based on multi-territorial and social-scale principles and where phenomena and actions at local, sub-national, national, and international scales are construed in interacting, concatenated ways (Lavell, 2002; UNISDR, 2009e, 2011; Chapters 5 through 9).

1.2. Extreme Events, Extreme Impacts, and Disasters

1.2.1. Distinguishing Extreme Events, Extreme Impacts, and Disasters

Both the disaster risk management and climate change adaptation literature define 'extreme weather' and 'extreme climate' events and discuss their relationship with 'extreme impacts' and 'disasters.' Classification of extreme events, extreme impacts, and disasters is influenced by the measured physical attributes of weather or climatic variables (see Section 3.1.2) or the vulnerability of social systems (see Section 2.4.1).

This section explores the quantitative definitions of different classes of extreme weather events, what characteristics determine that an impact is extreme, and how climate change affects the understanding of extreme climate events and impacts.

1.2.2. Extreme Events Defined in Physical Terms

1.2.2.1. Definitions of Extremes

Some literature reserve the term 'extreme event' for initial meteorological phenomena (Easterling et al., 2000; Jentsch et al., 2007), some include the consequential physical impacts, like flooding (Young, 2002), and some the entire spectrum of outcomes for humans, society, and ecosystems (Rich et al., 2008). In this report, we use 'extreme (weather or climate) event' to refer solely to the initial and consequent physical phenomena including some (e.g., flooding) that may have human components to causation other than that related to the climate (e.g., land use or land cover change or changes in water management; see Section 3.1.2 and Glossary). The spectrum of outcomes for humans, society, and physical systems, including ecosystems, are considered 'impacts' rather than part of the definition of 'events' (see Sections 1.1.2.1 and 3.1.2 and the Glossary).

In addition to providing a long-term mean of weather, 'climate' characterizes the full spectrum of means and exceptionality associated with 'unusual' and unusually persistent weather. The World Meteorological Organization (WMO, 2010) differentiates the terms in the following way (see also FAQ 6.1): "At the simplest level the weather is what is happening to the atmosphere at any given time. Climate in a narrow sense is usually defined as the 'average weather,' or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time."

Weather and climate phenomena reflect the interaction of dynamic and thermodynamic processes over a very wide range of space and temporal scales. This complexity results in highly variable atmospheric conditions, including temperatures, motions, and precipitation, a component of which is referred to as 'extreme events.' Extreme events include the passage of an intense tornado lasting minutes and the persistence of drought conditions over decades – a span of at least seven orders of magnitude of timescales. An imprecise distinction between extreme 'weather' and 'climate' events, based on their characteristic timescales, is drawn in Section 3.1.2. Similarly, the spatial scale of extreme climate or weather varies from local to continental.

Where there is sufficient long-term recorded data to develop a statistical distribution of a key weather or climate variable, it is possible to find the probability of experiencing a value above or below different thresholds of that distribution as is required in engineering design (trends may be sought in such data to see if there is evidence that the climate has not been stationary over the sample period; Milly et al., 2008). The extremity of a weather or climate event of a given magnitude depends on geographic context (see Section 3.1.2 and Box 3-1): a month of daily temperatures corresponding to the expected spring climatological daily maximum in Chennai, India, would be termed a heat wave in France; a snow storm expected every year in New York, USA, might initiate a disaster when it occurs in southern China. Furthermore, according to the location and social context, a 1-in-10 or 1-in-20 annual probability event may not be sufficient to result in unusual consequences. Nonetheless, universal thresholds can exist – for example, a reduction in the incidence or intensity of freezing days may allow certain disease vectors to thrive (e.g., Epstein et al., 1998). These various aspects are considered in the definition of 'extreme (weather and climate) events.'

The availability of observational data is of central relevance for defining climate characteristics and for disaster risk management; and, while data for temperature and precipitation are widely available, some associated variables, such as soil moisture, are poorly monitored, or, like extreme wind speeds and other low frequency occurrences, not monitored with sufficient spatial resolution or temporal continuity (Section 3.2.1).

1.2.2.2. Extremes in a Changing Climate

An extreme event in the present climate may become more common, or more rare, under future climate conditions. When the overall distribution of the climate variable changes, what happens to mean climate may be different from what happens to the extremes at either end of the distribution (see Figure 1-2).

For example, a warmer mean climate could result from fewer cold days, leading to a reduction in the variance of temperatures, or more hot days, leading to an expansion in the variance of the temperature distribution, or both. The issue of the scaling of changes in extreme events with respect to changes in mean temperatures is addressed further in Section 3.1.6.

In general, single extreme events cannot be simply and directly attributed to *anthropogenic* climate change, as there is always a possibility the event in question might have occurred without this contribution (Hegerl et al., 2007; Section 3.2.2; FAQ 3.2). However, for certain classes of regional, long-duration extremes (of heat and rainfall) it has proved possible to argue from climate model outputs that the probability of such an extreme has changed due to anthropogenic climate forcing (Stott et al., 2004; Pall et al., 2011).

Extremes sometimes result from the interactions between two unrelated geophysical phenomena such as a moderate storm surge coinciding with an extreme spring tide, as in the most catastrophic UK storm surge flood of the past 500 years in 1607 (Horsburgh and Horritt, 2006). Climate change may alter both the frequency of extreme surges and cause gradual sea level rise, compounding such future extreme floods (see Sections 3.5.3 and 3.5.5).

1.2.2.3. The Diversity and Range of Extremes

The specification of weather and climate extremes relevant to the concerns of individuals, communities, and governments depends on the affected stakeholder, whether in agriculture, disease control, urban design, infrastructure maintenance, etc. Accordingly, the range of such extremes is very diverse and varies widely. For example, whether it falls as rain, freezing rain (rain falling through a surface layer below freezing), snow, or hail, extreme precipitation can cause significant damage (Peters et al., 2001). The absence of precipitation (McKee et al., 1993) as well as excess evapotranspiration from the soil (see Box 3-3) can be climate extremes, and lead to drought. Extreme surface winds are chiefly associated with structured storm circulations (Emanuel, 2003; Zipser et al., 2006; Leckebusch et al., 2008). Each storm type, including the most damaging tropical cyclones and mid-latitude extratropical cyclones, as well as intense convective thunderstorms, presents a spectrum of size, forward speed, and intensity. A single intense storm can combine extreme wind and extreme rainfall.

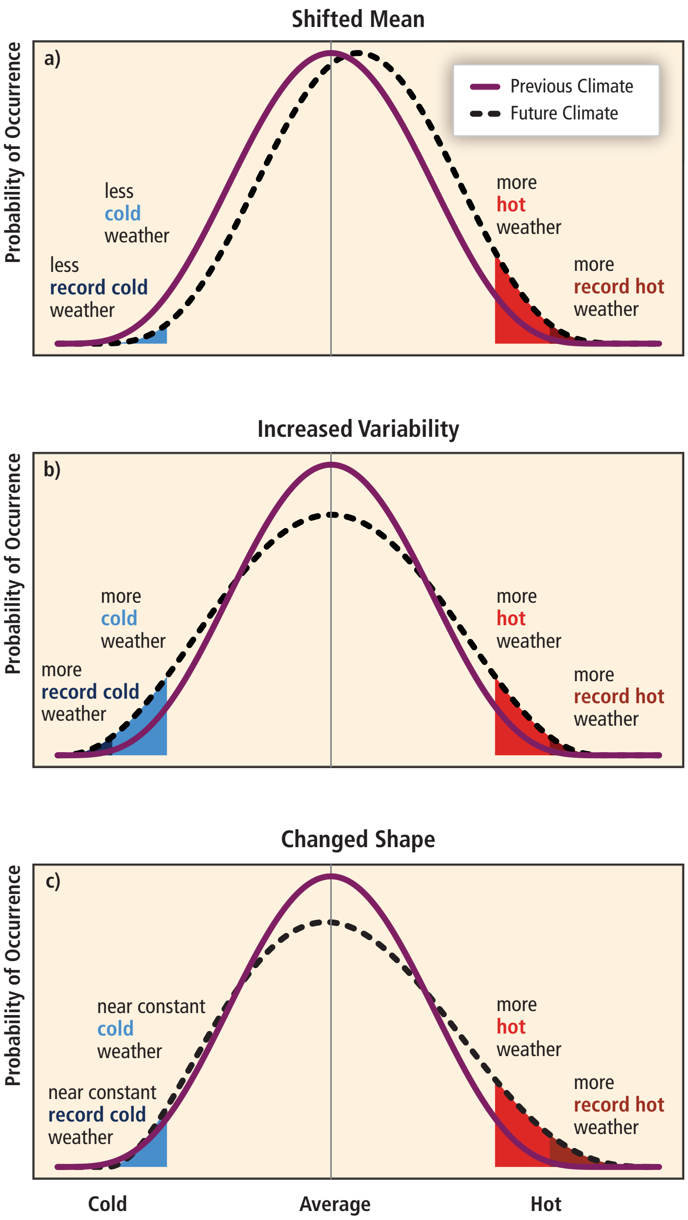

Figure 1-2 | The effect of changes in temperature distribution on extremes. Different changes in temperature distributions between present and future climate and their effects on extreme values of the distributions: a) effects of a simple shift of the entire distribution toward a warmer climate; b) effects of an increased temperature variability with no shift of the mean; and c) effects of an altered shape of the distribution, in this example an increased asymmetry toward the hotter part of the distribution.

The prolonged absence of winds is a climate extreme that can also be a hazard, leading to the accumulation of urban pollution and disruptive fog (McBean, 2006).

The behavior of the atmosphere is also highly interlinked with that of the hydrosphere, cryosphere, and terrestrial environment so that extreme (or sometimes non-extreme) atmospheric events may cause (or contribute to) other rare physical events. Among the more widely documented hydroclimatic extremes are:

- Large cyclonic storms that generate wind and pressure anomalies causing coastal flooding and severe wave action (Xie et al., 2004).
- Floods, reflecting river flows in excess of the capacity of the normal channel, often influenced by human intervention and water management, resulting from intense precipitation; rapid thaw of accumulated winter snowfall; rain falling on previous snowfall (Sui and Koehler, 2001); or an outburst from an ice, landslide, moraine, or artificially dammed lake (de Jong et al., 2005). According to the scale of the catchment, river systems have characteristic response times with steep short mountain streams, desert wadis, and urban drainage systems responding to rainfall totals over a few hours, while peak flows in major continental rivers reflect regional precipitation extremes lasting weeks (Wheater, 2002).
- Long-term reductions in precipitation, or dwindling of residual summer snow and ice melt (Rees and Collins, 2006), or increased evapotranspiration from higher temperatures, often exacerbated by human groundwater extraction, reducing ground water levels and causing spring-fed rivers to disappear (Konikow and Kendy, 2005), and contributing to drought.
- Landslides (Dhakal and Sidle, 2004) when triggered by raised groundwater levels after excess rainfall or active layer detachments in thawing slopes of permafrost (Lewcowicz and Harris, 2005).

1.2.3. Extreme Impacts

1.2.3.1. Three Classes of Impacts

In this subsection we consider three classes of 'impacts': 1) changes in the natural physical environment, like beach erosion from storms and mudslides; 2) changes in ecosystems, such as the blow-down of forests in hurricanes, and 3) adverse effects (according to a variety of metrics) on human or societal conditions and assets. However, impacts are not always negative: flood-inducing rains can have beneficial effects on the following season's crops (Khan, 2011), while an intense freeze may reduce insect pests at the subsequent year's harvest (Butts et al., 1997).

An **extreme impact** reflects highly significant and typically long-lasting consequences to society, the natural physical environment, or ecosystems. Extreme impacts can be the result of a single extreme event, successive extreme or non-extreme events, including non-climatic events (e.g., wildfire, followed by heavy rain leading to landslides and soil erosion), or simply the persistence of conditions, such as those that lead to drought (see Sections 3.5.1 and 9.2.3 for discussion and examples).

Whether an extreme event results in extreme impacts on humans and social systems depends on the degree of exposure and vulnerability to that extreme, in addition to the magnitude of the physical event (*high confidence*). Extreme impacts on human systems may be associated with non-extreme events where vulnerability and exposure are high (Sections 1.1.2.1 and 9.2.3). A key weather parameter may cross some critical value at that location (such as that associated with heat wave-induced mortality, or frost damage to crops), so that the distribution of the impact shifts in a way that is disproportionate to physical changes (see Section 4.2). A comprehensive assessment of projected impacts of climate changes would consider how changes in atmospheric conditions (temperature, precipitation) translate to impacts on physical (e.g., droughts and floods, erosion of beaches and slopes, sea level rise), ecological (e.g., forest fires), and human systems (e.g., casualties, infrastructure damages). For example, an extreme event with a large spatial scale (as in an ice storm or windstorm) can have an exaggerated, disruptive impact due to the systemic societal dependence on electricity transmission and distribution networks (Peters et al., 2006). Links between climate events and physical impacts are addressed in Section 3.5, while links to ecosystems and human systems impacts are addressed in 4.3.

Disaster signifies extreme impacts suffered by society, which may also be associated with extreme impacts on the physical environment and on ecosystems. Building on the definition set out in Section 1.1.2.1, extreme impacts resulting from weather, climate, or hydrological events can become disasters once they surpass thresholds in at least one of three dimensions: spatial – so that damages cannot be easily restored from neighboring capacity; temporal – so that recovery becomes frustrated by further damages; and intensity of impact on the affected population – thereby undermining, although not necessarily eliminating, the capacity of the society or community to repair itself (Alexander, 1993). However, for the purposes of tabulating occurrences, some agencies only list 'disasters' when they exceed certain numbers of killed or injured or total repair costs (Below et al., 2009; CRED, 2010).

1.2.3.2. Complex Nature of an Extreme 'Event'

In considering the range of weather and climate extremes, along with their impacts, the term 'event' as used in the literature does not adequately capture the compounding of outcomes from successive physical phenomena, for example, a procession of serial storms tracking across the same region (as in January and February 1990 and December 1999 across Western Europe, Ulbrich et al., 2001). In focusing on the social context of disasters, Quarantelli (1986) proposed the use of the notion of 'disaster occurrences or occasions' in place of 'events' due to the abrupt and circumstantial nature of the connotation commonly attributed to the word 'event,' which belies the complexity and temporality of disaster, in particular because social context may precondition and extend the duration over which impacts are felt.

Sometimes locations affected by extremes within the 'same' large-scale stable atmospheric circulation can be far apart, as for example the Russian heat wave and Indus valley floods in Pakistan in the summer of 2010 (Lau and Kim, 2011). Extreme events can also be interrelated through the atmospheric teleconnections that characterize the principal drivers of oceanic equatorial sea surface temperatures and winds in the El Niño–Southern Oscillation. The relationship between modes of climate variability and extremes is discussed in greater detail in Section 3.1.1.

The aftermath of one extreme event may precondition the physical impact of successor events. High groundwater levels and river flows can persist for months, increasing the probability of a later storm causing flooding, as on the Rhine in 1995 (Fink et al., 1996). A thickness reduction in Arctic sea ice preconditions more extreme reductions in the summer ice extent (Holland et al., 2006). A variety of feedbacks and other interactions connect extreme events and physical system and ecological responses in a way that may amplify physical impacts (Sections 3.1.4 and 4.3.5). For example, reductions in soil moisture can intensify heat waves (Seneviratne et al., 2006), while droughts following rainy seasons turn vegetation into fuel that can be consumed in wildfires (Westerling and Swetman, 2003), which in turn promote soil runoff and landslides when the rains return (Cannon et al., 2001). However, extremes can also interact to reduce disaster risk. The wind-driven waves in a hurricane bring colder waters to the surface from beneath the thermocline; for the next month, any cyclone whose path follows too closely will have a reduced potential maximum intensity (Emanuel, 2001). Intense rainfall accompanying monsoons and hurricanes also brings great benefits to society and ecosystems; on many occasions it helps to fill reservoirs, sustain seasonal agriculture, and alleviate summer dry conditions in arid zones (e.g., Cavazos et al., 2008).

1.2.3.3. Metrics to Quantify Social Impacts and the Management of Extremes

Metrics to quantify social and economic impacts (thus used to define extreme impacts) may include, among others (Below et al., 2009):

- Human casualties and injuries
- Number of permanently or temporarily displaced people
- Number of directly and indirectly affected persons
- Impacts on properties, measured in terms of numbers of buildings damaged or destroyed
- Impacts on infrastructure and lifelines
- Impacts on ecosystem services
- Impacts on crops and agricultural systems
- Impacts on disease vectors
- Impacts on psychological well being and sense of security
- Financial or economic loss (including insurance loss)
- Impacts on coping capacity and need for external assistance.

All of these may be calibrated according to the magnitude, rate, duration, and degree of irreversibility of the effects (Schneider et al., 2007). These metrics may be quantified and implemented in the context of probabilistic risk analysis in order to inform policies in a variety of contexts (see Box 1-2).

Box 1-2 | Probabilistic Risk Analysis

In its simplest form, probabilistic risk analysis defines risk as the product of the probability that some event (or sequence) will occur and the adverse consequences of that event.

Risk = Probability x Consequence (1)

For instance, the risk a community faces from flooding from a nearby river might be calculated based on the likelihood that the river floods the town, inflicting casualties among inhabitants and disrupting the community's economic livelihood. This likelihood is multiplied by the value people place on those casualties and economic disruption. Equation (1) provides a quantitative representation of the qualitative definition of disaster risk given in Section 1.1. All three factors – hazard, exposure, and vulnerability – contribute to 'consequences.' Hazard and vulnerability can both contribute to the 'probability': the former to the likelihood of the physical event (e.g., the river flooding the town) and the latter to the likelihood of the consequence resulting from the event (e.g., casualties and economic disruption).

When implemented within a broader risk governance framework, probabilistic risk analysis can help allocate and evaluate efforts to manage risk. Equation (1) implies what the decision sciences literature (Morgan and Henrion, 1990) calls a decision rule – that is, a criterion for ranking alternative sets of actions by their ability to reduce overall risk. For instance, an insurance company (as part of a risk transfer effort) might set the annual price for flood insurance based on multiplying an estimate of the probability a dwelling would be flooded in any given year by an estimate of the monetary losses such flooding would cause. Ideally, the premiums collected from the residents of many dwellings would provide funds to compensate the residents of those few dwellings that are in fact flooded (and defray administrative costs). In another example, a water management agency (as part of a risk reduction effort) might invest the resources to build a reservoir of sufficient size so that, if the largest drought observed in their region over the last 100 years (or some other timeframe) occurred again in the future, the agency would nonetheless be able to maintain a reliable supply of water.

A wide variety of different expressions of the concepts in Equation (1) exist in the literature. The disaster risk management community often finds it convenient to express risk as a product of hazard, exposure, and vulnerability (e.g., UNISDR, 2009e, 2011). In addition, the decision sciences literature recognizes decision rules, useful in some circumstances, that do not depend on probability and consequence as combined in Equation (1). For instance, if the estimates of probabilities are sufficiently imprecise, decisionmakers might use a criterion that depends only on comparing estimates of potential consequences (e.g., mini-max regret, Savage, 1972).

In practice, probabilistic risk analysis is often not implemented in its pure form for reasons including data limitations; decision rules that yield satisfactory results with less effort than that required by a full probabilistic risk assessment; the irreducible imprecision of some estimates of important probabilities and consequences (see Sections 1.3.1.1 and 1.3.2); and the need to address the wide range of factors that affect judgments about risk (see Box 1-3). In the above example, the water management agency is not performing a full probabilistic risk analysis, but rather employing a hybrid decision rule in which it estimates that the consequences of running out of water would be so large as to justify any reasonable investment needed to keep the likelihood of that event below the chosen probabilistic threshold. Chapter 2 describes a variety of practical quantitative and qualitative approaches for allocating efforts to manage disaster risk.

The probabilistic risk analysis framework in its pure form is nonetheless important because its conceptual simplicity aids understanding by making assumptions explicit, and because its solid theoretical foundations and the vast empirical evidence examining its application in specific cases make it an important point of comparison for formal evaluations of the effectiveness of efforts to manage disaster risk.

Information on direct, indirect, and collateral impacts is generally available for many large-scale disasters and is systematized and provided by organizations such as the Economic Commission for Latin America, large reinsurers, and the EM-DAT database (CRED, 2010). Information on impacts of smaller, more recurrent events is far less accessible and more restricted in the number of robust variables it provides. The Desinventar database (Corporación OSSO, 2010), now available for 29 countries worldwide, and the Spatial Hazard Events and Losses Database for the United States (SHELDUS; HVRI, 2010), are attempts to satisfy this need. However, the lack of data on many impacts impedes complete knowledge of the global social and economic impacts of smaller-scale disasters (UNISDR, 2009e).

1.2.3.4. Traditional Adjustment to Extremes

Disaster risk management and climate change adaptation may be seen as attempts to duplicate, promote, or improve upon adjustments that society and nature have accomplished on many occasions spontaneously in the past, if over a different range of conditions than expected in the future.

Within the sphere of adaptation of natural systems to climate, among trees, for example, natural selection has the potential to evolve appropriate resilience to extremes (at some cost). Resistance to windthrow is strongly species-dependent, having evolved according to the climatology where that tree was indigenous (Canham et al., 2001). In their original habitat, trees typically withstand wind extremes expected every 10 to 50 years, but not extremes that lie beyond their average lifespan of 100 to 500 years (Ostertag et al., 2005).

In human systems, communities traditionally accustomed to periodic droughts employ wells, boreholes, pumps, dams, and water harvesting and irrigation systems. Those with houses exposed to high seasonal temperatures employ thick walls and narrow streets, have developed passive cooling systems, adapted lifestyles, or acquired air conditioning. In regions unaccustomed to heat waves, the absence of such systems, in particular in the houses of the most vulnerable elderly or sick, contributes to excess mortality, as in Paris, France, in August 2003 (Vandentorren et al., 2004) or California in July 2006 (Gershunov et al., 2009).

The examples given above of 'spontaneous' human system adjustment can be contrasted with explicit measures that are taken to reduce risk from an expected range of extremes. On the island of Guam, within the most active and intense zone of tropical cyclone activity on Earth, buildings are constructed to the most stringent wind design code in the world. Buildings are required to withstand peak gust wind speeds of 76 ms^{-1}, expected every few decades (International Building Codes, 2003). More generally, annual wind extremes for coastal locations will typically be highest at mid-latitudes while those expected once every century will be highest in the 10° to 25° latitude tropics (Walshaw, 2000). Consequently, indigenous building practices are less likely to be resilient close to the equator than in the windier (and storm surge affected) mid-latitudes (Minor, 1983).

While local experience provides a reservoir of knowledge from which disaster risk management and adaptation to climate change are drawing (Fouillet et al., 2008), it may not be available to other regions yet to be affected by such extremes. Thus, these experiences may not be drawn upon to provide guidance if future extremes go outside the traditional or recently observed range, as is expected for some extremes as the climate changes (see Chapter 3).

1.3. Disaster Management, Disaster Risk Reduction, and Risk Transfer

One important component of both disaster risk management and adaptation to climate change is the appropriate allocation of efforts among disaster management, disaster risk reduction, and risk transfer, as defined in Section 1.1.2.2. The current section provides a brief survey of the risk governance framework for making judgments about such an allocation, suggests why climate change may complicate effective management of disaster risks, and identifies potential synergies between disaster risk management and adaptation to climate change.

Disaster risks appear in the context of human choices that aim to satisfy human wants and needs (e.g., where to live and in what types of dwelling, what vehicles to use for transport, what crops to grow, what infrastructure to support economic activities, Hohenemser et al., 1984; Renn, 2008). Ideally, the choice of any portfolio of actions to address disaster risk would take into consideration human judgments about what constitutes risk, how to weigh such risk alongside other values and needs, and the social and economic contexts that determine whose judgments influence individuals' and societal responses to those risks.

The *risk governance* framework offers a systematic way to help situate such judgments about disaster management, risk reduction, and risk transfer within this broader context. Risk governance, under Renn's (2008) formulation, consists of four phases – pre-assessment, appraisal, characterization/evaluation, and management – in an open, cyclical, iterative, and interlinked process. Risk communication accompanies all four phases. This process is consistent with those in the UNISDR Hyogo Framework for Action (UNISDR, 2005), the best known and adhered to framework for considering disaster risk management concerns (see Chapter 7).

As one component of its broader approach, risk governance uses concepts from probabilistic risk analysis to help judge appropriate allocations in level of effort and over time and among risk reduction, risk transfer, and disaster management actions. The basic probabilistic risk analytic framework for considering such allocations regards risk as the product of the probability of an event(s) multiplied by its consequence (see Box 1-2; Bedford and Cooke, 2001). In this formulation, *risk reduction* aims to reduce exposure and vulnerability as well as the probability of occurrence of some events (e.g., those associated with landslides and forest fires induced by human intervention). *Risk transfer* efforts aim to compensate losses suffered by those who directly experience an event. *Disaster management* aims to respond to the immediate consequences and facilitate reduction of longer-term consequences (see Section 1.1).

Probabilistic risk analysis can help compare the efficacy of alternative actions to manage risk and inform judgments about the appropriate allocation of resources to reduce risk. For instance, the framework suggests that equivalent levels of risk reduction result from reducing an event's probability or by reducing its consequences by equal percentages. Probabilistic risk analysis also suggests that a series of relatively smaller, more frequent events could pose the same risk as a single, relatively less frequent, larger event. Probabilistic risk analysis can help inform decisions about alternative allocations of risk management efforts by facilitating the comparison of the increase or decrease in risk resulting from the alternative allocations (*high confidence*). Since the costs of available

Box 1-3 | Influence of Cognitive Processes, Culture, and Ideology on Judgments about Risk

A variety of cognitive, cultural, and social processes affect judgments about risk and about the allocation of efforts to address these risks. In addition to the processes described in Section 1.3.1.2, subjective judgments may be influenced more by emotional reactions to events (e.g., feelings of fear and loss of control) than by analytic assessments of their likelihood (Loewenstein et al., 2001). People frequently ignore predictions of extreme events if those predictions fail to elicit strong emotional reactions, but will also overreact to such forecasts when the events elicit feelings of fear or dread (Slovic et al., 1982; Slovic 1993, 2010; Weber, 2006). Even with sufficient information, everyday concerns and satisfaction of basic wants may prove a more pressing concern than attention and effort toward actions to address longer-term disaster risk (Maskrey, 1989, 2011; Wisner et al., 2004).

In addition to being influenced by cognitive shortcuts (Kahneman and Tversky, 1979), the perceptions of risk and extremes and reactions to such risk and events are also shaped by motivational processes (Weber, 2010). Cultural theory combines insights from anthropology and political science to provide a conceptual framework and body of empirical studies that seek to explain societal conflict over risk (Douglas, 1992). People's worldview and political ideology guide attention toward events that threaten their desired social order (Douglas and Wildavsky, 1982). Risk in this framework is defined as the disruption of a social equilibrium. Personal beliefs also influence which sources of expert forecasts of extreme climate events will be trusted. Different cultural groups put their trust into different organizations, from national meteorological services to independent farm organizations to the IPCC; depending on their values, beliefs, and corresponding mental models, people will be receptive to different types of interventions (Dunlap and McCright, 2008; Malka and Krosnick, 2009). Judgments about the veracity of information regarding the consequences of alternative actions often depend on the perceived consistency of those actions with an individual's cultural values, so that individuals will be more willing to consider information about consequences that can be addressed with actions seen as consistent with their values (Kahan and Braman, 2006; Kahan et al., 2007).

Factual information interacts with social, institutional, and cultural processes in ways that may amplify or attenuate public perceptions of risk and extreme events (Kasperson et al., 1988). The US public's estimates of the risk of nuclear power following the accident at Three Mile Island provide an example of the socio-cultural filtering of engineering safety data. Social amplification increased public perceptions of the risk of nuclear power far beyond levels that would derive only from analysis of accident statistics (Fischhoff et al., 1983). The public's transformation of expert-provided risk signals can serve as a corrective mechanism by which cultural subgroups of society augment a science-based risk analysis with psychological risk dimensions not considered in technical risk assessments (Slovic, 2000). Evidence from health, social psychology, and risk communication literature suggests that social and cultural risk amplification processes modify perceptions of risk in either direction and in ways that may generally be socially adaptive, but can also bias reactions in socially undesirable ways in specific instances (APA, 2009).

risk reduction, risk transfer, and disaster management actions will in general differ, the framework can help inform judgments about an effective mix of such actions in any particular case (see UNISDR, 2011, for efforts at stratifying different risk levels as a prelude to finding the most adequate mix of disaster risk management actions).

Probabilistic risk analysis is, however, rarely implemented in its pure form, in part because quantitative estimates of hazard and vulnerability are not always available and are not numbers that are independent of the individuals making those estimates. Rather, these estimates are determined by a combination of direct physical consequences of an event and the interaction of psychological, social, institutional, and cultural processes (see Box 1-3). For instance, perceptions of the risks of a nuclear power plant may be influenced by individuals' trust in the people operating the plant and by views about potential linkages between nuclear power and nuclear weapons proliferation – factors that may not be considered in a formal risk assessment for any given plant. Given this social construction of risk (see Section 1.1.2.2), effective allocations of efforts among risk reduction, risk transfer, and disaster management may best emerge from an integrated risk governance process, which includes the pre-assessment, appraisal, characterization/evaluation, and ongoing communications elements. Disaster risk management and adaptation to climate change each represent approaches that already use or could be improved by the use of this risk governance process, but as described in Section 1.3.1, climate change poses a particular set of additional challenges.

Together, the implications of probabilistic risk analysis and the social construction of risk reinforce the following considerations with regard to the effective allocation and implementation of efforts to manage risks in both disaster risk management and adaptation to climate change:

- As noted in Section 1.1, vulnerability, exposure, and hazard are each critical to determining disaster risk and the efficacy of actions taken to manage that risk (*high confidence*).
- Effective disaster risk management will in general require a portfolio of many types of risk reduction, risk transfer, and disaster management actions appropriately balanced in terms of resources applied over time (*high confidence*).

- Participatory and decentralized processes that are linked to higher levels of territorial governance (regions, nation) are a crucial part of all the stages of risk governance that include identification, choice, and implementation of these actions (*high confidence*).

1.3.1. Climate Change Will Complicate Management of Some Disaster Risks

Climate change will pose added challenges in many cases for attaining disaster risk management goals, and appropriately allocating efforts to manage disaster risks, for at least two sets of reasons. First, as discussed in Chapters 3 and 4, climate change is very likely to increase the occurrence and vary the location of some physical events, which in turn will affect the exposure faced by many communities, as well as their vulnerability. Increased exposure and vulnerability would contribute to an increase in disaster risk. For example, vulnerability may increase due to direct climate-related impacts on the development and development potential of the affected area, because resources otherwise available and directed towards development goals are deflected to respond to those impacts, or because long-standing institutions for allocating resources such as water no longer function as intended if climate change affects the scarcity and distribution of that resource. Second, climate change will make it more difficult to anticipate, evaluate, and communicate both probabilities and consequences that contribute to disaster risk, in particular that associated with extreme events. This set of issues, discussed in this subsection, will affect the management of these risks as discussed in Chapters 5, 6, 7, and 8 (*high confidence*).

1.3.1.1. Challenge of Quantitative Estimates of Changing Risks

Extreme events pose a particular set of challenges for implementing probabilistic approaches because their relative infrequency often makes it difficult to obtain adequate data for estimating the probabilities and consequences. Climate change exacerbates this challenge because it contributes to potential changes in the frequency and character of such events (see Section 1.2.2.2).

The likelihood of extreme events is most commonly described by the return period, the mean interval expected between one such event and its recurrence. For example, one might speak of a 100-year flood or a 50-year windstorm. More formally, these intervals are inversely proportional to the 'annual exceedance probability,' the likelihood that an event exceeding some magnitude occurs in any given year. Thus the 100-year flood has a 1% chance of occurring in any given year (which translates into a 37% chance of a century passing without at least one such flood ($(1-0.01)^{100} = 37\%$). Though statistical methods exist to estimate frequencies longer than available data time series (Milly et al., 2002), the long return period of extreme events can make it difficult, if not impossible, to reliably estimate their frequency. Paleoclimate records make clear that in many regions of the world, the last few decades of observed climate data do not represent the full natural variability of many important climate variables (Jansen et al., 2003). In addition, future climate change exacerbates the challenge of non-stationarity (Milly et al., 2008), where the statistical properties of weather events will not remain constant over time. This complicates an already difficult estimation challenge by altering frequencies and consequences of extremes in difficult-to-predict ways (Chapter 3; Meehl et al., 2007; TRB, 2008; NRC, 2009).

Estimating the likelihood of different consequences and their value is at least as challenging as estimating the likelihood of extreme events. Projecting future vulnerability and response capacity involves predicting the trends and changes in underlying causes of human vulnerability and the behavior of complex human systems under potentially stressful and novel conditions. For instance, disaster risk is endogenous in the sense that near-term actions to manage risk may affect future risk in unintended ways and near-term actions may affect perceptions of future risks (see Box 1-3). Section 1.4 describes some of the challenges such system complexity may pose for effective risk assessment. In addition, disasters affect socioeconomic systems in multiple ways so that assigning a quantitative value to the consequences of a disaster proves difficult (see Section 1.2.3.3). The literature distinguishes between direct losses, which are the immediate consequences of the disaster-related physical events, and indirect losses, which are the consequences that result from the disruption of life and activity after the immediate impacts of the event (Pelling et al., 2002; Lindell and Prater, 2003; Cochrane, 2004; Rose, 2004). Section 1.3.2 discusses some means to address these challenges.

1.3.1.2. Processes that Influence Judgments about Changing Risks

Effective risk governance engages a wide range of stakeholder groups – such as scientists, policymakers, private firms, nongovernmental organizations, media, educators, and the public – in a process of exchanging, integrating, and sharing knowledge and information. The recently emerging field of sustainability science (Kates et al., 2001) promotes interactive co-production of knowledge between experts and other actors, based on transdisciplinarity (Jasanoff, 2004; Pohl et al., 2010) and social learning (Pelling et al., 2008; Pahl-Wostl, 2009; see also Section 1.4.2). The literature on judgment and decisionmaking suggests that various cognitive behaviors involving perceptions and judgments about low-probability, high-severity events can complicate the intended functioning of such stakeholder processes (see Box 1-3). Climate change can exacerbate these challenges (*high confidence*).

The concepts of disaster, risk, and disaster risk management have very different meanings and interpretations in expert and non-expert contexts (Sjöberg, 1999a; see also Pidgeon and Fischhoff, 2011). Experts acting in formal private and public sector roles often employ quantitative estimates of both probability and consequence in making judgments about risk. In contrast, the general public, politicians, and the media tend to focus on the concrete adverse consequences of such events, paying less attention to their likelihood (Sjöberg, 1999b). As described in Box 1-3, expert estimates of probability and consequence may also not address the full range of concerns people bring to the consideration of risk. By definition (if not always in practice), expert understanding of risks associated with extreme events is based in large part on analytic tools. In particular, any estimates of changes in disaster risk due to climate change are often based on the results of complex climate models as described in Chapter 3. Non-experts, on the other hand, rely to a greater extent on more readily available and more easily processed information, such as their own experiences or vicarious experiences from the stories communicated through the news media, as well as their subjective judgment as to the importance of such events (see Box 1-1). These gaps between expert and non-expert understanding of extreme events present important communication challenges (Weber and Stern, 2011), which may adversely affect judgments about the allocation of efforts to address risk that is changing over time (*high confidence*).

Quantitative methods based on probabilistic risk analysis, such as those described in Sections 5.5 and 6.3, can allow people operating in expert contexts to use observed data, often from long time series, to make systematic and internally consistent estimates of the probability of future events. As described in Section 1.3.1.1, climate change may reduce the accuracy of such past observations as predictors for future risk. Individuals, including non-experts and experts making estimates without the use of formal methods (Barke et al., 1997), often predict the likelihood of encountering an event in the future by consulting their past experiences with such events. The 'availability' heuristic (i.e., useful shortcut) is commonly applied, in which the likelihood of an event is judged by the ease with which past instances can be brought to mind (Tversky and Kahneman, 1974). Extreme events, by definition, have a low probability of being represented in past experience and thus will be relatively unavailable. Experts and non-experts alike may essentially ignore such events until they occur, as in the case of a 100-year flood (Hertwig et al., 2004). When extreme events do occur with severe and thus memorable consequences, people's estimates of their future risks will, at least temporarily, become inflated (Weber et al., 2004).

1.3.2. Adaptation to Climate Change Contributes to Disaster Risk Management

The literature and practice of adaptation to climate change attempts to anticipate future impacts on human society and ecosystems, such as those described in Chapter 4, and respond to those already experienced. In recent years, the adaptation to climate change literature has introduced the concept of climate-related decisions (and climate proofing), which are choices by individuals or organizations, the outcomes of which can be expected to be affected by climate change and its interactions with ecological, economic, and social systems (Brown et al., 2006; McGray et al., 2007; Colls et al., 2009; Dulal et al., 2009; NRC, 2009). For instance, choosing to build in a low-lying area whose future flooding risk increases due to climate change represents a climate-related decision. Such a decision is climate-related whether or not the decisionmakers recognize it as such. The disaster risk management community may derive added impetus from the new context of a changing climate for certain of its pre-existing practices that already reflect the implementation of this concept. In many circumstances, choices about the appropriate allocation of efforts among disaster management, disaster risk reduction, and risk transfer actions will be affected by changes in the frequency and character of extreme events and other impacts of a climate change on the underlying conditions that affect exposure and vulnerability.

Much of the relevant adaptation literature addresses how expectations about future deviations from past patterns in physical, biological, and socioeconomic conditions due to climate change should affect the allocation of efforts to manage risks. While there exist differing views on the extent to which the adaptation to climate change literature has unique insights on managing changing conditions per se that it can bring to disaster risk management (Lavell, 2010; Mercer, 2010; Wisner et al., 2011), the former field's interest in anticipating and responding to the full range of consequences from changing climatic conditions can offer important new perspectives and capabilities to the latter field.

The disaster risk management community can benefit from the debates in the adaptation literature about how to best incorporate information about current and future climate into climate-related decisions. Some adaptation literature has emphasized the leading role of accurate regional climate predictions as necessary to inform such decisions (Collins, 2007; Barron, 2009; Doherty et al., 2009; Goddard et al., 2009; Shukla et al., 2009; Piao et al., 2010; Shapiro et al., 2010). This argument has been criticized on the grounds that predictions of future climate impacts are highly uncertain (Dessai and Hulme, 2004; Cox and Stephenson, 2007; Stainforth et al., 2007; Dessai et al., 2009; Hawkins and Sutton, 2009; Knutti, 2010) and that predictions are insufficient to motivate action (Fischhoff, 1994; Sarewitz et al., 2000; Cash et al., 2003, 2006; Rayner et al., 2005; Moser and Luers, 2008; Dessai et al., 2009; NRC, 2009). Other adaptation literature has emphasized that many communities do not sufficiently manage current risks and that improving this situation would go a long way toward preparing them for any future changes due to climate change (Smit and Wandel, 2006; Pielke et al., 2007). As discussed in Section 1.4, this approach will in some cases underestimate the challenges of adapting to future climate change.

To address these challenges, the adaptation literature has increasingly discussed an iterative risk management framework (Carter et al., 2007; Jones and Preston, 2011), which is consistent with risk governance as described earlier in this section. Iterative risk management recognizes that the process of anticipating and responding to climate change does not constitute a single set of judgments at some point in time, but rather an ongoing assessment, action, reassessment, and response that will continue – in the case of many climate-related decisions – indefinitely (ACC, 2010). In many cases, iterative risk management contends with conditions where the probabilities underlying estimates of future risk are imprecise and/or the structure of the models that relate events to consequences are under-determined (NRC, 2009; Morgan et al., 2009). Such deep or severe uncertainty (Lempert and Collins, 2007) can characterize not only understanding of future climatic events but also future patterns of human vulnerability and the capability to respond to such events. With many complex, poorly understood physical and socioeconomic systems, research and social learning may enrich understanding over time, but the amount of uncertainty, as measured by observers' ability to make specific, accurate predictions, may grow larger (Morgan et al., 2009, pp. 114–115; NRC, 2009, pp. 18–19; see related discussion of 'surprises' in Section 3.1.7). In addition, theory and models may change in ways that make them less, rather than more, reliable as predictive tools over time (Oppenheimer et al., 2008).

Recent literature has thus explored a variety of approaches that can help disaster risk management address such uncertainties (McGray et al., 2007; IIED 2009; Schipper, 2009), in particular approaches that help support decisions when it proves difficult or impossible to accurately estimate probabilities of events and their adverse consequences. Approaches for characterizing uncertainty include qualitative scenario methods (Parson et al., 2007); fuzzy sets (Chongfu, 1996; El-Baroudy and Simonovic, 2004; Karimi and Hullermeier, 2007; Simonovic, 2010); and the use of ranges of values or sets of distributions, rather than single values or single best-estimate distributions (Morgan et al., 2009; see also Mastrandrea et al., 2010). Others have suggested managing such uncertainty with robust policies that perform well over a wide range of plausible futures (Dessai and Hulme, 2007; Groves and Lempert, 2007; Brown, 2010; Means et al., 2010; Wilby and Dessai, 2010; Dessai and Wilby, 2011; Reeder and Ranger, 2011; also see discussion in Chapter 8). Decision rules based on the concept of robust adaptive policies go beyond 'no regrets' by suggesting how in some cases relatively low-cost, near-term actions and explicit plans to adjust those actions over time can significantly improve future ability to manage risk (World Bank, 2009; Hine and Hall, 2010; Lempert and Groves, 2010; Walker et al., 2010; Brown, 2011; Ranger and Garbett-Shiels, 2011; see also Section 1.4.5).

The resilience literature, as described in Chapter 8, also takes an interest in managing difficult-to-predict futures. Both the adaptation to climate change and vulnerability literatures often take an actor-oriented view (Wisner et al., 2004; McLaughlin and Dietz, 2007; Nelson et al., 2007; Moser 2009) that focuses on particular agents faced with a set of decisions who can make choices based on their various preferences; their institutional interests, power, and capabilities; and the information they have available. Robustness in the adaptation to climate change context often refers to a property of decisions specific actors may take (Hallegatte, 2009; Lempert and Groves, 2010; Dessai and Wilby, 2011). In contrast, the resilience literature tends to take a systems view (Olsson et al., 2006; Walker et al., 2006; Berkes, 2007; Nelson et al., 2007) that considers multi-interacting agents and their relationships in and with complex social, ecological, and geophysical systems (Miller et al., 2010). These literatures can help highlight for disaster risk management such issues as the tension between resilience to specific, known disturbances and novel and unexpected ones (sometimes referred to as the distinction between 'specified' and 'general' resilience, Miller et al., 2010), the tension between resilience at different spatial and temporal scales, and the tension between the ability of a system to persist in its current state and its ability to transform to a fundamentally new state (Section 1.4; Chapter 8; ICSU, 2002; Berkes, 2007).

Disaster risk management will find similarities to its own multi-sector approach in the adaptation literature's recent emphasis, consistent with the concept of climate-related decisions, on climate change as one of many factors affecting the management of risks. For instance, some resource management agencies now stress climate change as one of many trends such as growing demand for resources, environmental constraints, aging infrastructure, and technological change that, particularly in combination, could require changes in investment plans and business models (CCSP, 2008; Brick et al., 2010). It has become clear that many less-developed regions will have limited success in reducing overall vulnerability solely by managing climate risk because vulnerability, adaptive capacity, and exposure are critically influenced by existing structural deficits (low income and high inequality, lack of access to health and education, lack of security and political access, etc.). For example, in drought-ravaged northeastern Brazil, many vulnerable households could not take advantage of risk management interventions such as seed distribution programs because they lacked money to travel to pick up the seeds or could not afford a day's lost labor to participate in the program (Lemos, 2003). In Burkina Faso, farmers had limited ability to use seasonal forecasts (a risk management strategy) because they lacked the resources (basic agricultural technology such as plows, alternative crop varieties, fertilizers, etc.) needed to effectively respond to the projections (Ingram et al., 2002). In Bangladesh, however, despite persisting poverty, improved disaster preparedness and response and relative higher levels of household adaptive capacity have dramatically decreased the number of deaths as a result of flooding (del Ninno et al., 2002, 2003; Section 9.2.5).

Scholars have argued that building adaptive capacity in such regions requires a dialectic, two-tiered process in which climatic risk management (specific adaptive capacity) and deeper-level socioeconomic and political reform (generic adaptive capacity) iterate to shape overall vulnerability (Lemos et al., 2007; Tompkins et al., 2008). When implemented as part of a systems approach, managing climate risks can create positive synergies with development goals through participatory and transparent approaches (such as participatory vulnerability mapping or local disaster relief committees) that empower local households and institutions (e.g., Degg and Chester, 2005; Nelson, 2005).

1.3.3. Disaster Risk Management and Adaptation to Climate Change Share Many Concepts, Goals, and Processes

The efficacy of the mix of actions used by communities to reduce, transfer, and respond to current levels of disaster risk could be vastly increased. Understanding and recognition of the many development-based instruments that could be put into motion to achieve disaster risk reduction is a prerequisite for this (Lavell and Lavell, 2009; UNISDR, 2009e, 2011; Maskrey 2011; Wisner et al., 2011). At the same time, some aspects of disaster risk will increase for many communities due to climate change and other factors (Chapters 3 and 4). Exploiting the potential synergies between disaster risk management and adaptation to climate change literature and practice will improve management of both current and future risks.

Both fields share a common interest in understanding and reducing the risk created by the interactions of human with physical and biological systems. Both seek appropriate allocations of risk reduction, risk transfer, and disaster management efforts, for instance balancing pre-impact risk management or adaptation with post-impact response and recovery. Decisions in both fields may be organized according to the risk governance framework. For instance, many countries, are gaining experience in implementing cooperative, inter-sector and multi- or interdisciplinary approaches (ICSU, 2002; Brown et al., 2006; McGray et al., 2007; Lavell and Lavell, 2009). In general, disaster risk management can help those practicing adaptation to climate change to learn from addressing current impacts. Adaptation to climate change can help those practicing disaster risk management to more effectively address future conditions that will differ from those of today.

The integration of concepts and practices is made more difficult because the two fields often use different terminology, emerge from different academic communities, and may be seen as the responsibility of different government organizations. As one example, Section 1.4 will describe how the two fields use the word 'coping' with different meanings and different connotations. In general, various contexts have made it more difficult to recognize that the two fields share many concepts, goals, and processes, as well as to exploit the synergies that arise from their differences. These include differences in historical and evolutionary processes; conceptual and definitional bases; processes of social knowledge construction and the ensuing scientific compartmentalization of subject areas; institutional and organizational funding and instrumental backgrounds; scientific origins and baseline literature; conceptions of the relevant causal relations; and the relative importance of different risk factors (see Sperling and Szekely, 2005; Schipper and Pelling, 2006; Thomalla et al., 2006; Mitchell and van Aalst, 2008; Venton and La Trobe, 2008, Schipper and Burton, 2009; Lavell, 2010). These aspects will be considered in more detail in future chapters.

Potential synergies from the fields' different emphases include the following.

First, disaster risk management covers a wide range of hazardous events, including most of those of interest in the adaptation to climate change literature and practice. Thus, adaptation could benefit from experience in managing disaster risks that are analogous to the new challenges expected under climate change. For example, relocation and other responses considered when confronted with sea level change can be informed by disaster risk management responses to persistent or large-scale flooding and landslides or volcanic activity and actions with pre- or post-disaster relocation; responses to water shortages due to loss of glacial meltwater would bear similarities to shortages due to other drought stressors; and public health challenges due to modifications in disease vectors due to climate change have similarities to those associated with current climate variability, such as the occurrence of

FAQ 1.2 | What are effective strategies for managing disaster risk in a changing climate?

Disaster risk management has historically operated under the premise that future climate will resemble that of the past. Climate change now adds greater uncertainty to the assessment of hazards and vulnerability. This will make it more difficult to anticipate, evaluate, and communicate disaster risk. Uncertainty, however, is not a 'new' problem. Previous experience with disaster risk management under uncertainty, or where long return periods for extreme events prevail, can inform effective risk reduction, response, and preparation, as well as disaster risk management strategies in general.

Because climate variability occurs over a wide range of timescales, there is often a historical record of previous efforts to manage and adapt to climate-related risk that is relevant to risk management under climate change. These efforts provide a basis for learning via the assessment of responses, interventions, and recovery from previous impacts. Although efforts to incorporate learning into the management of weather- and climate-related risks have not always succeeded, such adaptive approaches constitute a plausible model for longer-term efforts. Learning is most effective when it leads to evaluation of disaster risk management strategies, particularly with regard to the allocation of resources and efforts between risk reduction, risk sharing, and disaster response and recovery efforts, and when it engages a wide range of stakeholder groups, particularly affected communities.

In the presence of deeply uncertain long-term changes in climate and vulnerability, disaster risk management and adaptation to climate change may be advanced by dealing adequately with the present, anticipating a wide range of potential climate changes, and promoting effective 'no-regrets' approaches to both current vulnerabilities and to predicted changes in disaster risk. A robust plan or strategy that both encompasses and looks beyond the current situation with respect to hazards and vulnerability will perform well over a wide range of plausible climate changes.

El Niño. Moreover, like disaster risk management, adaptation to climate change will often take place within a multi-hazard locational framework given that many areas affected by climate change will also be affected by other persistent and recurrent hazards (Wisner et al., 2004, 2011; Lavell, 2010; Mercer, 2010). Additionally, learning from disaster risk management can help adaptation, which to date has focused more on changes in the climate mean, increasing its focus on future changes in climate extremes and other potentially damaging events.

Second, disaster risk management has tended to encourage an expanded, bottom-up, grass roots approach, emphasizing local and community-based risk management in the framework of national management systems (see Chapters 5 and 6), while an important segment of the adaptation literature focuses on social and economic sectors and macro ecosystems over large regional scales. However, a large body of the adaptation literature – in both developed and developing countries – is very locally focused. Both fields could benefit from the body of work on the determinants of adaptive capacity that focus on the interaction of individual and collective action and institutions that frame their actions (McGray et al., 2007; Schipper, 2009).

Third, the current disaster risk management literature emphasizes the social conditioning of risk and the construction of vulnerability as a causal factor in explaining loss and damage. Early adaptation literature and some more recent output, particularly from the climate change field, prioritizes physical events and exposure, seeing vulnerability as what remains after all other factors have been considered (O'Brien et al., 2007). However, community-based adaptation work in developing countries (Beer and Hamilton, 2002; Brown et al., 2006; Lavell and Lavell, 2009; UNISDR, 2009b,c) and a growing number of studies in developed nations (Burby and Nelson, 1991; de Bruin et al., 2009; Bedsworth and Hanak, 2010; Brody et al., 2010; Corfee-Morlot et al., 2011; Moser and Eckstrom, 2011) have considered social causation. Both fields could benefit from further integration of these concepts.

Overall, the disaster risk management and adaptation to climate change literatures both now emphasize the value of a more holistic, integrated, trans-disciplinary approach to risk management (ICSU-LAC, 2009). Dividing the world up sectorally and thematically has often proven organizationally convenient in government and academia, but can undermine a thorough understanding of the complexity and interaction of the human and physical factors involved in the constitution and definition of a problem at different social, temporal, and territorial scales. A more integrated approach facilitates recognition of the complex relationships among diverse social, temporal, and spatial contexts; highlights the importance of decision processes that employ participatory methods and decentralization within a supporting hierarchy of higher levels; and emphasizes that many disaster risk management and other organizations currently face climate-related decisions whether they recognize them or not.

The following areas, some of which have been pursued by governments, civil society actors, and communities, have been recommended or proposed to foster such integration between, and greater effectiveness of, both adaptation to climate change and disaster risk management (see also WRI, 2008; Birkmann and von Teichman, 2010; Lavell, 2010):

- Development of a common lexicon and deeper understanding of the concepts and terms used in each field (Schipper and Burton, 2009)
- Implementation of government policymaking and strategy formulation that jointly considers the two topics
- Evolution of national and international organizations and institutions and their programs that merge and synchronize around the two themes, such as environmental ministries coordinating with development and planning ministries (e.g., National Environmental Planning Authority in Jamaica and Peruvian Ministries of Economy and Finance, Housing, and Environment)
- Merging and/or coordinating disaster risk management and adaptation financing mechanisms through development agencies and nongovernmental organizations
- The use of participatory, local level risk and context analysis methodologies inspired by disaster risk management that are now strongly accepted by many civil society and government agencies in work on adaptation at the local levels (IFRC, 2007; Lavell and Lavell, 2009; UNISDR, 2009 b,c)
- Implementing bottom-up approaches whereby local communities integrate adaptation to climate change, disaster risk management, and other environmental and development concerns in a single, causally dimensioned intervention framework, commensurate many times with their own integrated views of their own physical and social environments (Moench and Dixit, 2004; Lavell and Lavell, 2009).

1.4. Coping and Adapting

The discussion in this section has four goals: to clarify the relationship between adaptation and coping, particularly the notion of coping range; to highlight the role of learning in an adaptation process; to discuss barriers to successful adaptation and the issue of maladaptation; and to highlight examples of learning in the disaster risk management community that have already advanced climate change adaptation.

A key conclusion of this section is that learning is central to adaptation, and that there are abundant examples (see Section 1.4.5 and Chapter 9) of the disaster risk management community learning from prior experience and adjusting its practices to respond to a wide range of existing and evolving hazards. These cases provide the adaptation to climate change community with the opportunity not only to study the specifics of learning as outlined in these cases, but also to reflect on how another community that also addresses climate-related risk has incorporated learning into its practice over time.

As disaster risk management includes both coping and adapting, and these two concepts are central for adaptation to climate change in both scholarship and practice, it is important to start by clarifying the meanings of these terms. Without a clear conception of the distinctions between the concepts and overlaps in their meanings, it is difficult to fully understand a wide range of related issues, including those concerned with the coping range, adaptive capacity, and the role of institutional learning in promoting robust adaptation to climate change. Clarifying such distinctions carries operational significance for decisionmakers interested in promoting resilience, a process that relies on coping for immediate survival and recovery, as well as adaptation and disaster risk reduction, which entail integrating new information to moderate potential future harm.

1.4.1. Definitions, Distinctions, and Relationships

In both the disaster risk management and climate change adaptation literature, substantial differences are apparent as to the meaning and significance of coping as well as its relationship with and distinction from adaptation. Among the discrepancies, for example, some disaster risk management scholars have referred to coping as a way to engage local populations and utilize indigenous knowledge in disaster preparedness and response (Twigg, 2004), while others have critiqued this idea, concerned that it would divert attention away from addressing structural problems (Davies, 1993) and lead to a focus on 'surviving' instead of 'thriving.' There has also been persistent debate over whether coping primarily occurs before or after a disastrous event (UNISDR, 2008b,c, 2009e). This debate is not entirely resolved by the current UNISDR definition of coping, the "ability of people, organizations, and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disasters" (UNISDR, 2009d). Clearly, emergencies and disasters are post facto circumstances, but 'adverse conditions' is an indeterminate concept that could include negative pre-impact livelihood conditions and disaster risk circumstances or merely post-impact effects.

The first part of this section is focused on parsing these two concepts. Once the terms are adequately distinguished, the focus shifts in the second part to important relationships between the two terms and other related concepts, which taken together have operational significance for governments and stakeholders.

1.4.1.1. Definitions and Distinctions

Despite the importance of the term coping in the fields of both disaster risk management and adaptation to climate change, there is substantial confusion regarding the term's meaning (Davies, 1996) and how it is distinguished from adaptation.

In order to clarify this aspect, it is helpful first to look outside of the disaster risk and adaptation contexts. The *Oxford English Dictionary* defines *coping* as "the action or process of overcoming a problem or difficulty" or "managing or enduring a stressful situation or condition" and *adapting* as "rendering suitable, modifying" (OED, 1989). As noted in Table 1-1, contrasting the two terms highlights several important dimensions in which they differ – exigency, constraint, reactivity, and orientation – relevant examples of which can be found in the literature cited.

Table 1-1 | The various dimensions of coping and adapting.

Dimension	Coping	Adapting
Exigency	Survival in the face of immediate, unusually significant stress, when resources, which may have been minimal to start with, are taxed (Wisner et al., 2004).	Reorientation in response to recent past or anticipated future change, often without specific reference to resource limitations.
Constraint	Survival is foremost and tactics are constrained by available knowledge, experience, and assets; reinvention is a secondary concern (Bankoff, 2004).	Adjustment is the focus and strategy is constrained less by current limits than by assumptions regarding future resource availability and trends.
Reactivity	Decisions are primarily tactical and made with the goal of protecting basic welfare and providing for basic human security after an event has occurred (Adger, 2000).	Decisions are strategic and focused on anticipating change and addressing this proactively (Füssel, 2007), even if spurred by recent events seen as harbingers of further change.
Orientation	Focus is on past events that shape current conditions and limitations; by extension, the focus is also on previously successful tactics (Bankoff, 2004).	Focus on future conditions and strategies; past tactics are relevant to the extent they might facilitate adjustment, though some experts believe past and future orientation can overlap and blend (Chen, 1991).

Overall, coping focuses on the moment, constraint, and survival; adapting (in terms of human responses) focuses on the future, where learning and reinvention are key features and short-term survival is less in question (although it remains inclusive of changes inspired by already-modified environmental conditions).

1.4.1.2. Relationships between Coping, Coping Capacity, Adaptive Capacity, and the Coping Range

The definitions of coping and adapting used in this report reflect the dictionary definitions. As an example, a community cannot adapt its way through the aftermath of a disastrous hurricane; it must cope instead. Its coping capacity, or capacity to respond (Gallopín, 2003), is a function of currently available resources that can be used to cope, and determines the community's ability to survive the disaster intact (Bankoff, 2004; Wisner et al., 2004). Repeated use of coping mechanisms without adequate time and provisions for recovery can reduce coping capacity and shift a community into what has been termed transient poverty (Lipton and Ravallion, 1995). Rather than leaving resources for adaptation, communities forced to cope can become increasingly vulnerable to future hazards (O'Brien and Leichenko, 2000).

Adaptation in anticipation of future hurricanes, however, can limit the need for coping that may be required to survive the next storm. A community's adaptive capacity will determine the degree to which adaptation can be pursued (Smit and Pilofosova, 2003). While there is

Box 1-4 | Adaptation to Rising Levels of Risk

Before AD 1000, in the low-lying coastal floodplain of the southern North Sea and around the Rhine delta, the area that is now The Netherlands, the inhabitants lived on dwelling mounds, piled up to lie above the height of the majority of extreme storm surges. By the 10th century, with a population estimated at 300,000 people, inhabitants had begun to construct the first dikes, and within 400 years had ringed all significant areas of land above spring tide, allowing animals to graze and people to live in the protected wetlands. The expansion of habitable land encouraged a significant increase in the population exposed to catastrophic floods (Borger and Ligtendag, 1998). The weak sea dikes broke in a series of major storm surge floods through the stormy 13th and 14th centuries (in particular in 1212, 1219, 1287, and 1362), flooding enormous areas (often permanently) and causing more than 200,000 fatalities, reflecting an estimated lifetime mortality rate from floods for those living in the region in excess of 5% (assuming a 30-year average lifespan; Gottschalk, 1971, 1975, 1977).

To adapt to increasingly adverse environmental conditions (reflecting long-term delta subsidence), major improvements in the technology of dike construction and drainage engineering began in the 15th century. As the country became richer and population increased (to an estimated 950,000 by 1500 and 1.9 million by 1700), it became an imperative not only to provide better levels of protection but also to reclaim land from the sea and from the encroaching lakes, both to reduce flood hazard and expand the land available for food production (Hoeksma, 2006). Examples of the technological innovations included the development of windmills for pumping, and methods to lift water at least 4 m whether by running windmills in series or through the use of the wind-powered Archimedes screw. As important was the availability of capital to be invested in joint stock companies with the sole purpose of land reclamation. In 1607, a company was formed to reclaim the 72 km^2 Beemster Lake north of Amsterdam (12 times larger than any previous reclamation). A 50-km canal and dike ring were excavated, a total of 50 windmills installed that after five years pumped dry the Beemster polder, 3 to 4 m below the surrounding countryside, which, within 30 years, had been settled by 200 farmhouses and 2,000 people.

After the major investment in raising and strengthening flood defenses in the 17th century, there were two or three large floods, one in 1717 (when 14,000 people drowned) and two notable floods in 1825 and 1953; since that time the average flood mortality rate has been around 1,000 per century, equivalent to a lifetime mortality rate (assuming a 50-year average lifetime) of around 0.01%, 500 times lower than that which had prevailed through the Middle Ages (Van Baars and Van Kempen, 2009). This change reflects increased protection rather than any reduction in storminess. The flood hazard and attendant risk is now considered to be rising again (Bouwer and Vellinga, 2007) and plans are being developed to manage further rises, shifting the coping range in anticipation of the new hazard distribution.

some variability in how coping capacity and adaptive capacity are defined, the literature generally recognizes that adaptive capacity focuses on longer-term and more sustained adjustments (Gallopín, 2006; Smit and Wandel, 2006). However, in the same way that repeatedly invoking coping mechanisms consumes resources available for subsequent coping needs, it also consumes resources that might otherwise be available for adaptation (Adger, 1996; Risbey et al., 1999).

There is also a link between adaptation and the **coping range** – that is, a system's capacity to reactively accommodate variations in climatic conditions and their impacts (a system can range from a particular ecosystem to a society) (IPCC, 2007b). In the adaptation literature, Yohe and Tol (2002, p. 26) have used the term to refer to the range of "circumstances within which, by virtue of the underlying resilience of the system, significant consequences are not observed" in response to external stressors. Outside the coping range, communities will "feel significant effects from change and/or variability in their environments" (Yohe and Tol, 2002, p. 25). Within its coping range, a community can survive and even thrive with significant natural hazards. This is particularly the case when the historical distribution of hazard intensity is well known and relatively stable (see Section 1.2.3.4). A community's coping range is determined, in part, by prior adaptation (Hewitt and Burton, 1971; de Vries, 1985; de Freitas, 1989), and a community is most likely to survive and thrive when adaptation efforts have matched its coping range with the range of hazards it typically encounters (Smit and Pilifosova, 2003). As climate change alters future variability and the occurrence of extreme events, and as societal trends change human systems' vulnerability, adaptation is required to adjust the coping range so as to maintain societal functioning within an expected or acceptable range of risk (Moser and Luers, 2008).

Box 1-4 provides an example of this process in the region that is now The Netherlands. As this box illustrates, the process of shifting a society's coping range both depends on and facilitates further economic development (i.e., requires adaptive capacity and enhances coping capacity). The box also illustrates that the process requires continuous reassessment of risk and adjustment in response to shifting hazard distributions in order to avoid increasing, and maladaptive, hazard exposure. Successful adjustments, facilitated in part by institutional learning, can widen and shift a community's coping range, promoting resilience to a wider range of future disaster risk (Yohe and Tol, 2002), as illustrated in Box 1-4 and discussed further in Section 1.4.2 (*high confidence*).

1.4.2. Learning

Risk management decisions are made within social-ecological systems (a term referring to social systems intimately tied to and dependent on environmental resources and conditions). Some social-ecological systems are more resilient than others. The most resilient are characterized by their capacity to learn and adjust, their ability to reorganize after disruption, and their retention of fundamental structure and function in the face of system stress (Folke, 2006). The ability to cope with extreme stress and resume normal function is thus an important component of resilience, but learning, reorganizing, and changing over time are also key. As Chapter 8 highlights, transformational changes are required to achieve a future in which society's most important social-ecological systems are sustainable and resilient. Learning, along with adaptive management, innovation, and leadership, is essential to this process.

Learning related to social-ecological systems requires recognizing their complex dynamics, including delays, stock-and-flow dynamics, and feedback loops (Sterman, 2000), features that can complicate management strategies by making it difficult to perceive how a system operates. Heuristic devices and mental models can sometimes inhibit learning by obscuring a problem's full complexity (Kahneman et al., 1982; Section 1.3.1.2) and complicating policy action among both experts and lay people (Cronin et al., 2009). For instance, common heuristics (see Section 1.3.1.2) lead to misunderstanding of the relationship between greenhouse gas emission rates and their accumulation in atmospheric stocks, lending credence to a 'wait and see' approach to mitigation (Sterman, 2008). Through a variety of mechanisms, such factors can lead to paralysis and failure to engage in appropriate risk management strategies despite the availability of compelling evidence pointing to particular risk management pathways (Sterman, 2006). The resulting learning barriers thus deserve particular attention when exploring how to promote learning that will lead to effective adaptation.

Given the complex dynamics of social-ecological systems and their interaction with a changing climate, the literature on adaptation to climate change (usually referred to here, as above, simply as 'adaptation') emphasizes iterative learning and management plans that are explicitly designed to evolve as new information becomes available (Morgan et al., 2009: NRC, 2009). Unlike adaptation, the field of disaster risk management has not historically focused as explicitly on the implications of climate change and the need for iterative learning. However, the field provides several important examples of learning, including some presented in Chapter 9, that could be instructive to adaptation practitioners. Before introducing these case studies in Section 1.4.5, we will outline relevant theory of institutional learning and 'learning loops.'

Extensive literature explores both the role of learning in adaptation (Armitage et al., 2008; Moser, 2010; Pettengell, 2010) and strategies for facilitating institutional and social learning in 'complex adaptive systems' (Pahl-Wostl, 2009). Some important strategies include the use of knowledge co-production, wherein scientists, policymakers, and other actors work together to exchange, generate, and apply knowledge (van Kerkhoff and Lebel, 2006), and action research, an iterative process in which teams of researchers develop hypotheses about real-world

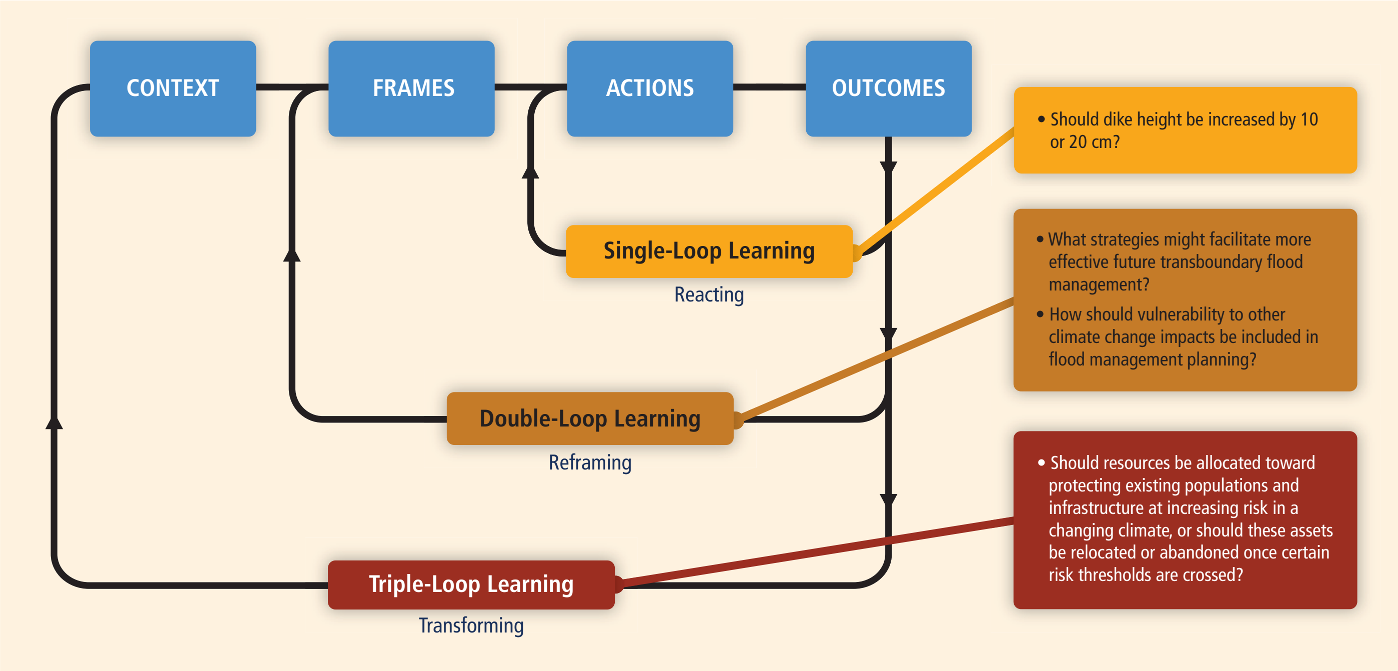

Figure 1-3 | Learning loops: pathways, outcomes, and dynamics of single-, double-, and triple-loop learning and applications to flood management. Adapted from Argyris and Schön, 1978; Hargrove, 2002; Sterman et al., 2006; Folke et al., 2009; and Pahl-Wostl, 2009.

problems and revise management strategies based on the results (List, 2006). Prior work on learning theories, for example, experiential learning (Kolb, 1984) and transformative learning (Mezirow, 1995), emphasize the importance of action-oriented problem-solving, learning-by-doing, concrete learning cycles, and how these processes result in reflection, reconsideration of meaning, and re-interpretation of value structures. The learning loop framework (Kolb and Fry, 1975; Argyris and Schön, 1978; Keen et al., 2005) integrates these theories and divides learning processes into three different loops depending on the degree to which the learning promotes transformational change in management strategies. Figure 1-3 outlines this framework and its application to the issue of flood management.

In single-loop learning processes, changes are made based on the difference between what is expected and what is observed. Single-loop learning is primarily focused on improving the efficiency of action (Pelling et al., 2008) and answering the question of "whether things are being done right" (Flood and Romm, 1996), that is, whether management tactics are appropriate or adequate to achieve identified objectives. In flood management, for example, when floodwaters threaten to breach existing flood defenses, flood managers may ask whether dike and levee heights are sufficient and make adjustments accordingly. As Figure 1-3 indicates, single-loop learning focuses primarily on actions; data are integrated and acted on but the underlying mental model used to process the data is not changed.

In double-loop learning, the evaluation is extended to assess whether actors are "doing the right things" (Flood and Romm, 1996), that is, whether management goals and strategies are appropriate. Corrective actions are made after the problem is reframed and different management goals are identified (Pelling et al., 2008); data are used to promote critical thinking and challenge underlying mental models of what works and why. Continuing with the flood management example, double-loop learning results when the goals of the current flood management regime are critically examined to determine if the regime is sustainable and resilient to anticipated shifts in hydrological extremes over a particular time period. For instance, in a floodplain protected by levees built to withstand a 500-year flood, a shift in the annual exceedance probability from 0.002 to 0.005 (equivalent to stating that the likelihood that a 500-year flood will occur in a given year has shifted to that seen historically for a 200-year event) will prompt questions about whether the increased likelihood of losses justifies different risk management decisions, ranging from increased investments in flood defenses to changed insurance policies for the vulnerable populations.

Many authors also distinguish triple-loop learning (Argyris and Schön, 1978; Hargrove, 2002; Peschl, 2007), or learning that questions deeply held underlying principles (Pelling et al., 2008). In triple-loop learning, actors question how institutional and other power relationships determine perceptions of the range of possible interventions, allowable costs, and appropriate strategies (Flood and Romm, 1996). In response to evidence that management strategies are not serving a larger agreed-upon goal, that is, they are maladaptive, triple-loop learning questions how the social structures, cultural norms, dominant value structures, and other constructs that mediate risk and risk management (see Box 1-3) might be changed or transformed. Extending the flood control example, triple-loop learning might entail entirely new approaches to governance and participatory risk management involving additional parties, crossing cultural, institutional, national, and other boundaries that contribute significantly to flood risk, and planning aimed at robust actions instead of strategies considered optimal for particular constituents (Pahl-Wostl, 2009).

Different types of learning are more or less appropriate in given circumstances (Pahl-Wostl, 2009, p. 359). For example, overreliance on single-loop learning may be problematic in rapidly changing circumstances. Single-loop learning draws on an inventory of existing skills and memories specific to particular circumstances. As a result, rapid, abrupt, or surprising changes may confound single-loop learning processes (Batterbury, 2008). Coping mechanisms, even those that have developed over long periods of time and been tested against observation and experience, may not confer their usual survival advantage in new contexts. Double- and triple-loop learning are better suited to matching coping ranges with new hazard regimes (Yohe and Tol, 2002). Integrating double- and triple-loop learning into adaptation projects, particularly for populations exposed to multiple risks and stressors, is more effective than more narrowly planned approaches dependent on specific future climate information (McGray et al., 2007; Pettengell, 2010).

Easier said than done, triple-loop learning is analogous to what some have termed 'transformation' (Kysar, 2004; see Section 1.1.3; Chapter 8), in that it can lead to recasting social structures, institutions, and constructions that contain and mediate risk to accommodate more fundamental changes in world view (Pelling, 2010). Translating double- and triple-loop learning into policy requires not only articulation of a larger risk-benefit universe, but also mechanisms to identify, account for, and compare the costs associated with a wide range of interventions and their benefits and harms over various time horizons. Stakeholders would need also to collaborate to an unusual degree in order to collectively and cooperatively consider the wide range of risk management possibilities and their impacts.

1.4.3. Learning to Overcome Adaptation Barriers

Learning focused on barriers to adaptation can be particularly useful. Resource limitations are universally noted as a significant impediment in pursuing adaptation strategies, to a greater or lesser degree depending on the context. In addition, some recent efforts to identify and categorize adaptation barriers have focused on specific cultural factors (Nielsen and Reenberg, 2010) or issues specific to particular sectors (Huang et al., 2011), while others have discussed the topic more comprehensively (Moser and Ekstrom, 2010). Some studies identify barriers in the specific stages of the adaptation process. Moser and Ekstrom (2010), for instance, outline three phases of adaptation: understanding, planning, and management. Each phase contains several key steps, and barriers can impede progress at each. Barriers to understanding, for instance, can include difficulty recognizing a changing signal due to difficulty with its detection, perception, and appreciation; preoccupation with other pressing concerns that divert attention from the growing signal; and lack of administrative and social support for making adaptive decisions. While this study offers a diagnostic framework and avoids prescriptions about overcoming adaptation barriers, other studies, such as those mentioned above, offer more focused prescriptions relevant to particular sectors and contexts.

Research on barriers has generally focused on adaptation as a process, recognizing the difficulty in furnishing a universally acceptable *a priori* definition of successful adaptation outcomes (Adger et al., 2005). This skirts potentially important normative questions, however, and some researchers have considered whether particular activities should be considered maladaptive, defined as an "action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors, or social groups" (Barnett and O'Neill, 2009, p. 211). They identify activities that increase greenhouse gas releases, burden vulnerable populations disproportionately, and require excessive commitment to one path of action (Barnett and O'Neill, 2009). Other candidates include actions that offset one set of risks but increase others, resulting in net risk increase, for example, a dam that reduces flooding but increases the threat of zoonotic diseases, and actions that amplify risk to those who remain exposed (or are newly exposed as a result of a maladaptive action), of which there are abundant examples in the public health literature (Sterman, 2006) and other fields.

These issues have a long history in disaster risk management. For instance, in 1942, deriving from study and work in the 1930s, Gilbert White asserted that levees can provide a false sense of security and are eventually fallible, ultimately leading to increased risk, and advocated, among other 'adjustment' measures, land use planning and environmental management schemes in river basins in order to face up to flooding hazards (see Burton et al., 1978). Such findings are among the early advances in the field of 'human adjustment to hazards,' which derived from an ecological approach to human-environmental relationships. In the case of levees for example, the distinction between adaptive and maladaptive actions depends on the time period over which risks are being assessed. From a probabilistic perspective, the overall likelihood of a catastrophic flood overwhelming a levee's protective capacity is a function of time. The wrinkle that climate change introduces is that many climate-related hazards may become more frequent, shrinking the timescale over which certain decisions can be considered 'adaptive' and communities can consider themselves 'adapted' (Nelson et al., 2007).

While frameworks that help diagnose barriers to adaptation are helpful in identifying the origin of maladaptive decisions, crafting truly adaptive policies is still difficult even when the barriers are fully exposed. For instance, risk displacement is a common concern in large insurance systems when risk is not continuously reassessed, risk management strategies and mechanisms for distributing risk across populations (such as risk pricing in insurance schemes) are inadequately maintained, or if new risk management strategies are not recruited as necessary. This was the case with the levees in New Orleans prior to Hurricane Katrina, wherein the levees were built to make a hazardous area safer but paradoxically facilitated the exposure of a much larger population to a large hazard. As a result of multiple factors (Burby, 2006), inadequate levee infrastructure increased the likelihood of flooding but no other adequate risk reduction and management measures were implemented, resulting in catastrophic loss of life and property when the city was hit with the surge from a strong Category 3 storm (Comfort, 2006). Some have suggested that, as a result of the U.S. federal government's historical approach to disasters, those whose property was at risk in New Orleans anticipated that they would receive federal recovery funds in the event of a flooding disaster. This, in turn, may have distorted the risk management landscape, resulting in improper pricing of flooding risks, decreased incentives to take proper risk management actions, and exposure of a larger population to flood risk than might otherwise have been the case (Kunreuther, 2006).

This example illustrates how an adaptation barrier may have resulted in an ultimately maladaptive risk management regime, and demonstrates the importance of considering how risk, in practice, is assumed and shared. One goal of risk sharing is to properly price risk so that, in the event risk is realized, there is an adequate pool of capital available to fund recovery. When risk is improperly priced and risk sharing is not adequately regulated, as can occur when risk-sharing devices are not monitored appropriately, an adequate pool of reserves may not accumulate. When risk is realized, the responsibility for funding the recovery falls to the insurer of last resort, often the public.

The example also illustrates how an insurance system designed to motivate adaptation (by individual homeowners or flood protection agencies) can function properly only if technical rates – rates that properly reflect empirically determined levels of risk – can be established and matched with various levels of risk at a relatively high level of spatial and temporal resolution. Even in countries with free-market flood insurance systems, insurers may be reluctant to charge the full technical rate because consumers have come to assume that insurance costs should be relatively consistent in a given location. Without charging technical rates, however, it is difficult to use pricing to motivate adaptation strategies such as flood proofing or elevating the ground floor of a new development (Lamond et al., 2009), restricting where properties can be built, or justifying the construction of communal flood defenses. In such a case, barriers to adaptation (in both planning and management, in this case) can result in a strategy with maladaptive consequences in the present. In places where risk levels are rising due to climate change under prevailing negative conditions of exposure and vulnerability, reconsideration of these barriers – a process that includes double- and triple-loop learning – could promote more adaptive risk management. Otherwise, maladaptive risk management decisions may commit collective resources (public or private) to coping and recovery rather than successful adaptation and may force some segments of society to cope with disproportionate levels of risk.

1.4.4. 'No Regrets,' Robust Adaptation, and Learning

The mismatch between adaptation strategies and projected needs has been characterized as the potential for regret, that is, opportunity costs associated with decisions (and related path dependence, wherein earlier choices constrain future circumstances and decisions) that are optimal for one or a small number of possible climate futures but not necessarily robust over a wider range of scenarios (Lempert and Schlesinger, 2001). 'No regrets' adaptation refers to decisions that have net benefits over the entire range of anticipated future climate and associated impacts (Callaway and Hellmuth, 2007; Heltberg et al., 2009).

To address the challenge of risk management in the dynamically complex context of climate change and development, as well as under conditions where probabilistic estimates of future climatic conditions remain imprecise, several authors have advanced the concept of robustness (Wilby and Dessai, 2010), of which 'no regrets' adaptation is a special case (Lempert and Groves, 2010). Robustness is a property of a plan or strategy that performs well over a wide range of plausible future scenarios even if it does not perform optimally in any particular scenario. Robust adaptation plans may perform relatively well even if probabilistic assessments of risk prove wrong because they aim to address both expected and surprising changes, and may allow diverse stakeholders to agree on actions even if they disagree about values and expectations (Brown and Lall, 2006; Dessai and Hulme; 2007; Lempert and Groves, 2010; Means et al., 2010; see also Section 1.3.2).

As Section 1.4.3 highlights, currently, in many instances risks associated with extreme weather and other climate-sensitive hazards are often not well managed. To be effective, adaptation would prioritize measures that increase current as well as future resilience to threats. Robustness over time would increase if learning were a central pillar of adaptation efforts, including learning focused on addressing current vulnerabilities and enhancing current risk management (*high confidence*). Single-, double-, and triple-loop learning will all improve the efficacy of management strategies.

The case studies in Chapter 9 highlight some important examples of learning in disaster risk management relevant to a wide range of climate-sensitive threats and a variety of sectors. Section 9.2 provides examples of how single- and double-loop learning processes – enhancing public health response capacity, augmenting early warning systems, and applying known strategies for protecting health from the threat of extreme heat in new settings – had demonstrable impacts on heat-related mortality, quickly shifting a region's coping range with regard to extreme heat (Section 9.2.1). Other case studies, examining risk transfer (Section 9.2.13) and early warning systems (Section 9.2.11), provide instances of how existing methods and tools can be modified and deployed in new settings in response to changing risk profiles – examples of both double- and triple-loop learning. Similarly, the case studies on governance (Section 9.2.12) and on the limits to adaptation in small island developing states (Section 9.2.9) provide examples of third-loop learning and transformative approaches to disaster risk management.

References

A digital library of non-journal-based literature cited in this chapter that may not be readily available to the public has been compiled as part of the IPCC review and drafting process, and can be accessed via either the IPCC Secretariat or IPCC Working Group II web sites.

ACC, 2010: *Informing an Effective Response to Climate Change*. America's Climate Choices, National Academies Press, Washington, DC.

Adger, W.N., 1996: *Approaches to Vulnerability to Climate Change*. CSERGE Working Papers. University of East Anglia, Norwich, UK.

Adger, W.N., 2000: Social and ecological resilience: Are they related? *Progress in Human Geography*, **24(3)**, 347-364.

Adger, W.N., 2006: Vulnerability. *Global Environmental Change*, **16**, 268-281.

Adger, W.N., N. Arnell, and E.M. Thompkins, 2005: Successful adaptation to climate change across scales. *Global Environmental Change*, **15**, 77-86.

Alexander, D., 1993: *Natural Disasters*. UCL Press, London, 632 pp.

Alexander, D., 2000: *Confronting Catastrophe*. Oxford University Press, New York.

Anderson, M. and P. Woodrow, 1989: *Rising from the Ashes: Development Strategies in Times of Disasters*. Westview Press, Boulder, CO.

APA, 2009: *Psychology and Global Climate Change: Addressing a Multi-faceted Phenomenon and Set of Challenges*. American Psychological Association Task Force on the Interface between Psychology and Global Climate Change, American Psychological Association, Washington, DC.

Argyris, C. and D. Schön, 1978: *Organizational Learning: A Theory of Action Perspective*. Addison-Wesley, Reading, MA.

Armitage, D., M. Marschke, and R. Plummer, 2008: Adaptive co-management and the paradox of learning. *Global Environmental Change*, **18**, 86-98.

Aven, T., 2011. On some recent definitions and analysis frameworks for risk, vulnerability, and resilience. *Risk Analysis*, **31(4)**, 515-522.

Bahadur, A.V., M. Ibrahim, and T. Tanner, 2010: *The resilience renaissance? Unpacking of Resilience for Tackling Climate Change and Disasters*. Institute of Development Studies (for the Strengthening Climate Resilience (SCR) consortium), Brighton, UK.

Baird, A., P. O'Keefe, K. Westgate, and B. Wisner, 1975: *Towards an Explanation of and Reduction of Disaster Proneness*. Occasional Paper number 11, Disaster Research Unit, University of Bradford, Bradford, UK.

Balamir, M., 2005: Ways of understanding urban earthquake risks. In: *Book of Abstracts from 'Rethinking Inequalities,'* 7th Conference of the European Sociological Association, Institute of Sociology, Nicolaus Copernicus University of Torun, Poland, p. 132.

Ball, N., 1975: The myth of the natural disaster. *The Ecologist*, **5**(**10**), 368-369.

Bankoff, G., 2001: Rendering the world safe: vulnerability as western discourse. *Disasters*, **25** (**10**), 19-35.

Bankoff, G., 2004: The historical geography of disaster: "vulnerability" and "local knowledge" in western discourse. In: *Mapping Vulnerability: Disasters, Development, and People* [G. Bankoff, G. Frerks, and D. Hillhorst (eds.)]. Earthscan, London, pp. 25-36.

Barke, R, H. Jenkins-Smith, and P. Slovic, 1997: Risk perceptions of men and women scientists. *Social Science Quarterly*, **78**, 167-176.

Barnett, J. and S. O'Neill, 2009: Maladaptation. *Global Environmental Change*, **20**, 211-213.

Barron, E.J., 2009: Beyond climate science. *Science*, **326**, 643.

Batterbury, S., 2008: Anthropology and global warming: the need for environmental engagement. *Australian Journal of Anthropology*, **1**, 62-67.

Bedford, T.J. and R.M. Cooke, 2001: *Probabilistic Risk Analysis: Foundations and Methods*. Cambridge University Press, New York, NY and Cambridge, UK.

Bedsworth, L.W. and E. Hanak, 2010: Adaptation to climate change: A review of challenges and tradeoffs in six areas. *Journal of the American Planning Association*, **76**(**4**), 477-495.

Beer, T. and R. Hamilton, 2002: *Natural Disaster Reduction: Safer Sustainable Communities, Making Better Decisions about Risk*. International Council for Science, ICSU Position Paper.

Below, R., A. Wirtz and D. Guha-Sapir, 2009: *Disaster Category Classification and Peril Terminology for Operational Purposes*. Common Accord Centre for Research on the Epidemiology of Disasters (CRED) and Munich Re, Brussels, Belgium and Munich, Germany, cred.be/sites/default/files/DisCatClass_264.pdf.

Berkes, F., 2007: Understanding uncertainty and reducing vulnerability: Lessons from resilience thinking. *Natural Hazards*, **41**, 283-295.

Berkes, F., J. Colding, and C. Folke (eds.), 2004: *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*. Cambridge University Press, Cambridge, UK.

Birkmann, J., and K. von Teichman, 2010: Integrating disaster risk reduction and climate change adaptation: key challenges – scales, knowledge, and norms. *Sustainability Science*, **5(2)**, 171-184.

Blaikie, P., T. Cannon, I. Davis, and B. Wisner, 1994: *At Risk: Natural Hazards, People's Vulnerability and Disasters*. 1st edition. Routledge, London.

Borger, G.J. and W.A. Ligtendag, 1998: The role of water in the development of the Netherlands – a historical perspective. *Journal of Coastal Conservation*, **4**, 109-114.

Bosher, L.S. (ed.), 2008: *Hazards and the Built Environment: Attaining Built-in Resilience*. Taylor and Francis, London.

Bouwer, L.M. and Vellinga P., 2007: On the flood risk in the Netherlands. *Advances in Natural and Technological Hazard Research*, **25**, 469-484.

Brand, F.S., and K. Jax, 2007: Focusing the meaning(s) of resilience: resilience as a descriptive concept and a boundary object. *Ecology and Society*, **12(1)**, 23, www.ecologyandsociety.org/vol12/iss21/art23/.

Brick, T., J. Kightlinger, and D. Mann, 2010: *Integrated Water Resources Plan 2010 Update*. Report No. 1373, Metropolitan Water District of Southern California, Los Angeles, CA.

Brody, S., H. Grover, E. Lindquist and A. Vedlitz, 2010: Examining climate change mitigation and adaptation behaviours among public sector organisations in the USA. *Local Environment: The International Journal of Justice and Sustainability*, **15**(**6**), 591-603.

Brown, C., 2010: The end of reliability. *Journal of Water Resources Planning and Management*. **March/April**, 143-145.

Brown, C., 2011: *Decision-scaling for Robust Planning and Policy under Climate Uncertainty*. World Resources Report, World Resources Institute, Washington, DC, www.worldresourcesreport.org/files/wrr/papers/wrr_brown_uncertainty.pdf.

Brown, C. and U. Lall, 2006: Water and economic development: The role of variability and a framework for resilience. *Natural Resources Forum*, **30**(**4**), 306-317.

Brown, O., A. Crawford, and A. Hammill, 2006: *Natural Disaster and Resource Rights: Building Resilience, Rebuilding Lives*. International Institute for Sustainable Development, Winnipeg, Canada.

Burby, R., 2006: Hurricane Katrina and the paradoxes of government disaster policy: Bringing about wise governmental decisions for hazardous areas. *Annals of the American Academy of Political and Social Science*, **604**, 171-191.

Burby, R.J. and A.C. Nelson, 1991: Local government and public adaptation to sea-level rise. *Journal of Urban Planning and Development*, **117(4)**, 140-163.

Burton, I., R. Kates, and G. White (eds.), 1978: *The Environment as Hazard*. Guildford, New York, NY.

Butts, R.A., R.A. Schaalje, and G. Bruce, 1997: Impact of subzero temperatures on survival, longevity, and natality of adult Russian wheat aphid (Homoptera: Aphididae). *Environmental Entomology*, **26**(**3**), 661-667.

Callaway, J. and M. Hellmuth, 2007: Assessing the incremental benefits and costs of coping with development pressure and climate change: A South African case study. *Submissions from admitted non-governmental organizations on socio-economic information under the Nairobi work programme.* United Nations, Geneva, Switzerland.

Canham, C.D., M.J. Papaik, and E.F. Latty, 2001: Interspecific variation in susceptibility to windthrow as a function of tree size and storm severity for northern temperate tree species. *Canadian Journal of Forest Research*, **31(1)**, 1-10.

Cannon, S.H, R.M. Kirkham, and M. Parise, 2001: Wildfire-related debris-flow initiation processes, Storm King Mountain, CO. *Geomorphology*, **39**, 171-188.

Cannon, T., 2006: Vulnerability analysis, livelihoods and disasters. In: *Risk21. Coping with Risks due to Natural Hazards in the 21st Century* [Amman, W., S. Dannenmann, and L. Vulliet (eds.)]. Taylor and Francis Group, London, UK, pp. 41-50.

Cardona, O.D., 1986: Estudios de vulnerabilidad y evaluación del riesgo sísmico: Planificación física y urbana en áreas propensas. *Boletín Técnico de la Asociación Colombiana de Ingeniería Sismica*, **33(2)**, 32-65.

Cardona, O.D. 1996: Manejo ambiental y prevención de desastres: dos temas asociados. In: *Ciudades en Riesgo* [Fernandez, M.A. (ed.)]. La RED-USAID, Lima, Peru, pp. 79-101.

Cardona, O.D., 2001: *Estimación Holística del Riesgo Sísmico utilizando Sistemas Dinámicos Complejos*. Doctoral dissertation, Department of Terrain Engineering, Technical University of Catalonia, Spain, www.desenredando.org/public/varios/2001/ehrisusd/index.html.

Cardona, O.D., 2004: The Need for rethinking the concepts of vulnerability and risk from a holistic perspective: A necessary review and criticism for effective risk management. In: *Mapping Vulnerability: Disasters, Development and People* [Bankoff, G., G. Frerks, and D. Hilhorst (eds.)]. Earthscan Publishers, London, UK, pp. 37-51.

Cardona, O.D., 2005. Indicators of Disaster Risk and Risk Management: Program for Latin America and the Caribbean – Summary Report. English and Spanish edition, Inter-American Development Bank, Washington, DC.

Cardona, O.D., 2008. Indicators of Disaster Risk and Risk Management: Program for Latin America and the Caribbean – Summary Report – Second Edition. English and Spanish edition, Inter-American Development Bank, Washington, DC.

Cardona, O.D., 2011: Disaster risk and vulnerability: Notions and measurement of human and environmental insecurity. In: *Coping with Global Environmental Change, Disasters and Security – Threats, Challenges, Vulnerabilities and Risks* [Brauch, H.G., U. Oswald Spring, C. Mesjasz, J. Grin, P. Kameri-Mbote, B. Chourou, P. Dunay, and J. Birkmann (eds.)]. Hexagon Series on Human and Environmental Security and Peace, Vol. 5, Springer Verlag, Heidelberg, Berlin and New York, pp. 107-121.

Carter, T.R., R.N. Jones, X. Lu, S. Bhadwal, C. Conde, L.O. Mearns, B.C. O'Neill, M.D.A. Rounsevell, and M.B. Zurek, 2007: New Assessment Methods and the Characterisation of Future Conditions. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson, (eds.)]. Cambridge University Press, Cambridge, UK, pp. 133-171.

Cash, D.W., W.C. Clark, F. Alcock, N.M. Dickson, N. Eckley, D.H. Guston, J. Jager, and R.B. Mitchell, 2003: Knowledge systems for sustainable development. *Proceedings of the National Academy of Sciences*, **100**, 8086-8091.

Cash, D.W., J.C. Borck, and A.G. Patt, 2006: Countering the loading-dock approach to linking science and decision making: Comparative analysis of El Niño/Southern Oscillation (ENSO) forecasting systems. *Science*, *Technology and Human Values*, **31**, 465-494.

Cavazos, T., C. Turrent, and D. P. Lettenmaier, 2008: Extreme precipitation trends associated with tropical cyclones in the core of the North American monsoon. *Geophysical Research Letters*, **35**, L21703, doi:10.1029/2008GL035832.

CCSP, 2008: *Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources* [Julius, S.H. and J.M. West (eds.)]. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, U.S. Environmental Protection Agency, Washington, DC, 873 pp.

Chen, M. (ed.), 1991: *Coping with Seasonality and Drought*. Sage Publications, New Delhi, India.

Chongfu, H., 1996: Fuzzy risk assessment of urban natural hazards. *Fuzzy Sets and Systems*, **83**, 271-282.

Coburn, A. and R. Spence, 2002: *Earthquake Protection*. 2nd edition. John Wiley and Sons, Chichester, UK.

Cochrane, H., 2004: Economic loss: Myth and measurement. *Disaster Prevention and Management*, **13**, 290-296.

Collins, M., 2007: Ensembles and probabilities: A new era in the prediction of climate change. *Philosophical Transactions of the Royal Society A*, **365**, 1957-1970.

Colls, A., N. Ash, and N. Ikkala, 2009: *Ecosystem-based Adaptation: a natural response to climate change*. IUCN, Gland, Switzerland, 16 pp.

Comfort, L., 2006: Cities at risk: Hurricane Katrina and the drowning of New Orleans. *Urban Affairs Review*, **41(4)**, 501-516.

Corfee-Morlot, J., I. Cochran, S. Hallegatte, and P.-J. Teasdale, 2011: Multilevel risk governance and urban adaptation policy. *Climatic Change*, **104**(**1**) (Special Issue: Understanding Climate Change Impacts, Vulnerability and Adaptation at City Scale), 169-197.

Corporación OSSO, La Red de Estudios Sociales en Prevención de Desastres en América Latina, 2010: *.DesInventar online 8.1.9-2: sistema de inventario de efectos de desastres*. OSSO/La Red de Estudios Sociales en Prevención de Desastres en América Latina, Cali, Columbia, online.desinventar.org/.

Cox, P. and D. Stephenson, 2007: A changing climate for prediction. *Science*, **317**, 207-208.

CRED, 2010: *EM-DAT: The OFDA/CRED International Disaster Data Base*. Centre for Research on the Epidemiology of Disasters, Université Catholique de Louvain, Louvain, Belgium, www.emdat.be/Database/.

Cronin, M., C. Gonzalez, and J.D. Sterman, 2009: Why don't well-educated adults understand accumulation? A challenge to researchers, educators, and citizens. *Organizational Behavior and Human Decision Processes*, **108(1)**, 116-130.

Cuny, F.C., 1983: *Disaster and Development*. Oxford University Press, New York, NY.

Cutter, S.L., 1996: Vulnerability to environmental hazards. *Progress in Human Geography*, **20**, 529-239.

Cutter, S. L., L. Barners, M. Berry, C. Burton, E. Evans, E. Tate, and J. Webb, 2008: A place-based model for understanding community resilience to natural disasters, *Global Environmental* Change, **18**, 598-606.

Davies, S., 1993: Are coping strategies a cop out? *Institute of Development Studies Bulletin*, **24(4)**, 60-72.

Davies, S., 1996: *Adaptable Livelihoods: Coping with Food Insecurity in the Malian Sahel*. Macmillan Press, London, UK.

de Bruin, K., R. Dellink, A. Ruijs, L. Bolwidt, A. van Buuren, J. Graveland, R. de Groot, P. Kuikman, S. Reinhard, R. Roetter, V. Tassone, A. Verhagen, and E. van Ierland, 2009: Adapting to climate change in The Netherlands: an inventory of climate adaptation options and ranking of alternatives. *Climatic Change*, **95(1)**, 23-45.

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, UK, pp. 98-113.

de Jong, C., D. Collins, and R. Ranzi (eds.), 2005: *Climate and Hydrology in Mountain Areas*. John Wiley and Sons, New York, NY.

de Vries, J., 1985: Analysis of historical climate-society interaction. In: *Climate Impact Assessment* [Kates, R., J. Ausubel, and M. Berberian (eds.)]. John Wiley and Sons, New York, NY.

Degg, M.R. and D.K. Chester, 2005: Seismic and volcanic hazards in Peru: changing attitudes to disaster mitigation. *The Geographical Journal*, **171**, 125-145.

del Ninno, C., P.A. Dorosh, and N. Islam, 2002: Reducing vulnerability to natural disasters – Lessons from 1998 floods in Bangladesh. *Ids Bulletin–Institute of Development Studies*, **33**, 98-107.

del Ninno, C., P.A. Dorosh, and L.C. Smith, 2003: Public policy, markets and household coping strategies in Bangladesh: Avoiding a food security crisis following the 1998 floods. *World Development*, **31**, 1221-1238.

Dessai, S., and M. Hulme, 2004: Does climate adaptation policy need probabilities? *Climate Policy*, **4**, 107-128.

Dessai, S., and M. Hulme, 2007: Assessing the robustness of adaptation decisions to climate change uncertainties: A case study on water resources management in the East of England. *Global Environmental Change*, **17(1)**, 59-72.

Dessai, S. and R. Wilby, 2011: *How Can Developing Country Decision Makers Incorporate Uncertainty about Climate Risks into Existing Planning and Policymaking Processes?* World Resources Report, World Resources Institute, Washington, DC, http://www.worldresourcesreport.org/files/wrr/papers/wrr_dessai_and_wilby_uncertainty.pdf.

Dessai, S., M. Hulme, R. Lempert, and R. Pielke Jr., 2009: Climate prediction: a limit to adaptation? In: *Adapting to Climate Change: Thresholds, Values, Governance* [Adger, W.N., I. Lorenzoni, and K.L. O'Brien (eds.)]. Cambridge University Press, Cambridge, UK.

DFID, 2004: *Adaptation to Climate Change: Making Development Disaster Proof*. Key Sheet 06, UK Department for International Development, London, UK.

DFID, 2005: *Disaster Risk Reduction: A Development Concern*. Policy Briefing Document, DFID-ODG, UK Department for International Development, London, UK.

Dhakal, A.S. and R.C. Sidle, 2004: Distributed simulations of landslides for different rainfall conditions, *Hydrological Processes*, **18(4)**, 757-776.

Doherty, S.J., et al., 2009: Lessons learned from IPCC AR4: Scientific developments needed to understand, predict, and respond to climate change. *Bulletin of the American Meteorological Society*, **90**, 497-513.

Douglas, M., 1992: *Risk and Blame: Essays in Cultural Theory*. Routledge, London, UK and New York, NY.

Douglas, M. and A. Wildavsky, 1982: *Risk and Culture: An Essay on the Selection of Technical and Environmental Dangers*. University of California Press, Berkeley, CA.

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

Dulal, H.B., K.U. Shah, and N. Ahmad, 2009: Social equity considerations in the implementation of Caribbean climate change adaptation policies. *Sustainability*, **1**, 363-383.

Dunlap, R.E. and A.M. McCright, 2008: A widening gap: republican and democratic views on climate change. Environment, **50**, 26-35.

Eakin, H., and A. L. Luers, 2006. Assessing the vulnerability of social-environmental systems. *Annual Review of Environment and Resources*, **31**, 365-394.

Easterling, D., G. Meehl, C. Parmesan, S. Changnon, T. Karl, and L. Mearns, 2000: Climate extremes, observations, modeling and impacts. Science, **289**, 2068-2074.

El-Baroudy, I. and S.P. Simonovic, 2004: Fuzzy criteria for the evaluation of water resources systems performance. *Water Resources Research*, **40(10)**, W10503, doi:10.1029/2003WR002828.

Emanuel, K, 2001: Contribution of tropical cyclones to meridional heat transport by the oceans. *Journal of Geophysical Research*, **106(D14)**, 14771-14781.

Emanuel, K., 2003: Tropical cyclones. *Annual Review of Earth and Planetary Sciences*, **31**, 75-104.

Epstein, P., H. Diaz, S. Elias, G. Grabherr, N. Graham, W. Martens, E.M. Thompson, and J. Susskind, 1998: Biological and physical signs of climate change: focus on mosquito borne diseases. *Bulletin of the American Meteorological Society*, **79**, 409-417.

ERN-AL, 2011: *Probabilistic Modelling of Natural Risk at Global Level: The Hybrid Loss Exceedance Curve – Development of a Methodology and Implementation of Case Studies, Phase 1A: Colombia, Mexico, Nepal*. Report for the GAR 2011, Consortium Evaluación de Riesgos Naturales – América Latina, Bogotá, Colombia.

Fink, A.H., U. Ulbrich, and H. Engel, 1996: Aspects of the January 1995 flood in Germany. *Weather*, **51(2)**, 34-39.

Fischhoff, B., 1994: What forecasts (seem to) mean. *International Journal of Forecasting*, **10**, 387-403.

Fischhoff, B., P. Slovic, and S. Lichtenstein, 1983: The "public" vs. the "experts": Perceived vs. actual disagreement about the risks of nuclear power. In: *Analysis of Actual vs. Perceived Risks* [Covello,V., G. Flamm, J. Rodericks, and R. Tardiff (eds.)]. Plenum, New York, NY, pp. 235-249.

Flood, R. and N. Romm, 1996: *Diversity Management: Triple Loop Learning*. Wiley, Chichester, UK.

Folke, C., 2006: Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change*, **16**, 253-267.

Folke, C., F.S. Chapin III, and P. Olsson, 2009: Transformations in ecosystem stewardship. In: *Principles of Ecosystem Stewardship: Resilience-Based Natural Resource Management in a Changing World* [Chapin III, F.S., G.P. Kofinas, and C. Folke (eds.)]. Springer, New York, NY, pp. 103-125.

Fouillet, A., G. Rey, V. Wagner, K. Laaidi, P. Empereur-Bissonnet, A. Le Tertre, P. Frayssinet, P. Bessemoulin, F. Laurent, P. De Crouy-Chanel, E. Jougla, and D. Hemon, 2008: Has the impact of heat waves on mortality changed in France since the European heat wave of summer 2003?A study of the 2006 heat wave. *International Journal of Epidemiology*, **37(2)**, 309-317.

Füssel, H., 2007: Vulnerability: A generally applicable conceptual framework for climate change research. *Global Environmental Change*, **17(2)**, 155-167.

Gaillard, J.C., 2007: Resilience of traditional societies in facing natural hazard. *Disaster Prevention and Management*, **16**, 522-544.

Gaillard, J.C., 2010: Vulnerability, capacity, and resilience: Perspectives for climate and development policy. *Journal of International Development*. **22**, 218-232.

Gallopín, G.C., 2003: Box 1. A systemic synthesis of the relations between vulnerability, hazard, exposure and impact, aimed at policy identification. In: *Handbook for Estimating the Socio-Economic and Environmental Effects of Disasters*. Economic Commission for Latin American and the Caribbean, LC/MEX/G.S., Mexico, pp. 2-5.

Gallopín, G.C., 2006: Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change*, **16**, 293-303.

Gasper, D., 2010: The idea of human security. In: *Climate Change, Ethics and Human Security* [O'Brien, K. A.L. St. Clair, and B. Kristoffersen (eds.)]. Cambridge University Press, Cambridge, UK, pp. 23-46.

Gershunov, A., D. R. Cayan, and S. F. Iacobellis, 2009: The great 2006 heat wave over California and Nevada: Signal of an increasing trend*. Journal of Climate*, **22**, 6181-6203.

Goddard, L., W. Baethgen, B. Kirtman, and G. Meehl, 2009: The urgent need for improved climate models and predictions. *EOS*, **90(39)**, 343.

Gordon, J.E., 1978: *Structures*. Penguin Books, Harmondsworth, UK.

Gottschalk, M.K.E., 1971: *Stormvloeden en rivieroverstromingen in Nederland Deel I* (Storm surges and river floods in the Netherlands, part I). Van Gorcum, Assen, The Netherlands.

Gottschalk, M.K.E., 1975: *Stormvloeden en rivieroverstromingen in Nederland Deel II* (Storm surges and river floods in the Netherlands, part II). Van Gorcum, Assen, The Netherlands.

Gottschalk, M.K.E., 1977: *Stormvloeden en rivieroverstromingen in Nederland Deel III* (Storm surges and river floods in the Netherlands, part III). Van Gorcum, Assen, The Netherlands.

Groves, D.G. and R.J. Lempert, 2007: A new analytic method for finding policy-relevant scenarios. *Global Environmental Change*, **17**, 73-85.

Hagman, G., 1984: *Prevention Better than Cure*. Swedish Red Cross, Stockholm, Sweden.

Hallegatte, S., 2009: Strategies to adapt to an uncertain climate change. *Global Environmental Change*, **19(2)**, 240-247.

Hargrove, R., 2002. *Masterful Coaching*. Revised Edition. Jossey-Bass/Pfeiffer, Wiley, San Francisco, CA, USA.

Hawkins, E. and R. Sutton, 2009: The potential to narrow uncertainty in regional climate predictions. *Bulletin of the American Meteorological Society*, **90**, 1095-1107.

Hegerl, G.C., F.W. Zwiers, P. Braconnot, N.P. Gillett, Y. Luo, J.A. Marengo Orsini, N. Nicholls, J.E. Penner, and P.A. Stott, 2007: Understanding and attributing climate change. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, pp. 663-745.

Heltberg, R., P.B. Siegel, and S.L. Jorgensen, 2009: Addressing human vulnerability to climate change: Toward a "no-regrets" approach. *Global Environmental Change*, **19(1)**, 89-99.

Hertwig, R., G. Barron, E.U. Weber, and I. Erev, 2004: Decisions from experience and the effect of rare events. *Psychological Science*, **15**, 534-539.

Hewitt, K., 1983: The idea of calamity in a technocratic age. In: *Interpretations of Calamity from the Viewpoint of Human Ecology* [Hewitt, K. (ed.)]. Allen and Unwin, Boston, MA and London, UK, pp 3-32.

Hewitt, K., 1997: *Regions of Risk: A Geographical Introduction to Disasters*. Longman, Harlow, Essex, UK.

Hewitt, K., 2007: Preventable disasters: addressing social vulnerability, institutional risks and civil ethics. *Geographisches Bundschau. International Edition*, **3**(**1**), 43-52.

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

Hine, D. and J.W. Hall, 2010: Information gap analysis of flood model uncertainties and regional frequency analysis. *Water Resources Research*, **46(19)**, W01514, doi:10.1029/2008WR007620.

Hoeksma, R.J., 2006: *Designed for Dry feet: Food Protection and Land Reclamation in the Netherlands*. American Society of Civil Engineers, Reson, VA.

Hohenemser, C., R.E. Kasperson, and R.W. Kates, 1984: Causal structure. In: *Perilous Progress: Managing the Hazards of Technology* [Kates, R.W., C. Hohenemser and J.X. Kasperson (eds.)]. Westview Press, Boulder, CO, pp. 25-42.

Holland, M.M., C.M. Bitz, and B. Tremblay, 2006: Future abrupt reductions in the summer Arctic sea ice. *Geophysical Research Letters*, **33**, L23503, doi:10.1029/2006GL028024.

Holling, C.S., 1973: Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics*, **4**, 1-23.

Horsburgh, K.J. and M. Horritt, 2006: The Bristol Channel Floods of 1607 – reconstruction and analysis. *Weather*, **61(10)**, 272-277.

Huang, C., P. Vaneckova, X. Wang, G. FitzGerald, Y. Guo, and S. Tong, 2011: Constraints and barriers to public health adaptation to climate change. *American Journal of Preventive Medicine*, **40(2)**, 183-190.

HVRI, 2010: *The Spatial Hazard Events and Losses Database for the United States*. Version 8.0 (online database). Hazards and Vulnerability Research Institute, University of South Carolina, Columbia, SC, www.sheldus.org.

ICSU, 2002: *Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformations.* Series on Science for Sustainable Development: Resilience and Sustainable Development No. 3, International Council for Science, Paris, France, 37 pp.

ICSU, 2008: *A Science Plan for Integrated Research on Disaster Risk: addressing the challenge of natural and human induced environmental hazards*. International Council for Science, Paris, France.

ICSU-LAC, 2009: *Understanding and Managing Risk Associated with Natural Hazards: An Integrated Scientific Approach in Latin America and the Caribbean*. International Council for Science Regional Office for Latin America and the Caribbean, Rio de Janeiro, Brazil and Mexico City, Mexico.

IDB, 2007: *Disaster Risk Management Policy*. GN-2354-5, Inter-American Development Bank, Washington, DC.

IFRC, 2007. *How to Do a VCA: A Practical Step-by-Step Guide for Red Cross Red Crescent Staff and Volunteers*. International Federation of Red Cross and Red Crescent Societies.

IIED, 2009: *Natural Resilience: Healthy ecosystems as climate shock insurance*. IIED Policy Brief, International Institute for Environment and Development, London, UK.

Ingram, K.T., M.C. Roncoli, and P.H. Kirshen, 2002: Opportunities and constraints for farmers of West Africa to use seasonal precipitation forecasts with Burkina Faso as a case study. *Agricultural Systems*, **74(3)**, 331-349.

International Building Codes, 2003: International Code Council (paperback), 656 pp. ISBN 1892395568.

IPCC, 2007a: *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri, and A. Reisinger (eds.)]. IPCC, Geneva, Switzerland, 104 pp.

IPCC, 2007b: *Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY.

IPCC, 2007c: Appendix I: Glossary. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, pp. 869-883.

IPCC, 2009. *Scoping Meeting for an IPCC Special Report on Extreme Events and Disasters: Managing the Risks. Proceedings* [Barros, V., et al. (eds.)]. 23-26 March 2009, Oslo, Norway.

ISO, 2009: *Guide 73: 2009. Risk Management – Vocabulary*. International Organization for Standardization, Geneva, Switzerland.

Jansen, V., N. Stollenwerk, H.J. Jensen, M.E. Ramsay, W.J. Edmunds, and C.J. Rhodes, 2003: Measles outbreaks in a population with declining vaccine uptake. *Science*, **301**, 804.

Jasanoff, S., 2004: *States of Knowledge: The Co-Production of Science and Social Order*. Routledge, London, UK.

Jentsch, A., J. Kreyling, and C. Beierkuhnlein, 2007: A new generation of climate change experiments: events not trends. *Frontiers in Ecology and the Environment*, **6(6)**, 315-324.

Jones, R.N. and B.L. Preston, 2011: Adaptation and Risk Management. *WIREs Climate Change*, **2**, 296-308, doi:10.1002/wcc.97.

Kahan, D.M. and D. Braman, 2006: Cultural cognition and public policy. *Yale Law and Policy Review*, **24(1)**, 149-172.

Kahan, D.M., D. Braman, J. Gastil, P. Slovic, and C.K. Mertz, 2007: Culture and identity – protective cognition: Explaining the white male effect in risk perception. *Journal of Empirical Legal Studies*, **4(3)**, 465-505.

Kahneman, D. and A. Tversky, 1979: Prospect theory: An analysis of decisions under risk. *Econometrica*, **47**, 313-327.

Kahneman, D., P. Slovic, and A. Tversky (eds.), 1982: *Judgment under Uncertainty: Heuristics and Biases*. Cambridge University Press, New York, NY.

Karimi, I. and E. Hullermeier, 2007: Risk assessment system of natural hazards: A new approach based on fuzzy probability. *Fuzzy Sets and Systems*, **158**, 987-999.

Kasperson, R.E., O. Renn, P. Slovic, H.S. Brown, J.Emel, R. Goble, J.X. Kasperson, and S. Ratick, 1988: The social amplification of risk: A conceptual framework. *Risk Analysis*, **8**,177-187.

Kates, R.W., et al., 2001: Sustainability science. *Science*, **292(5517)**, 641-642.

Keen, M., V.A. Brown, and R. Dyball, 2005: *Social Learning in Environmental Management: Towards a Sustainable Future*. Earthscan, London, UK.

Kelman, I., 2008. Relocalising disaster risk reduction for urban resilience. *Urban Design and Planning*, **161(DP4)**, 197-204.

Khan, T.A., 2011: Floods increase wheat yield in KP. *Inpaper Magazine*, Pakistan, 16 May 2011.

Klein, R.J.T, R.J. Nicholls, and F. Thomalla, 2003: Resilience to natural hazards: how useful is this concept? *Global Environmental Change*, **5**, 35-45.

Knutti, R., 2010: The end of model democracy? *Climatic Change*, **102**, 395-404.

Kolb, D.A., 1984: *Experiential Learning: Experience as the Source of Learning and Development*. Prentice-Hall, Englewood Cliffs, NJ.

Kolb, D.A. and R. Fry, 1975: Toward an applied theory of experiential learning. In: *Theories of Group Process* [Cooper, C. (ed.)]. John Wiley, London, UK, pp. 33-57.

Konikow, L.F. and E. Kendy, 2005: Groundwater depletion: a global problem. *Hydrogeology Journal*, **13**, 317-320.

Kunreuther, H., 2006: Disaster mitigation and insurance: Learning from Katrina. *The Annals of the American Academy of Political and Social Science*, **604(1)**, 208-227.

Kysar, D., 2004: Climate change, cultural transformation, and comprehensive rationality. *Boston College Environmental Affairs Law Review*, **31(3)**, 555-590.

Lamond, J.E., D.G. Proverbs, and F.N. Hammond, 2009: Accessibility of flood risk insurance in the UK: confusion, competition and complacency. *Journal of Risk Research*, **12**, 825-841.

Lau, W.K.M. and K.-M. Kim, 2011: The 2010 Pakistan flood and Russian heat wave: Teleconnection of hydrometeorologic extremes. *Journal of Hydrometeorology*, doi:10.1175/JHM-D-11-016.1.

Lavell, A., 1996: Degradación ambiental, riesgo y desastre urbano. Problemas y conceptos: hacia la definición una agenda de investigación. In: *Ciudades en Riesgo* [Fernandez, M.A. (ed.)]. La RED-USAID, Lima, Peru, pp. 21-59.

Lavell, A., 1999: Environmental degradation, risks and urban disasters. Issues and concepts: Towards the definition of a research agenda. In: *Cities at Risk: Environmental Degradation, Urban Risks and Disasters in Latin America* [Fernandez, M.A. (ed.)]. La RED, US AID, Quito, Ecuador, pp. 19-58.

Lavell, A., 2002: *Riesgo y Territorio: los niveles de intervención en la Gestión del Riesgo (Risk and Territory: Levels of Intervention and Risk Management)*. Anuario Social y Político de América Latina y el Caribe. FLACSO-Nueva Sociedad, Latin American School of Social Sciences.

Lavell, A., 2003: *Local level risk management: Concept and practices*. CEPREDENAC-UNDP. Quito, Ecuador.

Lavell, A., 2009: *Technical Study in Integrating Climate Change Adaptation and Disaster Risk Management in Development Planning and Policy*. Study undertaken for the Inter-American Development Bank, Washington, DC.

Lavell, A., 2010: *Unpacking Climate Change Adaptation and Disaster Risk Management: Searching for the Links and the Differences: A Conceptual and Epistemological Critique and Proposal*. IUCN-FLACSO, International Union for Conservation of Nature - Latin American School of Social Sciences.

Lavell A. and E. Franco (eds.), 1996: *Estado, Sociedad y Gestión de los Desastres en América Latina*. Red de Estudios Sociales en Prevención de Desastres en América Latina, La RED, Tercer Mundo Editores, Bogotá, Colombia.

Lavell, A. and C. Lavell, 2009: *Local Disaster Risk Reduction Lessons from the Andes*. Series: Significant Local Development Initiatives in the Face of Disaster Risk. General Secretariat of the Andean Community, Lima, Peru.

Leckebusch, G.C., D. Renggli, and U. Ulbrich, 2008: Development and application of an objective storm severity measure for the Northeast Atlantic region. *Meteorologische Zeitschrift*, **17**, 575-587.

Lemos, M.C., 2003: A tale of two policies: the politics of seasonal climate forecast use in Ceará, Brazil. *Policy* Sciences, **32(2)**, 101-123.

Lemos, M.C., E. Boyd, E.L. Tompkins, H. Osbahr, and D. Liverman, 2007: Developing adaptation and adapting development. *Ecology and Society*, **12(2)**, 26, www.ecologyandsociety.org/vol12/iss2/art26/.

Lempert, R.J. and M. Collins, 2007: Managing the risk of uncertain threshold responses: Comparison of robust, optimum, and precautionary approaches. *Risk Analysis*, **27(4)**, 1009-1026.

Lempert, R.J. and D.G. Groves, 2010: Identifying and evaluating robust adaptive policy responses to climate change for water agencies in the American west. *Technological Forecasting and Social Change*, **77**, 960-974.

Lempert, R.J. and M. Schlesinger, 2001: Climate-change strategy needs to be robust. *Nature*, **412**, 375.

Lewcowicz, A.G. and C. Harris, 2005: Frequency and magnitude of active-layer detachment failures in discontinuous and continuous permafrost, northern Canada. *Permafrost and Periglacial Processes*, **16**,115-130.

Lewis, J., 1979: The vulnerable state: An alternative view. In: *Disaster Assistance: Appraisal, Reform and New Approaches* [Stephens, L. and S.J. Green (eds.)]. New York University Press, New York, NY, pp. 104-129.

Lewis, J., 1984: Environmental interpretations of natural disaster mitigation: The crucial need. *The Environmentalist*, **4(3)**, pp. 177-180.

Lewis, J., 1999: *Development in Disaster-prone Places: Studies in Vulnerability*. IT Publications (Practical Action), London, UK.

Lewis, J., 2009: An island characteristic: Derivative vulnerabilities to indigenous and exogenous hazards. *Shima: The International Journal of Research into Island Cultures*. **3(1)**, 3-15.

Lewis, J. and I. Kelman, 2009: Housing, flooding and risk-ecology: Thames Estuary South-Shoreland and North Kent. *Journal of Architectural and Planning Research*, **26(1)**, 14-29.

Lindell, M. and C. Prater, 2003: Assessing community impacts of natural disasters. *Natural Hazards* Review, **4(4)**, 176-185.

Lipton, M. and M. Ravallion, 1995: Poverty and policy. In: *Handbook of Development Economics, Vol. 3B* [Behrman, J.S. and T.N. Srinivasan (eds.)]. Elsevier Science, Amsterdam, New York, and Oxford, pp. 2551-2657.

List, D., 2006: Action research cycles for multiple futures perspectives. *Futures*, **38**, 673-684.

Loewenstein, G.F., E.U. Weber, C.K. Hsee, and E. Welch, 2001: Risk as feelings. *Psychological Bulletin*, **127**, 267-286.

Malka, A. and J.A. Krosnick, 2009: The association of knowledge with concern about global warming: trusted information sources shape public thinking. *Risk Analysis*, **29**, 633-647.

Manyena, S.B., 2006: The concept of resilience revisited. *Disasters*, **30(4)**, 433-450.

Maskrey, A., 1989: *Disaster Mitigation: A Community Based Approach*. Oxfam, Oxford, UK.

Maskrey, A., 2011: Revisiting community based risk management. *Environmental Hazards*, **10**, 1-11.

Mastrandrea, M.D., C.B. Field, T.F. Stocker, O. Edenhofer, K.L. Ebi, D.J. Frame, H. Held, E. Kriegler, K.J. Mach, P.R. Matschoss, G.-K. Plattner, G.W. Yohe, and F.W. Zwiers, 2010: *Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties*. IPCC, www.ipcc-wg2.gov/meetings/CGCs/Uncertainties-GN_IPCCbrochure_lo.pdf.

McBean, G., 2006: An integrated approach to air pollution, climate and weather hazards. *Policy Options*, October 2006, pp. 18-24.

McGray, H., A. Hammill, and R. Bradley, 2007: *Weathering the Storm: Options for Framing Adaptation and Development*. World Resources Institute, Washington, DC.

McKee, T.B., N.J. Doesken, and J. Kleist, 1993: The duration of drought frequency and duration to time scales. In: *Eighth Conference on Applied Climatology*, 17-22 January 1993, Anaheim, California, ccc.atmos.colostate.edu/relationshipof-droughtfrequency.pdf.

McLaughlin, P. and T. Dietz, 2007: Structure, agency and environment: Toward an integrated perspective on vulnerability. *Global Environmental Change*, **39(4)**, 99-111.

Means, E., M. Laugier, J. Daw, L. Kaatz, and M. Waage, 2010: *Decision Support Planning Methods: Incorporating Climate Change Uncertainties into Water Planning*. Water Utility Climate Alliance, San Francisco, CA, www.wucaonline.org/assets/pdf/actions_whitepaper_012110.pdf.

Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper, Watterson, I.G., A.J. Weaver and Z.-C. Zhao, 2007: Global climate projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, pp. 747-843.

Mercer, J., 2010: Disaster risk reduction or climate change adaptation: are we reinventing the wheel? *Journal of International Development*, **22**, 247-264.

Mezirow, J., 1995: Transformation theory in adult learning. In: *In Defense of the Life World* [Welton, M.R. (ed.)]. State University of New York Press, Albany, NY, pp. 39-70.

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

Miller, F., H. Osbahr, E. Boyd, F. Thomalla, S. Bharwani, G. Ziervogel, B. Walker, J. Birkmann, S. Van der Leeuw, J. Rockström, J. Hinkel, T. Downing, C. Folke, and D. Nelson, 2010: Resilience and vulnerability: complementary or conflicting concepts? *Ecology and Society*, **15(3)**, 11.

Milly, P.C.D., R.T. Wetherald, K.A. Dunne, and T.L. Delworth, 2002: Increasing risk of great floods in a change climate. *Nature*, **415**, 514-517.

Milly, P.C.D., J. Betancourt, M. Falkenmark, R. Hirsch, Z. Kundzewicz, D. Lettenmaier, and R. Stouffer, 2008: Stationarity is dead: Whither water management? *Science*, **319(5863)**, 573-574.

Minor, J.E., 1983: Construction tradition for housing determines disaster potential from severe tropical cyclones. *Journal of Wind Engineering and Industrial Aerodynamics*, **14**, 55-66.

Mitchell, T. and M. van Aalst, 2008: *Convergence of Disaster Risk Reduction and Climate Change Adaptation*. Technical Paper, October 2008, UK Department of International Development, London, UK.

Moench, M. and A. Dixit (eds.), 2004: *Adaptive Capacity and Livelihood Resilience: Adaptive Capacities for Responding to Floods and Droughts in South Asia*. Institute for Social and Environmental Transition, Boulder, CO and Nepal.

Morgan, M.G. and M. Henrion, 1990: *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis*. Cambridge University Press, Cambridge, UK.

Morgan, M.G., H. Dowlatabadi, M. Henrion, D. Keith, R.J. Lempert, S. McBride, M. Small, and T. Wilbanks, 2009: *Best Practice Approaches for Characterizing, Communicating, and Incorporating Scientific Uncertainty in Decisionmaking*. Synthesis and Assessment Product 5.2 of the U.S. Climate Change Science Program, National Oceanic and Atmospheric Administration, Washington, DC.

Moser, S.C., 2009. Whether our levers are long enough and the fulcrum strong? Exploring the soft underbelly of adaptation decisions and actions. In: *Adapting to Climate Change: Thresholds, Values, Governance* [Adger, W.N., I. Loronzoni, and K. O'Brien (eds.)]. Cambridge University Press, Cambridge, UK, pp. 313-343.

Moser, S.C., 2010: Now more than ever: The need for more socially relevant research on vulnerability and adaptation to climate change. *Applied Geography*, **30(4)**, 464-474.

Moser, S.C. and J.A. Ekstrom, 2010: Barriers to climate change adaptation: A diagnostic framework. *Proceedings of the National Academy of Sciences*, **107(51)**, 22026-22031.

Moser, S.C. and J.A. Ekstrom, 2011: Taking ownership of climate change: Participatory adaptation planning in two local case studies from California. *Journal of Environmental Studies and Sciences*, **1(1)**, 63-74.

Moser, S.C. and A.L. Luers, 2008: Managing climate risks in California: The need to engage resource managers for successful adaptation to change. *Climatic Change*, **87**, S309-S322.

Nelson, D.R., 2005: *The Public and Private Sides of Persistent Vulnerability to Drought: An Applied Model for Public Planning in Ceará, Brazil*. PhD Thesis, University of Arizona, Tucson, AZ.

Nelson, D. R., N. Adger, and K. Brown, 2007: Adaptation to environmental change: contributions of a resilience framework. *The Annual Review of Environment and Resources*, **32**, 395-419.

Nielsen, J.Ø. and A. Reenberg, 2010: Cultural barriers to climate change adaptation: A case study from Northern Burkina Faso. *Global Environmental Change*, **20(1)**, 142-152.

Noji, E., 1997: *The Public Health Impacts of Disasters*. Oxford University Press, New York, NY.

Norris, F.H., S.P. Stevens, B. Pfefferbaum, K.F. Wyche, and R.L. Pfefferbaum, 2008: Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. *American Journal of Community Psychology*, **41**, 127-150

NRC, 2006: *Facing Hazards and Disasters: Understanding Human Dimensions*. National Research Council, National Academies Press, Washington DC.

NRC, 2009: *Informing Decisions in a Changing Climate*. Panel on Strategies and Methods for Climate-Related Decision Support, Committee on the Human Dimensions of Global Change, Division of Behavioral and Social Sciences and Education, National Research Council, The National Academies Press, Washington, DC, 188 pp.

O'Brien, K. and R. Leichenko, 2000: Double exposure: assessing the impacts of climate change within the context of economic globalization. *Global Environmental Change*, **10**, 221-232.

O'Brien, K., S. Eriksen, L.P. Nygaard, and A. Schjolden, 2007: Why different interpretations of vulnerability matter in climate change discourses. *Climate Policy*, **7(1)**, 73-88.

O'Keefe, P., K. Westgate, and B. Wisner, 1976: Taking the naturalness out of natural disasters. *Nature*, **260(5552)**, 566-577.

OED, 1989: *The Oxford English Dictionary*. Oxford University Press, Oxford, UK.

Olsson, P., L.H. Gunderson, S.R. Carpenter, P. Ryan, L. Lebel, C. Folke, and C.S. Holling, 2006: Shooting the rapids: navigating transitions to adaptive governance of social-ecological systems. *Ecology and Society*, **11(1)**, 18.

Oppenheimer, M., B.C. O'Neill, and M. Webster, 2008: Negative learning. *Climatic Change*, **89**, 155-172.

Ostertag, R., W.L. Silver, and A.E. Lugo, 2005: Factors affecting mortality and resistance to damage following hurricanes in a rehabilitated subtropical moist forest. *Biotropica*, **37(1)**, 16-24.

Pahl-Wostl, C., 2009: A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. *Global Environmental Change*, **19(3)**, 354.

Pall, P., T. Aina, D.A. Stone, P.A. Stott, T. Nozawa, A.G. Hilberts, D. Lohmann, and M.R. Allen, 2011: Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000. *Nature*, **470**, 382-386

Parson, E., V. Burkett, K. Fisher-Vanden, D. Keith, L. Means, H. Pitcher, C. Rosenzweig, and M. Webster, 2007: *Global Change Scenarios: Their Development and Use*. Sub-report 2.1B of Synthesis and Assessment Product 2.1 by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, Department of Energy, Office of Biological and Environmental Research, Washington, DC, 106 pp.

Pelling, M., 2003: *The Vulnerability of Cities: Social Resilience and Natural Disaster.* Earthscan, London, UK.

Pelling, M., 2010: *Adaptation to Climate Change: From Resilience to Transformation*. Routledge, London, UK.

Pelling, M., A. Özerdem, and S. Barakat, 2002: The Macroeconomic impact of disasters. *Progress in Development Studies*, **2**, 283-305.

Pelling, M., C. High, J. Dearing, and D. Smith, 2008: Shadow spaces for social learning: a relational understanding of adaptive capacity to climate change within organisations. *Environment and Planning A*, **40(4)**, 867-884.

Pendalla, R., K.A. Foster, and M. Cowella, 2010: Resilience and regions: building understanding of the metaphor. *Cambridge Journal of Regions, Economy and Society*, **3(1)**, 71-84

Peschl, M.F., 2007: Triple-loop learning as foundation for profound change, individual cultivation, and radical innovation. Construction processes beyond scientific and rational knowledge. *Constructivist Foundations*, **2(2-3)**, 136-145.

Peters, G., A.M. DiGioia Jr, C. Hendrickson, and J. Apt, 2006: *Transmission Line Reliability: Climate Change and Extreme Weather*. Carnegie Mellon Electricity Industry Center Working Paper CEIC-05-06, Carnegie Mellon University, Pittsburgh, PA.

Peters, O., C. Hertlein, and K. Christensen, 2001: A complexity view of rainfall. *Physical Review Letters*, **88**, 018701, doi:10.1103/PhysRevLett.88.018701.

Pettengell, C., 2010: *Climate Change Adaptation: Enabling People Living in Poverty to Adapt*. Oxfam International Research Report, Oxfam International, Oxford, UK.

Piao, S., P. Ciais, Y. Huang, Z. Shen, S. Peng, J. Li, L. Zhou, H. Liu, Y. Ma, Y. Ding, P. Friedlingstein, C. Liu, K. Tan, Y. Yu, T. Zhang, and J. Fang, 2010: The impact of climate change on water resources and agriculture in China. *Nature*, **467**, 43-51.

Pidgeon, N. and B. Fischhoff, 2011: The role of social and decision sciences in communicating uncertain climate risks. *Nature Climate Change*, **1**, 35-41.

Pielke, Jr., R.A., 2007: Future economic damage from tropical cyclones: sensitivities to societal and climate changes. *Philosophical Transactions of the Royal Society A*, **365(1860)**, 2717-2729.

Pohl, C., S. Rist, A. Zimmermann, P. Fry, G.S. Gurung, F. Schneider, C. Ifejika Speranza, B. Kiteme, S. Boillat, E. Serrano, G. Hirsch Hadorn, and U. Wiesmann, 2010: Researchers' roles in knowledge co-production: experience from sustainability research in Kenya, Switzerland, Bolivia and Nepal*. Science and Public Policy*, **37(4)**, 267-281.

Quarantelli, E.L, 1986: *Disaster Crisis Management*. Preliminary Papers 113, University of Delaware, Disaster Research Center. Newark, DE, http://dspace.udel.edu:8080/dspace/handle/19716/487.

Ramírez, F. and O.D. y Cardona, 1996: Sistema nacional para la prevención y atención de desastres de Colombia, Estado, sociedad y gestión de los desastres en América Latina. In: *Red de Estudios Sociales en Prevención de Desastres en América Latina* [Lavell, A. and E. y Franco (eds.)]. Tercer Mundo Editores, Bogotá, Colombia.

Ranger, N. and S.-L. Garbett-Shiels, 2011: *How can Decision-Makers in Developing Countries Incorporate Uncertainty about Future Climate Risks into Existing Planning and Policymaking Processes*? Policy Paper, Centre for Climate Change Economics and Policy and Grantham Research Institute on Climate Change and the Environment in collaboration with the World Resources Report, World Resources Institute, Washington, DC, www.worldresourcesreport.org/files/wrr/papers/wrr_ranger_uncertainty.pdf.

Rayner, S., D. Lach, and H. Ingram, 2005: Weather forecasts are for wimps: Why water resource managers do not use climate forecasts. *Climatic Change*, **69**, 197-227.

Reeder, T. and N. Ranger, 2011: *How Do You Adapt In an Uncertain World? Lessons from the Thames Estuary 2100 Project*. World Resources Report, World Resources Institute, Washington, DC, www.worldresourcesreport.org/files/wrr/papers/wrr_reeder_and_ranger_uncertainty.pdf.

Rees, H.G. and D.N. Collins, 2006: Regional differences in response of flow in glacier-fed Himalayan rivers. *Hydrological Processes*, **20(10)**, 2157-2169.

Renn, O., 2008: *Risk Governance. Coping with Uncertainty in a Complex World*. Earthscan, London, UK.

Rich, P.M., D.D. Breshears, and A.B. White, 2008: Phenology of mixed woody-herbaceous ecosystems. *Ecology*, **89(2)**, 342-352.

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(2)**, 137-165.

Rose, A., 2004: Economic principles, issues, and research priorities in hazard loss estimation. In: *Modeling Spatial and Economic Impacts of Disasters* [Okuyama, Y. and S. Chang (eds.)]. Springer, Berlin, Germany, pp. 14–36.

Sarewitz, D., R.A. Pielke, Jr., and R. Byerly, Jr. (eds.), 2000: *Prediction: Science, Decision Making, and the Future of Nature.* Island Press, Washington, DC, 405 pp.

Savage, L.J., 1972: *Foundations of Statistics*. Dover Publications, New York, NY.

Schipper, L., 2009: Meeting at the crossroads? Exploring the linkages between climate change adaptation and disaster risk reduction. *Climate and Development*, **1**, 16-30.

Schipper, L. and I. Burton (eds.), 2009: *The Earthscan Reader on Adaptation to Climate Change*. Earthscan, London, UK.

Schipper, L. and M. Pelling, 2006: Disaster risk, climate change and international development: scope for, and challenges to, integration. *Disasters*, **30(1)**, 19-38.

Schneider, S.H., S. Semenov, A. Patwardhan, I. Burton, C.H.D. Magadza, M. Oppenheimer, A.B. Pittock, A. Rahman, J.B. Smith, A. Suarez, and F. Yamin, 2007: Assessing key vulnerabilities and the risk from climate change. In: *Climate Change* 2007*: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson, (eds.)]. Cambridge University Press, Cambridge, UK, pp. 779-810.

Sen, A.K., 1983: *Poverty and famines: an essay on entitlement and deprivation*. Oxford University Press, Oxford, UK.

Seneviratne, S.I., D. Lüthi, M. Litschi, and C. Schär, 2006: Land-atmosphere coupling and climate change in Europe. *Nature*, **443**, 205-209.

Shapiro, M., J. Shukla, G. Brunet, C. Nobre, M. Beland, R. Dole, K. Trenberth, R. Anthes, G. Asrar, L. Barrie, P. Bougeault, G. Brasseur, D. Burridge, A. Busalacchi, J. Caughey, D. Chen, J. Church, T. Enomoto, B. Hoskins, O. Hov, A. Laing, H. Le Treut, J. Marotzke, G. McBean, G. Meehl, M. Miller, B. Mills, J. Mitchell, M. Moncrieff, T. Nakazawa, H. Olafsson, T. Palmer, D. Parsons, D. Rogers, A. Simmons, A. Troccoli, Z. Toth, L. Uccellini, C. Velden, and J.M. Wallace, 2010: An earth-system prediction initiative for the twenty-first century. *Bulletin of the American Meteorological Society*, **91**, 1377-1388.

Shukla, J., R. Hagedorn, B. Hoskins, J. Kinter, J. Marotzke, M. Miller, T.N. Palmer, and J. Slingo, 2009: Revolution in climate prediction is both necessary and possible: A declaration at the World Modelling Summit for Climate Prediction. *Bulletin of the American Meteorological Society*, **90**, 175-178.

Simonovic, S.P., 2010: *Systems Approach to Management of Disasters: Methods and Applications*. John Wiley and Sons, New York, NY, 348 pp.

Sjöberg, L., 1999a: Risk perception by the public and by experts: A dilemma in risk management. *Human Ecology Review*, **6(2)**.

Sjöberg, L., 1999b: Consequences of perceived risk: Demand for mitigation. *Journal of Risk Research*, **(2)**, 129-149.

Slovic, P., 1993: Perceived risk, trust, and democracy. *Risk Analysis*, **13**(**6**), 675-676.

Slovic, P. (ed.), 2000: *The Perception of Risk*. Earthscan, Sterling, VA.

Slovic, P. (ed.), 2010: *The Feeling of Risk: New Perspectives on Risk Perception*. Earthscan, London, UK.

Slovic, P., B. Fischhoff, and S. Lichtenstein, 1982. Facts versus fears: Understanding perceived risk. In: *Judgment Under Uncertainty: Heuristics and Biases* [Kahneman, D., P. Slovic, and A. Tversky (eds.)]. Cambridge University Press, New York, NY.

Smit, B. and O. Pilifosova, 2003. From adaptation to adaptive capacity and vulnerability reduction. In: *Climate Change, Adaptive Capacity and Development* [Smith, J.B., R.J.T. Klein, and S. Huq (eds.)]. Imperial College Press, London, UK.

Smit, B. and J. Wandel, 2006: Adaptation, adaptive capacity and vulnerability. *Global Environmental Change*, **16**, 282-292.

Smith, K., 1996: *Environmental Hazards: Assessing Risk and Reducing Disaster*. Second Edition. Routledge, London, UK.

Sperling, F. and F. Szekely, 2005: *Disaster Risk Management in a Changing Climate*. Discussion Paper prepared for the World Conference on Disaster Reduction on behalf of the Vulnerability and Adaptation Resource Group, Washington, DC.

Stainforth, D.A., M.R. Allen, E.R. Tredger, and L.A. Smith, 2007: Confidence, uncertainty, and decision-support relevance in climate predictions. *Philosophical Transactions of the Royal Society A*, **365**, 2145-2161.

Sterman, J.D., 2000: *Business Dynamics: Systems Thinking and Modeling for a Complex World*. Irwin/McGraw-Hill, Boston, MA.

Sterman, J.D., 2006: Learning from evidence in a complex world. *American Journal of Public Health*, **96**(**3**), 505-514.

Sterman, J.D., 2008: Risk communication on climate: mental models and mass balance. *Science*, **322(5901)**, 532-533.

Stott, P.A., D.A. Stone, and M.R. Allen, 2004: Human contribution to the European heatwave of 2003. *Nature*, **432**, 610-614.

Sui, J. and G. Koehler, 2001: Rain-on-snow induced flood events in Southern Germany. *Journal of Hydrology*, **252(1-4**), 205-220.

Thomalla, F., T. Downing, E. Spanger-Siegfried, G. Han and J. Rockström, 2006: Reducing hazard vulnerability: towards a common approach between disaster risk reduction and climate adaptation. *Disasters*, **30(1)**, 39-48.

Timmerman, P., 1981: *Vulnerability, Resilience and Collapse in Society*. Environmental Monograph No. 1, Institute for Environmental Studies, University of Toronto, Toronto, Canada.

Tobin, G.A. and B.E. Montz, 1997: *Natural Hazards: Explanation and Integration*. The Guildford Press, London, UK.

Tompkins, E.L., M.C. Lemos, and E. Boyd, 2008: A less disastrous disaster: Managing response to climate-driven hazards in the Cayman Islands and NE Brazil. *Global Environmental Change – Human and Policy Dimensions*, **18**, 736-745.

Torry, W., 1979: Intelligence, resilience and change in complex social systems: famine management in India. *Mass Emergencies*, **2**, 71-85.

TRB, 2008: *The Potential Impacts of Climate Change on U.S. Transportation*. Special Report 290, Transportation Research Board, National Academy of Sciences, Washington, DC. (See Appendix C: Commissioned paper: Climate Variability and Change with Implications for U.S. Transportation, Dec. 2006).

Tversky, A., and Kahneman, D., 1974: Judgment under uncertainty: Heuristics and biases. *Science*, **185**, 1124-1131.

Twigg, J., 2004: *Disaster Risk Reduction: Mitigation and Preparedness in Development and Emergency Programming*. Overseas Development Institute, London, UK.

Ulbrich, U., A.H. Fink, M. Klawa, and J.G. Pinto, 2001: Three extreme storms over Europe in December 1999. *Weather*, **56**, 70-80.

UNDP, 2004: *Reducing Disaster Risk: A Challenge for Development. A Global Report*. United Nations Development Programme, New York, NY.

UNEP, 1972: *Declaration of the United Nations Conference on the Human Environment*. United Nations Environment Programme, Nairobi, Kenya.

UNISDR, 2005: *Hyogo Framework for Action 2005-2015*. *Building the Resilience of Nations and Communities to Disasters*. United Nations International Strategy for Disaster Reduction, Geneva, Switzerland.

UNISDR, 2008a: *Climate Change and Disaster Risk Reduction*. Briefing Note 01, United Nations International Strategy for Disaster Reduction, Geneva, Switzerland.

UNISDR, 2008b: *Indigenous Knowledge for Disaster Risk Reduction - Good Practices and Lessons Learned from Experiences in the Asia-Pacific Region*. United Nations International Strategy for Disaster Reduction, Bangkok, Thailand.

UNISDR, 2008c: *Linking Disaster Risk Reduction and Poverty Reduction, Good Practices and Lessons Learned*. United Nations International Strategy for Disaster Reduction, UNDP, Geneva, Switzerland.

UNISDR, 2009a: *Adaptation to Climate Change by Reducing Disaster Risk: Country Practices and Lessons*. Briefing Note 02, United Nations International Strategy for Disaster Reduction, Geneva, Switzerland.

UNISDR, 2009b: *Reducing Disaster Risk through Science: Issues and Actions*. Full Report of the Scientific and Technical Committee 2009, United Nations International Strategy for Disaster Reduction, Geneva, Switzerland.

UNISDR, 2009c: *After Action Review: Second Session Global Platform for Disaster Risk Reduction*. United Nations International Strategy for Disaster Reduction, Geneva, Switzerland.

UNISDR (United Nations International Strategy for Disaster Reduction), 2009d: *Terminology: Basic Terms of Disaster Risk Reduction*. UNISDR, Geneva, Switzerland, www.unisdr.org/eng/library/lib-terminology-eng%20home.htm.

UNISDR, 2009e: *Global Assessment Report on Disaster Risk Reduction: Risk and Poverty in a Changing Climate – Invest Today for a Safer Tomorrow*. United Nations International Strategy for Disaster Reduction, Geneva, Switzerland, 207 pp.

UNISDR, 2011: *Global Assessment Report on Disaster Risk Reduction. Revealing Risk, Redefining Development*. United Nations International Strategy for Disaster Reduction, Geneva, Switzerland.

Vale, L.J. and T.J. Campanella, 2005: *The Resilient City: How Modern Cities Recover from Disaster*. Oxford University Press, Oxford, UK.

van Baars, S. and I.M. Van Kempen, 2009: The causes and mechanisms of historical dike failures in the Netherlands. *E-Water Official Publication of the European Water Association*, Hennef, Germany, 14 pp., www.dwa.de/portale/ewa/ewa.nsf/C125723B0047EC38/8428F628AB57BECFC125766C003024B6/$FILE/Historical%20Dike%20Failures.pdf.

van Kerkhoff, L. and L. Lebel, 2006: Linking knowledge and action for sustainable development. *Annual Review of Environment and Resources*, **31**,445-477.

van Niekerk, D., 2007: Disaster risk reduction, disaster risk management and disaster management: Academic rhetoric or practical reality? *Disaster Management South Africa*, **4**(**1**), 6.

Vandentorren, S., F. Suzan, S. Medina, M. Pascal, A. Maulpoix, J.C. Cohen, and M. Ledrans, 2004: Mortality in 13 French cities during the August 2003 heat wave. *American Journal of Public Health*, **94(9)**, 1518-1520.

Venton, P. and S. La Trobe, 2008: *Linking Climate Change Adaptation and Disaster Risk Reduction*. Technical Paper, Tearfund, Teddington, UK.

Walker, B.H., J.M. Anderies, A.P. Kinzig, and P. Ryan (eds), 2006: *Exploring Resilience in Social-Ecological Systems: Comparative Studies and Theory Development*. CSIRO Publishing, Collingwood, Australia.

Walker, W.E., A.W. Vincent, J. Marchau, and D. Swanson, 2010: Addressing deep uncertainty using adaptive policies. *Technological Forecasting and Social Change*, **77**, 917-923.

Walshaw, D., 2000: Modelling extreme wind speeds in regions prone to hurricanes. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, **49**, 51-62.

Watts, M., 1983: On the poverty of theory: natural hazards research in context. In: *Interpretations of Calamity* [Hewitt, K. (ed.)]. Allen and Unwin, Boston, MA, pp. 231-262.

Weber, E.U., 2006: Experience-based and description-based perceptions of long-term risk: why global warming does not scare us (yet). *Climatic Change*, **77**, 103-120.

Weber, E.U., 2010: What shapes perceptions of climate change? *Wiley Interdisciplinary Reviews: Climate Change*, **1**, 332-342.

Weber, E.U. and P.C. Stern, 2011: Public understanding of climate change in the United States. *American Psychologist*, **66(4)**, 315-328.

Weber, E.U., S. Shafir, and A.R. Blais, 2004: Predicting risk-sensitivity in humans and lower animals: Risk as variance or coefficient of variation. *Psychological Review*, **111**, 430-445.

Weichselgartner, J., 2001: Disaster mitigation: the concept of vulnerability revisited. *Disaster Prevention and Management*, **10(2)**, 85-94.

Werner, E.E., J.M. Bierman, and F.E. French, 1971: *The Children of Kauai Honolulu*. University of Hawaii Press, Honolulu, Hawaii.

Westerling, A.L. and T.W. Swetman, 2003: Interannual to decadal drought and wildfire in the Western United States. *EOS, Transactions American Geophysical Union*, **84(49)**, 545-555, doi:10.1029/2003EO490001.

Wheater, H.S., 2002: Progress in and prospects for fluvial flood modeling. *Philosophical Transactions of the Royal Society A*, **360**, 1409-1431.

Wijkman, A. and L. Timberlake, 1988: *Natural Disasters: Acts of God or Acts of Man*? New Society Publishers, Philadelphia, PA.

Wilby, R.L. and S. Dessai, 2010: Robust adaptation to climate change. *Weather*, **65(7)**, 180-185.

Wisner, B., P. O'Keefe, and K. Westgate, 1977: Global systems and local disasters: the untapped power of peoples' science. *Disasters*, **1(1)**, 47-57.

Wisner, B., P. Blaikie, T. Cannon, and I. Davis, 2004: *At Risk: Natural Hazards, People's Vulnerability, and Disasters*, 2nd edition. Routledge, London, UK.

Wisner, B., J.C. Gaillard, and I. Kellman (eds.), 2011: *Handbook of Hazards and Disaster Risk Reduction*. Routledge, London, UK.

WMO, 2010: *Understanding Climate*. World Meteorological Organization, Geneva, Switzerland, www.wmo.int/pages/themes/climate/understanding_climate.php.

World Bank, 2001: *World Development Report 2000-2001*. World Bank, Washington, DC.

World Bank, 2009: *World Development Report 2010: Development and Climate Change*. World Bank, Washington, DC.

WRI (World Resources Institute), United Nations Development Programme, United Nations Environment Programme, and World Bank, 2008: *World Resources 2008: Roots of Resilience: Growing the Wealth of the Poor*. WRI, Washington, DC.

Xie, L., L.J. Pietrafesa, and M. Peng, 2004: Incorporation of a mass-conserving inundation scheme into a three dimensional storm surge model. *Journal of Coastal Research*, **20**, 1209-1233.

Yohe, G. and R.S.J. Tol, 2002: Indicators for social and economic coping capacity – moving toward a working definition of adaptive capacity. *Global Environmental Change*, **12(1)**, 25-40.

Young, P.C. 2002: Advances in real-time flood forecasting. *Philosophical Transactions of the Royal Society*, **A360**, 1433-1450.

Zipser, E.J., D.J. Cecil, C. Liu, S.W. Nesbitt and D.P. Yorty, 2006: Where are the most intense thunderstorms on Earth? *Bulletin of the American Meteorological Society*, **87**, 1057-1071.