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Case Studies

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This chapter should be cited as:

Murray, V., G. McBean, M. Bhatt, S. Borsch, T.S. Cheong, W.F. Erian, S. Llosa, F. Nadim, M. Nunez, R. Oyun, and A.G. Suarez, 2012: Case studies. 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. 487-542.

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Executive Summary

Case studies contribute more focused analyses which, in the context of human loss and damage, demonstrate the effectiveness of response strategies and prevention measures and identify lessons about success in disaster risk reduction and climate change adaptation. The case studies were chosen to complement and be consistent with the information in the preceding chapters, and to demonstrate aspects of the key messages in the Summary for Policymakers and the Hyogo Framework for Action Priorities.

The case studies were grouped to examine types of extreme events, vulnerable regions, and methodological approaches. For the extreme event examples, the first two case studies pertain to events of extreme temperature with moisture deficiencies in Europe and Australia and their impacts including on health. These are followed by case studies on drought in Syria and *dzud*, cold-dry conditions in Mongolia. Tropical cyclones in Bangladesh, Myanmar, and Mesoamerica, and then floods in Mozambique are discussed in the context of community actions. The last of the extreme events case studies is about disastrous epidemic disease, using the case of cholera in Zimbabwe, as the example.

The case studies chosen to reflect vulnerable regions demonstrate how a changing climate provides significant concerns for people, societies, and their infrastructure. These are: Mumbai as an example of a coastal megacity; the Republic of the Marshall Islands, as an example of small island developing states with special challenges for adaptation; and Canada's northern regions as an example of cold climate vulnerabilities focusing on infrastructures.

Four types of methodologies or approaches to disaster risk reduction (DRR) and climate change adaptation (CCA) are presented. Early warning systems; effective legislation; risk transfer in developing countries; and education, training, and public awareness initiatives are the approaches demonstrated. The case studies demonstrate that current disaster risk management (DRM) and CCA policies and measures have not been sufficient to avoid, fully prepare for, and respond to extreme weather and climate events, but these examples demonstrate progress.

A common factor was the need for greater information on risks before the events occur, that is, early warnings. The implementation of early warning systems does reduce loss of lives and, to a lesser extent, damage to property and was identified by all the extreme event case studies (heat waves, wildfires, drought, *dzud,* cyclones, floods, and epidemic disease) as key to reducing impacts from extreme events. A need for improving international cooperation and investments in forecasting was recognized in some of the case studies but equally the need for regional and local early warning systems was heavily emphasized, particularly in developing countries.

A further common factor identified overall was that it is better to invest in preventative-based DRR plans, strategies, and tools for adaptation than in response to extreme events. Greater investments in proactive hazard and vulnerability reduction measures, as well as development of capacities to respond and recover from the events were demonstrated to have benefits. Specific examples for planning for extreme events included increased emphasis on drought preparedness; planning for urban heat waves; and tropical cyclone DRM strategies and plans in coastal regions that anticipate these events. However, as illustrated by the small island developing states case study, it was also identified that DRR planning approaches continue to receive less emphasis than disaster relief and recovery.

One recurring theme is the value of investments in knowledge and information, including observational and monitoring systems, for cyclones, floods, droughts, heat waves, and other events from early warnings to clearer understanding of health and livelihood impacts. In all cases, the point is made that with greater information available it would be possible to know the risks better and ensure that response strategies were adequate to face the coming threat. Research improves our knowledge, especially when it integrates the natural, social, health, and engineering sciences and their applications. The case studies have reviewed past events and identified lessons which could be considered for the future. Preparedness through DDR and DRM can help to adapt to climate change and these case studies offer examples of measures that could be taken to reduce the damage that is inflicted as a result of extreme events. Investment in increasing knowledge and warning systems, adaptation techniques, and tools and preventive measures will cost money now but will save money and lives in the future.

9.1. Introduction

In this chapter, case studies are used as examples of how to gain a better understanding of the risks posed by extreme weather and climate-related events while identifying lessons and best practices from past responses to such occurrences. Using the information in Chapters 1 to 8, it was possible to focus on particular examples to reflect the needs of the whole Special Report. The chosen case studies are illustrative of an important range of disaster risk reduction, disaster risk management, and climate change adaptation issues. They are grouped to examine representative types of extreme events, vulnerable regions, and methodological approaches.

For the extreme event examples, the first two case studies pertain to extreme temperature with moisture deficiencies: the European heat waves of 2003 and 2006 and response to disaster induced by hot weather and wildfires in Australia. Managing the adverse consequences of drought is the third case study, with the focus on Syrian droughts. The combination of drought and cold is examined through two recent *dzud* disasters in Mongolia, 1999-2002 and 2009-2010. Tropical cyclones in Bangladesh, Myanmar, and Mesoamerica are used as examples of how a difference can be made via enabling policies and responsive institutions for community action. The next case study shifts the geographical focus to floods in Mozambique in 2000 and 2007. The last of the extreme events case studies is about disastrous epidemic disease, using the case of cholera in Zimbabwe, as the example.

The case studies chosen to reflect a few vulnerable regions all demonstrate how a changing climate provides significant concerns for people, societies, and their infrastructure. The case of Mumbai is used as an example of a coastal megacity and its risks. Small island developing states have special challenges for adaptation, with the Republic of the Marshall Islands being the case study focus. Cold climate vulnerabilities, particularly the infrastructure in Canada's northern regions, provide the final vulnerable region case study.

Following examples of extreme events and vulnerable regions, this chapter presents case study examination of four types of methodologies or approaches to DRR and CCA. Early warning systems provide the opportunity for adaptive responses to reduce impacts. Effective legislation to provide multi-level governance is another way of reducing impacts. The case study on risk transfer examines the role of insurance and other instruments in developing countries. The final case study is on education, training, and public awareness initiatives. This selection provides a good basis of information and serves as an indicator of the resources needed for future DRR and CCA. Additionally, it allows good practices to be identified and lessons to be extracted.

The case studies provide the opportunity for connecting with common elements across the other chapters. Each case study is presented in a consistent way to enable better comparison of approaches. After an introduction, authors provide background to the event, vulnerable region, or methodology. Then the description of the events, vulnerability, or strategy is given as appropriate. Next is the discussion of interventions, followed by the outcomes and/or consequences. Each case study concludes with a discussion of lessons identified. These case studies relate to the key messages of the Summary for Policymakers and also to the Hyogo Framework for Action Priorities (see Table 9-1).

Case studies are widely used in many disciplines including health care (Keen and Packwood, 1995; McWhinney, 2001), social science (Flyvbjerg, 2004), engineering, and education (Verschuren, 2003). In addition, case studies have been found to be useful in previous IPCC Assessment Reports, including the 2007 Working Group II report (Parry et al., 2007). Case studies offer records of innovative or good practices. Specific problems or issues experienced can be documented as well as the actions taken to overcome these. Case studies can validate our understanding and encourage re-evaluation and learning. It is apparent that (i) case studies capture the complexity of disaster risk and disaster situations; (ii) case studies appeal to a broad audience; and (iii) case studies should be fully utilized to provide lessons identified for DRR and DRM for adaptation to climate change (Grynszpan et al., 2011). Several projects have identified lessons from case studies (Kulling et al., 2010). The Forensic Investigation of Disaster (Burton, 2011; FORIN, 2011) Project of the Integrated Research on Disaster Risk (ICSU, 2008) program has developed a methodology and template for future case study investigations to provide a basis for future policy analysis and literature for assessments. The FORIN template lays out the elements: (a) critical cause analysis; (b) meta-analysis; (c) longitudinal analysis; and (d) scenarios of disasters.

Case studies included in this chapter have been extracted from a variety of literature sources from many disciplines. As a result, an integrated approach examining scientific, social, health, and economic aspects of disasters was used where appropriate and included different spatial and temporal scales, as needed. The specialized insights they provide can be useful in evaluating some current disaster response practices.

This chapter addresses events whose impacts were felt in many dimensions. A single event can produce effects that are felt on local, regional, national, and international levels. These effects could have been the direct result of the event itself, from the response to the event, or through indirect impacts such as a reduction in food production or a decrease in available resources. In addition to the spatial scales, this chapter also addresses temporal scales, which vary widely in both event-related impacts and responses. However, the way effects are felt is additionally influenced by social, health, and economic factors. The resilience of a society and its economic capacity to allay the impact of a disaster and cope with the after effects has significant ramifications for the community concerned (UNISDR, 2008a). Developing countries with fewer resources, experts, equipment, and infrastructure have been shown to be particularly at risk (see Chapter 5). Developed nations are usually better equipped with technical, financial, and institutional support to enable better adaptive planning including preventive measures and/or quick and effective responses (Gagnon-Lebrun and Agrawala, 2006). However, they still remain at risk of high-impact events, as exemplified by the European heat wave of 2003 and by Hurricane Katrina (Parry et al., 2007).

Table 9-1 | Matrix demonstrating the connectivity between the case studies (9.2.1-9.2.14) and the Summary for Policymakers messages. Those with the strongest relationship are shown. Connectivity between the case studies and the Hyogo Framework for Action Priority Areas (UNISDR, 2005b) are also shown.

	Key Message	9.2.1 Heat-waves	9.2.2 Hot weather and wildfires	9.2.3 Drought	9.2.4 Dzud	9.2.5 Cyclones	9.2.6 Floods	9.2.7 Epidemic Disease	9.2.8 Mega-cities	9.2.9 SIDS	9.2.10 Cold Climate	9.2.11 EWS	9.2.12 Legislation	9.2.13 Risk Transfer	9.2.14 Education
A. Context	Exposure and vulnerability are key determinants of disaster risk.	●		●		●	●								
	A changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events, and can result in unprecedented extreme weather and climate events.	●	●		●			●							
B. Observations of Exposure, Vulnerability, Climate Extremes, Impacts, and Disaster Losses	Exposure and vulnerability are dynamic, varying across temporal and spatial scales, and depend on economic, social, geographic, demographic, cultural, institutional, governance, and environmental factors.								●		●		●		
	Settlement patterns, urbanization, and changes in socioeconomic status have all influenced observed trends in exposure and vulnerability to climate extremes.					●			●	●					
C. Disaster Risk Management and Adaptation to Climate Change: Past Experience with Climate Extremes	Trends in exposure and vulnerability are major drivers of changes in disaster risk.	●		●				●							
	Inequalities influence local coping and adaptive capacity, and pose disaster risk management and adaptation challenges from the local to national levels.					●			●					●	
	Humanitarian relief is often required when disaster risk reduction measures are absent or inadequate.			●	●		●	●							
	Post-disaster recovery and reconstruction provide an opportunity for reducing weather and climate-related disaster risk and for improving adaptive capacity.					●	●						●		●
	Risk sharing and transfer mechanisms at local, national, regional, and global scales can increase resilience to climate extremes.		●											●	
	Attention to the temporal and spatial dynamics of exposure and vulnerability is particularly important given that the design and implementation of adaptation and disaster risk management strategies and policies can reduce risk in the short term, but may increase exposure and vulnerability over the longer term.	●								●					
	Closer integration of disaster risk management and climate change adaptation, along with the incorporation of both into local, subnational, national, and international development policies and practices, could provide benefits at all scales.								●	●		●	●		
D. Future Climate Extremes, Impacts, and Disaster Losses	Models project substantial warming in temperature extremes by the end of the 21st century.	●	●								●				
	It is *likely* that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe.						●								
	There is *medium confidence* that droughts will intensify in the 21st century in some seasons and areas, due to reduced precipitation and/or increased evapotranspiration.			●											

Continued next page →

Table 9-1 (continued)

	Key Message	9.2.1 Heat-waves	9.2.2 Hot weather and wildfires	9.2.3 Drought	9.2.4 Dzud	9.2.5 Cyclones	9.2.6 Floods	9.2.7 Epidemic Disease	9.2.8 Mega-cities	9.2.9 SIDS	9.2.10 Cold Climate	9.2.11 EWS	9.2.12 Legislation	9.2.13 Risk Transfer	9.2.14 Education
E. Managing Changing Risk of Climate Extremes and Disasters	Measures that provide benefits under current climate and a range of future climate change scenarios, called low-regrets measures, are available starting points for addressing projected trends in exposure, vulnerability, and climate extremes. They have the potential to offer benefits now and lay the foundation for addressing projected changes.										●	●	●	●	
	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.					●			●	●			●		
	Multi-hazard risk management approaches provide opportunities to reduce complex and compound hazards.		●									●			
	Integration of local knowledge with additional scientific and technical knowledge can improve disaster risk reduction and climate change adaptation.			●	●		●				●				●
	Appropriate and timely risk communication is critical for effective adaptation and disaster risk management.		●									●		●	
Hyogo Framework for Action – Priorities for Action	1: Ensure that disaster risk reduction is a national and a local priority with a strong institutional basis for implementation.					●	●				●		●		●
	2: Identify, assess and monitor disaster risks and enhance early warning.	●	●					●				●			
	3: Use knowledge, innovation and education to build a culture of safety and resilience at all levels.						●							●	●
	4: Reduce the underlying risk factors.	●		●							●			●	
	5: Strengthen disaster preparedness for effective response at all levels.				●	●			●	●		●	●		

Most importantly, this chapter highlights the complexities of disasters in order to encourage effective solutions that address these complexities rather than just one issue or another. The lessons of this chapter provide examples of experience that can help develop strategies to adapt to climate change.

9.2. Case Studies

9.2.1. European Heat Waves of 2003 and 2006

9.2.1.1. Introduction

Extreme heat is a prevalent public health concern throughout the temperate regions of the world and extreme heat events have been encountered recently in North America, Asia, Africa, Australia, and Europe. It is *very likely* that the length, frequency, and/or intensity of warm spells, including heat waves, will continue to increase over most land areas (Section 3.3.1). As with other types of hazards, extreme heat can have disastrous consequences, particularly for the most vulnerable populations. Risk from extreme heat is a function of hazard severity and population exposure and vulnerability. Extreme heat events do not necessarily translate into extreme impacts if vulnerability is low. It is important, therefore, to consider factors that contribute to hazard exposure and population vulnerability. Recent literature has identified a host of factors that can amplify or dampen hazard exposure. Experience with past heat waves and public health interventions suggest that it is possible to manipulate many of these variables to reduce both exposure and vulnerability and thereby limit the impacts of extreme heat events. This case study, which compares the European heat wave of 2003 with 2006, demonstrates developments in disaster risk management and adaptation to climate change.

9.2.1.2. Background/Context

Extreme heat is a prevalent public health concern throughout the temperate regions of the world (Kovats and Hajat, 2008), in part because heat-related extreme events are projected to result in increased mortality (Peng et al., 2010). Extreme heat events have been encountered recently in North America (Hawkins-Bell and Rankin, 1994; Klinenberg, 2002), Asia (Kumar, 1998; Kalsi and Pareek, 2001; Srivastava et al., 2007), Africa (NASA, 2008), Australia (DSE, 2008b), and Europe (Robine et al., 2008; Founda and Giannakopoulos, 2009). This concern may also be present in non-temperate regions, but there is little research on this.

As with other types of hazards, extreme heat events can have disastrous consequences, partly due to increases in exposure and particular types of vulnerabilities. However, it is important to note that reducing the impacts of extreme heat events linked to climate change will necessitate further actions, some of which may be resource intensive and further exacerbate climate change.

9.2.1.2.1. Vulnerabilities to heat waves

Physiological: Several factors influence vulnerability to heat-related illness and death. Most of the research related to such vulnerability is derived from experiences in industrialized nations. Several physiological factors, such as age, gender, body mass index, and preexisting health conditions, play a role in the body's ability to respond to heat stress. Older persons, babies, and young children have a number of physiological and social risk factors that place them at elevated risk, such as decreased ability to thermoregulate (the ability to maintain temperature within the narrow optimal physiologic range; Havenith, 2001). Preexisting chronic disease – more common in the elderly – also impairs compensatory responses to sustained high temperatures (Havenith, 2001; Shimoda, 2003). Older adults tend to have suppressed thirst impulse resulting in dehydration and increased risk of heat-related illness. In addition, multiple diseases and/or drug treatments increase the risk of dehydration (Hodgkinson et al., 2003; Ebi and Meehl, 2007).

Social: A wide range of socioeconomic factors are associated with increased vulnerability (see Sections 2.3 and 2.5). Areas with high crime rates, low social capital, and socially isolated individuals had increased vulnerability during the Chicago heat wave in 1995 (Klinenberg, 2002). People in areas of low socioeconomic status are generally at higher risk of heat-related morbidity and mortality due to higher prevalence of chronic diseases – from cardiovascular diseases such as hypertension to pulmonary disease, such as chronic obstructive pulmonary disease and asthma (Smoyer et al., 2000; Sheridan, 2003). Minorities and communities of low socioeconomic status are also frequently situated in higher heat stress neighborhoods (Harlan et al., 2006). Protective measures are often less available for those of lower socioeconomic status, and even if air conditioning, for example, is available, some of the most vulnerable populations will choose not to use it out of concern over the cost (O'Neill et al., 2009). Other groups, like the homeless and outdoor workers, are particularly vulnerable because of their living situation and being more acutely exposed to heat hazards (Yip et al., 2008). Older persons may also often be isolated and living alone, and this may increase vulnerability (Naughton et al., 2002; Semenza, 2005).

9.2.1.2.2. Impact of urban infrastructure

Addressing vulnerabilities in urban areas will benefit those at risk. Around half of the world's population live in urban areas at present, and by 2050, this figure is expected to rise to about 70% (UN, 2008). Cities across the world are expected to absorb most of the population growth over the next four decades, as well as continuing to attract migrants from rural areas (UN, 2008). In the context of a heat-related extreme event, certain infrastructural factors can either amplify or reduce vulnerability of exposed populations. The built environment is important since local heat production affects the urban thermal budget (from internal combustion engines, air conditioners, and other activities). Other factors also play a role in determining local temperatures, including surface reflectivity or albedo, the percent of vegetative cover, and thermal conductivity of building materials. The urban heat island effect, caused by increased absorption of infrared radiation by buildings and pavement, lack of shading, evapotranspiration by vegetation, and increased local heat production, can significantly increase temperatures in the urban core by several degrees Celsius, raising the likelihood of hazardous heat exposure for urban residents (Clarke, 1972; Shimoda, 2003). Street canyons where building surfaces absorb heat and affect air flow are also areas where heat hazards may be more severe (Santamouris et al., 1999; Louka et al., 2002). The restricted air flow within street canyons may also cause accumulation of traffic-related air pollutants (Vardoulakis et al., 2003).

Research has also identified that, at least in the North American and European cities where the phenomenon has been studied, these factors can have a significant impact on the magnitude of heat hazards on a neighborhood level (Harlan et al., 2006). One study in France has shown that higher mortality rates occurred in neighborhoods in Paris that were characterized by higher outdoor temperatures (Cadot et al., 2007). High temperatures can also affect transport networks when heat damages roads and rail tracks. Within cities, outdoor temperatures can vary significantly (Akbari and Konopacki, 2004), resulting in the need to focus preventive strategies on localized characteristics.

Systems of power generation and transmission partly explain vulnerability since electricity supply underpins air conditioning and refrigeration – a significant adaptation strategy particularly in developed countries, but one that is also at increased risk of failure during a heat wave (Sailor and Pavlova, 2003). It is expected that demand for electricity to power air conditioning and refrigeration units will increase with rising ambient temperatures. Areas with lower power capacities face increased risk of disruptions to generating resources and transmission under excessive heat events.

In addition to increased demand, there can be a risk of reduced output from power generating plants (UNEP, 2004). The ability of inland thermal power plants, both conventional and nuclear, to cool their generators is restricted by rising river temperatures. Additionally, fluctuating levels of water availability will affect energy outputs of hydropower complexes. During the summer of 2003 in France, six power plants were shut down and others had to control their output (Parry et al., 2007).

9.2.1.2.3. Heat waves and air pollution

Concentrations of air pollutants such as particulate matter and ozone are often elevated during heat waves due to anticyclonic weather conditions, increased temperatures, and light winds. Photochemical production of ozone and emissions of biogenic ozone precursors increase during hot, sunny weather, and light winds do little to disperse the build-up of air pollution. Air pollution has well-established acute effects on health, particularly associated with respiratory and cardiovascular illness, and can result in increased mortality and morbidity (WHO, 2006a). Background ozone levels in the Northern Hemisphere have doubled since preindustrial times (Volz and Kley, 1988) and increased in many urban areas over the last few decades (Vingarzan, 2004). Air quality standards and regulations are helping to improve air quality, although particles and ozone are still present in many areas at levels that may cause harm to human health, particularly during heat waves (Royal Society, 2008; EEA, 2011). The effects of climate change (particularly temperature increases) together with a steady increase in background hemispheric ozone levels is reducing the efficacy of measures to control ozone precursor emissions in the future (Derwent et al., 2006). The increased frequency of heat waves in the future will probably lead to more frequent air pollution episodes (Stott et al., 2004; Jones et al., 2008).

9.2.1.3. Description of Events

9.2.1.3.1. European heat wave of 2003

During the first two weeks of August 2003, temperatures in Europe soared far above historical norms. The heat wave stretched across much of Western Europe, but France was particularly affected (InVS, 2003). Maximum temperatures recorded in Paris remained mostly in the range of 35 to 40°C between 4 and 12 August, while minimum temperatures recorded by the same weather station remained almost continuously above 23°C between 7 and 14 August (Météo France, 2003). The European heat wave had significant health impacts (Lagadec, 2004). Initial estimates were of costs exceeding €13 billion, with a death toll of over 30,000 across Europe (UNEP, 2004). It has been estimated that mortality over the entire summer could have reached about 70,000 (Robine et al., 2008) with approximately 14,800 excess deaths in France alone (Pirard et al., 2005). The severity, duration, geographic scope, and impact of the event were unprecedented in recorded European history (Grynszpan, 2003; Kosatsky, 2005; Fouillet et al., 2006) and put the event in the exceptional company of the deadly Beijing heat wave of 1743, which killed at least 11,000, and possibly many more (Levick, 1859; Bouchama, 2004; Lagadec, 2004; Pirard et al., 2005; Robine et al., 2008).

During the heat wave of August 2003, air pollution levels were high across much of Europe, especially surface ozone (EEA, 2003). A rapid assessment was performed for the United Kingdom after the heat wave, using published exposure-response coefficients for ozone and PM_{10} (particulate matter with an aerodynamic diameter of up to 10 μm). The assessment associated 21 to 38% of the total 2,045 excess deaths in the United Kingdom in August 2003 to elevated ambient ozone and PM_{10} concentrations (Stedman, 2004). The task of separating health effects of heat and air pollution is complex; however, statistical and epidemiological studies in France also concluded that air pollution was a factor associated with detrimental health effects during August 2003 (Dear et al., 2005; Filleul et al., 2006).

9.2.1.3.2. European heat wave of 2006

Three years later, between 10 and 28 July 2006, Europe experienced another major heat wave. In France, it ranked second only to the one in 2003 as the most severe heat wave since 1950 (Météo France, 2006; Fouillet et al., 2008). The 2006 heat wave was longer in duration than that of 2003, but was less intense and covered less geographical area (Météo France, 2006). Ozone levels were high across much of southern and northwestern Europe in July 2006, with concentrations reaching levels only exceeded in 2003 to date (EEA, 2007). Across France, recorded maximum temperatures soared to 39 to 40°C, while minimum recorded temperatures reached 19 to 23°C (compared with 23 to 25°C in 2003) (Météo France, 2006). Based on a historical model, the temperatures were expected to cause around 6,452 excess deaths in France alone, yet only around 2,065 excess deaths were recorded (Fouillet et al., 2008).

9.2.1.4. Interventions

Efforts to minimize the public health impact for the heat wave in 2003 were hampered by denial of the event's seriousness and the inability of many institutions to instigate emergency-level responses (Lagadec, 2004). Afterwards several European countries quickly initiated plans to prepare for future events (WHO, 2006b). France, the country hit hardest, developed a national heat wave plan, surveillance activities, clinical treatment guidelines for heat-related illness, identification of vulnerable populations, infrastructure improvements, and home visiting plans for future heat waves (Laaidi et al., 2004).

9.2.1.5. Outcomes/Consequences

The difference in impact between the heat waves in 2003 and 2006 may be at least partly attributed to the difference in the intensity and geographic scope of the hazard. It has been considered that in France at least, some decrease in 2006 mortality may also be attributed to increased awareness of the ill effects of a heat wave, the preventive measures instituted after the 2003 heat wave, and the heat health watch system set up in 2004 (Fouillet et al., 2008). While the mortality reduction may demonstrate the efficacy of public health measures, the persistent excess mortality highlights the need for optimizing existing public health measures such as warning and watch systems (Hajat et al., 2010), health communication with vulnerable populations (McCormick, 2010a), vulnerability mapping (Reid et al., 2009), and heat wave response plans (Bernard and McGeehin, 2004). It also highlights the need for other, novel measures such as modification of the urban form to reduce exposure (Bernard and McGeehin, 2004; O'Neill et al., 2009; Reid et al., 2009; Hajat et al., 2010; Silva et al., 2010). Thus the outcomes from the two European heat waves of 2003 and 2006 are extensive and are considered below. They include public health approaches to reducing exposure, assessing heat mortality, communication and education, and adapting the urban infrastructure.

9.2.1.5.1. Public health approaches to reducing exposure

A common public health approach to reducing exposure is the Heat Warning System (HWS) or Heat Action Response System. The four components of the latter include an alert protocol, community response plan, communication plan, and evaluation plan (Health Canada, 2010). The HWS is represented by the multiple dimensions of the EuroHeat plan, such as a lead agency to coordinate the alert, an alert system, an information outreach plan, long-term infrastructural planning, and preparedness actions for the health care system (WHO, 2007). The European Network of Meteorological Services has created Meteoalarm as a way to coordinate warnings and to differentiate them across regions (Bartzokas et al., 2010). There are a range of approaches used to trigger alerts and a range of response measures implemented once an alert has been triggered. In some cases, departments of emergency management lead the endeavor, while in others public health-related agencies are most responsible (McCormick, 2010b).

As yet, there is not much evidence on the efficacy of heat warning systems. A few studies have identified an effect of heat preparedness programming. For example, the use of emergency medical services during heat wave events dropped by 49% in Milwaukee, Wisconsin, between 1995 and 1999; an outcome that may be partly due to heat preparedness programming or to differences between the two heat waves (Weisskopf et al., 2002). Evidence has also indicated that interventions in Philadelphia, Pennsylvania, are *likely* to have reduced mortality rates by 2.6 lives per day during heat events (Ebi et al., 2004). An Italian intervention program found that caretaking in the home resulted in decreased hospitalizations due to heat (Marinacci et al., 2009). However, for all these studies, it is not clear whether the observed reductions were due to the interventions. Questions remain about the levels of effectiveness in many circumstances (Cadot et al., 2007).

Heat preparedness plans vary around the world. Philadelphia, Pennsylvania – one of the first US cities to begin a heat preparedness plan – has a ten-part program that integrates a 'block captain' system where local leaders are asked to notify community members of dangerous heat (Sheridan, 2006; McCormick, 2010b). Programs like the Philadelphia program that utilize social networks have the capacity to shape behavior since networks can facilitate the sharing of expertise and resources across stakeholders; however, in some cases the influence of social networks contributes to vulnerability (Crabbé and Robin, 2006). Other heat warning systems, such as that in Melbourne, Australia, are based solely on alerting the public to weather conditions that threaten older populations (Nicholls et al., 2008). Addressing social factors in preparedness promises to be critical for the protection of vulnerable populations. This includes incorporating communities themselves into understanding and responding to extreme events. It is important that top-down measures imposed by health practitioners account for community-level needs and experiences in order to be more successful. Greater attention to and support of community-based measures in preventing heat mortality can be more specific to local context, such that participation is broader (Semenza et al., 2007). Such programs can best address the social determinants of health outcomes.

9.2.1.5.2. Assessing heat mortality

Assessing excess mortality is the most widely used means of assessing the health impact of heat-related extreme events. Mortality represents only the 'tip of the iceberg' of heat-related health effects; however, it is more widely and accurately reported than morbidity, which explains its appeal as a data source. Nonetheless, assessing heat mortality presents particular challenges. Accurately assessing heat-related mortality faces challenges of differences in contextual variations (Hémon and Jougla, 2004; Poumadere et al., 2005), and coroner's categorization of deaths (Nixdorf-Miller et al., 2006). For example, there are a number of estimates of mortality for the European heat wave that vary depending on geographic and temporal ranges, methodological approaches, and risks considered (Assemblée Nationale, 2004). The different types of analyses used to assess heat mortality, such as certified heat deaths and heat-related mortality measured as an excess of total mortality over a given time period, are important distinctions in assessing who is affected by the heat (Kovats and Hajat, 2008). Learning from past and other countries' experience, a common understanding of definitions of heat waves and excess mortality, and the ability to streamline death certification in the context of an extreme event could improve the ease and quality of mortality reporting.

9.2.1.5.3. Communication and education

One particularly difficult aspect of heat preparedness is communicating risk. In many locations populations are unaware of their risk and heat wave warning systems go largely unheeded (Luber and McGeehin, 2008). Some evidence has even shown that top-down educational messages do not result in appropriate resultant actions (Semenza et al., 2008). The receipt of information is not sufficient to generate new behaviors or the development of new social norms. Even when information is distributed through pamphlets and media outlets, behavior of at-risk populations often does not change and those targeted by such interventions have suggested that community-based organizations be involved in order to build on existing capacity and provide assistance (Abrahamson et al., 2008). Older people, in particular, engage better with prevention campaigns that allow them to maintain independence and do not focus on their age, as many heat warning programs do (Hughes et al., 2008). More generally, research shows that communication about heat preparedness centered on engaging with communities results in increased awareness compared with top-down messages (Smoyer-Tomic and Rainham, 2001).

9.2.1.5.4. Adapting the urban infrastructure

Several types of infrastructural measures can be taken to prevent negative outcomes of heat-related extreme events. Models suggest that significant reductions in heat-related illness would result from land use modifications that increase albedo, proportion of vegetative cover, thermal conductivity, and emissivity in urban areas (Yip et al., 2008; Silva et al., 2010). Reducing energy consumption in buildings can improve resilience, since localized systems are less dependent on vulnerable energy infrastructure. In addition, by better insulating residential dwellings, people would suffer less effect from heat hazards. Financial incentives have been tested in some countries as a means to increase energy efficiency by supporting those who are insulating their homes. Urban greening can also reduce temperatures, protecting local populations and reducing energy demands (Akbari et al., 2001).

9.2.1.6. Lessons Identified

With climate change, heat waves are *very likely* to increase in frequency and severity in many parts of the world (Section 3.3.1). Smarter urban planning, improvements in existing housing stock and critical infrastructure, along with effective public health measures will assist in facilitating climate change adaptation.

Through understanding local conditions and experiences and current and projected risks, it will be possible to develop strategies for improving heat preparedness in the context of climate change. The specificity of heat risks to particular sub-populations can facilitate appropriate interventions and preparedness.

Communication and education strategies are most effective when they are community-based, offer the opportunity for changing social norms, and facilitate the building of community capacity.

Infrastructural considerations are critical to reducing urban vulnerability to extreme heat events. Effective preparedness includes building techniques that reduce energy consumption and the expansion of green space.

Heat wave preparedness programs may be able to prevent heat mortality; however, testing and development is required to assess the most effective approaches.

Further research is needed on the efficacy of existing plans, how to improve preparedness that specifically focuses on vulnerable groups, and how to best communicate heat risks across diverse groups. There are also methodological difficulties in describing individual vulnerability that need further exploration.

9.2.2. Response to Disaster Induced by Hot Weather and Wildfires

9.2.2.1. Introduction

Climate change is expected to increase global temperatures and change rainfall patterns (Christensen et al., 2007). These climatic changes will increase the risk of temperature- and precipitation-related extreme weather and climate events. The relative effects will vary by regions and localities (Sections 3.3.1, 3.3.2, and 3.5.1). In general, an increase in mean temperature, and a decrease in mean precipitation can contribute to increased fire risk (Flannigan et al., 2009). When in combination with severe droughts and heat waves, which are also expected to increase in many fire regions (Sections 3.3.1 and 3.5.1), fires can become catastrophic (Bradstock et al., 2009). Wildfires occur in many regions of the world, and due to their extreme nature, authorities and the public in general are acquainted with such extreme situations, and plans have been enacted to mitigate them. However, at times, the nature of fire challenges these plans and disasters emerge. This case study uses the example from Victoria, Australia, in 2009. The goal is to present hot weather and wildland fire hazards and their effects and potential impacts, and to provide an overview of experience to learn to manage these extreme risks, as well as key lessons for the future.

9.2.2.2. Background

Wildfire risk occurs in many regions of the globe; however embodying this risk in a single and practical universal index is difficult. The relationships between weather and wildfires have been studied for many areas of the world; in some, weather is the dominant factor in ignitions, while in others, human activities are the major cause of ignition, but weather and environmental factors mainly determine the area burned (Bradstock et al., 2009). Wildfire behavior is also modified by forest and land management and fire suppression (Allen et al., 2002; Noss et al., 2006). Wildfires do not burn at random in the landscape (Nunes et al., 2005), and occur at particular topographic locations or distances from towns or roads (Mouillot et al., 2003; Badia-Perpinyà and Pallares-Barbera, 2006; Syphard et al., 2009). The intensity and rate of spread of a wildfire is dependent on the amount, moisture content, and arrangement of fine dead fuel, the wind speed near the burning zone, and the terrain and slope where it is burning. Wildfire risk is a combination of all factors that affect the inception, spread, and difficulty of fire control and damage potential (Tolhurst, 2010).

9.2.2.3. Description of Events

An episode of extreme heat waves began in South Australia on 25 January 2009. Two days later they had become more widespread over southeast Australia. The exceptional heat wave was caused by a slow-moving high-pressure system that settled over the Tasman Sea, in combination with an intense tropical low located off the northwest

Australian coast and a monsoon trough over northern Australia. This produced ideal conditions for hot tropical air to be directed over southeastern Australia (National Climate Centre, 2009).

In Melbourne the temperature was above 43°C for three consecutive days (28 to 30 January 2009), reaching a peak of 45.1°C on 30 January 2009. This was the second-highest temperature on record. The extremely high day and night temperatures combined to produce a record high daily mean temperature of 35.4°C on 30 January (Victorian Government, 2009). The 2008 winter season was characterized by below-average precipitation across much of Victoria. While November and December 2008 experienced average and above average rainfall, respectively, in January and February the rainfall was substantially below average (Parliament of Victoria, 2010a). During the 12 years between 1998 and 2007, Victoria experienced warmer than average temperatures and a 14% decline in average rainfall (DSE, 2008a). In central Victoria the 12-year rainfall totals were approximately 10 to 20% below the 1961 to 1990 average (Australian Government, 2009).

This heat wave had a substantial impact on the health of Victorians, particularly the elderly (National Climate Centre, 2009; Parliament of Victoria, 2009). A 25% increase in total emergency cases and a 46% increase over the three hottest days were reported for the week of the heat wave. Emergency departments reported a 12% overall increase in presentations, with a greater proportion of acutely ill patients and a 37% increase in patients 75 years or older (Victorian Government, 2009). Attribution of mortality to a heat wave can be difficult, as deaths tend to occur from exacerbations of chronic medical conditions as well as direct heat-related illness; this is particularly so for the frail and elderly (Kovats and Hajat, 2008). However, excess mortality can provide a measure of the impact of a heat wave. With respect to total all-cause mortality, there were 374 excess deaths with a 62% increase in total all-cause mortality. The total number of deaths during the four days of the heat wave was 980, compared to a mean of 606 for the previous five years. Reported deaths in people 65 years and older more than doubled compared to the same period in 2008 (Victorian Government, 2009).

On 7 February 2009, the temperatures spiked again. The Forest Fire Danger Index, which is calculated using variables such as temperature, precipitation, wind speed, and relative humidity (Hennessy et al., 2005), this time reached unprecedented levels, higher than the fire weather conditions experienced on Black Friday in 1939 and Ash Wednesday in 1983 (National Climate Centre, 2009) – the two previous worse fire disasters in Victoria.

By the early afternoon of 7 February, wind speeds were reaching their peak, resulting in a power line breaking just outside the town of Kilmore, sparking a wildfire that would later generate extensive pyrocumulus cloud and become one of the largest, deadliest, and most intense firestorms ever experienced in Australia's history (Parliament of Victoria, 2010a). The majority of fire activity occurred between midday and midnight on 7 February, when wind speeds and temperature were at their highest and humidity at its lowest. A major wind change occurred late afternoon across the fire ground, turning the northeastern flank into a new wide fire front, catching many people by surprise. This was one of several hundred fires that started on this day, most of which were quickly controlled; however, a number went on to become major fires resulting in much loss of life. The worst 15 of these were examined in detail by the Victorian Bushfires Royal Commission (Parliament of Victoria, 2010a). A total of 173 people died as a result of the Black Saturday bushfires (Parliament of Victoria, 2010a). They also destroyed almost 430,000 ha of forests, crops, and pasture, and 61 businesses (Parliament of Victoria, 2009). The Victorian Bushfires Royal Commission conservatively values the cost of the 2009 fire at AUS$ 4.4 billion (Parliament of Victoria, 2010a).

9.2.2.4. Interventions

The Victorian Government had identified the requirement to respond to predicted heat events in the Sustainability Action Statement and Action Plan (released in 2006 and revised in January 2009), which committed to a Victorian Heat Wave Plan involving communities and local governments. As a part of this strategy, the Victorian Government has established the heat wave early warning system for metropolitan Melbourne and is undertaking similar work for regional Victoria. The government is also developing a toolkit to assist local councils in preparing for a heat wave response that could be integrated with existing local government public health and/or emergency management plans (Victorian Government, 2009).

The 'Prepare, Stay and Defend, or Leave Early' (SDLE) approach instructs that residents decide well before a fire whether they will choose to leave when a fire threatens but is not yet in the area, or whether they will stay and actively defend their property during the fire. SDLE also requires residents to make appropriate preparations in advance for either staying or leaving. Prior to 7 February 2009, the Victorian State Government devoted unprecedented efforts and resources to informing the community regarding fire risks. The campaign clearly had benefits, but there were a number of weaknesses and failures with Victoria's information and warning systems (Bushfire CRC, 2009; Parliament of Victoria, 2010b).

Another key focus during the wildfire season is protecting the reservoirs, especially the Upper Yarra and Thomson catchments that provide the majority of Melbourne's water supply (Melbourne Water, 2009a). During the February 2009 fires, billions of liters of water were moved from affected reservoirs to other safe reservoirs to protect Melbourne's drinking water from contamination with ash and debris (Melbourne Water, 2009b).

The Victorian Bushfires Royal Commission made wide-ranging recommendations about the way fire is managed in Victoria. These have included proposals to replace all single-wire power lines in Victoria, and new building regulations for bushfire-prone areas (Parliament of Victoria, 2010c).

9.2.2.5. Outcomes/Consequences

Following the findings from the various inquiries into the 2009 Victorian Bushfires, which found failings in assumptions, policies, and implementation, a number of far-reaching recommendations were developed (Parliament of Victoria, 2010c). National responses have been adopted through the National Emergency Management Committee, including: (i) revised bushfire safety policies to enhance the roles of warning and personal responsibility; (ii) increased fuel reduction burning on public lands; (iii) community refuges established in high-risk areas; (iv) improved coordination and communication between fire organizations; (v) modifying the 'Prepare, stay and defend, or leave early' approach (now 'Prepare, act, survive') to recognize the need for voluntary evacuations on extreme fire days; and (vi) further ongoing investment in bushfire research, including a national research center.

9.2.2.6 Lessons Identified

Australia has recognized the need for strengthening risk management capacities through measures including: (i) prior public campaigns for risk awareness; (ii) enhanced information and warning systems; (iii) translation of messages of awareness and preparedness into universal action; (iv) sharing responsibility between government and the people; (v) development of integrated plans; and (vi) greater investment in risk mitigation and adaptation actions.

Predicted changes in future climate will only exacerbate the impact of other factors through increased likelihood of extreme fire danger days (Hennessy et al., 2005). We are already seeing the impact of many factors on wildfires and heat waves, for example, demographic and land use changes. In the future, a better understanding of the interplay of all the causal factors is required. The Victorian Bushfires Royal Commission stated "It would be a mistake to treat Black Saturday as a 'one off' event. With populations at the rural-urban interface growing and the impact of climate change, the risks associated with bushfire are likely to increase" (Parliament of Victoria, 2010c).

9.2.3. Managing the Adverse Consequences of Drought

9.2.3.1. Introduction

Water is a critical resource throughout the world (Kundzewicz et al., 2007). Drought can increase competition for scarce resources, cause population displacements and migrations, and exacerbate ethnic tensions and the likelihood of conflicts (Barnett and Adger, 2007; Reuveny, 2007; UNISDR, 2011a). Mediterranean countries are prone to droughts that can heavily impact agricultural production, cause economic losses, affect rural livelihoods, and may lead to urban migration (UNISDR, 2011b). This case study focuses on Syria as one of the countries that has been affected by drought in recent years (2007-2010) (Erian et al., 2011).

9.2.3.2. Background

The Eastern Mediterranean region is subject to frequent soil moisture droughts, and in areas where annual rainfall ranges between 120-150 and 400 mm, rain-fed crops are strongly affected (Erian et al., 2011). During the period from 1960 to 2006, a severe decrease in annual rainfall has been documented in some major cities in Syria. These reductions were related to decreases in spring and winter rainfall (Skaff and Masbate, 2010). The negative trend in precipitation in Syria during the past century and the beginning of the 21st century is of a similar magnitude to that predicted by most general circulation models for the Mediterranean region in the coming decades (Giannakopoulos et al., 2009).

9.2.3.3. Description of Events

Syria is considered to be a dry and semi-arid country (FAO and NAPC, 2010). Three-quarters of the cultivated land depends on rainfall and the annual rate is less than 350 mm in more than 90% of the overall area (FAO, 2009; FAO and NAPC, 2010). Syria has a total population of 22 million people, 47% of whom live in rural areas (UN, 2011). The National Programme for Food Security in the Syrian Arab Republic reported that in the national economy of Syria, the agricultural and rural sector is vital, but with the occurrence of frequent droughts, this sector is less certain of maintaining its contribution of about 20 to 25% of GDP and employment of about 38 to 47% of the work force (UNRCS and SARPCMSPC, 2005; FAO and NAPC, 2010).

The prolonged drought, that in 2011 was in its fourth consecutive year, has affected 1.3 million people, and the loss of the 2008 harvest has accelerated migration to urban areas and increased levels of extreme poverty (UN, 2009, 2011; Sowers et al., 2011). During the 2008-2009 winter grain-growing season there were significant losses of both rain-fed and irrigated winter grain crops (USDA, 2008a). This was exacerbated by abnormally hot spring temperatures (USDA, 2008a). Wheat production decreased from 4,041 kt in 2007 to 2,139 kt in 2008, an almost 50% reduction (SARPMETT, 2010). Of the farmers who depended on rain-fed production, most suffered complete or near-total loss of crops (FAO, 2009). Approximately 70% of the 200,000 affected farmers in the rain-fed areas have produced minimal to no yields because seeds were not planted due to poor soil moisture conditions or failed germination (USDA, 2008b; FAO, 2009).

Herders in the region were reported to have lost around 80% of their livestock due to barren grasslands, and animal feed costs rose by 75%, forcing sales at 60 to 70% below cost (FAO, 2008). Many farmers and herders sold off productive assets, eroding their source of livelihoods, with only few small-scale herders retaining a few animals, possibly as few as 3 to 10% (FAO, 2009).

Drought has affected the livelihoods of small-scale farmers and herders, threatening food security and having negative consequences for entire families living in affected areas (FAO, 2009; UN, 2009). It is estimated that 1.3 million people have been affected by drought with up to 800,000 (75,641 households) being severely affected (FAO, 2009; UN, 2009). Of those severely affected, around 20% (160,000 people) are considered to be highly vulnerable, including female-headed households, pregnant women, children 14 and under, those with illness, the elderly, and the disabled (UN, 2009).

The United Nations (UN) estimates that a large number of the severely affected population are living below the poverty line (US$ 1/person/day) (UN, 2009). When combined with an increase in the price of food and basic resources, this reduced income has resulted in negative consequences for whole households (FAO, 2009). Many cannot afford basic supplies or food, which has led to a reduction in their food intake, the selling of assets, a rise in the rate of borrowing money, the degradation of land, urban migration, and children leaving school (FAO, 2009; UN, 2009; Solh, 2010). The UN assessment mission stated that the reasons for removing children from school included financial hardship, increased costs of transport, migration to cities, and the requirement for children to work to earn extra income for families (UN, 2009). Consequently, due to poor food consumption, the rates of malnutrition have risen between 2007 and 2008, with the Food and Agriculture Organization (FAO) estimating a doubling of malnutrition cases among pregnant women and children under five (FAO, 2008). Due to inadequate consumption of micro- and macronutrients in the most-affected households, it has been estimated that the average diet contains less than 15% of the recommended daily fat intake and 50% of the advised energy and protein requirements (UN, 2009).

One of the most visible effects of the drought was the large migration of between 40,000 and 60,000 families from the affected areas (UN, 2009; Solh, 2010; Sowers and Weinthal, 2010). In June 2009, it was estimated that 36,000 households had migrated from the Al-Hasakah Governorate (200,000-300,000 persons) to the urban centers of Damascus, Dara'a, Hama, and Aleppo (UN, 2009; Solh, 2010). Temporary settlements and camps were required, creating further strains on resources and public services, that had already been attempting to support approximately 1 million Iraqi refugees (UN, 2009; Solh, 2010). In addition, migration leads to worse health, educational, and social indicators among the migrant population (IOM, 2008; Solh, 2010).

Deficits in water resources exceeding 3.5 billion cubic meters have arisen in recent years due to growing water demands and drought (FAO and NAPC, 2010; SARPMETT, 2010). Interventions by a project further upstream to control the flow of the Euphrates and Tigris rivers have been initiated and these have had a significant impact on water variability downstream in Iraq and Syria, which, added to the severe drought, have caused these rivers to flow at well-below normal levels (USDA, 2008a; Daoudy, 2009; Sowers et al., 2011).

9.2.3.4. Interventions

The UN Syria Drought Response Plan was published in 2009. It was designed to address the emergency needs of, and to prevent further impact on, the 300,000 people most affected by protracted drought (FAO, 2009). The Response Plan identified as its strategic priorities the rapid provision of humanitarian assistance, the strengthening of resilience to future drought and climate change, and assisting in the return process and ensuring socioeconomic stability among the worst-affected groups (UN, 2009). Syria also welcomed international assistance provided to the drought-affected population through multilateral channels (Solh, 2010). Various loans to those affected, including farmers and women entrepreneurs, were provided (UN, 2009).

9.2.3.5. Outcomes/Consequences

A combination of actions including food and agriculture assistance, supplemented by water and health interventions, and measures aimed at increasing drought resilience, were identified as required to allow affected populations to remain in their villages and restart agricultural production (UN, 2009). Ongoing interventions with the aim of reducing vulnerability and increasing resilience to drought were summarized by the UN Syrian Drought Response Plan (UN, 2009) and FAO (FAO, 2009). These interventions were aimed at providing support through four main approaches: (1) the rapid distribution of wheat, barley, and legume seeds to 18,000 households in the affected areas, potentially assisting 144,000 people; (2) sustaining the remaining asset base of the approximately 20,000 herders by providing animal feed and limited sheep restocking to approximately 1,000 herders; (3) the development of a drought early warning system to facilitate the government taking early actions before serious and significant losses occur and to develop this to ensure sustainability; and (4) building capability to implement the national drought strategy by developing and addressing all stages of the disaster management cycle (FAO, 2009). Conservation agriculture (which has been defined as no-tillage, direct drilling/seeding, and drilling/seeding through a vegetative cover) is considered to be a way forward for sustainable land use (Stewart et al., 2008; Lalani 2011). However, how to take this forward has caused considerable debate (Stewart et al., 2008).

9.2.3.6. Lessons Identified

The need for the UN Syrian Drought Response Plan was identified and has facilitated the understanding of the work programs and links to the interventions listed in Case Study 9.2.3.4 (UN, 2009). Other response strategies that have been considered include:

- Development of capacities to identify, assess, and monitor drought risks through national and local multi-hazard risk assessment; building systems to monitor, archive, and disseminate data (Lalani, 2011), taking into account decentralization of resources, community participation, and regional early warning systems and networks (UNISDR, 2011a).
- Integrating activities in the national strategy for CCA and DRR, including drought risk loss insurance; improved water use efficiency; adopting and adapting existing water harvesting techniques; integrating use of surface and groundwater; upgrading irrigation

practices at both the farm level and on the delivery side; developing crops tolerant to salinity and heat stress; changing cropping patterns; altering the timing or location of cropping activities; diversifying production systems into higher value and more efficient water use options; and capacity building of relevant stakeholders in vulnerable national and local areas (Abou Hadid, 2009; El-Quosy, 2009).

- Building resilience through knowledge, advocacy, research, and training by making information on drought risk accessible (UNISDR, 2007a), and having any adaptation measures be developed as part of, and closely integrated into, overall and country-specific development programs and strategies that should be understood as a 'shared responsibility' (Easterling et al., 2007). This could be achieved through educational material and training to enhance public awareness (UN, 2009).

9.2.4. Recent *Dzud* Disasters in Mongolia

9.2.4.1. Introduction

This case study introduces *dzud* disaster: the impacts, intervention measures, and efforts toward efficient response using the example of two events that occurred in Mongolia in 1999-2002 and 2009-2010. Mongolia is a country of greatly variable, highly arid and semi-arid climate, with an extensive livestock sector dependent upon access to grasslands (Batima and Dagvadorj, 2000; Dagvadorj et al., 2010; Marin, 2010). The Mongolian term *dzud* denotes unusually extreme weather conditions that result in the death of a significant number of livestock over large areas of the country (Morinaga et al., 2003; Oyun, 2004). Thus, the term implies both exposure to such combinations of extreme weather conditions but also the impacts thereof (Marin, 2010).

9.2.4.2. Background

The climate of Mongolia is continental with sharply defined seasons, high annual and diurnal temperature fluctuations, and low rainfall (Batima and Dagvadorj, 2000). Summer rainfall seldom exceeds 380 mm in the mountains and is less than 50 mm in the desert areas (Dagvadorj et al., 2010). *Dzud* is a compound hazard (see Section 3.1.3 for discussion of compound events) occurring in this cold dry climate, and encompasses drought, heavy snowfall, extreme cold, and windstorms. It can last all year round and can cause mass livestock mortality and dramatic socioeconomic impacts – including unemployment, poverty, and mass migration from rural to urban areas, giving rise to heavy pressure on infrastructure and social and ecosystem services (Batima and Dagvadorj, 2000; Batjargal et al., 2001; Oyun, 2004; AIACC, 2006; Dagvadorj et.al., 2010).

There are several types of *dzud.* If there is heavy snowfall, the event is known as a *white dzud*, conversely if no snow falls, a *black dzud* occurs, which results in a lack of drinking water for herds (Morinaga et al., 2003; Dagvadorj et al., 2010). The trampling of plants by passing livestock migrating to better pasture or too high a grazing pressure leads to a *hoof dzud*, and a warm spell after heavy snowfall resulting in an icy crust cover on short grass blocking livestock grazing causes an *iron dzud* (Batjargal et al., 2001; Marin, 2008). Livestock have been the mainstay of Mongolian agriculture and the basis of its economy and culture for millennia (Mearns, 2004; Goodland et al., 2009). This sector is likely to continue to be the single most important sector of the economy in terms of employment (Mearns, 2004; Goodland et al., 2009).

In the last decades, *dzuds* occurred in 1944-1945, 1954-1955, 1956-1957, 1967-1968, 1976-1977, 1986-1987, 1993-1994, and 1996-1997, with further *dzuds* discussed below (Morinaga et al., 2003; Sternberg, 2010). The *dzud* of 1944-1945 was a record for the 20th century with mortality of one-third of Mongolia's total livestock (Batjargal et al., 2001). The 2009-2010 *dzud* caused similarly high animal mortality (NSO, 2011). The large losses of animals in *dzud* events demonstrates that Mongolia as a whole has low capacity to combat natural disaster (Batjargal et al., 2001). These potential losses are considered to be beyond the financial capacity of the government and the domestic insurance market (Goodland et al., 2009).

9.2.4.3. Description of Events – *Dzud* of 1999-2002 and of 2009-2010

Dzud disasters occurred in 1999-2002 and 2009-2010, causing social and economic impacts. These disasters occurred as a result of environmental and human-induced factors. The environmental factors included drought resulting in very limited pasture grass and hay with additional damage to pasture by rodents and insects (Batjargal et al., 2001; Begzsuren et al., 2004; Saizen et al., 2010). Human factors included budgetary issues for preparedness in both government and households, inadequate pasture management and coordination, and lack of experience of new and/or young herders (Batjargal et al., 2001). Climatic factors contributing to both *dzuds* were summer drought followed by extreme cold and snowfall in winter. However the autumn of 1999-2000 brought heavy snowfall and unusual warmth with ice cover, while the winter and spring of 2009-2010 also brought windstorms. Summer drought was a more significant contributor to the 1999-2000 *dzud* (Batjargal et al., 2001), while winter cold was more extreme in the 2009-2010 *dzud*.

9.2.4.3.1. *Dzud* of 1999-2002

The *dzud* began with summer drought followed by heavy snowfall and unusual warmth with ice cover in the autumn and extreme cold and snowfall in the winter. The sequence of events was as follows (Batjargal et al., 2001):

- ***Drought***: In the summer of 1999, 70% of the country suffered drought. Air temperature reached 41 to 43°C, exceeding its highest value recorded at meteorological stations since the 1960s. The condition persisted for a month and grasslands dried up. As a result, animals were unfit for the winter, with insufficient haymaking for winter preparedness.

- ***Iron dzud***: Autumn brought early snowfall and snow depth reached 30 to 40 cm, even 70 to 80 cm in some places. Heavy snowfall exceeding climatic means was recorded in October. Moreover, a warming in November and December by 1.7 to 3.5°C above the climatic mean resulted in snow cover compaction and high density, reaching 0.37 g cm^{-3}, and ice cover formation, both of which blocked livestock pasturing.
- ***White dzud***: In January, air temperature dropped down to -40 to -50°C over the western and northern regions of the country. The monthly average air temperature was lower than climatic means by 2 to 6°C. The cold condition persisted for two months. Abundant snowfall resulted with 80% of the country's territory being covered in snow of 24 to 46 cm depth.
- ***Black dzud***: Lack of snowfall in the Gobi region and Great Lake depression caused water shortages for animals.
- ***Hoof dzud***: The improper pasture management led to unplanned concentration of a great number of livestock in a few counties in the middle and south Gobi provinces that were not affected by drought and snowfall.

Animals were weakened as a result of long-lasting climatic hardship and forage shortage of this *dzud* (Batjargal et al., 2001). After three years of *dzuds* that occurred in sequence, the country had lost nearly one-third (approximately 12 million) of its livestock and Mongolia's national gross agricultural output in 2003 decreased by 40% compared to that in 1999 (Mearns, 2004; Oyun, 2004; AIACC, 2006; Lise et al., 2006; Saizen et al., 2010). It was reported that in 1998 there were an estimated 190,000 herding households but as a result of the *dzud,* 11,000 families lost all their livestock (Lise et al., 2006). Thus the *dzud* had severe impacts on the population and their livelihoods, including unemployment, poverty, and negative health impacts (Batjargal et al., 2001; Oyun, 2004; AIACC, 2006; Morris, 2011).

9.2.4.3.2. *Dzud* of 2009-2010

In the summer of 2009, Mongolia suffered drought conditions, restricting haymaking and foraging (UNDP Mongolia, 2010; Morris, 2011). Rainfall at the end of November became a sheet of ice, and, in late December, 19 of 21 provinces recorded temperatures below -40°C; this was followed by heavy and continuous snowfall in January and February 2010 (Sternberg, 2010; UNDP Mongolia, 2010). Over 50% of all the country herders' households and their livestock were affected by the *dzud* (Sternberg, 2010). By April, 75,000 herder families had lost all or more than half their livestock (Sternberg, 2010).

9.2.4.4. Interventions

9.2.4.4.1. *Dzud* of 1999-2002

The government of Mongolia issued the order for intensification of winter preparedness in August 1999, but allocated funding for its implementation in January 2000, by which time significant animal mortality had already occurred (Batjargal et al., 2001). The government then appealed to its citizens and international organizations for assistance and relief, including distribution of money, fodder, medicine, clothes, flour, rice, high energy and high protein biscuits for children, health and veterinary services, medical equipment, and vegetable seeds (Batjargal et al., 2001). Capacity-building activities through mass media campaigns were also carried out, focused on providing advice on methods of care and feeding for weak animals (Batjargal et al., 2001).

Herders rely upon traditional informal coping mechanisms and ad hoc support from government and international agencies (Mahul and Skees, 2005). For affected areas, after immediate relief, the main longer term support has conventionally been through restocking programs (Mahul and Skees, 2005). Evaluation has shown that these can be expensive, relatively inefficient, and fail to provide the right incentives for herders (Mahul and Skees, 2005). Restocking in areas with drought, poor pasture condition, and unfit animals can actually increase livestock vulnerability in the following year (Mahul and Skees, 2005) as a result of greater competition for scarce resources.

The government has prioritized the livestock sector with parliament-approved state policy (MGH, 2003) and, with support from donors, responded to *dzud* disasters with reforms that include greater flexibility in pasture land tenure, coupled with increased investment in rural infrastructure and services (Mahul and Skees, 2005). However, livestock sector reforms and approaches have not yet proved sufficient to cope with catastrophic weather events (Mahul and Skees, 2005). Although the State Reserves Agency is working to reduce the effects of *dzud,* catastrophic livestock mortality persists (Mahul and Skees, 2005).

9.2.4.4.2. *Dzud* of 2009-2010

At a local level: The National Climate Risk Management Strategy and Action Plan (MMS, 2009*)* sets a goal of building climate resilience at the community level through reducing risk and facilitating adaptation by: (i) improving access to water through region-specific activities such as rainwater harvesting and creation of water pools from precipitation and flood waters, for use for animals, pastureland, and crop irrigation purposes; (ii) improving the quality of livestock by introducing local selective breeds with higher productivity and more resilient to climate impacts; (iii) strengthened veterinarian services to reduce animal diseases and parasites and cross-border epidemic infections; and (iv) using traditional herding knowledge and techniques for adjusting animal types and herd structure to make appropriate for the carrying capacity of the pastureland and pastoral migration patterns. The formation of herders' community groups and establishment of pasture co-management teams (Ykhanbai et al., 2004), along with better community-based disaster risk management, could also facilitate effective DRR and CCA (Baigalmaa, 2010).

At a national level: Mongolia's millennium development priorities clearly state an aim to adapt to climate change and desertification and to implement strategies to minimize negative impacts (Mijiddorj, 2008; UNDP Mongolia, 2009a). The recent national CCA report outlines government strategy priorities as: (i) education and awareness campaigns among the decisionmakers, rural community, herders, and the general public; (ii) technology and information transfer to farmers and herdsmen; (iii) research and technology to ensure the development of agriculture that could successfully deal with various environmental problems; and (iv) improved coordination of stakeholders' activities based on research, inventory, and monitoring findings (Dagvadorj et al., 2010). The management of risk in the livestock sector requires a combination of approaches. Traditional herding and pastoral risk reduction practices can better prepare herders for moderate weather events. For country-wide *dzud* events, however, high levels of livestock mortality are often unavoidable, even for the most experienced herders, and pasture resource and herd management must be complemented by risk-financing mechanisms that provide herders with instant liquidity in the aftermath of a disaster (Goodland et al., 2009).

At an international level: As Mongolia is a country extremely prone to natural disasters, addressing climate change risks is a priority in Mongolia. In 2009, the Mongolian Government undertook the project 'Strengthening the Disaster Mitigation and Management Systems in Mongolia' under the National Emergency Management Agency (UNDP Mongolia, 2009b; Sternberg, 2010).

9.2.4.5. Consequences

The most critical consequences of *dzud* are increased poverty and mass migration from rural to urban and from remote to central regions (Oyun, 2004; Dagvadorj et al., 2010). According to national statistics there has been a continuous increase in poverty over the last decade (NSO, 2011).

In response to the climatic hardship, a growing proportion of the rural population has migrated to urban areas and the central region (Dagvadorj et al., 2010; UNDP Mongolia, 2010). Livestock-herding families are forced to migrate because of poverty caused by loss of livestock from catastrophic weather events (Sternberg, 2010). Besides poverty, there are reasons why members of herding families may wish to leave the livestock sector, including obtaining a better education for their children and access to health care (Mahul and Skees, 2005). Many migrants travel from Western Mongolia to the capital city Ulaanbaatar (Saizen et al., 2010; Sternberg, 2010).

9.2.4.6. Lessons Identified

Current policies and measures are mainly limited to post-disaster government relief and restocking activities with donors' funding and individual herder's traditional knowledge and practices (Batjargal et al., 2001; AIACC, 2006). These can be insufficient to avoid, prepare for, and respond to a *dzud* (Goodland et al., 2009). Various practices have been identified as effective for DRR, and could further contribute to promote CCA. These include localized seasonal climate prediction and improvement of early warning (Morinaga et al., 2003; MMS, 2009), risk-insuring systems (Skees and Enkh-Amgalan, 2002; Mahul and Skees, 2005), and policy (Batjargal et al., 2001; AIACC, 2006; Goodland et al., 2009).

At present, adaptation occurs through increased mobility of herders in search of better pasture for their animals in *dzud* disasters (Batjargal et al., 2001), and as a response to changed rain patterns occurring over small areas, which the herders call 'silk embroidery rain' (Marin, 2010). Livelihood diversification to create resilient livelihoods for herders has also been seen as being effective for building climate resilience (Mahul and Skees, 2005; Borgford-Parnell, 2009; MMS, 2009, Dagvadorj et al., 2010).

9.2.5. Cyclones: Enabling Policies and Responsive Institutions for Community Action

9.2.5.1. Introduction

Tropical cyclones, also called typhoons and hurricanes, are powerful storms generated over tropical and subtropical waters. Their extremely strong winds damage buildings, infrastructure and other assets; the torrential rains often cause floods and landslides; and high waves and storm surge often lead to extensive coastal flooding and erosion – all of which have major impacts on people. Tropical cyclones are typically classified in terms of their intensity, based on measurements or estimates of near-surface wind speed (sometimes categorized on a scale of 1 to 5 according to the Saffir-Simpson scale). The strongest storms (Categories 3, 4, and 5) are comparatively rare but are generally responsible for the majority of damage (Section 3.4.4).

The focus of this case study is the comparison between the response to Indian Ocean cyclones in Bangladesh (Sidr in 2007) and in Myanmar (Nargis in 2008) in the context of the developments in preparedness and response in Bangladesh resulting from experiences with Cyclone Bhola in 1970, Gorky in 1991, and other events. To provide a more global context, the impacts and responses to 2005 Hurricanes Stan and Wilma in Central America and Mexico are also discussed. These clearly demonstrate that climate change adaptation efforts can be effective in limiting the impacts from extreme tropical cyclone events by use of disaster risk reduction methods.

Changes in tropical cyclone activity due to anthropogenic influences are discussed in Section 3.4.4. There is *low confidence* that any observed long-term increases in tropical cyclone activity are robust, after accounting for past changes in observing capabilities. The uncertainties in the historical tropical cyclone records, the incomplete understanding of the physical mechanisms linking tropical cyclone metrics to climate change, and the degree of tropical cyclone variability provide only *low confidence* for the attribution of any detectable changes in tropical cyclone activity to anthropogenic influences. There is *low confidence* in projections of changes in tropical cyclone genesis, location, tracks, duration, or areas of impact. Based on the level of consistency among models, and physical reasoning, it is *likely* that tropical cyclone-related rainfall rates will increase with greenhouse warming. It is *likely* that the global frequency of tropical cyclones will either decrease or remain essentially unchanged. An increase in mean tropical cyclone maximum wind speed is *likely*, although increases may not occur in all tropical regions. While it is *likely* that overall global frequency will either decrease or remain essentially unchanged, it is *more likely than not* that the frequency of the most intense storms will increase substantially in some ocean basins. Although there is evidence that surface sea temperature (SST) in the tropics has increased due to increasing greenhouse gases, the increasing SST does not yet have a fully understood physical link to increasingly strong tropical cyclones (Section 3.4.4).

9.2.5.2. Indian Ocean Cyclones

Although only 15% of world tropical cyclones occur in the North Indian Ocean (Reale et al., 2009), Bangladesh and India account for 86% of mortality from tropical cyclones (UNISDR, 2009c). The 2011 Global Assessment Report (UNISDR, 2011b) provides strong evidence that weather-related mortality risk is highly concentrated in countries with low GDP and weak governance. Many of the countries exposed to tropical cyclones in the North Indian Ocean are characterized by high population density and vulnerability and low GDP.

9.2.5.2.1. Description of events – Indian Ocean cyclones

In 2007, Cyclone Sidr made landfall in Bangladesh on 15 November and caused over 3,400 fatalities (Paul, 2009). Cyclone Nargis hit Myanmar on 2 May 2008 and caused over 138,000 fatalities (CRED, 2009; Yokoi and Takayabu, 2010), making it the eighth deadliest cyclone ever recorded (Fritz et al., 2009). Sidr and Nargis were both Category 4 cyclones of similar severity; affecting coastal areas with a comparable number of people exposed (see Table 9-2). Although Bangladesh and Myanmar both are considered least developed countries (Giuliani and Peduzzi, 2011), these two comparable events had vastly different impacts. The reasons for the differences follow.

9.2.5.2.2. Interventions – Indian Ocean cyclones

Bangladesh has a significant history of large-scale disasters (e.g., Cyclones Bhola in 1970 and Gorky in 1991; see Table 9-2). The Government of Bangladesh has made serious efforts aimed at DRR from tropical cyclones. It has worked in partnership with donors, nongovernmental organizations (NGOs), humanitarian organizations and, most importantly, with coastal communities themselves (Paul, 2009).

First, they constructed multi-storied cyclone shelters with capacity for 500 to 2,500 people (Paul and Rahman, 2006) that were built in coastal regions, providing safe refuge from storm surges for coastal populations. Also, killas (raised earthen platforms), which accommodate 300 to 400 livestock, have been constructed in cyclone-prone areas to safeguard livestock from storm surges (Paul, 2009).

Second, there has been a continued effort to improve forecasting and warning capacity in Bangladesh. A Storm Warning Center has been established in the Meteorological Department. System capacity has been enhanced to alert a wide range of user agencies with early warnings and special bulletins, soon after the formation of tropical depressions in the Bay of Bengal. Periodic training and drilling practices are conducted at the local level for cyclone preparedness program (CPP) volunteers for effective dissemination of cyclone warnings and for raising awareness among the population in vulnerable communities.

Third, the coastal volunteer network (established under the CPP) has proved to be effective in disseminating cyclone warnings among the coastal communities. These enable time-critical actions on the ground, including safe evacuation of vulnerable populations to cyclone shelters (Paul, 2009). With more than sevenfold increase in cyclone shelters and twofold increase in volunteers from 1991 to 2007, 3 million people were safely evacuated prior to landfall of Sidr in 2007 (Government of Bangladesh, 2008).

In addition, a coastal reforestation program, including planting in the Sundarbans, was initiated in Bangladesh in the late 1960s, covering riverine coastal belt and abandoned embankments (Saenger and Siddiqi, 1993). Sidr made landfall on the western coast of Bangladesh, which is

Table 9-2 | Key data for extreme cyclones in Bangladesh, Myanmar, and Mexico. Sources: García et al., 2006; National Hurricane Center, 2006; Government of Bangladesh, 2008; Karim and Mimura, 2008; Webster, 2008; CRED, 2009; Paul, 2009; Giuliani and Peduzzi, 2011.

Cyclone Event	Year	Storm Surge (m)	Maximum Wind Speed (km h^{-1})	Category (Saffir-Simpson)	Number of Affected People (approximate in millions)	Mortality (approximate)	Damages (US$ billion)
Bhola	1970	6 - 9	223	3	1	300,000 - 500,000	Unknown
Gorky	1991	6 - 7.5	260	4	15.4	138,000	1.8
Sidr	2007	5 - 6	245	4	8 - 10	4,200	2.3
Nargis	2008	~ 4	235	4	2 - 8	138,000	4.0
Stan[a]	2005	Negligible	130	1	3 - 8	1,726	3.9
Wilma	2005	12.8	295	5	10[b]	62 (8 in Mexico)	29 (7.5 in Mexico)

Notes:
[a] Most of damage and mortality caused by landslides and river flooding.
[b] Affecting Jamaica, Bahamas, Haiti, Cayman Islands, Belize, Honduras, El Salvador, Nicaragua, Honduras, Yucatán Peninsula (Mexico), and Florida (USA).

lined by the world's largest mangrove forest, the Sundarbans. This region is the least-populated coastal area in the country and has been part of a major reforestation effort in recent years (Hossain et al., 2008). The Sundarbans provided an effective attenuation buffer during Sidr, greatly reducing the impact of the storm surge (Government of Bangladesh, 2008).

In contrast to Bangladesh, Myanmar has very little experience with previous powerful tropical cyclones. The landfall of Nargis was the first time in recorded history that Myanmar experienced a cyclone of such a magnitude and severity (Lateef, 2009) and little warning was provided.

9.2.5.2.3. Outcomes – Indian Ocean cyclones

Despite Nargis being both slightly less powerful and affecting fewer people than Sidr, it resulted in human losses that were much higher. Bangladesh and Myanmar are both very poor countries with low levels of HDI (World Bank, 2011a). The relatively small differences in poverty and development cannot explain the discrepancy in the impacts of Sidr and Nargis. However, the governance indicators developed by the World Bank (Kaufmann et al., 2010) suggest significant differences between Bangladesh and Myanmar in the quality of governance, notably in voice and accountability, rule of law, regulatory quality, and government effectiveness. Low quality of governance, and especially voice and accountability, has been highlighted as a major vulnerability component for human mortality due to tropical cyclones (Peduzzi et al., 2009).

9.2.5.3. Mesoamerican Hurricanes

9.2.5.3.1. Description of events – Mesoamerican hurricanes

Central America and Mexico (Mesoamerica) are heavily affected by strong tropical storms. From 1-13 October 2005, Hurricane Stan affected the Atlantic coast of Central America and the Yucatan Peninsula in Mexico. Stan was a relatively weak storm that only briefly reached hurricane status. It was associated with a larger non-tropical storm system that resulted in torrential rains and caused debris flows, rockslides, and widespread flooding. Guatemala reported more than 1,500 fatalities and thousands of missing people. El Salvador reported 69 fatalities while Mexico reported 36 (CRED, 2009). Wilma hit one week later (19-24 October). It was an intense cyclone in the Atlantic (National Hurricane Center, 2006; Table 9-2), with winds reaching a speed of 297 km h^{-1}. Wilma caused 12 fatalities in Haiti, 8 in Mexico, and 4 in the United States. Most residents in western Cuba, and tourists and local inhabitants in the Yucatan Peninsula in Mexico, were evacuated (CRED, 2009).

9.2.5.3.2. Interventions – Mesoamerican hurricanes

While Stan mainly affected the poor indigenous regions of Guatemala, El Salvador, and Chiapas, Wilma affected the international beach resort of Cancun. A joint study of Mexico's response to the hurricanes funded by the World Bank and conducted through the Economic Commission for Latin America and the Caribbean (ECLAC, 2006) and its Commission for Latin American and the Caribbean and the Mexican National Center for Prevention of Disasters (García et al., 2006) showed that Stan caused about US$ 2.2 billion damage in that country, 65% of which were direct losses and 35% due to future impacts on agricultural production. About 70% of these damages were reported in the state of Chiapas (Oswald Spring, 2011), representing 5% of the GDP of the state.

Comparing the management of the two hurricanes by the Mexican authorities, in the same month and year, highlights important issues in DRM. Evacuation of areas in Mexico affected by Stan only started during the emergency phase, when floods in 98 rivers had already affected 800 communities. 100,000 people fled from the mountain regions to improvised shelters – mostly schools – and 'guest families' (Oswald Spring, 2010). In comparison, following the early alert for Wilma, people were evacuated from dangerous places, most tourists were moved to safe areas, and local inhabitants and remaining tourists were taken to shelters (García et al., 2006). Before the hurricane hit the coast, heavy machines and emergency groups were mobilized in the region, to reestablish water, electricity, communications, and health services immediately after the event. After the disaster, all ministries were involved in reopening the airport and tourist facilities as quickly as possible. By December, most hotels were operating, and the sand lost from the beaches had been reestablished (Oswald Spring, 2011).

9.2.5.3.3. Outcomes – Mesoamerican hurricanes

Comparing government responses to these two hurricanes in the same month, it is possible to note vastly different official actions in terms of early warning, evacuation, and reconstruction (Oswald Spring, 2011). The federal institutions in charge of DRM functioned well during Hurricane Wilma. A massive recovery support strategy restored almost all services and hotels in Cancun within two months, with a significant portion of costs being covered by insurance companies (García et al., 2006). The government response to Stan left the poor indigenous population with limited advice, insufficient disaster relief, and scant reconstruction support, especially among the most marginal groups (Oswald Spring, 2011).

9.2.5.4. Lessons Identified

Comparative studies of disaster risk management practices for tropical cyclones demonstrate that choices and outcomes for response to climatic extreme events are triggered by multiple interacting processes, and competing priorities. Indigenous, poor, and illiterate people have low resilience, limited resources, and are highly exposed without early warnings and DRM. Government response to similar extreme events may be quite different in neighboring countries, or even within the same country.

Tropical cyclone DRM strategies in coastal regions that create protective measures, and anticipate and plan for extreme events, along with continuing changes in vulnerability and in causal processes, increase the resilience of potentially exposed communities. International cooperation and investment in the following measures are essential in improving the capacity of developing nations in coping with extreme tropical cyclone events:

- Improvement of forecasting capacity and implementation of improved early warning systems (including evacuation plans and infrastructure)
- Protection of healthy ecosystems
- Post-disaster support service to dispersed communities
- Transparent management of recovery funds directly with the victims.

Awareness, early warnings and evacuation, hurricane experience, disaster funds, and specialized bodies reduce the impact of tropical cyclones on socially vulnerable people. Good governance and participation of people at risk in the decisionmaking process may overcome conflicting governmental priorities. Disaster risk management is most effectively pursued by understanding the diverse ways in which social processes contribute to the creation, management, and reduction of disaster risk with the involvement of people at risk. A development planning perspective that includes disaster risk management as an integral part of the development framework is the key to a coherent strategy for the reduction of risk associated with extreme weather events.

9.2.6. Managing the Adverse Consequences of Floods

9.2.6.1. Introduction

Floods are a major natural hazard in many regions of the world (Ahern et al., 2005). Averaged over 2001 to 2010, floods and other hydrological events accounted for over 50% of the disasters (Guha-Sapir et al., 2011); for example, it was reported that, in 2007, flooding worldwide accounted for four of the top five deadliest natural disasters (Subbarao et al., 2008). Currently about 800 million people live in flood-prone areas and about 10% are annually exposed to floods (Chapter 4; Peduzzi et al., 2011; UNISDR, 2011b). Causes of floods are varied, but may occur as a result of heavy, persistent, and sustained rainfall or as a result of coastal flooding (Ahern et al., 2005; see also Section 3.5.2). Flooding impacts are wide ranging, potentially interrupting food and water supplies, affecting economic development, and causing acute as well as subsequent long-term health impacts (Ahern et al., 2005; Subbarao et al., 2008). It is important to study flooding events to develop or enhance reliable approaches to risk reduction as well as systems for forecasting and informing the population, in order to help minimize negative consequences (ICSU, 2008). This case study examines the impacts on the population and economy of Mozambique from the 2000 and 2007 flooding events.

Effective functioning of DRR and DRM programs at all levels can help to reduce the risks from extreme events including floods (UNISDR, 2005a). These programs operate best with a combination of local, national, and international strategies (Hellmuth et al., 2007; UNISDR, 2011a). A variety of strategies have been used to reduce the impact of floods. For example, dams and sea walls prevent flooding of coastal areas but are expensive and difficult to maintain and these facilities can be breached (ProAct Network, 2008). Furthermore, urban drainage systems are recognized as an important tool to reduce urban flood risk, but less than half (46%) of low-income countries have invested in drainage infrastructure in flood-prone areas (UNISDR, 2011b). Timely flood warnings in many countries have been developed as part of DRR and DRM programs (Case Study 9.2.11).

The Global Assessment Report (UNISDR, 2011b) reported that the 2000 floods in Mozambique are one of the four examples of large disasters that have highlighted DRM capacity gaps that have led to institutional and legislative changes.

9.2.6.2. Background

Mozambique has high socioeconomic vulnerability with approximately 50% of its population of 21 million living below the poverty line (see Sections 2.3 and 2.5; WMO, 2011a; World Bank, 2011b). Its development has been restricted by previous civil war and conflict with neighboring South Africa. Further examples of its vulnerability include rising HIV/AIDS rates, an almost 70% female illiteracy rate, and most of the population depending on subsistence farming (Hellmuth et al., 2007; World Bank, 2011b).

Geographic position and climatic factors contribute to Mozambique's high physical vulnerability. Mozambique has a 2,700-km coastline and the whole country and neighboring countries are subjected to cyclones and resultant flooding (Hellmuth et al., 2007; WMO, 2011a; World Bank, 2011b). Nine of the 11 rivers in Mozambique are transboundary (Hellmuth et al., 2007) making its location downstream more susceptible to rainfall events across a large region such that increases in river levels and flows in neighboring countries can result in or exacerbate floods. Therefore the development and operating of early warning and flood control systems in Mozambique depend on a close collaboration with other countries of the Southern Africa Development Community and its protocol on shared watercourse systems (SADC, 2000).

The World Bank (2005a) reported that Mozambique experienced 12 major floods, 9 major droughts, and 4 major cyclone events between 1965 and 1998. In 1999, a national government policy on disaster management was articulated and a National Institute for Disaster Management (NIDM), with an emphasis on coordination rather than delivery, created (World Bank, 2005a).

9.2.6.3. Description of Events – 2000 Floods in Mozambique

In February 2000, catastrophic floods caused the loss of more than 700 lives with over half a million people losing their homes, and more than

4.5 million affected (Mirza, 2003; Hellmuth et al., 2007; WMO, 2011a; World Bank, 2011b).

The flooding was the result of a cascade of events. It started with above-average rainfall in southern Mozambique and adjacent countries from October to December 1999 (Hellmuth et al., 2007). Exacerbating the situation was the series of cyclones Astride, Connie, Eline, and Gloria with the main impact coming from cyclone Eline (UNESC, 2000; Asante et al., 2007; Hellmuth et al., 2007). Cyclone Eline, after tracking over 7,000 km west across the tropical south Indian Ocean (Reason and Keibel, 2004), made landfall on 22 February 2000, crossing the Mozambique coastline and moving over the headwater basins of the Limpopo River, making a critical situation worse.

The rainfall that occurred over Mozambique and the northeastern parts of South Africa and Zimbabwe was exceptional; record flooding ensued downstream on the Limpopo and Zambezi rivers (Carmo Vaz, 2000; Kadomura, 2005), and in parts of the Sabie catchment the return period was in excess of 200 years (Smithers et al., 2001).

As a result of the floods it was reported that many small towns and villages remained under water for approximately two months (Hellmuth et al., 2007). Access roads were rendered impassable with railways, bridges, water management systems (including water intake and treatment plants), and more than 600 primary schools damaged or destroyed (UNESC, 2000; Dyson and van Heerden, 2001; Reason and Keibel, 2004). The UN World Food Programme reported that Mozambique lost 167,000 ha of agricultural land (FAO and WFP, 2000). Dams were overwhelmed; for example, the total inflow to Massingir reservoir between January and March was approximately eight times the storage capacity of the reservoir at that time (Carmo Vaz, 2000).

Although floodwaters can wash away breeding sites and, hence, reduce mosquito-borne disease transmission (Sidley, 2000), the collection of emergency clinic data and interviews of 62 families found that the incidence of malaria was reported as increasing by a factor of 1.5 to 2.0. Diarrhea also increased by a factor of 2 to 4 (Kondo et al., 2002).

The government declared an emergency, mobilized its disaster response mechanisms, and made appeals for assistance from other countries (Hellmuth et al., 2007).The enormous material damage and human losses during the floods in Mozambique in 2000 were associated with the following problems:

- ***Institutional problems***: It was only in 1999 that the National Policy on Disaster Management in Mozambique began to shift from a reactive to a proactive approach, with an aim to develop a culture of prevention (Asante et al., 2005; Hellmuth et al., 2007).
- ***Technological problems***: In 2000, in Mozambique, there were problems with the installation and maintenance of *in situ* gauging equipment due to financial constraints. In addition, the hydrological and precipitation gauges were washed away and many key stations were destroyed, leaving Mozambican water authorities with no source of information on the actual magnitude of floodwaters (Dyson and van Heerden, 2001; Smithers et al., 2001; Asante et al., 2005).
- ***Financial problems***: The UN Economic and Social Council (UNESC, 2000) reported that the Government of Mozambique responded to the emergency despite limited means, but due to the extensive international financial support requested help in its coordination from the UN. The World Bank estimates that the direct losses as a result of the 2000 floods amounted to US$ 273 million (UNESC, 2000).

9.2.6.4. Interventions

After the catastrophic floods in 2000, the Government of Mozambique took a range of measures to improve the effectiveness of disaster risk management. In 2001, an Action Plan for the Reduction of Absolute Poverty (PARPA I) was adopted (Republic of Mozambique, 2001); and this was revised for the period 2006 to 2009 (PARPA II) (Republic of Mozambique, 2006a,b; Foley, 2007). In 2006, the government also adopted a Master Plan, which provides a comprehensive strategy for dealing with Mozambique’s vulnerability to natural disasters (Republic of Mozambique, 2006a).

After the 2000 floods, Mozambique implemented intensive programs to move people to safe areas (World Bank, 2005a). Since the 2000 floods, a large resettlement program for communities affected by the floods and tropical cyclones was initiated, with about 59,000 families resettled although a lack of funds for improved livelihoods has reduced the success of this program (WMO, 2011a).

Success and effectiveness of warnings depend not only on the accuracy of the forecast, but also their delivery in adequate time before the disaster to put in place prevention strategies. From November 2006 to November 2007 the Severe Weather Forecasting Demonstration Project, conducted by the World Meteorological Organization in southeastern Africa, tested a new concept for capacity building and this service contributed to the forecasting and warnings about Cyclone Favio in February 2007 (Poolman et al., 2008). The demonstration phase was found to be valuable, and the implementation phase – with training, supported with efficient and effective forecasting and warning of tropical cyclones in developing countries – continues (WMO, 2011b).

Besides high-level alerting it is important that a warning is received by each person in the disaster zone, in an easily understandable way (UNISDR, 2010). In 2005 and 2006 the German Agency for Technical Cooperation developed a simple but effective early warning system along the River Búzi (Bollin et al., 2005; Loster and Wolf, 2007). This warning system was adapted to the specific needs and skills of the people. The village officials receive daily precipitation and water levels at strategic points along the Búzi River basin. If precipitation is particularly heavy or the river reaches critical levels, this information is passed on by radio and blue, yellow, or red flags are raised depending on the flood alert level (Bollin et al., 2005; UNISDR, 2010).

9.2.6.5. Outcomes/Consequences – 2007 Floods in Mozambique

Seven years after the catastrophic floods of 2000, similar flooding occurred in Mozambique, but the country was prepared to a greater extent than before. Between December 2006 and February 2007, heavy rains across northern and central Mozambique together with a severe downpour in neighboring countries led to flooding in the Zambezi River basin (IFRC, 2007). Additional flooding was caused by the approach of tropical cyclone Favio, which struck the Búzi area at the end of February 2007 (Poolman et al., 2008). During the flood period on the southern coast of Mozambique, 29 people were killed, 285,000 people affected, and approximately 140,000 displaced (Kienberger, 2007; World Bank, 2011b). The heavy rains and floods damaged health centers, public buildings, drug stocks, and medical equipment and affected safe water and sanitation facilities (UNOCHA, 2007). In total, the floods and cyclone caused approximately US$ 71 million of damage to local infrastructure and destroyed 277,000 ha of crops (USAID, 2007).

During the course of January 2007, it became clear that there was an imminent threat of severe flooding in the Zambezi River basin valley (Foley, 2007). A multinational flood warning covering Zambia, Malawi, and Mozambique was issued on 26 January 2007. With forecasts and warnings increasing over the next week, NIDM increased the flood warning until a 'Red Alert' was issued (UNISDR, 2010). This was a test of the earlier work undertaken by Bollin et al. (2005); when the rivers rose rapidly, it was reported that approximately 12,800 people who were at risk had been well prepared by prior training (Loster and Wolf, 2007). The district's disaster mitigation committee had alerted threatened villages two days previously (blue-flag alert) and now with a red-flag alert announced evacuations, which were completed in less than two days, with approximately 2,300 going to accommodation centers (Loster and Wolf , 2007).

In the emergency period, NIDM, with local and international partner organizations, established networks with local centers to coordinate the emergency operations. The International Federation of Red Cross and Red Crescent Societies and its local partners, the US Agency for International Development, and other organizations worked to distribute basic goods, food, and medical assistance during the emergency period (IFRC, 2007; USAID, 2007).

A resettlement program, although a policy of last resort, to move inhabitants from flood-prone areas to safer areas was initiated (Stal, 2011; WMO, 2011a). Resettlement is not an easy option. Although brick-built housing was provided in flood-safe areas with new (or nearby) schools and health facilities, these have not been as well received as intended as these flood-safe resettlements suffer from water scarcity and drought, and growing crops is therefore difficult (Stal, 2011).

The floods of 2000 and 2007 along with other natural hazards are considered to have undone years of development efforts (Sietz et al., 2008) and to have undermined national efforts in realizing Mozambique's poverty reduction strategy (IMF, 2011).

9.2.6.6. Lessons Identified

This comparison of the two floods events that occurred in Mozambique in 2000 and 2007 shows:

- Floods, as one of the most dangerous natural phenomena, are a real threat to the sustainable development of nations (Ahern et al., 2005; Guha-Sapir et al., 2011)
- The consequences of floods depend on the long-term adaptation to extremes of climate, and associated hydrologic extremes require further understanding. After the 2000 floods in Mozambique, national and international organizations updated their strategies to include disaster preparedness, risk management, and contingency and response capacities according to the lessons of catastrophic floods. The Government of Mozambique introduced new DRM structures between 2000 and 2007, illustrating the flexibility needed to accommodate the scientific and communication systems that need to be in place to adapt to a climate change-driven disaster and that this can be done in liaison with and with guidance from external agencies. Realization of the new program of DRM led to a reduction in consequences from the floods in 2007 (Republic of Mozambique, 2006a).
- Experience in Mozambique shows that creation and development of effective and steadily functioning systems of hydrological monitoring and early warning systems at a local, regional, and national level as key components of DRM allowing more realistic warnings of flooding threats (WMO, 2011a).
- The implementation of resettlement programs in periodically flooded areas in 2007 has reduced flood damage, but these measures are not easy to implement (WMO, 2011a).
- Limited available resources are one of the most important problems for both disaster preparedness and disaster response. The extreme poverty of the people makes them highly vulnerable to floods and other natural disasters, despite the best efforts of the government to protect them (World Bank, 2011b).
- The example of Mozambique shows that climate change adaptation needs to be achieved through the understanding of vulnerability in all sectors (social, infrastructure, production, and environmental) and this knowledge needs to be used for the formulation of preparedness and response mechanisms (Sietz et al., 2008).

9.2.7. Disastrous Epidemic Disease: The Case of Cholera

9.2.7.1. Introduction

Weather and climate have a wide range of health impacts and play a role in the ecology of many infectious diseases (Patz et al., 2000). The relationships between health and weather, climate variability, and long-term climate change are complex and often indirect (McMichael et al., 2006). As with other impacts explored in this report, not all extreme health impacts associated with weather and climate result from extreme events; some result instead from less dramatic events unfolding in the context of high population vulnerability. In such cases, impacts are typically indirect and are mediated by a constellation of factors, as opposed to the direct health impacts of severe weather, for example, traumatic injuries resulting directly from exposure to kinetic energy associated with storms (Noji, 2000).

Commonly, underdeveloped health and other infrastructure, poverty, political instability, and ecosystem disruptions interact with weather to impact health adversely, sometimes to a disastrous degree (Myers and Patz, 2009). For example, cholera is an infectious disease that is perpetuated by poverty and associated factors, though outbreaks are commonly associated with rainy season onset. Research in the last decade has demonstrated that cholera is also sensitive to climate variability (Rodó et al., 2002; Koelle et al., 2005a; Constantin de Magny et al., 2007). Assuming persistence of these vulnerability factors, cholera outbreaks may become more widespread as the climate continues to change (Lipp et al., 2002) due to the projected *likely* increase in frequency of heavy precipitation over many areas of the globe, and tropical regions in particular (see Table 3-1). Insights into the disease's ecology, however, including its climate sensitivity, may one day inform early warning systems and other interventions that could blunt its disastrous impact. Equally, if not more important, poverty reduction and improvements in engineering, critical infrastructure, and political stability and transparency can reduce vulnerability among exposed populations to the degree that cholera could be contained.

9.2.7.2. Background

Cholera has a long history as a human scourge. The world is in the midst of the seventh global pandemic, which began in Indonesia in 1961 and is distinguished by continued prevalence of the El Tor strain of the *Vibrio cholerae* bacterium (Zuckerman et al., 2007; WHO, 2010). Primarily driven by poor sanitation, cholera cases are concentrated in areas burdened by poverty, inadequate sanitation, and poor governance. Between 1995 and 2005, the heaviest burden was in Africa, where poverty, water source contamination, heavy rainfall and floods, and population displacement were the primary risk factors (Griffith et al., 2006).

V. cholerae is flexible and ecologically opportunistic, enabling it to cause epidemic disease in a wide range of settings and in response to climate forcings (Koelle et al., 2005b). Weather, particularly seasonal rains, has long been recognized as a risk factor for cholera epidemics.

Cholera is one of a handful of diseases whose incidence has been directly associated with climate variability and long-term climate change (Rodó et al., 2002). One driver of cholera's presence and pathogenicity is the El Niño-Southern Oscillation (ENSO), which brings higher temperatures, more intense precipitation, and enhanced cholera transmission. ENSO has been associated with cholera outbreaks in coastal and inland regions of Africa (Constantin de Magny et al., 2007), South Asia (Constantin de Magny et al., 2007), and South America (Gil et al., 2004). There is concern that climate change will work synergistically with poverty and poor sanitation to increase cholera risk.

As with other disasters, the risk of disastrous cholera epidemics can be deconstructed into hazard probability, exposure probability, and population vulnerability, which can be further broken down into population susceptibility and adaptive capacity. As noted in the introduction, some disastrous cholera epidemics are not associated with discrete extreme weather events, but extreme impacts are triggered instead by exposure to a less dramatic weather event in the context of high population vulnerability. We focus on factors affecting exposure and vulnerability in general, then apply this discussion to the Zimbabwe cholera epidemic that began in 2008.

9.2.7.2.1. Exposure

Cholera epidemics occur when susceptible human hosts are brought into contact with toxigenic strains of *V. cholerae* serogroup O1 or serogroup O139. A host of ecological factors affect *V. cholerae*'s environmental prevalence and pathogenicity (Colwell, 2002) and the likelihood of human exposure (Koelle, 2009). In coastal regions, there is a commensal relationship between *V. cholerae*, plankton, and algae (Colwell, 1996). Cholera bacteria are attracted to the chitin of zooplankton exoskeletons, which provide them with stability and protect them from predators. The zooplankton feed on algae, which bloom in response to increasing sunlight and warmer temperatures. When there are algal blooms in the Bay of Bengal, the zooplankton prosper and cholera populations grow, increasing the likelihood of human exposure. Precipitation levels, sea surface temperature, salinity, and factors affecting members of the marine and estuarine ecosystem, such as algae and copepods, affect exposure probability (Huq et al., 2005). Many of these factors appear to be similar across regions, although their relative importance varies, such as the association of *V. cholerae* with chitin (Pruzzo et al., 2008) and the importance of precipitation and sea level (Emch et al., 2008). For example, marine and estuarine sources were the source of pathogenic *V. cholerae* strains responsible for cholera epidemics in Mexico in recent El Niño years (Lizarraga-Partida et al., 2009).

Other variables are associated with increased likelihood of exposure, including conflict (Bompangue et al., 2009), population displacement, crowding (Shultz et al., 2009), and political instability (Shikanga et al., 2009). Many of these factors are actually mediated by the more conventional cholera risk factors of poor sanitation and lack of access to improved water sources and sewage treatment.

9.2.7.2.2. Population susceptibility

Population susceptibility includes both physiological factors that increase the likelihood of infection after cholera exposure, as well as social and structural factors that drive the likelihood of a severe, persistent epidemic once exposure has occurred. Physiologic factors that affect cholera risk or severity include malnutrition and co-infection with intestinal parasites (Harris et al., 2009) or the bacterium *Helicobacter pylori*. Infections are more severe for people with blood group O, for children, and for those with increased health-related vulnerability. Waxing and waning immunity as a result of prior exposure has a significant impact on population vulnerability to cholera over long periods (Koelle et al., 2005b).

While physiologic susceptibility is important, social and economic drivers of population susceptibility persistently seem to drive epidemic risk. Poverty is a strong predictor of risk on a population basis (Ackers et al., 1998; Talavera and Perez, 2009), and political factors, as illustrated by the Zimbabwe epidemic, are often important drivers of epidemic severity and persistence once exposure occurs. Many recent severe epidemics exhibit population susceptibility dynamics similar to Zimbabwe, including in other poor communities (Hashizume et al., 2008), in the aftermath of political unrest (Shikanga et al., 2009), and following population displacement (Bompangue et al., 2009).

9.2.7.2.3. Adaptive capacity

Cholera outbreaks are familiar sequelae of complex emergencies. The DRM community has much experience with prevention efforts to reduce the likelihood of cholera epidemics, containing them once they occur, and reducing the associated morbidity and mortality among the infected. Best practices include guidelines for water treatment and sanitation and for population-based surveillance (Sphere Project, 2004).

9.2.7.3. Description of Event

Zimbabwe has had cholera outbreaks every year since 1998, with the 2008 epidemic the worst the world had seen in two decades, affecting approximately 92,000 people and killing over 4,000 (Mason, 2009). The outbreak began on 20 August 2008, slightly lagging the onset of seasonal rains, in Chitungwiza city, just south of the capital Harare (WHO, 2008a). In the initial stages, several districts were affected. In October, the epidemic exploded in Harare's Budiriro suburb and soon spread to include much of the country, persisting well into June 2009 and ultimately seeding outbreaks in several other countries. Weather appears to have been crucial in the outbreak, as recurrent point-source contamination of drinking water sources (WHO, 2008a) was almost certainly amplified by the onset of the rainy season (Luque Fernandez et al., 2009). In addition to its size, this epidemic was distinguished by its urban focus and relatively high case fatality rate (CFR; the proportion of infected people who die) ranging from 4 to 5% (Mason, 2009). Most outbreaks have CFRs below 1% (Alajo et al., 2006). Underlying structural vulnerability with shortages of medicines, equipment, and staff at health facilities throughout the country compounded the effects of the cholera epidemic (WHO, 2008b).

9.2.7.4. Intervention

There are several risk management considerations for preventing cholera outbreaks and minimizing the likelihood that an outbreak becomes a disastrous epidemic (Sack et al., 2006). Public health has a wide range of interventions for preventing and containing outbreaks, and several other potentially effective interventions are in development (Bhattacharya et al., 2009). As is the case in managing all climate-sensitive risks, the role of institutional learning is becoming ever more important in reducing the risk of cholera and other epidemic disease as the climate shifts.

9.2.7.4.1. Conventional public health strategies

The conventional public health strategies for reducing cholera risk include a range of primary, secondary, and tertiary prevention strategies (Holmgren, 1981).

Primary prevention, or prevention of contact between a hazardous exposure and susceptible host, includes promoting access to clean water and reducing the likelihood of population displacement; secondary prevention, or prevention of symptom development in an exposed host, includes vaccination; and tertiary prevention, or containment of symptoms and prevention of complications once disease is manifest, includes dehydration treatment with oral rehydration therapy.

9.2.7.4.2. Newer developments

Enhanced understanding of cholera ecology has enabled development of predictive models that perform relatively well (Matsuda et al., 2008) and fostered hope that early warning systems based on remotely sensed trends in sea surface temperature, algal growth, and other ecological drivers of cholera risk can help reduce risks of epidemic disease, particularly in coastal regions (Mendelsohn and Dawson, 2008). Strategies to reduce physiologic susceptibility through vaccination have shown promise (Calain et al., 2004; Chaignat et al., 2008; Lopez et al., 2008; Sur et al., 2009) and mass vaccination campaigns have potential to interrupt epidemics (WHO, 2006c), and may be cost effective in resource-poor regions or for displaced populations where provision of sanitation and other services has proven difficult (Jeuland and Whittington, 2009). Current World Health Organization policy on cholera vaccination holds that vaccination should be used in conjunction with other control strategies in endemic areas and be considered for populations at risk for epidemic disease, and that cholera immunization is a temporizing measure while more permanent sanitation improvements can be pursued (WHO, 2010). Ultimately, given the strong association with poverty, continued focus on development may ultimately have the largest impact on reducing cholera risk.

9.2.7.5. Outcomes

Managing the risk of climate-sensitive disease, like risk management of other climate-sensitive outcomes, will necessarily become more iterative and adaptive as climate change shifts the hazard landscape and heightens vulnerability in certain populations. Learning is an important component of this iterative process (see Sections 1.4 and 8.6.3.2).

There are multiple opportunities for learning to enhance risk management related to epidemic disease. First, while reactive containment processes can be essential for identifying and containing outbreaks, this approach often glosses over root causes in an effort to return to the status quo. As the World Health Organization states, "Current responses to cholera outbreaks are reactive, taking the form of a more or less well-organized emergency response," and prevention is lacking (WHO, 2006c). Without losing the focus on containment, institutional learning could incorporate strategies to address root causes, reducing the likelihood of future outbreaks. This includes continued efforts to better understand cholera's human ecology to explore deeper assumptions, structures, and policy decisions that shape how risks are constructed. In the case of cholera, such exploration has opened the possibility of devising warning systems and other novel risk management strategies. Another equally important conclusion – one that experts on climate's role in driving cholera risk have emphasized (Pascual et al., 2002) – is that poverty and political instability are the fundamental drivers of cholera risk, and that emphasis on development and justice are risk management interventions as well.

9.2.7.6. Lessons Identified

The 2008 cholera epidemic epitomized the complex interactions between weather events and population vulnerability that can interact to produce disastrous epidemic disease. Recent studies of cholera, including its basic and human ecology, demonstrate the potential for early warning and potential points of leverage that may be useful for interventions to contain future epidemics. The key messages from this work include:

- Variability in precipitation and temperature can affect important epidemic diseases such as cholera both through direct effects on the transmission cycle, but also potentially through indirect effects, for example through problems arising from inadequate basic water and sanitation services.
- If other determinants remained constant, climate change would be expected to increase risk by increasing exposure likelihood – through increased variability in precipitation and gradually rising temperatures and by increasing population vulnerability.
- The health impacts of cholera epidemics are strongly mediated through individual characteristics such as age and immunity, and population-level social determinants, such as poverty, governance, and infrastructure.
- Experience from multiple cholera epidemics demonstrates that non-climatic factors can either exacerbate or override the effects of weather or other infection hazards.
- The processes of DRM and preventive public health are closely linked, and largely synonymous. Strengthening and integrating these measures, alongside economic development, should increase resilience against the health effects of extreme weather and gradual climate change.

9.2.8. Coastal Megacities: The Case of Mumbai

9.2.8.1. Introduction

In July 2005, Mumbai, India, was struck by an exceptional storm (Revi, 2005). In one 24-hour span alone, the city received 94 cm of rain, and the storm left more than 1,000 dead, mostly in slum settlements (De Sherbinin et al., 2007; Sharma and Tomar, 2010). A week of heavy rain disrupted water, sewer, drainage, road, rail, air transport, power, and telecommunications systems (Revi, 2005). As a result of this 'synchronous failure,' Mumbai-based automated teller machine banking systems ceased working across much of the country, and the Bombay and National Stock Exchanges were temporarily forced to close (Revi, 2005; UNISDR, 2011b). This demonstrates that within megacities, risk and loss are both concentrated and also spread through networks of critical infrastructure as well as connected economic and other systems.

9.2.8.2. Background

At present, Mumbai is the city with the largest population exposed to coastal flooding – estimated at 2,787,000 currently, and projected to increase to more than 11 million people exposed by 2070 (Hanson et al., 2011). During that same period, exposed assets are expected to increase from US$ 46.2 billion to nearly US$ 1.6 trillion (Hanson et al., 2011).

Mumbai's significant, and increasing, exposure of people and assets – both within the urban fabric but also outside, connected to the city's functions through networks of critical infrastructure, financial, and resource flows – will be affected by changes in climate means and climate extremes (Nicholls et al., 2007; Revi, 2008; Fuchs et al., 2011; Ranger et al., 2011). It is difficult to associate a single extreme event with climate change, but it may be possible to discuss the changed probability of an event's occurrence in relation to a particular cause, such as global warming (see FAQ 3.2). For the Indian monsoon, for example, extreme rain events have an increasing trend between 1901 and 2005, with the trend being stronger since 1950 (see Section 3.4.1).

9.2.8.3. Description of Vulnerability

Attributing causes of changes in monsoons is difficult due to substantial differences between models, and the observed maximum rainfall on India's west coast, where Mumbai is located, is poorly simulated by many models (see Section 3.4.1). That being said, increases in precipitation are projected for the Asian monsoon, along with increased interannual seasonally averaged precipitation variability (see Section 3.4.1).

Furthermore, extreme sea levels can be expected to change in the future as a result of mean sea level rise and changes in atmospheric storminess, and it is *very likely* that sea level rise will contribute to increases in extreme sea levels in the future (see Section 3.5.3).

The development failures that have led to an accumulation of disaster risk in Mumbai and allowed its transmission beyond the urban core are common to many other large urban centers. The IPCC Fourth Assessment Report (AR4) stated with *very high confidence* that the impact of climate change on coasts is exacerbated by increasing human-induced pressures, with subsequent studies being consistent with this assessment (see Section 3.5.5).

The AR4 also reported with *very high confidence* that coasts will be exposed to increasing risks, including coastal erosion, over coming decades due to climate change and sea level rise, both of which will be exacerbated by increasing human-induced pressures (see Section 3.5.5).

The July 2005 flooding in Mumbai underscores the fact that coastal megacities are already at risk due to climate-related hazards (De Sherbinin et al., 2007; McGranahan et al., 2007). Refuse and debris commonly clog storm drains, causing flooding even on the higher ground in Mumbai's slums, and landslides are another threat to squatter communities that are near or on the few hillsides in the city (De Sherbinin et al., 2007). Urban poor populations often experience increased rates of infectious disease after flood events, and after the July 2005 floods the prevalence of leptospirosis rose eightfold in Mumbai (Maskey et al., 2006; Kovats and Akhtar, 2008).

To the present, drivers of flood risk have been largely driven by socioeconomic processes and factors, such as poverty, ecosystem degradation, and poorly governed rapid urbanization (Revi, 2005, 2008; De Sherbinin et al., 2007; Huq et al., 2007; UNISDR, 2009c, 2011b; Hanson et al., 2011; Ranger et al., 2011). These processes are interrelated, and within these cities, vulnerability is concentrated in the poorest neighborhoods, which often lack access to sanitation, health care, and transportation infrastructure, and whose homes and possessions are unprotected by insurance (Revi, 2005; De Sherbinin et al., 2007; UNISDR, 2009c; Ranger et al., 2011).

Slum settlements are often located in sites with high levels of risk due to environmental and social factors. For example, they are often located in floodplains or on steep slopes, which means their residents suffer from a considerable degree of physical exposure and social vulnerability to losses from flood events (Huq et al., 2007; McGranahan et al., 2007; Chatterjee, 2010).

Mumbai is one of many coastal megacities that have been built in part on reclaimed land, a process that increases flood risks to low-lying areas where slums are frequently located (Chatterjee, 2010). Its slums do not benefit from structural flood protection measures and are located in low-lying areas close to marshes and other marginal places and are frequently flooded during monsoon season, especially when heavy rainfall occurs during high tides (McGranahan et al., 2007; Chatterjee, 2010). A rise in sea level of 50 cm, together with storm surges, would render uninhabitable the coastal and low-lying areas (De Sherbinin et al., 2007) where many of Mumbai's informal settlements are currently located.

9.2.8.4. Outcomes/Consequences

India's 2001 census indicated that in Mumbai 5,823,510 people (48.9% of the population) lived in slums (Government of India, 2001). In 2005, the global slum population was nearly 1 billion, and it is projected to reach 1.3 to 1.4 billion by 2020, mostly concentrated in cities in developing countries (UN-HABITAT, 2006). In addition to Mumbai, Hanson et al. (2011) found that the following cities will have the greatest population exposure to coastal flooding in 2070: Kolkata, Dhaka, Guangzhou, Ho Chi Minh City, Shanghai, Bangkok, Rangoon, Miami, and Hai Phòng. Many of these cities are already characterized by significant population and asset exposure to coastal flooding, and all but Miami are located in developing countries in Asia.

Africa does not have a large share of the world's biggest coastal cities but most of its largest cities are on the coast and large sections of their population are at risk from flooding (Awuor et al., 2008; Adelekan, 2010). Compared to Asia, Europe, and the Americas, a greater percentage of Africa's population lives in coastal cities of 100,000 to 5 million people, which is noteworthy because Africa's medium-to-large cities tend to be poor and many are growing at much higher rates than cities on the other continents (McGranahan et al., 2007).

The amount of vulnerability concentrated within these cities will define their risks, and in the absence of adaptation there is *high confidence* that locations currently experiencing adverse effects, such as coastal erosion and inundation, will continue to do so in the future (see Section 3.5.5).

However, there is a certain limit to adaptation given that these cities are fixed in place and some degree of exposure to hazards is 'locked in' due to the unlikelihood of relocation (Hanson et al., 2011). For example, India's large infrastructure investments, which have facilitated Mumbai's rapid growth, were built to last 50 to 150 years (Revi, 2008). This forecloses some adaptation and DRR strategies, such as risk avoidance. Furthermore, all large coastal cities are centers of high population density, infrastructure, investments, networking, and information (McGranahan et al., 2007; Chatterjee, 2010). This concentration and connectivity make them important sources of innovation and economic growth, especially in developing countries where these ingredients may be absent elsewhere. This underscores the importance of governance and economic relations, including insurance and more general basic needs of health and education, in allowing urban systems and those at risk to build resilience if they cannot avoid hazard.

9.2.8.5. Lessons Identified

Measures to reduce exposure to existing weather-related hazards can also serve as means of adapting to climate change (McGranahan et al., 2007; UNISDR, 2009c, 2011b; Chapters 1 and 2). At the time of the 2005 flood, Mumbai lacked the capacity to address a complex portfolio of (interrelated) risks (De Sherbinin et al., 2007; Revi, 2008), and its multi-hazard risk plan from 2000 was not well implemented (Revi, 2005). Risk protection in most other megacities in developing countries was also found to be more informal than robust (Hanson et al., 2011). Multi-hazard risk models, based on probabilistic analysis, can help governments better reduce risks and facilitate better management of and preparedness for risks that cannot be reduced cost effectively (Revi, 2008; Ranger et al., 2011; UNISDR, 2011b).

Given that up to US$ 35 trillion (approximately 9% of projected global GDP) may be exposed to climate-related hazards in port cities by 2070 (in purchasing power parity, 2001 US$) (Hanson et al., 2011), managing – and reducing – these risks represents a high-leverage policy area for adaptation. The scale of economic assets at risk is impressive and to this must be added the livelihoods and health of the poor that may be disproportionately impacted by disaster events but have partial visibility in macroeconomic assessments.

The need to adapt is especially acute in developing countries in Asia given that 14 of the top 20 urban agglomerations projected to have the greatest exposure of assets in 2070 are in developing countries in this region (Hanson et al., 2011). This suggests that scaled-up financing for adaptation may be needed to safeguard the residents and economic activity in these cities to a level comparable to that of other coastal megacities that face similar population and asset exposure, such as New York or Tokyo. Two critical distinctions are the degree of poverty and the less complete reach of local government in those cities most at risk.

Despite efforts to assess the impacts of climate change at the city scale, analysis of the economic impacts of climate change at this scale has received relatively little attention to date (Hallegatte and Corfee-Morlot, 2011). In developing countries, the sometimes incomplete understanding of climate risks and the limited institutional capacity have meant that analysis of climate change impacts at the city scale has generally considered only flood risks and not yet assessed additional potential impacts (Hunt and Watkiss, 2011). A standardized, multi-hazard impact analysis at the city scale would be useful and facilitate comparisons between cities (Hunt and Watkiss, 2011).

9.2.9. Small Island Developing States: The Challenge of Adaptation

9.2.9.1. Introduction

Small Island Developing States (SIDS) are defined as those that are small island nations, have low-lying coastal zones, and share development challenges (UNCTAD, 2004). Strengthening of SIDS technical capacities to enable resilience building has been recommended (UNESC, 2011).

This case study explores the critical vulnerabilities of the Republic of the Marshall Islands (RMI). Additional data from the Maldives, also highly vulnerable to sea level rise and extreme weather events and where the tsunami caused significant damage, and Grenada, which is a country with a small open economy vulnerable to external shocks and natural disasters, are used to develop the full context of the limits of adaptation. Specifically, the RMI highlights the availability of fresh water as a major concern. "There is strong evidence that under most climate change scenarios, water resources in small islands are likely to be seriously compromised (*very high confidence*)" (Mimura et al., 2007).

9.2.9.2. Background

SIDS can be particularly vulnerable to hazards and face difficulties when responding to disasters (TDB, 2007). SIDS share similar development challenges including small but growing populations, economic dependence on international funders, and lack of resources (e.g., freshwater, land) (World Bank, 2005b; UNFCCC, 2007a). The IPCC (Mimura et al., 2007) concluded that "small islands, whether located in the tropics or higher latitudes, have characteristics which make them especially vulnerable to the effects of climate change, sea level rise, and extreme events (*very high confidence*)." Many SIDS share vulnerabilities with high levels of poverty and are reported to suffer serious environmental degradation and to have weak human and institutional capacities for land management that is integrated and sustainable (GEF, 2006). The range of physical resources available to states influences their options to cope with disasters and the relatively restricted economic diversity intrinsic to SIDS minimizes their capacity to respond in emergencies with measures such as shelter or evacuation (Boruff and Cutter, 2007). Hence SIDS are among the most vulnerable states to the impacts of climate change (UNFCCC, 2007b). As of 2010, 38 UN member nations and 14 non-UN Members/Associate Members of the Regional Commissions were classified as SIDS (UN-OHRLLS, 2011).

The RMI provides an example of critical vulnerabilities. It is made up of five islands and 29 atolls that are spread across more than 1.9 million square kilometers of Pacific Ocean (World Bank, 2006a). The country has a population of 64,522, approximately two-thirds of which is concentrated in urban areas on just two atolls (UNDESA, 2010; World Bank, 2011b). The other one-third live on the even more remote outer islands and atolls (World Bank, 2006a). Even the main inhabited islands remain extremely isolated; the nearest major port is over 4,500 km from Majuro, the capital atoll (World Bank, 2005b).

The Maldives and Grenada both provide other examples of vulnerability to extreme events and disasters and climate change adaptation needs:

- The Maldives consist of 1,192 small islands. 80% are 1 m or less above sea level (Quarless, 2007), of which only three islands have a surface area of more than 500 ha (De Comarmond and Payet, 2010). These characteristics make them highly vulnerable to damage from sea level rise and extreme weather events. The economic and survival challenges of the people of the Maldives were evident after the 2004 tsunami caused damage equivalent to 62% of national GDP (World Bank, 2005c). As of 2009, the country still faced a deficit of more than US$ 150 million for reconstruction.

Such devastation in a SIDS might be countered with further disaster preparation and efforts to maintain emergency funds to rebuild their economies (De Comarmond and Payet, 2010).

- Grenada is a small tri-island state in the Eastern Caribbean with a population of 102,000 and a per capita GDP of US$ 4,601 in 2004 (IMF, 2011). It is a small open economy, vulnerable to external shocks and natural disasters as seen by the effects of Hurricane Ivan, which created large fiscal and balance of payments financing needs in 2004, and Hurricane Emily, which struck in 2005 (IMF, 2004, 2006). Hurricane Ivan brought major disruption to an economic recovery process, eventually costing the island an estimated US$ 3 billion (Boruff and Cutter, 2007). It is projected that Ivan reduced the country's forecasted growth rate from 5.7% to -1.4% (Quarless, 2007). Hurricane Emily followed 10 months later, virtually completing the trail of destruction started by Ivan. The impact was seen in every sector of the economy. Capital stock was severely damaged and employment was significantly affected (UNDP, 2006).

9.2.9.3. Description of Vulnerability

Many SIDS face specific disadvantages associated with their small size, insularity, remoteness, and susceptibility to natural hazards. SIDS are particularly vulnerable to climate change because their key economic sectors such as agriculture, fisheries, and tourism are all susceptible (Barnett and Adger, 2003; Read, 2010) (a more extensive discussion is provided in Chapter 4, especially Sections 4.2.1, 4.4.4, 4.5.2, and 4.5.3). The hazards of extreme weather events are coupled with other long-term climate change impacts, especially sea level rise (see Box 3-4). Low-lying atoll communities, such as the Maldives and Cook Islands, are especially vulnerable (Ebi et al., 2006; Woodroffe, 2008; Kelman and West, 2009) and are expected to lose significant portions of land (Mimura et al., 2007). Small island states and particularly atoll countries may experience erosion, inundation, and saline intrusion resulting in ecosystem disruption, decreased agricultural productivity, changes in disease patterns, economic losses, and population displacement – all of which reinforce vulnerability to extreme weather events (Pernetta, 1992; Nurse and Sem, 2001; Mimura et al., 2007).

SIDS suffer higher relative economic losses from natural hazards and are less resilient to those losses so that one extreme event may have the effect of countering years of development gains (UN, 2005; Kelman, 2010). The distances between many SIDS and economic centers make their populations among the most isolated in the world (World Bank, 2005b).

Underdevelopment and susceptibility to disasters are mutually reinforcing: disasters not only cause heavy losses to capital assets, but also disrupt production and the flow of goods and services in the affected economy, resulting in a loss of earnings (Pelling et al., 2002). In both the short and the long term, those impacts can have sharp repercussions on the economic development of a country, affecting GDP, public finances, and foreign trade, thus increasing levels of poverty and public debt (Mirza, 2003; Ahrens and Rudolph, 2006). Climate change threatens to exacerbate existing vulnerabilities and hinder socioeconomic development (UNFCCC, 2007b).

The RMI faces major climate-related natural hazards including sea level rise, tropical storms or typhoons with associated storm surges, and drought. These hazards should be considered within the context of additional hazards and challenges such as ecosystem degradation, pollution of the marine environment, and coastal erosion as well as food security. The RMI faces physical and economic challenges that amplify the population's vulnerability to climate hazards, including high population density, high levels of poverty, low elevation, and fragile freshwater resources (World Bank, 2011b). The Global Facility for Disaster Reduction and Recovery report concludes that the hazard that poses the most threat is sea level rise, as the highest point on RMI is only 10 m above sea level (World Bank, 2011b). Consequently, multilateral donors considered the RMI 'high risk' and the Global Facility for Disaster Reduction and Recovery has identified it as a priority country for assistance (World Bank, 2011b).

9.2.9.4. Outcomes/Consequences

A range of both local and donor-supported actions have endeavored to build resilience among SIDS. The example of the RMI shows the benefits that risk reduction and climate change adaptation efforts may offer other island states.

Freshwater availability is a major concern for many SIDS (Quarless, 2007), including the RMI. Since SIDS are especially vulnerable to extreme weather events, their water supplies face rapid salinization due to seawater intrusion and contamination (PSIDS, 2009). According to one study, countries such as the RMI lack the financial and technical resources to implement seawater desalination for their populations (UNDESA, 2011). Some disaster and climate risk management gains may come from simple technology (UNDESA, 2010). New scavenger technology for wells has been introduced (UNESC, 2004) as one of the ways forward. Simple abstraction of freshwater from thin groundwater lenses (a typical practice in oceanic atolls) often results in upward coning of saltwater, which, in turn, causes contamination of the water supplies. The RMI has benefited from its use of new, pioneering technology to limit the effects of extreme weather events on its water supply (UNDESA, 2011). The improvement of climate sensitivity knowledge, particularly in the context of risk management, is key to adaptation to climate change. Climate and disaster risk are closely entwined and, for example, resilience to drought and resilience to climate change both stand to be enhanced through a single targeted program.

In addition to project-oriented development assistance, the RMI receives substantial financial assistance from the United States through a Compact of Free Association (Nuclear Claims Tribunal, Republic of the Marshall Islands, 2007). Grants and budget support provided under Compact I over the period of 1987 to 2001 totaled an average of over 30% of GDP, not including any other form of bilateral assistance (World

Bank, 2005b). The RMI stands out among other lower middle income countries, receiving average aid per capita of US$ 1,183, compared with the average of US$ 8 for other lower middle income countries (World Bank, 2005b). This assistance, buttressed by national disaster management policies dating back to the RMI's independence in 1986 and including the Global Facility for Disaster Reduction and Recovery's role in assessing the RMI's systems and noting existing gaps for future development partner projects, has resulted in a range of national and regional disaster and climate risk management initiatives (World Bank, 2009, 2011b).

9.2.9.5. Lessons Identified

The physical, social, and economic characteristics by which SIDS and developing countries are defined (education, income, and health, for example) increase their vulnerability to extreme climate events. Experiences from the Marshall Islands, the Maldives, and Grenada indicate that limited freshwater supplies and inadequate drainage infrastructure are key vulnerability factors. These examples also indicate an important difference between risk of frequent smaller hazards and catastrophic risk of infrequent but extreme events.

The cases of Grenada and the Maldives demonstrate the high relative financial impact that a hazard can have on a small island state. For the RMI, financial support from donors has enabled a range of risk management programs. Although the importance of disaster risk reduction strategies is apparent, preventive approaches continue to receive less emphasis than disaster relief and recovery (Davies et al., 2008). Considering the range of challenges facing policymakers in some SIDS, preventive climate adaptation policies can seem marginal compared with pressing issues of poverty, affordable energy, affordable food, transportation, health care, and economic development.

National policymaking in this context remains a major challenge and availability of funding for preventive action – such as disaster and climate risk management – may continue to be limited for many countries (Ahmad and Ahmed, 2002; Jegillos, 2003; Huq et al., 2006; Yohe et al., 2007). Although most developing countries participate in various international protocols and conventions relating to climate change and sustainable development and most have adopted national environmental conservation and natural disaster management policies (Yohe et al., 2007), the policy agendas of many developing countries do not yet fully address all aspects of climate change (Beg et al., 2002).

9.2.10. Changing Cold Climate Vulnerabilities: Northern Canada

9.2.10.1. Introduction

In cold climate regions all over the world, climate change is occurring more rapidly than over most of the globe (Anisimov et al., 2007). These changes have implications for the built environment. The vulnerability of residents of the Canadian North is complex and dynamic. In addition to the increasing risks from extreme weather events, there are climate impacts upon travel, food security, and infrastructural integrity, which in turn affect many other aspects of everyday life (Pearce et al., 2009; Ford et al., 2010). Additionally, the relative isolation of these northern communities makes exposure to climate-related risk more difficult to adapt to, thus increasing their level of vulnerability (Ford and Pearce, 2010). This case study will examine the increased vulnerabilities in regions of the Canadian North due to climate change's effect on infrastructure through changes in permafrost thaw and snow loading. The study illustrates existing and projected risks and governmental responses to them at the municipal, provincial/territorial, and national levels. Canada has three territories: the Yukon (YT); the Northwest Territories (NWT); and Nunavut (NU); this study deals with all three and, to a much lesser extent, the northern regions of the provinces, such as Nunavik in northern Quebec. Though both permafrost thaw and changing snow loads are slowly progressing events, as opposed to one-time extreme events, their impacts can result in disasters. Future protection relies upon risk reduction and adaptation. Sections 3.3.1 and 3.5.7 discuss changes in cold extremes and other climate variables at high latitudes.

9.2.10.2. Background

Over the past few decades, the northern regions of Canada have experienced a rate of warming about twice that of the rest of the world (McBean et al., 2005; Field et al., 2007; Furgal and Prowse, 2008). In northern Canada, winter temperatures are expected to rise by between 3.5 and 12.5°C by 2080, with smaller changes projected for spring and summer; in more southerly regions of northern Canada, temperatures could warm to be above freezing for much longer periods (Furgal and Prowse, 2008). For example, whereas it was estimated that the Northwest Passage would be navigable for ice-strengthened cargo ships in 2050 (Instanes et al., 2005), it has already been navigable in 2007 (Barber et al., 2008). Recent studies have suggested that some communities in northern Canada will be vulnerable to the accelerated rate of climate change (Ford and Smit, 2004; Ford and Furgal, 2009).

Higher temperatures have several implications for infrastructure that plays an important role in maintaining the social and economic functions of a community (CSA, 2010). Permafrost thaw and changing snow loads have the potential to affect the structural stability of essential infrastructure (Nelson et al., 2002; Couture and Pollard, 2007). Design standards in northern Canada were based on permafrost and snow load levels of a previous climate regime (CSA, 2010). Adaptation is essential to avoid higher operational and maintenance costs for structures and to ensure that the designed long lifespan of each structure remains viable (Allard et al., 2002). Addressing these impacts of climate change is a complex task. Naturally each structure will be differently affected and the resulting damage can exacerbate existing weaknesses and create new vulnerabilities. For example, although increasing snow loads alone can have negative impacts on infrastructure, the fact that many buildings have been structurally weakened by permafrost thaw adds to the damage potential during any snow event (CSA, 2010).

9.2.10.3. Description of Vulnerability

9.2.10.3.1. Permafrost thaw

Permafrost thaw is one of the leading factors increasing climate-related vulnerability. Permafrost is by definition dependent on a sub-zero temperature to maintain its state (CSA, 2010; NRCAN, 2011a). With a changing climate, it is difficult to predict where permafrost is most likely to thaw, but about half of Canada's permafrost zones are sensitive to small, short-term increases in temperature, compromising the ability of the ground to support infrastructure (Nielson, 2007; NRTEE, 2009; CSA, 2010). The rate of thaw (and hence implications for infrastructure stability) is also dependent on soil type within the permafrost zone (Nielson, 2007). Areas that have ice-rich soil are much more likely to be affected than those with a lower ice-soil ratio or those that are underlain by bedrock (Nelson et al., 2002). Municipalities in discontinuous or sporadic permafrost zones may feel the impacts of a warming climate more intensely since the permafrost is thinner than it would be in continuous zones where ice has built up over time (Nelson et al., 2002).

Though some infrastructure maintenance will always be required, climate-related permafrost thaw will increase the needs for infrastructure maintenance and the rate of damage that is inflicted (Allard et al., 2002). Permafrost thaw affects different types of infrastructure in radically different ways. In northern Canada, municipalities have experienced many different climate-related impacts on physical infrastructure including the following (Infrastructure Canada, 2006; Nielson, 2007; NRTEE, 2009):

- Nunavik, in northern Quebec, reported that local roads and airport runways have suffered from severe erosion, heaving, buckling, and splitting (Nielson, 2007; Fortier et al., 2011).
- In Iqaluit, in Nunavut, 59 houses have required foundation repair and/or restoration and buildings with shallow foundation systems have been identified as needing attention in the near future (Nielson, 2007). In Inuvik, in the Northwest Territories, a recent study estimated that 75% of the buildings in the municipality would experience structural damage (Bastedo, 2007) depending on the rate of permafrost thaw.
- The Tibbitt to Contwoyto winter road (Northwest Territories) experienced climate-related closures in 2006, remaining open for only 42 days compared to 76 in 2005 (Bastedo, 2007). This resulted in residents and businesses having to airlift materials to their communities instead. In particular, the Diavik Diamond Mine was forced to spend millions of dollars flying in materials (Bastedo, 2007; Governments of Northwest Territories, Nunavut, and Yukon, 2010).
- The Northwest Territories reported that the airport runway in Yellowknife required extensive retrofitting when the permafrost below it began to thaw (Infrastructure Canada, 2006).

The impacts of permafrost thaw on infrastructure have implications for the health, economic livelihood, and safety of northern Canadian communities. The costs of repairing and installing technologies to adapt to climate change in existing infrastructure can range from several million to many billions of dollars, depending on the extent of the damage and the type of infrastructure that is at risk (Infrastructure Canada, 2006). Lessons from municipalities in the United States have proven that these costs can be large. For instance, while the Yukon had financial difficulties with CDN$ 4,000 km^{-1} yr^{-1} costs related to permafrost damage to highways, Alaska is experiencing costs of up to CDN$ 30,000 km^{-1} yr^{-1} for an annual cost of over CDN$ 6 million over a 200-km stretch (Governments of Northwest Territories, Nunavut, and Yukon, 2010). In the future, as infrastructure needs to be replaced, costs will multiply rapidly (Larsen et al., 2008).

9.2.10.3.2. Snow loading

In most northern Canadian communities, buildings and roadways are built using historical snow load standards (Nielson, 2007; Auld, 2008). This makes them particularly vulnerable to climate change since snow loads are expected to increase with higher levels of winter precipitation (Christensen et al., 2007; NRTEE, 2009). Already in the Northwest Territories, 10% of public access buildings have been retrofitted since 2004 to address critical structural malfunctions. An additional 12% of buildings are on high alert for snow load-related roof collapse (Auld et al., 2010). In Inuvik, NWT, a local school suffered a complete roof collapse under a particularly heavy snowfall (Bastedo, 2007). As permafrost continues to thaw, resulting in a loss of overall structural integrity, greater impacts will be linked to the increase in snow loads as previously weakened or infirm structures topple under larger or heavier snowfalls.

9.2.10.4. Outcomes

In response to these vulnerabilities, government and community leaders have put emphasis on action and preparedness (Government of Northwest Territories, 2008; Governments of Northwest Territories, Nunavut, and Yukon, 2010). The social impacts of relocating communities or complete restoration after a major disaster, as well as the financial costs, provide a strong deterrent to complacency and relocation will be utilized where necessary as a last resort (USARC, 2003). Though each government tier, from federal to municipal levels, tackles the issue from a different angle, their approaches are proving complementary as is demonstrated below. This section explores adaptation efforts from each level of government and the contribution they make to adaptive capacity in northern Canadian communities.

9.2.10.4.1. Federal level

The Canadian government contributes to numerous adaptation efforts at different levels and through various programs (Lemmen et al., 2008).

Some federal-level climate change adaptation programs are reactive; for example, at the most basic level, the federal government is responsible for the provision of assistance after a disaster or in order to relocate structures and communities (Henstra and McBean, 2005). Other programs are more proactive, designed to prevent disasters from occurring; for example, climate change is currently being incorporated into the 2015 version of the National Building Code (Environment Canada, 2010), which would help ensure that future infrastructure is built to a more appropriate standard and that adaptive measures are incorporated into the design and building of any new infrastructure. This could also help ensure that adaptation measures are implemented in a uniform way across the country.

In addition, several federal-level departments have programs specially designed to prevent damage from climate-related impacts. As part of the Climate Change Adaptation Program offered by the Aboriginal Affairs and Northern Development Canada, the Assisting Northerners in Assessing Key Vulnerabilities and Opportunities helps to support aboriginal and northern communities, organizations and territories in addressing the urgent climate-related risks (INAC, 2010). For example, the program offers risk assessments for existing infrastructure, water quality, and management programs and helps to identify new infrastructure designs to reduce risk from climate change (INAC, 2010).

Similarly, the Regional Adaptation Collaborative (RAC) funding provided by Natural Resources Canada was designed to assist communities that are adapting to climate change (NRCAN, 2011b). The Northern RAC initiatives are focused on identifying vulnerabilities in the mining sector. Permafrost thaw and snow loading are examples of factors that the program will examine (NRCAN, 2011b).

Another adaptation initiative that has come from the federal level is the site selection guidelines developed by the Canadian Standards Association (CSA, 2010). Though voluntary, this set of guidelines encourages engineers, land use planners, and developers to consider environmental factors including the rate of permafrost thaw and type of soil when building (CSA, 2010). Additionally, it strongly encourages the use of projections and models in the site selection process, instead of relying on extrapolated weather trends (CSA, 2010).

Similarly, federal-level design requirements such as the Canadian environmental assessment process are required to account for climate change in the design phase of significant new projects such as tailings containment, water retention, pipelines, or roads (Furgal and Prowse, 2008). Facilitating use of the guidelines and environmental assessment requirements are proactive responses that aim to prevent future permafrost-related damage to infrastructure.

9.2.10.4.2. Provincial/territorial level

The territorial governments are contributing to the protection of infrastructure in several ways, including conducting and funding research to identify vulnerable areas and populations (INAC, 2010). The Yukon transportation department has undertaken several adaptation initiatives including the design and implementation of road embankments to minimize melting; construction of granular blankets on ice-rich slopes to provide for stability and to prevent major slope failure; and the installation of culverts in thawed streambeds (Government of Yukon, 2010). Ground-penetrating radar and resistivity to assess permafrost conditions underground are being used in Nunavik, Quebec (Fortier et al., 2011). To protect existing permafrost, light-colored pavement on roadways is being used to reflect greater amounts of sunlight and prevent heat absorption (Walsh et al., 2009). Collaborations with federal-level departments to address community infrastructure resilience are being conducted with, for example, the Nunavut Climate Change Partnership, which involves the Government of Nunavut, Natural Resources Canada, Aboriginal Affairs and Northern Development Canada, and the Canadian Institute of Planners (NRCAN, 2011c). These programs help communities to develop action plans that detail suitable options for addressing issues related to climate change. The Yukon government is providing funding for municipalities to develop their own climate change adaptation plans through the Northern Strategy Trust Fund to the Northern Climate ExChange (Government of Yukon, 2009).

About 85 flat-loop thermosyphons, a sort of ground-source heat pump, which extract heat from the ground (through convection) during the winter and reduce thawing, have been constructed in territorial-owned buildings including schools and hospitals, prisons, and visitor centers in Nunavut, the Northwest Territories, and the Yukon (Holubec, 2008; CSA, 2010). The installation of thermosyphon technology is not, in itself, a long-term strategy but merely prolongs the lifetime of most infrastructures (CSA, 2010). Finally, screw jack foundations, a technology that helps to stabilize vulnerable foundations and has been used to prevent damage due to permafrost thaw and related shifting of house foundations, have been implemented in new buildings built by the Northwest Territories Housing Corporation (Government of Northwest Territories, 2008).

9.2.10.4.3. Municipal level

The municipal level is often most involved in building adaptive capacity and implementing adaptation strategies (Black et al., 2010) because municipal governments feel the effects of damaged infrastructure more keenly than higher levels of government (Richardson, 2010). Municipalities, community groups, and businesses all over the three territories have contributed in many ways. Some examples include:

- Urban planning and design are being used to reduce exposure to wind and snowdrifts as well as minimize heat loss from buildings in Iqaluit, NU (NRCAN, 2010).
- Insulated lining was placed underneath a 100-m section of runway to prevent damage from permafrost thaw in Yellowknife, NWT (Infrastructure Canada, 2006).
- Ice-rich soil under important infrastructure has been replaced with gravel and heat-absorbing pavement in Yellowknife, NWT (Bastedo, 2007).

- Wind deflection fins are being used to prevent snow loading on roofs and obstructions around exits in NWT (Waechter, 2005).
- In Tuktoyaktuk, NWT, important buildings, including the police station and a school at risk of severe damage or loss have been moved inland (Governments of Northwest Territories, Nunavut, and Yukon, 2010) and concrete mats bound together with chains are being used to limit erosion (Johnson et al., 2003).
- Shims or pillars to elevate buildings are being used to make them less vulnerable to permafrost thaw (USARC, 2003).
- Construction of new bridges and all-weather roads to replace ice roads that are no longer stable is underway (Infrastructure Canada, 2006).

9.2.10.5. Lessons Identified

Northern Canada can be considered a vulnerable region given the expected climate-related risks. As the climate continues to warm in the North, infrastructure in many remote communities will become more vulnerable as well.

More research, especially into vulnerabilities in northern regions of the globe, and the identification of adaptation options for established communities would be of benefit for adaptation. Additionally, while governmental programs and support are available, a significant portion of it has been devoted to adaptation planning and strategizing. An important issue is the funding needed to help northern Canadian communities implement adaptation actions.

Finally, codes and standards are an integral part of addressing climate impacts on infrastructure. Given the importance of this task, building codes in vulnerable regions need more review and attention to protect communities. An evaluation and monitoring program that focuses on codes and structures as well as adaptation options is noticeably lacking. Despite the complexity of these risks, however, a concerted effort from three tiers of government and community can work to reduce the vulnerability of infrastructure and northern communities.

9.2.11. Early Warning Systems: Adapting to Reduce Impacts

9.2.11.1. Introduction

It is recognized that vulnerability and exposure can never be reduced to zero but risk can be reduced by effective systems for early warning of extreme events that may occur in the near- through to longer-term future (Broad and Agrawala, 2000; Da Silva et al., 2004; Haile, 2005; Patt et al., 2005; Hansen et al., 2011). This sense of 'seeing the future' by understanding current and projected risks is essential to effectively prepare for, respond to, and recover from extreme events and disasters. It is important to recognize that a changing climate poses additional uncertainty and therefore early warning systems can contribute to climate-smart disaster risk management. Effective disaster risk management in a changing climate is facilitated by strong coordination within and between sectors to realize adaptation potentials through assessing vulnerabilities and taking anticipatory actions (Choularton, 2007; Braman et al., 2010).

9.2.11.2. Background

The Hyogo Framework for Action (UNISDR, 2010; Chapter 7) stresses that early warning systems should be "people centered" and that warnings need to be "timely and understandable to those at risk" and need to "take into account the demographic, gender, cultural, and livelihood characteristics of the target audiences." "Guidance on how to act upon warnings" should be included. An early warning system is thus considerably more than just a forecast of an impending hazard.

In 2006, the United Nations International Strategy for Disaster Reduction completed a global survey of early warning systems. The executive summary opened with the statement that "If an effective tsunami early warning system had been in place in the Indian Ocean region on 26 December 2004, thousands of lives would have been saved. … Effective early warning systems not only save lives but also help protect livelihoods and national development gains" (Basher, 2006; UN, 2006). Improved early warning systems have contributed to reductions in deaths, injuries, and livelihood losses over the last 30 years (IFRC, 2009). Early warning systems are important at local (Chapter 5), national (Chapter 6), and international scales (Chapter 7). Toward the achievement of sustainable development, early warning systems provide important information for decisionmaking and in avoiding tipping points (Chapter 8).

9.2.11.3. Description of Strategy of Early Warning Systems

Early warning systems are to alert and inform citizens and governments of changes on time scales of minutes to hours for immediate threats requiring urgent evasive action; weeks for more advanced preparedness; and seasons and decades for climate variations and changes (Brunet et al., 2010). To date most early warning systems have been based on weather predictions, which provide short-term warnings often with sufficient lead time and accuracy to take evasive action. However, the range of actions that can be taken is limited. Weather predictions often provide less than 24 hours notice of an impending extreme weather event and options in resource-poor areas may not extend beyond the emergency evacuations of people (Chapter 5). Thus although lives may be saved, livelihoods can be destroyed, especially those of the poorest communities.

While most of the successfully implemented early warning systems to date have focused on shorter time scales, for example, for tornadoes (Doswell et al., 1993), benefits of improved predictions on sub-seasonal to seasonal scales are being addressed (Nicholls, 2001; Brunet et al., 2010; Webster et al., 2010). While hazardous atmospheric events can develop in a matter of minutes (in the case of tornadoes), it can be across seasons and decades that occurrence of extremes can change climatically (McBean, 2000). Since planning for hazardous events involves decisions across a full range of time scales, 'An Earth-system Prediction Initiative for the 21st Century' covering all scales has been proposed (Shapiro et al., 2007, 2010).

With the rapid growth in the number of humanitarian disasters, the disaster risk management community has become attentive to changes in extreme events possibly attributed to climate change including floods, droughts, heat waves, and storms that cause the most frequent and economically damaging disasters (Gall et al., 2009; Munich Re, 2010; Vos et al., 2010). Early warning systems provide an adaptation option to minimize damaging impacts resulting from projected severe events. Such systems also provide a mechanism to increase public knowledge and awareness of natural risks and may foster improved policy- and decisionmaking at various levels.

Important developments in recent years in the area of sub-seasonal and seasonal-to-interannual prediction have led to significant improvements in predictions of weather and climate extremes (Nicholls, 2001; Simmons and Hollingsworth, 2002; Kharin and Zwiers, 2003; Medina-Cetina and Nadim, 2008). Some of these improvements, such as the use of soil moisture initialization for weather and (sub-) seasonal prediction (Koster et al., 2010), have potential for applications in transitional zones between wet and dry climates, and in particular in mid-latitudes (Koster et al., 2004). Such applications may potentially be relevant for projections of temperature extremes and droughts (Lawrimore et al., 2007; Schubert et al., 2008; Koster et al., 2010). Decadal and longer time scale predictions are improving and could form the basis for early warning systems in the future (Meehl et al., 2007, 2009; Palmer et al., 2008; Shukla et al., 2009, 2010).

Developing resiliency to weather and climate involves developing resiliency to its variability on a continuum of time scales, and in an ideal world, early warnings would be available across this continuum (Chapters 1 and 2; McBean, 2000; Hellmuth et al., 2011). However, investments in developing such resiliency are usually primarily informed by information only over the expected lifetime of the investment, especially among poorer communities. For the decision of which crops to grow next season, some consideration may be given to longer-term strategies but the more pressing concern is likely to be the expected climate over the next season. Indeed, there is little point in preparing to survive the impacts of possible disasters a century in the future if one is not equipped to survive more immediate threats. Thus, within the disaster risk management community, preparedness for climate change must involve preparedness for climate variability (Chapters 3 and 4).

Improving prediction methods remains an active area of research and it is hoped significant further progress will be reached in coming years (Brunet et al., 2010; Shapiro et al., 2010). However for such predictions to be of use to end users, improved communication will be required to develop indices appropriate for specific regional impacts. A better awareness of such issues in the climate modeling community through greater feedback from the disaster risk management community (and other user communities) may lead to the development of additional applications for weather and climate hazard predictions. Prediction systems, if carefully targeted and sufficiently accurate, can be useful tools for reducing the risks related to climate and weather extremes (Patt et al., 2005; Goddard et al., 2010).

Despite an inevitable focus on shorter-term survival and hence interest in shorter-term hazard warnings, the longer time scales cannot be ignored if reliable predictions are to be made. Changing greenhouse gas concentrations are important even for seasonal forecasting, because including realistic greenhouse gas concentrations can significantly improve forecast skill (Doblas-Reyes et al., 2006; Liniger et al., 2007). Similarly, adaptation tools traditionally based on long-term records (e.g., stream flow measurements over 50 to 100 years) coupled with the assumption that the climate is not changing may lead to incorrect conclusions about the best adaptation strategy to follow (Milly et al., 2008). Thus reliable prediction and successful adaptation both need a perspective that includes consideration of short to long time scales (days to decades).

While there are potential benefits of early warning systems (NRC, 2003; Shapiro et al., 2007) that span a continuum of time scales, for much of the disaster risk management community the idea of preparedness based on predictions is a new concept. Most communities have largely operated in a reactive mode, either to disasters that have already occurred or in emergency preparedness for an imminent disaster predicted with high confidence (Chapter 5). The possibility of using weather and climate predictions longer than a few days to provide advanced warning of extreme conditions has only been a recent development (Brunet et al., 2010; Shapiro et al., 2010). Despite over a decade of operational seasonal predictions in many parts of the globe, examples of the use of such information by the disaster risk management community are scarce, due to the uncertainty of predictions and comprehension of their implications (Patt et al., 2005; Meinke et al., 2006; Hansen et al., 2011). Most seasonal rainfall predictions, for example, are presented as probabilities that total rainfall over the coming few (typically three) months will be amongst the highest or lowest third of rainfall totals as measured over a historical period and these are averaged over large areas (typically tens of thousands of square kilometers). Not only are the probabilities lacking in precision but the target variable – seasonal rainfall total – does not necessarily map well onto flood occurrence. Although higher-than-normal seasonal rainfall will often be associated with a higher risk of floods, it is possible for the seasonal rainfall total to be unusually high yet no flooding occurs. Alternatively, the total may be unusually low, yet flooding might occur because of the occurrence of an isolated heavy rainfall event (Chapter 3). Thus even when seasonal predictions are understood properly, it may not be obvious how to utilize them. These problems emphasize the need for the development of tools to translate such information into quantities directly relevant to end users. Better communication between modeling centers and end users is needed (Chapters 5 and 6). Where targeted applications have been developed, some success has been reported (e.g., for malaria prediction) (Thomson et al., 2006; Jones et al., 2007). Nonetheless there may be additional obstacles such as policy constraints that restrict the range of possible actions.

9.2.11.4. Interventions

There are many examples of interventions of early warning systems outlined in the other case studies of this chapter and also in Chapters 5, 6, and 7. As a part of their strategy of reducing risk, the Victorian Government in Australia has established the heat wave early warning system for metropolitan Melbourne and is undertaking similar work for regional Victoria (see Case Study 9.2.2). A Storm Warning Center and associated coastal volunteer network has been established in Bangladesh and has been proven effective (Case Study 9.2.5). The absence of a storm warning system in Myanmar contributed to the tragedy of that event (Case Study 9.2.5). The benefits of early warning systems are also discussed with respect to floods (Case Study 9.2.6), heat waves (Case Study 9.2.1), epidemic disease (Case Study 9.2.7), and drought (Case Study 9.2.3).

9.2.11.5. Outcomes

There have been examples of major benefits of early warning systems (Einstein and Sousa, 2007). Assessments of community capacity to respond to cyclone warnings have been performed for India (Sharma et al., 2009), Florida (Smith and McCarty, 2009), New Orleans (Burnside et al., 2007), New South Wales, Australia (Cretikos et al., 2008), and China (Wang et al., 2008). Predictions of landfall for tropical cyclones are important (Davis et al., 2008). In Bangladesh (Case Study 9.2.5; Paul, 2009), the implementation of an early warning system enabled people to evacuate a hazardous area promptly (Paul and Dutt, 2010; Stein et al., 2010). If forecasts are frequently incorrect, the response of people is affected (Chapter 5; Dow and Cutter, 1998). Public health impacts of hazards also depend on the preparedness of the local community (Vogt and Sapir, 2009) and this can be improved by early warnings. However, accurate predictions alone are insufficient for a successful early warning system, as is demonstrated by the case in the United Kingdom – a country that regularly experiences flooding (Parker et al., 2009). Severe damage and health problems followed flooding in 2007 due to insufficiently clear warning communication, issued too late and inadequately coordinated, so that people, local government, and support services were unprepared (UNISDR, 2009c). Heat-health warnings (Case Study 9.2.1) have proved more effective (Fouillet et al., 2008; Hajat et al., 2010; Michelozzi et al., 2010; Rubio et al., 2010) although improvements are still needed (Kalkstein and Sheridan, 2007).

Notwithstanding the difficulties outlined for use of seasonal predictions in disaster risk management, the successful use of such predictions has been possible (IRI, 2011). Since all preparative actions have some direct cost and it is impractical to be always prepared for all eventualities, seasonal predictions can help to choose priorities from a list of actions.

9.2.11.6. Lessons Identified

Early warning systems for extreme weather- or climate-related events, such as heat waves, floods, and storms have been implemented to provide warnings on time scales of hours to days. The skill of warnings beyond a few days ahead is improving as seasonal predictions are now demonstrating benefits for drought, floods, and other phenomena, and decadal forecasts of increased numbers of intense precipitation events and heat waves are now being factored into planning decisions (NRC, 2003; Lazo et al., 2009; Goddard et al., 2010). It is expected that early warning systems will enable the implementation of DRR and CCA. Early warning systems rely on the ability of people to factor information on the future into plans and strategies and need to be coupled with education programs, legislative initiatives, and scientific demonstrations of the skill and cost value benefits of these systems.

9.2.12. Effective Legislation for Multilevel Governance of Disaster Risk Reduction and Adaptation

9.2.12.1. Introduction

This case study, through focus on South Africa's disaster risk management law and comparable legal arrangements in other states, such as the Philippines and Colombia, explores critical provisions for effective legislation. South Africa's legislation has served as a model for others (Pelling and Holloway, 2006; Van Niekerk, 2011) because it focuses on prevention, decentralizes DRR governance, mandates the integration of DRR into development planning, and requires stakeholder inclusiveness. Implementation has proven challenging, however, particularly at the local level (NDMC, 2007, 2010; Visser and Van Niekerk, 2009; Botha et al., 2011; Van Niekerk, 2011) as is the case for most states (GNDR, 2009; UNISDR, 2011b). Through analysis of South Africa's legislation and the difficulties that it faces in implementation, this study provides relevant information to other governments as they assess whether their own national legislation to reduce and manage disaster risk is adequate for adapting to climate change.

9.2.12.2. Background

A legal framework establishes legal authority for programs and organizations that relate to hazards, risk, and risk management. These laws may dictate – or encourage – policies, practices, processes, the assignment of authorities and responsibilities to individuals and/or institutions, and the creation of institutions or mechanisms for coordination or collaborative action among institutions (Mattingly, 2002). Law can be used to provide penalties and incentives by enforcing standards, to empower existing agencies or establish new bodies with new responsibilities, and to assign budget lines (Pelling and Holloway, 2006). In short, legislation enables and promotes sustainable engagement, helps to avoid disjointed action at various levels, and provides recourse for society when things go wrong.

Most states have some form of disaster risk management legislation or are in the process of enacting it (UNDP 2005; UNISDR 2005b). In 2011, 48 countries reported substantial achievements in developing national policy and legislation; importantly, almost half are low or lower-middle income countries (UNISDR, 2011b). An increasing number of countries have been adopting or updating existing legislation modeled on Hyogo Framework for Action principles. Countries with new or updated laws include India and Sri Lanka in 2005; El Salvador, Saint Lucia, Saint Vincent, and the Grenadines in 2006; Anguilla (United Kingdom) and Gambia in 2007; Indonesia in 2008; Egypt and the Philippines in 2009; and Zambia and Papua New Guinea in 2010 (UNISDR, 2011b). As yet some of the new laws addressing disaster risk have not been harmonized with preexisting legislative frameworks in relevant sectors, such as water, agriculture, and energy (UNISDR, 2011b). Although these national legislations for disaster management do not necessarily include a disaster risk reduction orientation (Pelling and Holloway 2006), the evidence suggests a global paradigm shift from the former responsive approach to disaster management toward more long-term, sustainable preventive action (Britton, 2006; Benson, 2009). India, Pakistan, Indonesia, South Africa, and several Central American states have enacted such paradigm-changing amendments to disaster management legislation and, in Ecuador, the "notion of risk-focused disaster management was rooted directly into its new constitution adopted in 2008" (IFRC, 2011).

In the case of South Africa, the country was impacted by floods and droughts, and there was a high motivation for change in the post-Apartheid era (Pelling and Holloway, 2006; NDMC, 2007), which starting in 1994 led to legislative reform for disaster risk reduction. A "Green Paper" first solicited public input and debate, and a second "White Paper" translated responses into policy options for further technical and administrative deliberations. These documents are noteworthy for their consultative approach and their emphasis on disaster risk reduction rather than traditional response (Pelling and Holloway, 2006; NDMC, 2007). Thereafter the Government passed three disaster management bills that culminated in the promulgation of the Disaster Management Act No. 57 of 2002 and of the National Disaster Management Framework in 2005 (Pelling and Holloway, 2006; NDMC, 2007).

9.2.12.3. Description of Strategy

South Africa's 2002 Disaster Management Act and its National Disaster Management Policy Framework of 2005 (Republic of South Africa, 2002, 2005) are noteworthy because they were among the first to focus on prevention, decentralize DRR governance, mandate the integration of DRR into development planning, and require stakeholder inclusiveness.

The Act and Framework define the hierarchical institutional structure that governs disaster risk reduction at national, provincial, and municipal levels. They effectively decentralize DRR by mandating each level of government to create:

- A disaster risk management framework – a policy focused on the prevention and mitigation of risk
- A disaster risk management center – *inter alia*, to promote an integrated and coordinated system of management, to integrate DRR into development plans, to maintain disaster risk management information, to monitor implementation, and to build capacity
- A disaster risk management advisory forum – for government and civil society stakeholders in DRR to coordinate their actions
- An interdepartmental disaster risk management committee – for government departments to coordinate or integrate activities for DRR, to compile disaster risk management plans, and to provide interdepartmental accountability (Republic of South Africa, 2002, 2005; Van Niekerk, 2006).

The Act further details each entity's responsibilities. South Africa's legislation makes a legal connection between disaster risk reduction and development planning. Some other countries adopting this approach include Comoros, Djibouti, Ethiopia, Hungary, Ivory Coast, Mauritius, Romania, and Uganda (Pelling and Holloway, 2006).

The Act requires that municipalities include risk management plans in their integrated development plans (Republic of South Africa, 2002; Van Niekerk, 2006). Municipal-level requirements are supported with a mandate for provincial governments to ensure that their disaster risk management plans "form an integral part of development planning" and for the National Centre of Disaster Management to develop guidelines for the integration of plans and strategies into development plans (Republic of South Africa, 2002).

Closely related to the ability to influence development planning is the authority to lead coordinated government action for DRR across government agencies. The interdepartmental committees mandated by the Act for each level provide the opportunity to communicate plans and develop strategies across ministries and departments, avoiding unilateral action that may increase risk. The forums established by the Act similarly give voice to additional stakeholders to participate in DRR decisionmaking. South Africa, Colombia, and the Philippines' DRR laws, for example, include provisions for the involvement of NGOs, traditional leaders, volunteers, community members, and the private sector in disaster risk reduction.

9.2.12.4. Outcomes

Implementation of South Africa's benchmark legislative provisions has proven challenging. Many district municipalities have not yet established the disaster management centers required by the Act or these are not yet functioning adequately (Van Riet and Diedericks, 2010; Botha et al., 2011). The majority of local municipalities (which are subdivisions of district municipalities) have not yet established advisory forums although it should be noted that the Act does not require their creation at this level (Botha et al., 2011). A greater percentage of metropolitan districts have established advisory forums. Similarly, interdepartmental committees, which facilitate cross-sectoral governmental collaboration and the integration of DRR into development planning, have also not yet been established in a majority of municipalities. Although municipalities reported good progress in integrating their disaster management plans into integrated development plans (Botha et al., 2011), such plans as yet contain little evidence of integration (Van Niekerk, 2011).

Provincial and municipal levels attribute the lack of progress in implementing the Act and Framework to inadequate resources for start-up costs for municipalities as well as for the continuous operations of disaster risk reduction projects (Visser and Van Niekerk, 2009; NDMC, 2010). There is also the continuing need for resources for response recovery and rehabilitation activities. Reasons for the lack of funding include a lack of clarity of the Act on funding sources and confusion regarding the processes to access various sources of funding (Visser and Van Niekerk, 2009). Although the mechanisms to obtain funding exist, not all municipalities and provinces are using them, hence the perception of inadequate funding persists (Van Niekerk, 2011). In some cases there appears to be an absolute lack of funds, such as in district municipalities, which are more rural and less densely populated, and have a narrower tax base to fund DRR (Van Riet and Diedericks, 2010). This situation is similar to that in other countries, such as Colombia, where more than 80% of municipalities are able to assign only 20% of their own non-earmarked resources to risk reduction and disaster response. Because the law does not stipulate percentages and amounts, municipalities allocate minimal sums for disaster risk reduction (MIJ, 2009) given competing infrastructure and social spending needs (Cardona and Yamín, 2007).

South Africa and Colombia's experiences are replayed around the world. Governments informed in their 2011 Hyogo Framework progress reports that the lack of efficient and appropriate budget allocations remains one of the major challenges for effective disaster risk reduction legislation (UNISDR, 2011a). Even in countries in which funding for disaster risk management is mandated by law, actual resource allocation for disaster risk reduction remains low and is concentrated in preparedness and response (UNDP, 2007). The Philippines has new legislation that attempts to address these issues. The Philippines new Disaster Risk Reduction and Management Act 10121 renames the Local Calamity Fund as the Local Disaster Risk Reduction and Management Fund and stipulates that no less than 5% shall be set aside for risk management and preparedness (Republic of the Philippines, 2010). Further, to carry out the provisions of the Act, the Commission allocated one billion pesos or US$ 21.5 million (Republic of the Philippines, 2010). Unspent money will remain in the fund to promote risk reduction and disaster preparedness. The adequacy of this provision has yet to be tested as the Act is recent and implementation has yet to begin.

In South Africa, all relevant national departments have yet to undertake required DRR activities or identified sectoral focal points; consequently, the advisory committee at the national level is not yet functioning optimally (Van Niekerk, 2011). Similarly, at provincial and municipal levels, departmental representatives are absent or too junior to make decisions at meetings, reflecting lack of understanding about their department's role in DRR and about DRR generally (Van Riet and Diedericks, 2010). Moreover, as mentioned above, between 55 and 73% of municipalities have not established a committee, which Botha et al. (2011) point out hampers local government's ability to implement integrated multi-sectoral DRM.

The Philippines' Climate Change Act, enacted in 2009, addresses the challenge of inter-sectoral government collaboration by creating a commission to be chaired by the president and attached to that office, thus ensuring highest-level political support for collaborative implementation of the law (Republic of the Philippines, 2009). The commission is composed of the secretaries of all relevant departments as well as the Secretary of the Department of National Defense, as Chair of the National Disaster Coordinating Council, and representatives from the disaster risk reduction community. The main functions of the Commission are to "ensure the mainstreaming of climate change, in synergy with disaster risk reduction, into the national, sectoral, and local development plans and programs" and to create a panel of technical experts, "consisting of practitioners in disciplines that are related to climate change, including disaster risk reduction" (Republic of the Philippines, 2009).

Implementing the multi-sectoral DRM envisioned by South Africa's legislation may be hindered by the placement of the National Disaster Management Centre within a line ministry (the Department of Cooperative Governance) (Van Niekerk, 2011). Sub-national levels have likewise placed their centers within sectors with insufficient political authority; consequently, local municipal and district levels rate current interdepartmental collaboration as low (Botha et al., 2011). This placement allows other departments to disregard DRM, as the National Disaster Management Centre cannot enforce punitive measures (Van Niekerk, 2011).

Similar to South Africa's arrangements, the Philippines' highest policymaking and coordinating body for disaster risk management, the National Disaster Risk Reduction and Management Council (formerly called the National Disaster Coordinating Council), sits within the Department of National Defense. As such, it is focused on disaster preparedness and response and does not have sustainable development and poverty reduction responsibilities. The Philippines' new Disaster Risk Reduction and Management Act of 2010 attempts to redress this issue by including experts from all relevant fields as members of the Council and expressly defining its mandate on mainstreaming disaster risk reduction into sustainable development and poverty reduction strategies, policies, plans, and budgets at all levels (Republic of the Philippines, 2010).

Positioning DRR institutions within the highest levels of government has proven effective because this position often determines the amount of political authority of the national disaster risk management body (UNDP, 2007; UNISDR, 2009a). National disaster risk management offices attached to prime ministers' offices usually can take initiatives affecting line ministries, while their colleagues operating at the sub-ministerial level often face administrative bottlenecks (UNDP, 2007). High-level support is particularly important to enable disaster risk reduction legislation to provide a framework for strategies to build risk reduction into development and reconstruction (Pelling and Holloway, 2006).

9.2.12.5. Lessons Identified

The main lesson that emerges from this case study is that carefully crafted legislation buttresses DRR activities, thus avoiding a gap between the law's vision and its implementation. The experiences of South Africa and the Philippines in implementing their DRR legislation (as described by Visser and Van Niekerk, 2009; NDMC, 2010; Van Riet and Diedericks, 2010; Botha et al., 2011; Van Niekerk, 2011) and the literature on DRR legislation (Mattingly, 2002; Britton, 2006; Pelling and Holloway, 2006; UNDP, 2007; Benson, 2009; UNISDR, 2009c) point to the following elements of effective legislation and implementation:

- The law allocates adequate funding for implementation at all levels with clarity about the generation of funds and procedures for accessing resources at every administrative level.
- The institutional arrangements provide both access to power for facilitating implementation and opportunities to 'mainstream' disaster risk reduction and adaptation into development plans.
- The law includes provisions that increase accountability and enable coordination and implementation, that is, the clear identification of roles and responsibilities and access to participate in decisionmaking.

An additional element is the need for periodic assessment and revision to ensure that legislation for disaster risk reduction and adaptation is dynamic and relevant (Llosa and Zodrow, 2011). For instance, the Philippines' Disaster Risk Reduction Management (DRRM) Act calls for the development of a framework to guide disaster risk reduction and management efforts to be reviewed "on a five-year interval, or as may be deemed necessary, in order to ensure its relevance to the times" (Republic of the Philippines, 2010). The DRRM Act also calls for the development of assessments on hazards and risks brought about by climate change (Republic of the Philippines, 2010). Likewise, the Philippines Climate Change Act calls for the framework strategy that will guide climate change planning, research and development, extension, and monitoring of activities to be reviewed every three years or as necessary (Republic of the Philippines, 2009). Similarly, the United Kingdom's Climate Change Act establishes the preparation of a report informing parliament on risks of current and predicted impact of climate change no later than five years after the previous report (United Kingdom, 2008). Thus an additional element for effective DRR-adaptation legislation may be that the law be based on up-to-date risk assessment and mandates periodic reassessment as risks evolve and knowledge of climate change impacts improves.

Developing and enacting legislation takes considerable time and political capital. It took South Africa and the Philippines about a decade to enact comprehensive disaster risk reduction frameworks. Linking the development of disaster risk reduction legislation to the politically prominent climate change discussion could substantially increase the sense of urgency and thus speed of parliamentary processes (Llosa and Zodrow, 2011).

Another method for hastening the legislative process would be to first assess the adequacy of existing disaster risk reduction legislation and strengthen these laws rather than starting a wholly new drafting and negotiations process for adaptation that may create a parallel legal and operational system (Llosa and Zodrow, 2011). As frequently reported (e.g., UNDP, 2007; UNISDR, 2009c), an overload of laws and regulations without a coherent and comprehensive framework, clear competencies, and budget allocations hinders the effective implementation of disaster risk reduction legislation.

9.2.13. Risk Transfer: The Role of Insurance and Other Instruments in Disaster Risk Management and Climate Change Adaptation in Developing Countries

9.2.13.1. Introduction

The human and economic toll from disasters can be greatly amplified by the long-term loss in incomes, health, education, and other forms of capital resulting from the inability of communities to restore infrastructure, housing, sanitary conditions, and livelihoods in a timely way (Mechler, 2004; Mills, 2005). By providing timely financial assistance following extreme event shocks, insurance and other risk-transfer instruments contribute to DRR by reducing the medium- and long-term consequences of disasters. These instruments are widespread in developed countries, and are gradually becoming part of disaster management in developing countries, where novel micro-insurance programs are helping to put cash into the hands of affected poor households so they can begin rebuilding livelihoods (Bhatt et al., 2010). These mechanisms can also contribute to reducing vulnerability and advancing development even before disasters strike by providing the requisite security for farmers and firms to undertake higher-return, yet more risky investments in the face of pervasive risk. Governments also engage in risk transfer. Investors can be encouraged to invest in a country if there is evidence that the government has reduced its risks (Gurenko, 2004).

9.2.13.2. Background

This case study focuses on instruments for risk transfer in order to manage catastrophe risk in developing countries (see also Sections 5.5.2, 6.5.3, and 7.4.4). Table 9-3 provides an overview of financial instruments and arrangements, including risk transfer, as they are employed by households, farmers, small- and medium-sized enterprises (SMEs), and governments, as well as international organizations and donors. Typically, losses are reimbursed on an ad hoc basis after disasters strike through appeals to solidarity, for example, from neighbors, governments, and international donors. Households and other agents also rely on savings and credit, and many governments set aside national or sub-national level reserve funds. Alternatively, agents can engage in risk transfer (the shaded cells

Table 9-3 | Examples of risk financing mechanisms (shaded cells) at different scales. Source: adapted from Linnerooth-Bayer and Mechler, 2009.

	Local *Households, Farmers, SMEs*	***National*** *Governments*	***International*** *Development organizations, donors, NGOs*
Solidarity	Help from neighbors and local organizations	Government post-disaster assistance; government guarantees/bailouts	Bilateral and multilateral assistance, regional solidarity funds
Informal risk transfer (sharing)	Kinship and other reciprocity obligations, semi-formal micro-finance, rotating savings and credit arrangements, remittances		
Savings, credit, and storage (inter-temporal risk spreading)	Savings; micro-savings; fungible assets; food storage; money lenders; micro-credit	Reserve funds; domestic bonds	Contingent credit; emergency liquidity funds
Insurance instruments	Property insurance; crop and livestock insurance; micro-insurance	National insurance programs; sovereign risk transfer	Re-insurance; regional catastrophe insurance pools
Alternative risk transfer	Weather derivatives	Catastrophe bonds	Catastrophe bonds; risk swaps, options, and loss warranties

in Table 9-3), which is defined by UNISDR as "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" (UNISDR, 2009b). Risk sharing can be considered synonymous with risk transfer, although the latter is often used to connote more informal forms of shifting risk without explicit compensation or payment, for example, mutual non-market arrangements among family or community. Insurance is the best known form of market risk transfer; yet, risks can be transferred with many formal and informal instruments as described in the following section.

Traditional channels for financing disaster relief and recovery, although in many cases less costly than risk transfer, have in the past proved to be inadequate for managing large-scale weather-related events in highly vulnerable countries (Cohen and Sebstad, 2003; Cardenas et al., 2007; Barnett et al., 2008). In poor countries, households and businesses usually do not have the resources to purchase commercial insurance to cover their risks with the additional difficulty that in many developing countries the commercial insurance providers do not exist. If there is no support from family or government, disasters can lead to a worsening of poverty in the absence of insurance. The victims then must either obtain high-interest loans (or default on existing loans), sell their important and valued assets and livestock, or engage in low-risk, low-yield farming to lessen their exposure to extreme events (Varangis et al., 2002). In recognition of these issues and to reduce the overall costs of disasters, investments in disaster risk reduction and proactive risk transfer are strongly encouraged by governments, the insurance sector, and the donor community (Kreimer and Arnold, 2000; Gurenko, 2004; Linnerooth-Bayer et al., 2005).

9.2.13.3. Description of Strategy – Catastrophe Risk Transfer Mechanisms and Instruments

As shown by the shaded cells in Table 9-3, risk transfer includes a range of pre-disaster mechanisms and instruments (Cummins and Mahul, 2009), the most important of which are briefly described below:

- **Informal mutual arrangements** involve pre-agreed non-market exchanges of post-disaster support (informal risk sharing).
- **Insurance** is a "well-known form of risk transfer, where coverage of a risk is obtained from an insurer in exchange for ongoing premiums paid to the insurer" (UNISDR, 2009b). A contractual transaction based on a premium is used to guarantee financial protection against potentially large loss; contracts typically cover losses to property, productive assets, commercial facilities, crops and livestock, public infrastructure (sovereign insurance), and business interruption.
- **Micro-insurance**, based on the same principles as insurance, is aimed, most often, at lower-income individuals who cannot afford traditional insurance and hence the premiums are lower but also the coverage may be restricted. In some cases, the individuals are unable to access more traditional insurance (Mechler et al., 2006). Often it is provided in innovative partnerships involving communities, NGOs, self-help groups, rural development banks, insurers, government authorities, and donors.
- **Alternative risk transfer** denotes a range of arrangements that hedge risk (Mechler et al., 2006). These include catastrophe bonds, which are instruments where the investor receives an above-market return when a pre-specified catastrophe does not occur within a specified time interval. However, the investor sacrifices interest or part of the principal following the event.
- **Weather derivatives** typically take the form of a parametric (indexed-based) transaction, where payment is made if a chosen weather index, such as 5-day rainfall amounts, exceeds some predetermined threshold.
- **Contingent credit** (also called deferred drawdown option) is a prearranged loan contingent on a specified event; it can be provided by the insurance industry to other insurers, or by international financial institutions to governments.
- **Risk pools** aggregate risks regionally (or nationally) allowing individual risk holders to spread their risk geographically.

9.2.13.4. Interventions – Examples of Local, National, and International Risk Transfer for Developing Countries

Development organizations working together with communities, governments, insurers, and NGOs have initiated or supported many recent pilot programs offering risk transfer solutions in developing countries. Three examples at the local, national, and international scales are briefly discussed below.

9.2.13.4.1. Covering local risks: index-based micro-insurance for crop risks in India

Micro-insurance to cover, for example, life and health is widespread in developing countries, but applications for catastrophic risks to crops and property are in the beginning phases (see Morelli et al., 2010 for a review, and Loster and Reinhard, 2010 for a focus on micro-insurance and climate change). Typically a micro-insurance company, often operating on a not-for-profit basis, evolves from an organization that has developed insurance products for a community. Most are based on the expectation that the pool of participants will provide payments that cover the costs incurred, including expected damage claims (which are generally low because of infrequent and small claims), administrative costs (which are reduced through group contracts or linking contracts to loans), taxes, and regulatory fees. Many depend on the support of government subsidies and international development organizations and participation of NGOs (Mechler et al., 2006).

An innovative insurance program set up in India in 2003 covers non-irrigated crops in the state of Andhra Pradesh against the risk of insufficient rainfall during key times during the cropping season. The index-based policies are offered by a commercial insurer and marketed to growers through microfinance banks. In contrast to conventional insurance, which is written against actual losses, this index-based (parametric) insurance is written against a physical or economic trigger, in this case rainfall measured by a local rain gauge. The scheme owes its existence to technical assistance provided by the World Bank (Hess and Syroka, 2005). Schemes replicating this approach are currently targeting 700,000 exposed farmers in India (Cummins and Mahul, 2009).

One advantage of index-based insurance is the substantial decrease in transaction costs due to eliminating the need for expensive post-event claims handling, which has impeded the development of insurance mechanisms in developing countries (Varangis et al., 2002). A disadvantage is basis risk, which is the lack of correlation of the trigger with the loss incurred. If the rainfall measured at the weather station is sufficient, but for isolated farmers insufficient, they will not receive compensation for crop losses. Similar schemes are implemented or underway, for instance, in Malawi, Ukraine, Peru, Thailand, and Ethiopia (Hellmuth et al., 2009). A blueprint for insuring farmers in developing countries who face threats to their livelihoods from adverse weather has been developed (World Bank, 2005d). Overcoming major institutional and other barriers must be done in order for these programs to achieve this target (Hellmuth et al., 2009).

Weather insurance and especially index-based contracts contribute, in at least two ways, to climate change adaptation and disaster risk reduction. Since farmers will receive payment based on rainfall and thus have an incentive to plant weather-resistant crops, indexed contracts eliminate moral hazard, which is defined as the disincentive for risk prevention provided by the false perception of security when purchasing insurance coverage. Second, an insurance contract renders high-risk farmers more creditworthy, which enables them to access loans for agricultural inputs. This was illustrated in the pilot program in Malawi, where farmers purchased index-based drought insurance linked to loans to cover costs of hybrid seed, with the result that their productivity was doubled (Linnerooth-Bayer et al., 2009). Increased productivity decreases vulnerability to weather extremes, thus contributing to climate change adaptation (to the extent that risks of weather extremes are increased by climate change). In another innovative micro-insurance project in Ethiopia, farmers can pay their premiums by providing labor on risk-reducing projects (Suarez and Linnerooth-Bayer, 2010).

9.2.13.4.2. Covering national risks: the Ethiopian weather derivative

The World Food Programme (WFP), to supplement and partly replace its traditional food-aid approach to famine, has recently supported the Ethiopian government-sponsored Productive Safety Net Programme (PSNP). The WFP is now insuring it against extreme drought (World Bank, 2006b). When there is a food emergency, the PSNP is able to provide immediate cash payments that may be sufficient to save lives even in the case of very severe droughts (Hess et al., 2006). However, these payments may not be sufficient to restore livelihoods (World Bank, 2006b). To provide extra capital in the case of extreme drought, an index-based contract, sometimes referred to as a weather derivative, was designed by the WFP. The amount of capital is based on contractually specified catastrophic shortfalls in precipitation based on the Ethiopia Drought Index (EDI). The EDI depends on rainfall amounts that were measured at 26 weather stations that represent the various agricultural areas of Ethiopia. In 2006, the WFP successfully obtained an insurance contract based on the EDI through an international reinsurer (Hess et al., 2006). A drawback of this arrangement, in contrast to the micro-insurance programs in India and Malawi, is that it perpetuates dependence on post-drought government assistance with accompanying moral hazard.

9.2.13.4.3. Intergovernmental risk sharing: the Caribbean Catastrophe Risk Insurance Facility (CCRIF)

The world's first regional catastrophe insurance pool was launched in 2007 in the Caribbean region; this is the Caribbean Catastrophe Risk Insurance Facility (discussed in Section 7.4.4). Sixteen participating governments secured insurance protection against costs associated with catastrophes such as hurricanes and earthquakes (Ghesquiere et al., 2006; World Bank, 2007). Several of the participating countries represent the countries experiencing the greatest economic losses from disasters in the last few decades, when measured as a share of GDP (CCRIF, 2010).

The aim of the Caribbean facility is to provide immediate liquidity to cover part of the costs that participating governments expect to incur while they provide relief and assistance for recovery and rehabilitation. Because it does not cover all costs, CCRIF provides an incentive for governments to invest in risk reduction and other risk transfer tools. The cost of participation is based on estimates of the respective countries' risk (measured as probability and cost). The advantage of pooling is that due to diversifying risk it greatly reduces the costs of reinsurance compared to the price each government would have paid individually. Funding for the program, although mainly the responsibility of participating countries, has been supported by a donor conference hosted by the World Bank.

Insofar as weather extremes are increased by climate change, the CCRIF contributes directly to disaster risk reduction and climate change adaptation. By providing post-event capital it enables governments to restore critical infrastructure so important for reducing the long-term human and economic impacts from hurricanes. Experience with CCRIF also shows the importance of designing programs that reflect the needs of the participating countries. Finally, it demonstrates how international assistance can support disaster management in tandem with national responsibility.

9.2.13.4.4. Outcomes – the role of risk transfer for advancing disaster risk reduction and climate change adaptation

As these examples illustrate, risk-transfer instruments and especially insurance can promote disaster risk reduction and climate change adaptation by enabling recovery and productive activities. By providing means to finance relief, recovery of livelihoods, and reconstruction, insurance reduces long-term indirect losses – even human losses – that do not show up in the disaster statistics. Risk transfer arrangements thus directly lead to the reduction of post-event losses from extreme weather events, what is commonly viewed as adaptation. Moreover, insured households and businesses can plan with more certainty, and because of the safety net provided by insurance, they can take on cost-effective, yet risky, investments. This ultimately reduces vulnerability to weather extremes and by so doing contributes to climate change adaptation.

Experience in developed countries has demonstrated additional ways in which insurance and other risk-transfer instruments have promoted DRR and CCA as listed below:

- Because risk-transfer instruments require detailed analysis of risk, they can both raise awareness and provide valuable information for its response and reduction; for example, in some developed countries insurers with other partners have made flood and other hazard maps publicly available (Botzen et al., 2009; Warner et al., 2009). Potential challenges include the technical difficulties related to risk assessment, dissemination of appropriate information, and overcoming education and language barriers in some areas.
- By pricing risk, insurance can provide incentives for investments and behavior that reduce vulnerability and exposure, especially if premium discounts are awarded. Differential premium pricing has been effective in discouraging construction in high-risk areas; for example, UK insurers price flood policies according to risk zones, but insurers are reluctant to award premium discounts for other types of mitigation measures, such as reinforcing windows and doors to protect against hurricanes (Kunreuther and Roth, 1998; Kunreuther and Michel-Kerjan, 2009). The incentive effect of actuarial risk pricing should be weighed against the benefits of increasing insurance penetration to those unable to afford risk-based premiums. The positive incentives provided by insurance should also not overshadow the potential for negative incentives or moral hazard.
- Insurers and other providers can make risk reduction a contractual stipulation, for example, by requiring fire safety measures as a condition for insuring a home or business (Surminski, 2010). The US National Flood Insurance Program requires communities to reduce risks as a condition for offering subsidized policies to their residents (Kunreuther and Roth, 1998; Linnerooth-Bayer et al., 2007). It was noted above that the WFP might require risk-reducing activities as a condition for its support for weather derivatives.
- Providers can partner with government and communities to establish appropriate regulatory frameworks and promote, for instance, land use planning, building codes, emergency response, and other types of risk-reducing policies. Ungern-Sternberg (2003) has shown that Swiss cantons having public monopolies that provide disaster insurance outperform cantons with private systems in reducing risks and premiums, mainly because the public monopolies have better access to land use planning institutions, fire departments, and other public authorities engaged in risk reduction. In many countries, insurers have co-financed research institutes and disaster management centers, and in other cases, have partnered with government to achieve changes in the planning system and investment in public protection measures (Surminski, 2010).

9.2.13.5. Lessons Identified

Governments, households, and businesses can experience liquidity gaps limiting their ability to recover from disasters (*high confidence*). There is *robust evidence* to suggest that risk-transfer instruments can help reduce this gap, thus enabling recovery.

There are a range of risk-transfer instruments, where insurance is the most common. With support from the international community, risk transfer is becoming a reality in developing countries at the local, national, and international scales, but the future is still uncertain. Index-based contracts greatly reduce transaction costs and moral hazard (*medium confidence*); while more costly than many traditional financing measures, insurance has benefits both before disasters (by enabling productive investment) and after disasters (by enabling reconstruction and recovery) (*medium confidence*). Insurance and other forms of risk transfer can be linked to disaster risk reduction and climate change adaptation by enabling recovery, reducing vulnerability, and providing knowledge and incentives for reducing risk (*medium confidence*).

9.2.14. Education, Training, and Public Awareness Initiatives for Disaster Risk Reduction and Adaptation

9.2.14.1. Introduction

Disasters can be substantially reduced if people are well informed and motivated to prevent risk and to build their own resilience (UNISDR, 2005b). Disaster risk reduction education is broad in scope: it encompasses primary and secondary schooling, training courses, academic programs, and professional trades and skills training (UNISDR, 2004), community-based assessment, public discourse involving the media, awareness campaigns, exhibits, memorials, and special events (Wisner, 2006). Given the breadth of the topic, this case study illustrates just a few practices in primary school education, training programs, and awareness-raising campaigns in various countries.

9.2.14.2. Background

The Hyogo Framework calls on states to "use knowledge, innovation, and education to build a culture of safety and resilience at all levels" (UNISDR, 2005b). States report minor progress in implementation, however (UNISDR, 2009c). Challenges noted include the lack of capacity among educators and trainers, difficulties in addressing needs in poor urban and rural areas, the lack of validation of methodologies and tools, and little exchange of experiences. On the positive side, the 2006-2007 international campaign "Disaster Risk Reduction Begins at School" (UNISDR, 2006) raised awareness of the importance of education with 55 governments undertaking awareness-raising activities and 22 governments reporting success in making schools safer (e.g., 175 schools developed disaster plans in Gujarat, India) by developing educational and training materials, introducing school drills, and implementing DRR teacher trainings (UNISDR, 2008b). Furthermore, the implementation scheme of the United Nations Decade of Education for Sustainable Development 2005-2014 seeks to improve the knowledge base on disaster reduction as one of the keys to sustainable development.

A related emerging trend is to engage children in disaster risk reduction and adaptation, as children are increasingly understood as effective agents of change (Mitchell et al., 2009). Children's inclusion also increases the likelihood that they will maintain their own DRR and adaptation learning (Back et al., 2009). A report from five NGOs (Twigg and Bottomley, 2011) states that their DRR work with children and young people involves risk identification and action planning for preparedness; training of school teachers and students; DRR curriculum development; youth-led prevention and risk reduction actions, such as mangrove and tree conservation; awareness raising (e.g., through peer-to-peer community exchanges and children's theater); and "lobbying and networking in promoting and supporting children's voice and action."

Effective DRR education initiatives seek to elicit behavioral change not only by imparting knowledge of natural hazards but also by engaging people in identifying and reducing risk in their surroundings. In formal education, disaster risk education should not be confined within the school but promoted to family and community (Shaw et al., 2004). Lectures can create knowledge, particularly if presented with visual aids and followed up with conversation with other students. Yet it is family, community, and self learning, coupled with school education, that transform knowledge into behavioral change (Shaw et al., 2004).

9.2.14.3. Description of Strategies

9.2.14.3.1. School curriculum

States are increasingly incorporating DRR in the curriculum (UNISDR, 2009c) and have set targets for so doing in all school curricula by 2015 (UNISDR, 2009c). Initiatives to integrate the teaching of climate change and DRR are also emerging, such as the described Philippines program. Importantly, the new Philippines disaster risk reduction and climate change laws mandate the inclusion of DRR and climate change, respectively, in school curricula; the following example predates these laws, however.

The Asian Disaster Preparedness Centre and UN Development Programme, with the National Disaster Coordinating Council and support from the European Commission Humanitarian Aid and Civil Protection, assisted the Ministry of Education in the Philippines, Cambodia, and Lao People's Democratic Republic to integrate disaster risk reduction into the secondary school curriculum. Each country team developed its own draft module, adapting it to local needs.

The Philippines added climate change and volcanic hazards into its disaster risk reduction curriculum. The relevant lessons addressed 'what is climate change,' they then asked 'what is its impact,' and finally 'how can you reduce climate change impact?' Other lessons focused on the climate system, typhoons, heat waves, and landslides, among other related topics (Luna et al., 2008). The Philippines' final disaster risk reduction module was integrated into 12 lessons in science and 16 lessons in social studies for the first year of secondary school (Grade 7) (Luna et al., 2008). Each lesson includes group activities, questions to be asked of the students, the topics that the teacher should cover in the lecture, and a learning activity in which students apply knowledge gained and methodology for evaluation of learning by the students (Luna et al., 2008). The project reports that it reached 1,020 students, including 548 girls, who learned about disaster risk reduction and climate change. Twenty-three teachers participated in the four-day orientation session. An additional 75 teachers and personnel were trained to train others and replicate the experience across the country (Luna et al., 2008).

9.14.2.3.2. Training for disaster risk reduction and adaptation

In order to effectively include disaster risk reduction and adaptation in the curriculum, teachers require (initial and in-service) training on the substantive matter as well as the pedagogical tools (hands-on, experiential learning) to elicit change (Shiwaku et al., 2006; Wisner, 2006). Education program proponents might have to overcome teachers' resistance to incorporate yet another topic into overburdened curricula. To enlist teachers' cooperation, developing a partnership with the ministry of education and school principals can be helpful (UNISDR, 2007b; World Bank et al., 2009). The following program in Indonesia and the evaluation results from Nepal demonstrate the importance of engaging teachers for effective education. The subsequent example from Nepal, Pakistan, and India focuses on training builders through extensive hands-on components in which new techniques are demonstrated and participants practice these techniques under expert guidance (World Bank et al., 2009).

The Disaster Awareness in Primary Schools project, which provides teacher training, was launched in Indonesia in 2005 with German support and is ongoing. By 2007, through this project, 2,200 school teachers had received DRR training. Project implementers found that existing teaching methods were not conducive to active learning. Students listened to teacher presentations, recited facts committed to memory, and were not encouraged to understand concepts and processes. The training took teachers' capabilities into account by emphasizing the importance of clarity and perseverance in delivering lessons so as to avoid passing on faulty life-threatening information (e.g., regarding evacuation routes). Scientific language was avoided and visual aids and activities encouraged. Teachers were asked to take careful notes and to participate in practical activities such as first-aid courses, thus modeling proactive learning. Continuity with the teachers' traditional teaching methods was maintained by writing training modules in narrative form and following the established lesson plan model. Moreover, to avoid further burdening teachers' heavy lesson requirements and schedules, the modules were designed to be integrated into many subjects, such as language and physical education, and to require minimum preparation (UNISDR, 2007b).

In Nepal, Kyoto University researchers evaluated the knowledge and perceptions of 130 teachers in 40 schools, most of whom were imparting disaster education (Shiwaku et al., 2006). Through responses to a survey, the researchers found that the content of the disaster risk education being imparted depended on the awareness of individual teachers. Teachers focused lessons on the effects of disasters with which they could relate from personal experience. The researchers concluded that teacher training is the most important step to improve disaster risk education in Nepal. Most social studies teachers reported a need for teacher training but the survey analysis recommended that training programs be designed to integrate DRR into any subject rather than taught in special classes (Shiwaku et al., 2006).

The National Society for Earthquake Technology in Nepal conducted large-scale training for masons, carpenters, bar benders, and construction supervisors in 2007 over a five-month period to impart risk-resilient construction practices and materials. Participants from Kathmandu and five other municipalities formed working groups to train other professionals. As the project was successful, a mason-exchange program was designed with the Indian NGO Seeds. Nepali masons were sent to Gujarat, India, to mentor local masons in the theory and practice of safer construction. Also in India, the government of Uttar Pradesh trained two junior engineers in the rural engineering service in each district to carry out supervisory inspection functions and delegated the construction management to school principals and village education committees. Similarly, the Department of Education of the Philippines mandated principals to take charge of the management of the repair and/or construction of typhoon-resistant classrooms after the 2006 typhoons. Assessment, design, and inspection functions were provided by the Department's engineers, who also assist with auditing procurement (World Bank et al., 2009).

9.2.14.3.3. Raising public awareness

In addition to the insights on the psychological and sociological aspects of risk perception, risk reduction education has benefited from lessons in social marketing. These include involving the community and customizing for audiences using cultural indicators to create ownership; incorporating local community perspectives and aggressively involving community leaders; enabling two-way communications and speaking with one voice on messages (particularly if partners are involved); and evaluating and measuring performance (Frew, 2002).

According to the UNISDR Hyogo Framework Mid-Term Review (UNISDR, 2011a), few DRR campaigns have translated into public action and greater accountability. However, successful examples include Central America and the Caribbean, where the media played an important role, including through radio soap operas. The UNISDR review also found a high level of risk acceptance, even among communities demonstrating heightened risk awareness. In some cultures, the spreading of alarming or negative news – such as information on disaster risks – is frowned upon (UNISDR, 2011a). The following examples from Brazil, Japan, and the Kashmir region illustrate good practice in raising awareness for risk reduction.

Between 2007 and 2009, the Brazilian Santa Catarina State Civil Defence Department, with the support of the Executive Secretariat and the state university, undertook a public awareness initiative to reduce social vulnerability to disasters induced by natural phenomena and human action (SCSCDD, 2008a,b). During the two-year initiative, 2,000 educational kits were distributed free of charge to 1,324 primary schools. Students also participated in a competition of drawings and slogans that were made into a 2010 calendar. As the project's goal was public awareness of risk, the project jointly launched a communications network in partnership with media and social networks to promote better dissemination of risk and disasters (SCSCDD, 2008a,b). The initiative also focused on the most vulnerable populations. A pilot project for 16 communities precariously perched on a hill prone to landslides featured a 44-hour course on risk reduction. Community participants elaborated risk maps and reduction strategies, which they had to put to use immediately. Shortly into the course, heavy rains battered the state, triggering a state of emergency; 10 houses in the pilot project area had to be removed and over 50 remained at risk. The participants' risk reduction plans highlighted the removal of garbage and large rocks as well as the building of barriers. The plans also identified public entities for partnership and the costs for services required. The training closed with a workshop on climate change and with the community leaders' presentation of the major risk reduction lessons learned (SCSCDD, 2008c). On international disaster risk reduction day, representatives of the community, Civil Defence, and other public entities visited the most at-risk areas of the hill community, planted trees, installed signs pointing out risky areas and practices, distributed educational pamphlets, and discussed risk. One of the topics of discussion was improper refuse disposal and the consequent blocking of drains, causing flooding (SCSCDD, 2008d).

In 2004, typhoons resulted in flooding in urban areas of Saijo City (Ehime Prefecture of Shikoku Island, Japan). There were also landslides in the mountains. As a result, a public awareness campaign was implemented. Saijo City, a small city with semi-rural mountainous areas, faces challenges in disaster risk reduction that are relatively unique. In Japan, young people have a tendency to leave smaller communities and move to larger cities. The result is that Japanese smaller towns have older than the national average populations. Since younger, able-bodied people are important for community systems of mutual aid and emergency preparedness, there is a special challenge. Saijo City has an urban plain, semi-rural and isolated villages on hills and mountains, and a coastal area and, hence, is spread over a mix of geographic terrains (Yoshida et al., 2009; ICTILO et al., 2010); this brings another challenge. In 2005, the Saijo City Government launched a risk awareness program to meet both of these challenges through a program targeted at school children. The project for 12-year olds has a 'mountain-watching' focus for the mountainside and a 'town-watching' focus for the urban area (ICTILO et al., 2010). The students are taken, accompanied by teachers, forest workers, local residents, and municipal officials, on risk-education field trips. In the mountains, the young urban dwellers meet with the elderly and they learn together about the risks the city faces. Part of the process is to remember the lessons learned from the 2004 typhoons. Additionally, a 'mountain and town watching' handbook has been developed, a teachers' association for disaster education was formed, a kids' disaster prevention club started, and a disaster prevention forum for children was set up (Yoshida et al., 2009; ICTILO et al., 2010). This is an example of a local government both conceiving and implementing the program. The city government led a multi-stakeholder and community-based disaster risk awareness initiative that then became self-sustaining. Professionals from disaster reduction and education departments were provided through government support. The government also funds the town and mountain watching and puts on an annual forum (ICTILO et al., 2010).

The Centre for Environment Education (CEE) Himalaya is undertaking a disaster risk reduction and climate change education campaign in 2,000 schools and 50 Kashmir villages in the Himalayas. In the schools, teachers and students are involved in vulnerability and risk mapping through rapid visual risk assessment and in preparing a disaster management plan for their school. Disaster response teams formed in selected schools have been trained in life-saving skills and safe evacuation (CEE Himalaya, 2009).

CEE Himalaya celebrated International Mountain Day 2009 with educators by conducting a week-long series of events on climate change adaptation and disaster risk reduction. About 150 participants including teachers and officials of the Department of Education, Ganderbal, participated in these events (CEE Himalaya, 2009). Participants worked together to identify climate change impacts in the local context, particularly in terms of water availability, variation in microclimate, impact on agriculture/horticulture and other livelihoods, and vulnerability to natural disasters. The concept of School Disaster Management Plans (SDMPs) was introduced. Participants actively prepared SDMPs for their schools through group exercises, and discussed their opinions about village contingency plans (CEE Himalaya, 2009). Some of the observations on impacts of climate change in the area discussed by participants included the melting, shrinking, and even disappearance of some glaciers and the drying up of several wetlands and perennial springs. Heavy deforestation, decline and extinction of wildlife, heavy soil erosion, siltation of water bodies, fall in crop yields, and reduced availability of fodder and other non- timber forest produce were some of the other related issues discussed (CEE Himalaya, 2009). Participants watched documentaries about climate change and played the Urdu version of 'Riskland: Let's Learn to Prevent Disasters.' They received educational kits on disaster risk reduction and on climate change, translated and adapted for Kashmir (CEE Himalaya, 2009).

9.2.14.4. Lessons Identified

The main lesson that can be drawn from the various initiatives described above is that effective DRR education does not occur in a silo. As the examples from Japan, Brazil, and the Himalayas illustrate, successful programs actively engage participants and their wider communities to elicit risk-reducing behavioral change (Shaw et al., 2004; Wisner, 2006; Bonifacio et al., 2010). Lessons on actively engaging participants include:

- Assessing community risk, discussing risk with others, and joining a risk-reducing activity in school or community forums provide opportunities for active learning. Engaging children and community members in vulnerability and capacity assessments has been found to be effective in disaster risk reduction and adaptation programs (Twigg and Bottomley, 2011; see Himalaya example).
- Interactive lectures with visual aids can be effective in building knowledge (Shaw et al., 2004; see teacher training in Indonesia example) and should be followed up with discussion with peers and family – and action – beyond the classroom (Shaw et al., 2004; Wisner, 2006).

Additional lessons of good practice illustrated above include:

- Integrating climate change information into DRR education and integrating both into various subject matters is simple and effective.

The Philippines example shows that such integration is underway, and the teacher training in Indonesia example concludes that such integration can be helpful in avoiding overburdening full curricula.

- Training of teachers and professionals in all relevant sectors can have a positive multiplier effect. As the Nepalese teachers' evaluation example shows, teacher training is critical to address risk self-perception and ensure that teachers pass on appropriate DRR knowledge. The training of builders example in Nepal, India, and the Philippines illustrates the successful dissemination of DRR methods and tools within a critical sector across borders.

As well as providing further examples of current adaptation and DRR initiatives, a United Nations Framework Convention on Climate Change synthesis report of initiatives undertaken by Nairobi Work Programme partners concludes that the integration of activities relating to education, training, and awareness-raising into relevant ongoing processes and practices is key to the long-term success of such activities (UNFCCC, 2010).

9.3. Synthesis of Lessons Identified from Case Studies

This chapter examined case studies of extreme climate events, vulnerable regions, and methodological management approaches in order to glean lessons and good practices. Case studies are provided to add context and value to this report. They contribute to a focused analysis and convey, in part, the reality of an event: the description of how certain extreme events develop; the extent of human loss and financial damage; the response strategies and interventions; the DRR, DRM, and CCA measures and their effect on the overall outcomes; and cultural or region-specific factors that may influence the outcome. Most importantly, case studies provide a medium through which to learn practical lessons about successes in DRR that are applicable for adaptation to climate change. The lessons identified will prove useful at various levels from the individual to national and international organizations as people try to respond to extreme events and disasters and adapt to climate change.

The case studies highlight several recurring themes and lessons.

A common factor was the need for greater amounts of useful information on risks before the events occur, including early warnings. The implementation of early warning systems does reduce loss of lives and to a lesser extent damage to property. Early warning was identified by all the extreme event case studies – heat waves, wildfires, drought, *dzud*, cyclones, floods, and epidemics – as key to reducing the impacts from extreme events. A need for improving international cooperation and investments in forecasting was recognized in some of the case studies, but equally the need for regional and local early warning systems was heavily emphasized, particularly in developing countries.

A further common factor identified overall was that it is better to invest in preventive-based DRR plans, strategies, and tools for adaptation than in response to extreme events. Greater investments in proactive hazard and vulnerability reduction measures, as well as development of capacities to respond and recover from the events were demonstrated to have benefits. Specific examples for planning for extreme events included increased emphasis on drought preparedness; planning for urban heat waves; and tropical cyclone DRM strategies and plans in coastal regions that anticipate these events. However, as illustrated by the SIDS case study, it was also identified that DRR planning approaches continue to receive less emphasis than disaster relief and recovery.

It was also identified that DRM and preventive public health are closely linked and largely synonymous. Strengthening and integrating these measures, along with economic development, should increase resilience against the health effects of extreme weather and facilitate adaptation to climate change. Extreme weather events and population vulnerability can interact to produce disastrous epidemic disease through direct effects on the transmission cycle and also potentially through indirect effects, such as population displacement.

Another lesson is that in order to implement a successful DRR or CCA strategy, legal and regulatory frameworks are beneficial in ensuring direction, coordination, and effective use of funds. The case studies are helpful in this endeavor as effective and implemented legislation can create a framework for governance of disaster risks. While this type of approach is mainly for national governments and the ways in which they devolve responsibilities to local administrations, there is an important message for international governance and institutions as well. Frameworks that facilitate cooperation with other countries to attain better analysis of the risks will allow institutions to modify their focus with changing risks and therefore maintain their effectiveness. This cooperation could be at the local through national to international levels. Here and in other ways, civil society has an important role.

Insurance and other forms of risk transfer can be linked to disaster risk reduction and climate change adaptation by providing knowledge and incentives for reducing risk, reducing vulnerability, and enabling recovery.

A lesson identified by many case studies was that effective DRR education contributes to reduce risks and losses, and is most effective when it is not done in isolation, but concurs with other policies. The integration of activities relating to education, training, and awareness-raising into relevant ongoing processes and practices is important for the long-term success of DRR and DRM activities. Investing in knowledge at primary to higher education levels produces significant DRR and DRM benefits.

Research improves our knowledge, especially when it includes integration of natural, social, health, and engineering sciences and their applications. In all cases, the point was made that with greater information available it would be possible to better understand the risks and to ensure that response strategies were adequate to face the risks. It further poses a set of questions to guide the investigations.

The case studies have reviewed past events and identified lessons that could be considered for the future. Preparedness through DDR and DRM can help to adapt for climate change and these case studies offer examples of measures that could be taken to reduce the damage that is inflicted as a result of extreme events. Investment in increasing knowledge and warning systems, adaptation techniques and tools, and preventive measures will cost money now but they will save money and lives in the future.

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