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Approaches to Disaster Management

Examining the Implications of Hazards, Emergencies and Disasters

Edited by John Tiefenbacher

APPROACHES TO DISASTER MANAGEMENT - EXAMINING THE IMPLICATIONS OF HAZARDS, EMERGENCIES AND DISASTERS

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Notice

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Meet the editor

Dr. John P. Tiefenbacher (B.S. Carroll College, Wisconsin; M.S. University of Idaho; and PhD in Geography Rutgers University) is currently Professor in the Department of Geography at Texas State University in San Marcos, Texas. Dr. Tiefenbacher's research focuses on environmental (nature-society) geography. He has published on a range of topics that regard spatial patterns of environmental problems, human perceptions of and responses to natural and technological hazards and attitudes about the places and natural communities people inhabit. His current research projects pertains to the challenges of urban hazards and evacuating cities, adaptation to climate change, and the responses of agricultural industries (particularly wine growers) to climate changes in several regions (principally South America, the U.S. and Europe) of the world.

Contents

Preface

Approaches to Disaster Management - Examining the Implications of Hazards, Emergencies and Disasters includes essays that demonstrate several issues that are critical to understanding risk and hazard and the prospects for disasters. The book is organized to group the research that relates to specific periods of the disaster management continuum. The chapters are original research reports by international scholars focused on unique aspects of disaster from their unique perspectives. The first set of three chapters pertains to the conceptualization of the issues that influence the distribution of hazard and the probabilities for disaster. The next three chapters regard the use and management of data during the run up to crises, the challenges to effective integration of information into management activities, and some potential information management remedies. The final set of four chapters pertains to crisis management and recovery. The over-arching goal of disaster management, of course, is eventually to solve the problems that make it necessary by eliminating risk, hazard and vulnerability; goals that are generally unrecognized by most, usually unspoken and indeed ambitious.

Ciurean, Malek, Schröter, Glade and Patt begin this volume with a discussion of the employment of vulnerability assessments to reduce disasters. Few terms have generated as much confusion as vulnerability has among scholars and practitioners; this confusion undermines its meaningful application. As often happens when concepts becomes popular, vulnerability's meaning relative to disaster management has become obscured through its overuse as a "hot button" and its misapplication in analyses. These authors attempt to clarify the notion of vulnerability to offer a revised disaster risk analysis methodology. Their paper provides rationale for choices that ought to be considered in the development of a practical vulnerability assessments.

The second chapter by Haque and Uddin presents a case study of an evolving disaster management system in a developing nation. The authors critique the nature of the organization of and present approach to disaster management used in Bangladesh. They find that, while institutional partnership-building efforts have successfully integrated and strengthened thinking about disaster management in Bangladesh, the real effect has been only a formalized policy; it has not been truly enacted in practice. The authors offer approaches for organizing not only governmental stakeholders, but also integrating the roles of local and non-governmental players and more rational assessment of patterns of risk, hazard, and vulnerability. The progression toward disaster management in the framework of progressive government is fraught with complexity, particularly in the circumstances of relatively new states.

But even in states committed to progressive government, hazard mitigation and disaster management are not easily accomplished. Jackman and Beruvides discuss the historical development of hazard mitigation and planning in the United States. Their evaluation of the accomplishments and prospects for continued development of mitigation plans at state and local levels demonstrates that there are still practical challenges and realities that exist even within systems that apparently have been committed to disaster prevention for many decades.

The data and information management realms of modern life have exploded in volume and complexity. The capacity to gather data and analyze it in real time not only benefits the disaster manager, but also makes decision making more complex. The second section of this volume pertains to the use of increasingly automated data collection systems that provide sophisticated measures of environmental conditions. These systems can not only increase the amount and detail of the operation of natural and social systems, but the use of the data requires increasing degrees of technical knowledge to use (extract facts, judge meaning, interpret and convert to messages for managers). The three papers included here discuss the cutting edge of the application of data in emergency planning and disaster management.

Houser's chapter reviews data assimilation theory and discusses several diverse applications of data that can be employed in spatial decision support for disaster management. Data networks increase not only the capacity to monitor the developments across a greater space, but in combination with advanced modeling, can yield views into the near future that promote proactive management rather than simply enabling faster reactions to the outcomes of hazardous events.

While data may typically amount to numbers reflecting measures of depth, height, strength, speed and other physical phenomena, their collection and tabulation rarely provides effective understanding for users of the information they contain. With the dramatic increases of speed and capacity that we have witnessed in the realm of computing resources, it has become increasingly possible to convert the data to visual products that make their meaning more apparent. The chapter by Allen, Sanchagrin and McLeod describe the coupled advances of modeling with geovisualization, techniques that enable spatial views of the implications of changing environments. Specifically, they discuss and exemplify the prospects for improving hurricane storm-surge risk predictions to advance the meaningfulness and spatial precision of the perceptions of coastal residents and disaster managers. They demonstrate the benefits and costs of choices among models, statistical techniques and graphical capabilities of the technologies, but exhibit the great value that such advances can provide.

Indeed, though the advanced technology that enables detailed geovisualization exists in some of the most modern parts of the world, there are regions that are relatively undeveloped in terms of their capacity to quickly and efficiently gather data across vast areas and use those data to guide disaster response. Ajami's chapter reviews the prospects for an earthquake information management system (EIMS) in Iran by deriving lessons from the challenges experienced in Afghanistan, India, Japan and Turkey. National-scale systems are particularly important for regions that are dependent upon centralized decisions, as is the case in Iran. When response, relief and coordination of recovery is dependent upon not only a centralized government and but also non-governmental organizations that are constrained by that government, it becomes even more critical to establish stronger data-gathering systems that extend to the hinterlands. In the context of developing nations, the lack of coordinated response based on near-real time data, information management systems may be the key to reducing the tolls of extreme events from catastrophic levels to mere disasters.

In our final section of the text, we examine four topics that pertain to the period of emergency or crisis and its aftermath. In the first chapter, Niininen examines disasters from the perspective of the host of non-resident populations during emergencies. The hoteliers in tourist destinations play an important role during sudden-onset hazardous events. Niininen reports the results of a survey of hotel managers from three very different contexts: London, Hong Kong and Finland. The analysis provides for a list of best management practices for hotel managers vis á vis their guests, their staff and their local municipal governments. It is vital for hotel managers to recognize the roles they have assumed in emergencies and crises by virtue of their attraction of visitors to their destinations.

The aftermath of disasters reveal much about the role societies play in creating the potential for disasters. Centuries of experience that modern societies have with disasters, particularly in urbanized or developed regions, has prompted activities aimed at managing risk, reducing hazard, preparing for disaster and to enabling faster recovery. The final three chapters examine aspects of the responses to disaster that either attenuate or magnify disruptions and suffering.

Brand and Nicholson examine the aftermath of the Lisbon, Portugal earthquake of 1755 and consider the lessons that contemporary urban systems might consider in their own responses to city-wide destruction they might experience. Indeed, the authors evaluate equivalent actions that have been (or have not been) taken by the city of Christchurch, New Zealand in their responses to two significant earthquakes in 2010 and 2011. The authors emphasize the value that urban design principles can provide for the improvement of not only the city's functional quality but for mitigation of hazards and increasing resilience. Their review of the Christchurch government's approach stresses that the lessons learned have not been adequately applied.

Bryant and Allen similarly consider urban form after earthquake devastation reduces the urban architecture to rubble. In their chapter, they examine the emergence of open space in the tightly constructed confines of Kobe, Japan. Modern urban design principles promote humanization of the built landscape, and in the processes of destruction one can find the creation of opportunities for the greening of the brick and mortar landscapes of cities, the mitigation of hazard, prospects for bottom-up governance, revitalization of communities and the augmentation of resilience.

And in the final chapter in the text, McIntosh takes the analysis deeper into the process of recovery in an examination of the provision of affordable housing for victims of Hurricane Katrina in New Orleans. An imperfect process in responses to most disasters, housing the displaced populations is often treated as a structural issue (in that it only requires roofs and walls). The author here shows that not only is the approach reflected in the response to Katrina insufficient, it was inefficient, ineffective and not sustainable. While the government's actions to meet the needs of the victims was largely a reaction to public outrage at the enormity of the calamity and the government's own failures, the eventual housing solutions were superficial and unsatisfactory. The lesson it leaves is that disaster recovery is not simply a matter of providing "temporary" material improvements for impacted communities, but it requires a deeper and more permanent effort to restore the community itself.

So in summary, this volume evidences that successful disaster management is rooted in both disaster prevention and, when necessary, effective, thoroughly planned actions that not only look to reduce the impacts of hazard events but also incorporate activities that improve other aspects of social systems and human spaces. While disaster management had its beginnings in simplified notions of engineering of the natural environments that generate risk, it has become abundantly clear that it must be a multifaceted ecological response between people, nature and our management systems. Where people and risk cannot be separated, they must be managed in ways that lesson the need for disaster management and improve the freedoms of both people and nature to live their lives unencumbered by the needs or torment of the other.

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Section 1

Overviews of Disaster Prevention and Management

Chapter 1

Conceptual Frameworks of Vulnerability Assessments for Natural Disasters Reduction

Roxana L. Ciurean, Dagmar Schröter and Thomas Glade

Additional information is available at the end of the chapter

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1. Introduction

The last few decades have demonstrated an increased concern for the occurrence of natural disasters and their consequences for leaders and organizations around the world. The EM-DAT International Disaster Database [1] statistics show that, in the last century, the mortality risk associated with major weather-related hazards has declined globally, but there has been a rapid increase in the exposure of economic assets to natural hazards.

Looking into more detail, UNISDR's Global Assessment Report 2011 (GAR11) [2] indicates that disasters in 2011 set a new record of $366 billion for economic losses, including $210 billion as a result of the Great East Japan Earthquake and the accompanying tsunami alone, and $40 billion as a result of the floods in Thailand. There were 29,782 deaths linked to 302 major disaster events including 19,846 deaths in the March earthquake/tsunami in Japan (figures presented by other disaster databases for 2011 summary e.g. NATCAT Service – MunichRE, are slightly different but in general agreement). Disaster databases, such as the ones referred to above, represent key resources for actors involved in policy and practice related with disaster risk reduction and response. However, considering their diversity and recognizing their different roles, one can identify at least one limitation in their use i.e. the inclusion criteria which inherently results in many hazard events not being registered. Compiling and analyzing an extensive natural disaster data set for the period 1993 – 2002, Alexander [3] showed that, for example, in the Philippines in 1996 there were 31 major floods, 29 earthquakes, 10 typhoons and 7 tornadoes. Due to population pressure, large areas of Luzon and other islands were denuded of their dense vegetation cover resulting in landslide prone slopes. Twelve major episodes of slope failure causing high damages to infrastructure and build up areas were registered in the archipelago during 1996. Although documentation of the Government expenditures to finance relief efforts for natural disasters during the 1996 – 2002 period is not completely contained in Figure 1 [4], one can observe that 1996 stands out as a particular year with high costs of rehabilitation.

Experience has shown that considering the frequency of disasters affecting the Philippines, its socio-economic context, and risk culture, the disaster management system tends to rely on a response approach. However, studies indicate that efforts are being made to engage more proactive approaches, involving mitigation and preparedness strategies [4]. In order to achieve this it is thus important to investigate not only the nature of the threat but also the underlying characteristics of the environment and society that makes them susceptible to damage and losses – in other words, the role of *vulnerability* in determining natural hazard risk levels.

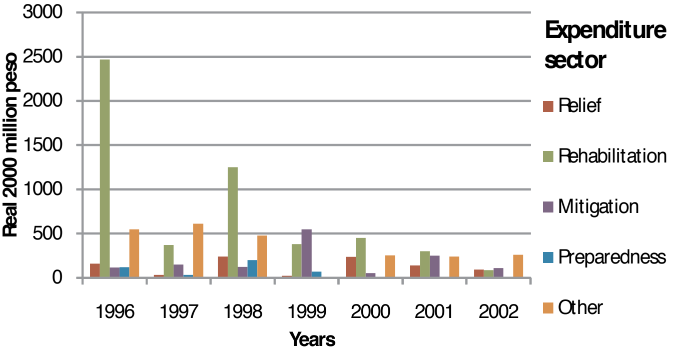

Figure 1. Philippines – annual expenditure under the National Calamity Fund (1996 – 2002) (Based on GDP at price market) [4]

BOX 1: Vulnerability – One term many meanings

In everyday use of language, the term vulnerability refers to the inability to withstand the effects of a hostile environment. The definition of vulnerability for the purpose of scientific assessment depends on the purpose of the study – is it to get a differential picture of global change threats to human well-being in different world regions? Is it to inform particular stakeholders about adaptation options to a potential future development? Is it to show that likelihood of harm and cost of harm have changed for a specific element of interest within the human-environment system? In scientific assessment the term vulnerability can have many meanings, differentiated mostly by (a) the vulnerable entity studied, (b) the stakeholders of the study.

The design of scientific assessment (as opposed to scientific research) has to respond to the scientific needs of the particular stakeholder who might use it [5]. An integral part of vulnerability assessment therefore is the collaboration with its stakeholders [6], [7]. Thus, the specific definition and the method of vulnerability assessment is specific to each study and needs to be made transparent in the specific context. An example set of definitions on vulnerability used in natural hazards risk assessment and global change research is presented in section 2.2, Table 1.

The objective of this work is to discuss and illustrate different approaches used in vulnerability assessment for hydro-meteorological hazards (i.e. landslides and floods, incl. flash floods) taking into account two perspectives: hazard vulnerability and global change vulnerability, which are rooted in the technical and environmental as well as social disciplines. The study is based on a review of recent research findings in global change and natural hazards risk management. The overall aim is to identify current gaps that can guide the development of future perspectives for vulnerability analysis to hydro-meteorological hazards. Following the introduction (section 1), the second section starts with a definition of vulnerability within the context of risk management to natural hazards (sub-section 2.1). Subsequently, various conceptual models (sub-section 2.2) and vulnerability assessment methodologies (sub-section 2.3) are analyzed and compared based on their different disciplinary foci. In the third section, the importance of addressing uncertainty in vulnerability analysis is discussed and lastly general observations and concluding remarks are presented.

2. Conceptual frameworks

2.1. Vulnerability and risk management to natural hazards

According to the UN International Strategy for Disaster Reduction (UNISDR) Report [8], there are two essential elements in the formulation of risk (Eq. 1): a potential event – hazard, and the degree of susceptibility of the elements exposed to that source – vulnerability.

$$\text{RISK} = \text{HAZARD X VULNERABILITY} \tag{1}$$

In UNISDR terminology on Disaster Risk Reduction [9], «risk» is defined as the combination of the probability of an event and its negative consequences". A «hazard» is "a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage".

Within the risk management framework, vulnerability pertains to consequence analysis. It generally defines the potential for loss to the elements at risk caused by the occurrence of a hazard, and depends on multiple aspects arising from physical, social, economic, and environmental factors, which are interacting in space and time. Examples may include poor design and construction of buildings, inadequate protection of assets, lack of public information and awareness, limited official recognition of risks and preparedness measures, and disregard for wise environmental management.

BOX 2: Risk management frameworks are generally designed to answer the following questions [10]:

What are the probable dangers and their magnitude? (*Danger Identification*)

How often do the dangers of a given magnitude occur? (*Hazard Assessment*)

What are the elements at risk? (*Elements at Risk Identification*)

What is the possible damage to the elements at risk? (*Vulnerability Assessment*)

What is the probability of damage? (*Risk Estimation*)

What is the significance of the estimated risk? (*Risk Evaluation*)

What should be done? (*Risk Management*)

2.2. Vulnerability models

There are multiple definitions, concepts and methods to systematize vulnerability denoting the plurality of views and meanings attached to this term. Birkmann [11] noted that 'we are still dealing with a paradox: we aim to measure vulnerability, yet we cannot define it precisely'. However, there are generally two perspectives in which vulnerability can be viewed and which are closely linked with the evolution of the concept [12]: (1) the amount of damage caused to a system by a particular hazard (technical or engineering sciences oriented perspective – dominating the disaster risk perception in the 1970s), and (2) a state that exists within a system before it encounters a hazard (social sciences oriented perspective – an alternative paradigm which uses vulnerability as a starting point for risk reduction since the 1980s). The former emphasizes 'assessments of hazards and their impacts, in which the role of human systems in mediating the outcomes of hazard events is downplayed or neglected'. The latter puts the human system on the central stage and focuses on determining the coping capacity of the society, the ability to resist, respond and recover from the impact of a natural hazard [13]. While the technical sciences perspective of vulnerability focuses primarily on physical aspects [14], the social sciences perspective takes into account various factors and parameters that influence vulnerability, such as physical, economic, social, environmental, and institutional characteristics [8]. Other approaches emphasize the need to account for additional global factors, such as globalization and climate change. Thus, the broader vulnerability assessment is in scope, the more interdisciplinary it becomes.

The different definitions of vulnerability can also be viewed from a functional and subject/object-oriented perspective i.e. considering the end-user of the scientific assessment results (e.g. technical boards, administration officers, representatives from the civil protection, international organizations, etc.) and the vulnerable entity (e.g. critical infrastructure, elderly population, communication networks, mountain ecosystems, etc.).

Working definitions(s): Vulnerability is…	Source
The degree of loss to a given element at risk or a set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total damage)	[14]
The conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards	[8]
The characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from impacts of a hazard	[13]
The intrinsic and dynamic feature of an element at risk that determines the expected damage/ harm resulting from a given hazardous event and is often even affected by the harmful event itself. Vulnerability changes continuously over time and is driven by physical, social, economic and environmental factors	[11]
The degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change	[15], [16]

Table 1. General definitions of vulnerability used in risk assessment due to natural hazards and climate change

Vogel and O'Brien [17] emphasize that vulnerability is: *(a) multi-dimensional and differential* (varies for different dimensions of a single element or group of elements and from a physical context to another)*; (b) scale dependent* (with regard to the unit of analysis e.g. individual, local, regional, national etc.) *and (c) dynamic* (the characteristics that influence vulnerability are continuously changing in time and space). With regards to the first characteristic, there are generally five components (or dimensions) that need to be investigated in vulnerability assessment: (1) the physical/functional dimension (relates to the predisposition of a structure, infrastructure or service to be damaged due to the occurrence of a harmful event associated with a specific hazard); (2) the economic dimension (relates to the economic stability of a region endangered by a a loss of production, decrease of income or consumption of goods due to the occurrence of a hazard); (3) the social dimension (relates with the presence of human beings, individuals or communities, and their capacities to cope with, resist and recover from impacts of hazards); (4) the environmental dimension (refers to the interrelation between different ecosystems and their ability to cope with and recover from impacts of hazards and to tolerate stressors over time and space); (5) the political/institutional dimension (refers to those political or institutional actions e.g. livelihood diversification, risk mitigation strategies, regulation control, etc., or characteristics that determine differential coping capacities and exposure to hazards and associated impacts).

During the last decades, various schools of thinking proposed different conceptual models with the final aim of developing methods for measuring vulnerability. The following sub-sections give a short overview of some of the conceptual models presented in [11], such as the double structure of vulnerability, vulnerability within the context of hazard and risk, vulnerability in the context of global environmental change community, the Presure and Release Model and a holistic approach to risk and vulnerability assessment. Other models not discussed herein are: The Sustainable Livelihood Framework, the UNISDR framework for disaster risk reduction, the 'onion framework', and the 'BBC conceptual framework', the last two developed by UNU-EHS (UN University, Institute for Environment and Human Security).

2.2.1. The double structure of vulnerability

According to Bohle [18] vulnerability can be seen as having an external and internal side (Figure 2). The *external* side is related to the exposure to risks and shocks and is influenced by Political Economy Approaches (e.g. social inequities, disproportionate division of assets), Human Ecology Perspectives (population dynamics and environmental management capacities) and the Entitlement Theory (relates vulnerability to the incapacity of people to obtain or manage assets via legitimate economic means). The *internal* side is called coping and relates to the capacity to anticipate, cope with, resist and recover from the impact of a hazard and is influenced by the Crisis and Conflict Theory (control of assets and resources, capacities to manage crisis situations and resolve conflicts), Action Theory Approaches (how people act and react freely as a result of social, economic or governmental constrains) and Model of Access to Assets (mitigation of vulnerability through access to assets). The conceptual framework of the double structure indicates that vulnerability cannot adequately be considered without taking into account coping[1] and response capacity[2].

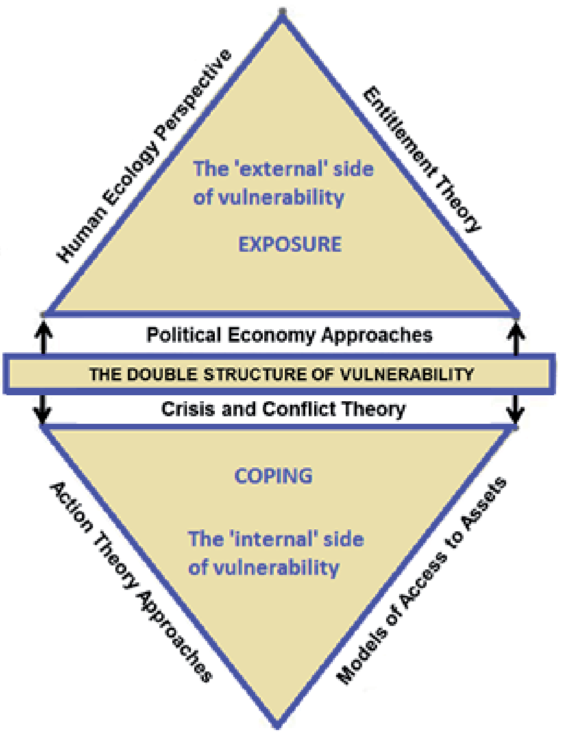

Figure 2. Bohle's conceptual framework for vulnerability analysis [18] in [11]

1 Coping capacity is the ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disasters [8]

2 Capacity is the combination of all the strengths attributes and resources available within a community, society or organization that can be used to achieve agreed goals [8]

2.2.2. Vulnerability within the framework of hazard and risk

The disaster risk community defines vulnerability as a component within the context of hazard and risk. This school usually views vulnerability, coping capacity and exposure as separate features. One example within this approach is Davidson's [19] conceptual framework, adopted in [20] and illustrated in Figure 3. This framework views risk as the sum of hazard, exposure[3], vulnerability and capacity measures. Hazard is characterized by probability and severity, exposure is characterized by structure, population and economy, while vulnerability has a physical, social, economic and environmental dimension. Capacity and measures are related with physical planning, management as well as social – and economic capacity.

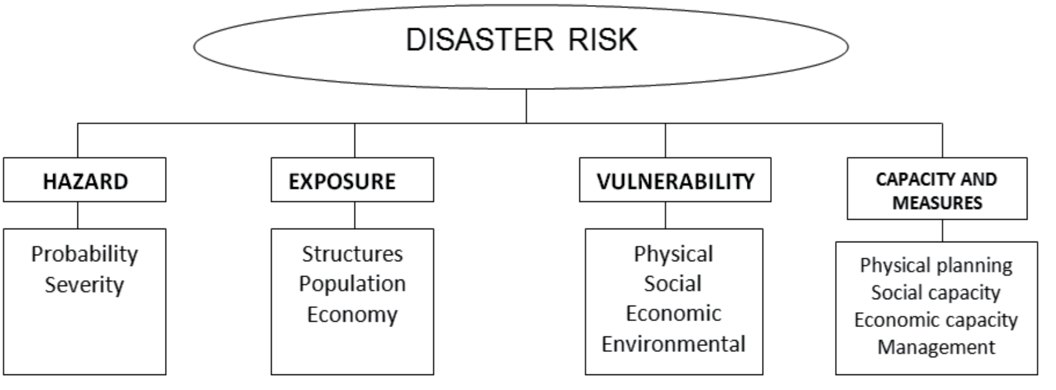

Figure 3. Conceptual framework to identify risk [20] in [11]

2.2.3. Vulnerability in the global environmental change community

Turner [21] developed a conceptual framework considered representative for the global environmental change community primarily due to its focus on the coupled human-environment systems. Their definition of vulnerability encompasses exposure, sensitivity and resilience. Exposure contains a set of components (i.e. threatened elements: individuals, households, states, ecosystem, etc.) subjected to damage and characteristics of the threat (frequency, magnitude, duration). The sensitivity is determined by the human (social capital and endowments) and environmental (natural capital or biophysical endowments) conditions of the system which influence its resilience[4]. The last component is enhanced through adjustments and adaptation.

A system's vulnerability to hazards consists of (Figure 4) (i) linkages to the broader human and biophysical (environmental) conditions and processes operating on the coupled system in

3 Exposure is defined as the totality of people, property, systems or other elements present in hazard zones that are thereby subject to potential losses [8]

4 Resilience is the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions [8]

question; (ii) perturbations and stressors/stresses[5] that emerge from this conditions and processes; and (iii) the coupled human – environment system of concern in which vulnerability resides, including exposure and responses (i.e. coping, impacts, adjustments, and adaptation) [21].

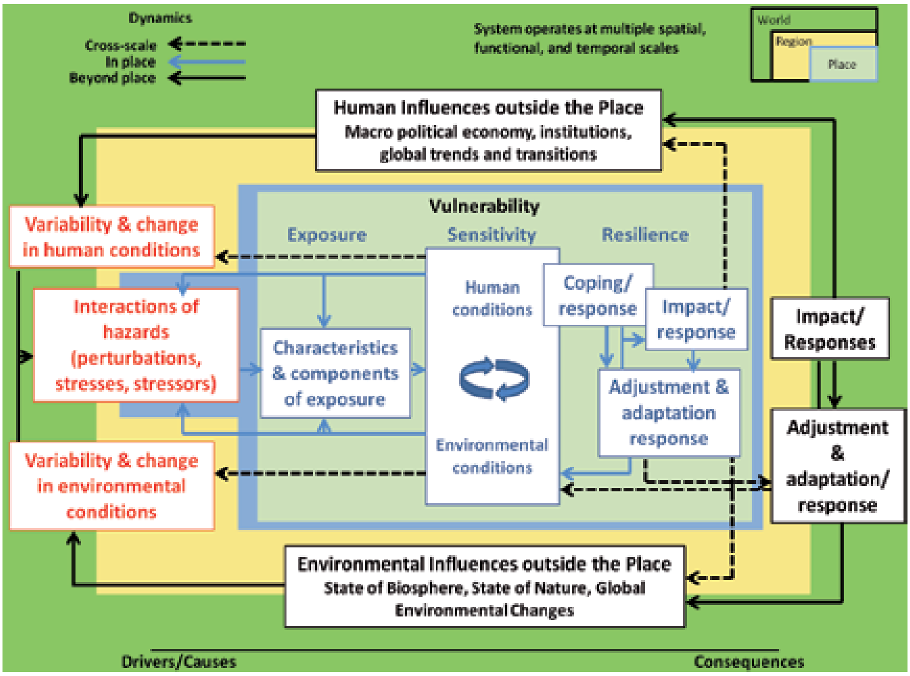

Figure 4. Vulnerability conceptual framework [21] in [11]

2.2.4. The Pressure and Release model (PAR model)

The model operates at different spatial (place, region, world), functional and temporal scales and takes into account the interaction of the multiple perturbations and stressor/stresses [22]. Hazards are regarded as being influenced from inside and outside of the analyzed system; however, due to their character they are commonly considered site-specific. Thus, given their complexity, hazards are located within and beyond the place of assessment. The Pressure and Release model (PAR model) is based on the commonly used equation which defines risk as a function of the hazard and vulnerability (Eq. 1). It emphasizes the underlying driving forces of vulnerability and the conditions existent in a system that contribute to disaster situations when a hazard occurs. Vulnerability is associated with these conditions at three progressive levels: (1) *Root causes*, which can be, for example, limited access to power, structures or resources; or related with political ideologies or economic systems; (2) *dynamic pressures* represented, for example, by demographic or social changes in time and space (e.g. rapid population decrease, rapid

5 Stress is a continuous or slowly increasing pressure, commonly within the range of normal variability. Stress often originates and stressors (the sources of stress) often reside within the system [21]

urbanization, lack of local institutions, appropriate skills or training); and (3) *unsafe conditions* posed by the physical environment (e.g. unprotected buildings and infrastructure, dangerous slopes) or socio-economic context (e.g. lack of local institutions, prevalence of endemic diseases). In Birkmann's opinion [11], this conceptual framework is an important approach which goes beyond identification of vulnerability towards addressing its root causes and driving forces embedded in the human-environment system.

2.2.5. A holistic approach to risk and vulnerability

In this approach vulnerability is conditions by three categories of factors [23]:

- Physical exposure and susceptibility – regarded as hazard dependent
- Fragility of the socio-economic system – non hazard dependent
- Lack of resilience to cope and recover – non hazard dependent

The authors emphasize the importance of measuring vulnerability from a comprehensive and multidisciplinary perspective. The model (Figure 5) takes into account the consequences of direct physical impacts (exposure and susceptibility) as well as indirect consequences (socio-economic fragility and lack of resilience) of potential hazardous event. Within each category, the vulnerability factors are described with sets of indicators or indices. The model includes a control system which alters indirectly the level of risk through corrective and prospective interventions (risk identification, risk reduction, disaster management).

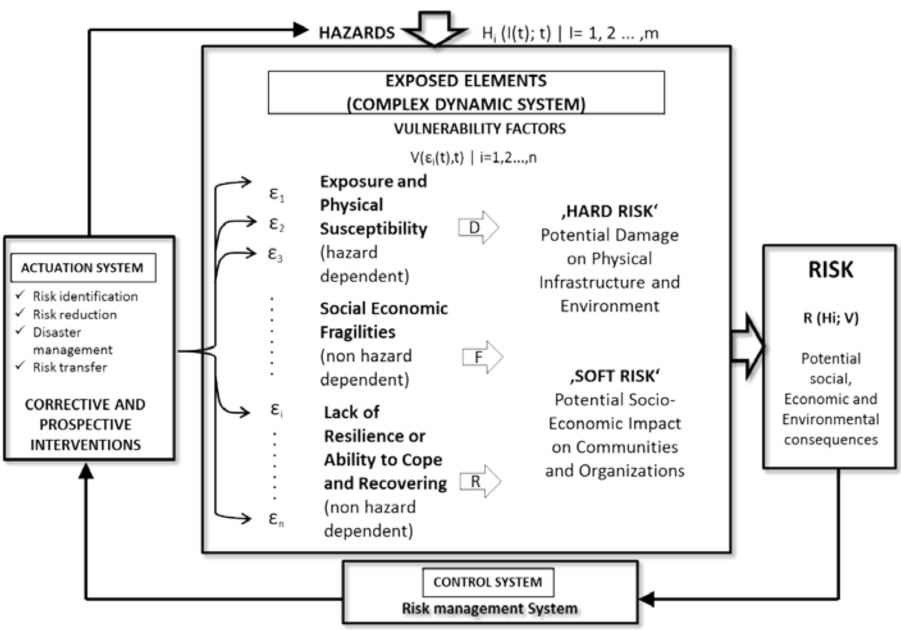

Figure 5. Conceptual framework for holistic approach to disaster risk assessment and management [23] in [11]

The conceptual frameworks described above are different in scope and thematic focus. The vulnerability definition encompasses exposure, coping capacities, sensitivity and adaptation responses in the model of double structure of vulnerability [18] and the global environmental change school model [21], while within the framework of hazard and risk, vulnerability is separated from these characteristics. The holistic approach and the PAR Model indicate factors and conditions of vulnerability able to measure direct physical impacts as well as indirect consequences of disasters. It is obvious that different vulnerability frameworks serve for different disciplinary groups and consequently there is no generally applicable model that can satisfy all specific needs. While our ability to understand vulnerability is enhanced by these conceptual models, only some of them result in paradigms of quantitative or qualitative vulnerability assessment. An illustration of the methods used in physical and social vulnerability evaluation is presented below.

2.3. Vulnerability assessment methods

In the last decades, methods of vulnerability assessment have been developed and tested within the framework of risk analysis, most of them designed for a specific hazard. Research has demonstrated that irrespective of the type of assessment (natural - or social science based), there are some key issues related with the definition of the vulnerable system that must be addressed. Of particular importance is to establish the objective and (time/space) scale of analysis. This will dictate the type of approach (method) employed taking into account data and resource availability. The most detailed vulnerability assessments are conducted at local level, often of individuals or households, but the data required at this level is not readily available. For decisional purposes, regional or national-level assessment can be employed, resulting though in inherent loss of information. An additional issue is the problem of down or up-scaling which implies different levels of generalization and assumption making. This is particularly important when the quality and quantity of data is low because it influences greatly the certainty of the outcome.

Vulnerability is not only site-specific and scale dependent but also varies for different types of hazards (e.g. floods, landslides, earthquakes, tsunamis), due to process characteristics (e.g. generation mode, rate of onset, intensity, area affected, temporal persistence in the environment, etc.) and type of element (or set of elements) at risk. Consequently, the methods used for the evaluation of earthquake vulnerability are not directly transferable to droughts, for example. Vulnerability of exposed objects or systems may vary also for similar processes ([24], [25]). Furthermore, it is acknowledged ([3], [24], [26]) that various types of the same process (e.g. debris flow vs. rock falls for landslide processes, fluvial floods vs. pluvial floods for flood processes) can result in different damage patterns.

An additional factor that must be considered in vulnerability assessment is the target of analysis i.e. the elements at risk. In general terms, these are the objects or systems which pose the potential to be adversely affected [27] by a hazardous event. In [28] the elements at risk are defined as the objects, population, activities and processes that may be differently affected by hazardous phenomena, in a particular area, either directly or indirectly.

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Damages or losses caused by the occurrence of hazards can be manifold. In short term, when a disaster strikes, the primary concern are the potential losses due to casualties (fatalities, injuries and missing persons), physical (functional) consequences on services, buildings and infrastructure and direct economic loss. In long term, indirect economic consequences, social 'disturbance' and environmental degradation may become of greater importance. Many consequences cannot be measured or quantified easily. These are referred to as intangible losses (e.g. loss of social cohesion due to disruption of community, loss of reputation, psychological consequences resulting from disaster impacts, cultural effects, etc.). In vulnerability assessment, tangible losses (which can be measured, quantified) are mostly evaluated whereas intangible losses are at best described. The difference between the two types of losses makes their aggregation in a comprehensive consequence analysis very challenging.

In general vulnerability can be measured either on a metric scale, e.g. in terms of a given currency, or a non-numerical scale, based on social values or perceptions and evaluations [24]. Direct human-social and physical losses can be described and quantified using different methodological approaches. A non-exhaustive description of frequently used methods for physical and social vulnerability assessment is given below.

2.3.1. Social vulnerability assessment

The concept of social vulnerability is complex. A number of studies developed within research projects specifically dedicated to measuring social vulnerability to natural hazards (for example, see [29]) showed that there are fundamental differences between the main types of assessment approaches. These are largely based on qualitative or quantitative research traditions which have important differences in their related paradigms.

There are two distinct perspectives on the social dimension in vulnerability assessment: (1) one refers to *intangible losses* and the related elements at risk whose value cannot be easily counted or valued in economic terms. Such factors may be categorized, for example (but are not limited to) in environmental (biodiversity, natural scenery/tourist attractions, environmental assets used in economic activity, etc.), cultural (structures, historical material, sites of particular cultural value/importance, etc.), institutional (loss of both human and material resources related to the functioning of public institutions including health, law enforcement, education and maintenance). Another interpretation refers to (2) *the underlying socio-economic factors in a society causing or producing vulnerability*. Methods in this category may look into the fabric of society to assess its preparedness and coping/adaptive capacity. A wide range of factors may be considered and there is no generally accepted methodology that covers all aspects of social vulnerability. A review of methodologies can be found in [11].

One central role in social vulnerability assessment is attributed to indicator based methods. In [11] a vulnerability *indicator for natural hazards* is defined as as 'a variable which is an operational representation of a characteristic or quality of a system able to provide information regarding the susceptibility, coping capacity and resilience of a system to an impact of an albeit ill-defined event linked with a hazard of natural. Social and environmental indicators research is common in the field of sustainable science. For example, United Nations Development Program's Human Development Index [30], proposes a composite indicator of human well-being, as well as gender disparity and poverty among nations. Similarly, the World Bank develops indicators that stress the links between environmental conditions and human welfare, especially in developing nations, in order to monitor national progress toward a more sustainable future [31]. In natural hazards risk management framework, many of the indicator based vulnerability studies are relying on measuring attributes or factors influencing vulnerability rather than understanding relationships or processes [32].

The composition and selection of vulnerability indicators is complex. Ideally, there are nine different phases in the development of indicators (Figure 6) [33]: first, a relevant *goal* must be selected and defined. Then, it is necessary to perform a *scoping process* in order to identify the target group and the associated purposes for which the indicators will be used. The third phase presumes the identification of an appropriate *conceptual framework*, which means structuring the potential themes and indicators. The fourth phase implies the definition of *selection criteria* for the potential indicators (see below). The fifth phase is the *identification of a set of potential indicators*. Finally, there is the evaluation and selection of each indicator (phase 6) taking into account the criteria developed at an earlier stage, which results in a final set of indicators. The outcome of previous phases must be validated against real data, which in many cases proofs to be the most challenging part of the process due to difficulties in measuring or quantifying some of the intangible elements or aspect of vulnerability (e.g. social cohesion, confidence, etc.). The last phases of the indicator development imply the preparation of a report and assessment of the indicator performance which may results in a re-evaluation of the results (iterative process).

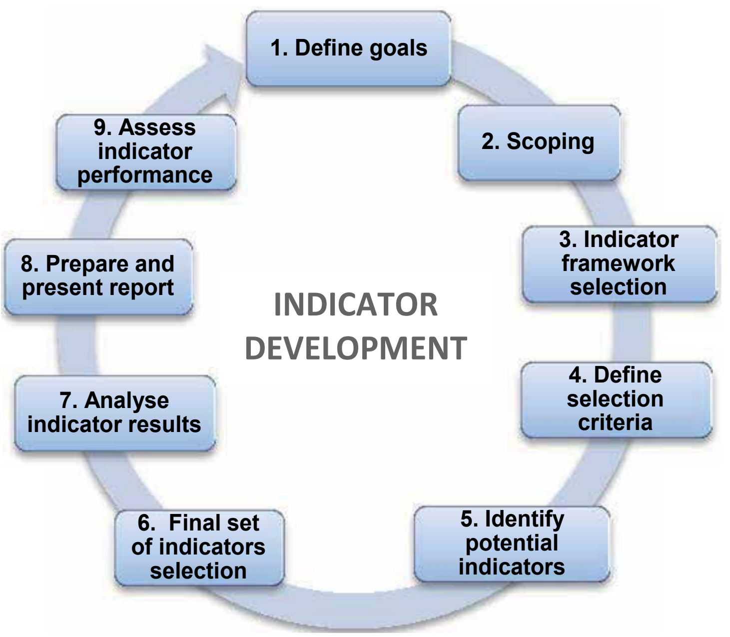

Figure 6. Development process of vulnerability indicators (based on the general figure according to [33] in [11])

Some important quality criteria for indicator and indicator development, as presented in [34], are: sensitivity (sensitive and specific to the underlying phenomenon), relevance, measurability, analytical and statistical soundness, validity/ accuracy, reproducibility, and cost effectiveness. The indicators should also measure only important key-elements instead of trying to indicate all aspects, and permit data comparability (across areas and/or over time).

In order to facilitate the use of indicators for decision-makers and summarize complex or multi-dimensional issues, sets of indices or composite indicators were developed. These are mathematical combinations of sub-indicators that can be easier to interpret than trying to find a trend in many separate indicators. However, there are no generally accepted methods of index aggregation (index construction) and their interpretation is not unique. An extensive description of construction methods and issues related with the combination of indicators is presented in [34].

An example set of factors used to assess social vulnerability at country level based on four main indices is [11]:

- *Disaster Deficit Index* (DDI; expected financial loss and capacity). The key factors describing economic resilience are insurance and reassurance payments, reserve funds for disasters, aid and donations, new taxes, budgetary reallocations, external credit and internal credit.
- *Local Disaster Index (*LDI; cumulative impact of smaller scale natural hazard events). A uniform distribution of disasters in the area under consideration gives a high value, whereas a high concentration of disasters in a low number of places a low value.
- *Prevalent Vulnerability Index* (PVI; composed of exposure, socio-economic fragility and lack of social resilience). Each of the three components has eight sub-indices. The indices are for example related to population and urban growth, poverty and inequality, import/exports, arable land/land degradation, unemployment, debts, human development index, gender inequality, governance and environmental sustainability.
- *Risk Management Index* (RMI; disaster management/mitigation strategies/systems). This index is composed of four factors estimating capacity related to risk identification, risk reduction, disaster management and financial protection. Sub-indices are related to the quality of, amongst others, loss inventories, monitoring and mapping, public information and training, land use planning, standards, retrofitting, emergency planning and response, community preparedness, reconstruction, decentralized organization and budget allocation.

2.3.2. Physical vulnerability assessment

If in social vulnerability assessment the focus is on determining the indicators of societies' coping capacities to any natural hazard and identifying the vulnerable groups or individuals based on these indicators, in physical (or technical) vulnerability assessment the role of hazard and their impacts is emphasized, while the human systems in mediating the outcomes is minimized. In the technical/engineering literature for natural hazards, physical vulnerability is generally defined on a scale ranging from 0 (no loss/damage) to 1 (total loss/damage), representing the degree of loss/potential damage of the element at risk (see Table 1). The evaluation of vulnerability and the combination of the hazard and the vulnerability to obtain the risk differs between natural phenomena. However, the majority of models see vulnerability as being dependent both on the acting agent (physical impact of a hazard event) and the exposed element (structural or physical characteristics of the vulnerable object). The most common expressions of physical vulnerability for different types of hazards (landslides, floods, earthquakes) are: vulnerability curves (stage-damage functions), fragility curves, damage matrices and vulnerability indicators [35]. In recent decades, research on flood vulnerability assessment has advanced substantially (especially with the aid of computational techniques) and different modeling approaches ranging from post-event damage observations to laboratory-based experiments and physical modeling have been developed. One major applications of flood vulnerability analysis is the development of guidelines for reducing structural vulnerability for different types of properties. Likewise, the results of these studies are used in spatial development strategies (spatial planning) and for identification of the elements or areas where damages would be expected in case of flood occurrence. There are two main approaches of flood vulnerability assessment: one (1) focuses on the economic damage and is essentially a quantification of the expected or actual damages to a structure expressed in monetary terms or through an evaluation of the percentage of the expected loss; (2) the other, deals with the physical vulnerability of individual structures and on the estimation of the likelihood of occurrence of physical damages or collapse of a single element (e.g. a building). Within the last category, two general methods can be identified:

Empirical methods are based on the analysis of observed consequences (collection of actual flood damage information after the event) through the use of interviews, questionnaires and field mapping. The main advantage of these methods is the use of real data. However, the results are very much dependent on the respondents' risk perception for the first two - and data availability (especially for deriving stage-damage curves) for the last collection method.

In **analytical methods** (i) different flood parameters (duration, velocity, impact pressure, etc.) are directly controlled during laboratory experiments and their effects on the structures are quantified; (ii) numerical models and computer simulation techniques are used to estimate the reliability of a structure and/or calculate its probability of failure (usually hydrologic and hydraulic modeling of the floodplain is a pre-requisite) [36]. This type of approaches are resource demanding (time and money) but allow for a better understanding of the relation between flood intensity and degree of damage for an exposed structure with definite characteristics. Moreover, due to data/resources requirement, they can only be used for assessment of individual structures.

The key parameters used in order to quantify physical vulnerability to floods are related with the forces (buoyancy, hydrostatic pressure and dynamic pressure) that flooding is likely to exert on a structure (e.g. building, bridge, dam, etc.). Directly linked with these forces are the characteristics of the damaging agent (water) which are reflected in a number of actions on the exposed structure: hydrostatic, hydrodynamic, erosion, buoyancy, etc. ([37] in [38]).

The most used approach for assessing and modeling direct flood damages is the stage-damage functions which relates the relative or absolute damage for a certain class of objects to the inundation depth (Figure 7). One limitation in their use is the assessment of the degree of damage based solely on one characteristic of the exposed element/group of elements (e.g. building type). Likewise, the flood damage influencing parameter e.g. inundation depth, may not be the only hazard indicator that contributes to the quantity of losses [39]. In [40] the importance of further influencing factors like 'duration of inundation, sediment concentration, availability and information content of flood warning and the quality of external response in a flood situation' are emphasized. For static floods (slow moving water) the depth is considered to be sufficient for the analysis, but for dynamic floods, velocity is regarded as more important.

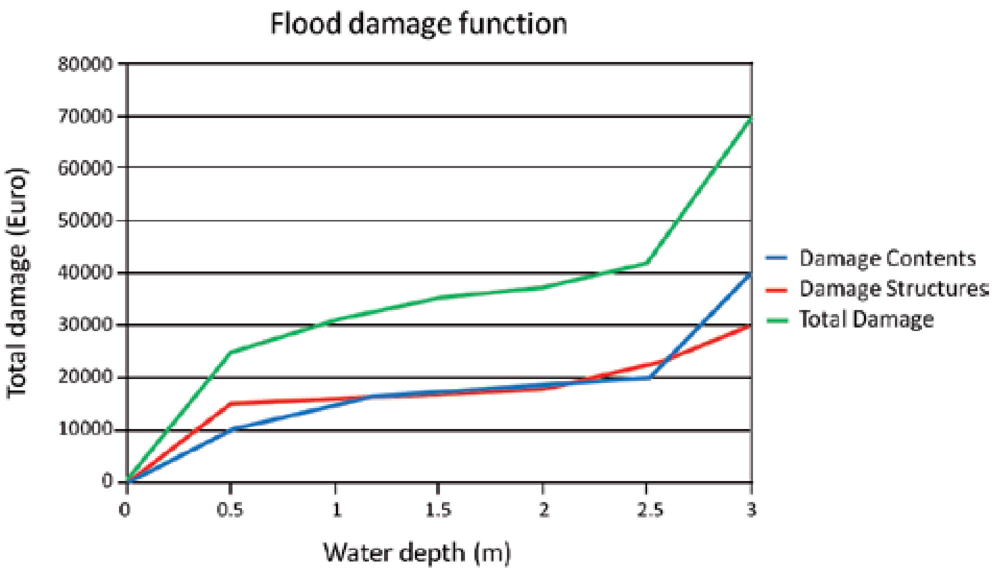

Figure 7. Example of flood damage curves showing damage to structures, contents and total damage as a function of inundation depths [41]

In HAZUS-MH Flood Model [42] the latter parameter is directly considered. A velocity-depth function is included indicating if building collapse has to be assumed. A threshold for collapse corresponding to 100% damage is set, while below this threshold the damage is estimated based on the inundation level only. The model also takes into account the effect of warning which is assessed based on a 'day-curve'. If a public response rate of 100% is assumed, a maximum of 35% of damage reduction can be achieved depending on the time of warning [26]. The flood hazard module addresses both riverine and coastal floods; flash-floods are not included in the model's capability.

The Swiss risk concept from the Nationale Platform Naturgefahren (PLANAT) defines three intensity classes for flood vulnerability analysis, based on flood depth and velocity which are used in spatial planning regulations (Table 2).

Intensity class	Criteria	Description
Low	h < 0.5 m or v x h < 0.5 m^2/s	Persons are barely at risk and only low damages at buildings or disruption have to be expected
Middle	2 m > h > 0.5 m or 2 m^2/s > v x h > 0.5 m^2/s	Persons outside of buildings are at risk and damage to buildings can occur while persons in buildings are quite safe and sudden destruction of buildings is improbable
High	h > 2 m or v x h > 2 m^2/s	Persons inside and outside of buildings are at risk and the destruction of buildings is possible or events with lower intensity occur but with higher frequency and persons outside of buildings are at risk

Table 2. Intensity classes based on flood depth and velocity from PLANAT in [26]

Damages caused by landslides to population, environment and built-up areas are significantly less than for other natural hazards due to the inherent characteristic of the process. However, the extent of these losses is frequently underestimated especially when landslides are associated with the occurrence of floods or earthquakes (their consequences tend to be aggregated). Generally, vulnerability to landslides depends on a variety of factors like: runout distance; volume and velocity of sliding; pressure caused by the movement; height of deposition; elements at risk (e.g. different structures), their nature and their proximity to the slide; elements at risk (e.g. persons), their proximity to the slide, the nature of the building/roads they are in [43].

Research in the field of landslide hazard and risk ([24], [44], [45],[46]) has demonstrated that in contrast to other natural processes (flooding, earthquakes) landslide vulnerability is more difficult to assess due to a number of reason, such as:

i. The complexity and the wide range of variety of landslide processes (landslides are determined by different predisposing and triggering factors which results in various mechanisms of failure and mobility, size, shape, etc.)

ii. The lack of systematic methods for expressing landslide intensity - there is no general indicator of landslide intensity (e.g. for rock falls, impact pressure or volume can be used whereas for debris flow deposit height is common; other indicators such as flow velocity are rarely considered) and in practice data scarcity reduces their number significantly

iii. The quantitative heterogeneity of vulnerability of different elements at risk for qualitatively similar landslide mechanisms due to their intrinsic characteristics (here, human life constitutes a special case)

iv. The variability in spatial and temporal vulnerability

v. The lack of historical damage databases – usually only events which cause extensive damage are recorded and data about the type and extent of damage is often missing

vi. Non-physical factors influence the vulnerability of people (e.g. early warning, hazard and risk perception, etc.)

Landslide vulnerability assessment approaches range significantly due to various foci and objectives addressed. Some consider vulnerability within the landslide risk management framework, others evaluate exclusively physical vulnerability. Three general types of methodologies can be identified (without excluding the possibility of other classification schemes):

Qualitative methods ([47], [48], [35]) - given a particular landslide type and the characteristics of the elements at risk, the appropriate vulnerability factor is assessed by expert judgment, field mapping or based on historical records. These methods are flexible (e.g. indicator based methods) valuable and easy to use/understand by decision makers. However, a major limitation of this approach is that most of the data have to be assumed and there is no direct (quantified) relation between hazard intensities and degree of damage.

As an example, in [47] an empirical GIS-based geomorphological approach for landslide and risk analysis was proposed, using stereoscopic aerial photographs and field mapping in order to represent the changes in distribution and shape of landslides and assess their expected frequency of occurrence and intensity. The damages were classified in three classes using a qualitative relationship between landslide intensity/type and their consequences: *superficial* (aesthetic, minor) damage where the functionality of the elements at risk is not compromised and damage can be repaired, rapidly and at low costs; *functional* (medium) damage, where the functionality of the structures is compromised, and the damage takes time and large resources to be fixed; *structural* (total) damage, where buildings or transportation routes are severely or completely damaged, and require extensive (and costly) work to be fixed (demolition and reconstruction may be required).

Semi-quantitative methods are reducing the level of generalization in comparison with qualitative methods. They are flexible and can, to a certain degree, reduce subjectivity, compared with the methods mentioned above. Within this category, damage matrices, for example, are composed by classified intensities and stepwise damage levels. In [49] damage matrices were suggested based on damaging factors and the resistance of the elements at risk to the impact of landslides. Figure 8 shows a correlation, in terms of vulnerability, between exposed elements and the characteristics of the hazard. The applicability of this method, requires statistical analysis of detailed records on landslides and their consequences [50]. This proves to be a challenge in data scarce environments.

Quantitative methods ([51], [52], [53], [54]) are mostly applied at local scale (often, for individual structures) due to complexity of procedures involved and detailed data requirements. Quantitative methods are usually employed by engineers or actors involved in technical decision making, as they allow for a more explicit objective output. The results can be directly integrated in a Quantitative Risk Assessment (QRA) also taking into account the uncertainty in vulnerability analysis. The procedures involved can rely on i) expert judgment (heuristic), ii) damage records (empirical) or iii) statistical analysis (probabilistic).

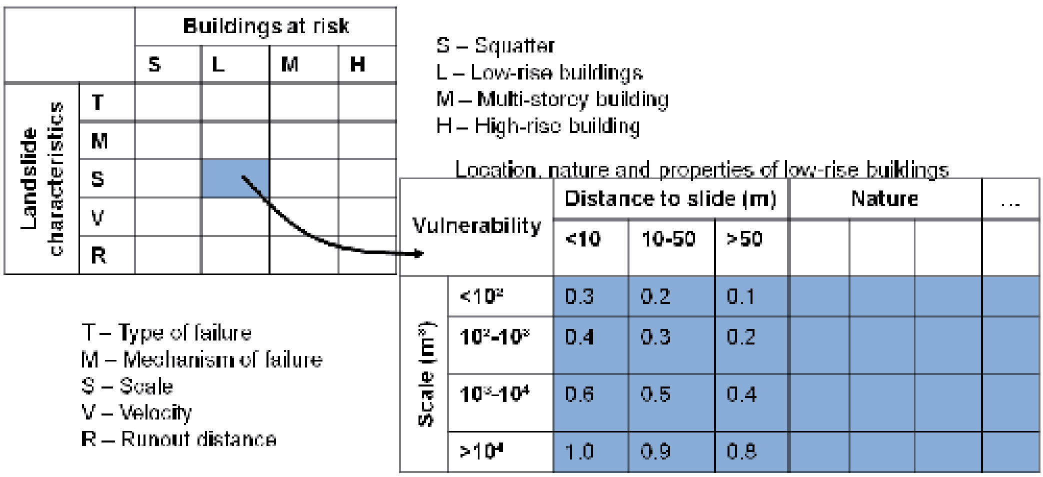

Figure 8. Structural vulnerability matrix [49]

One example of quantitative expert judgment used to evaluate physical vulnerability of roads to debris flows was used in [55]. 147 respondents from 17 countries were asked to use their expert knowledge to assess the probability of a certain damage state being exceeded given that a volume of debris impacts a road (Table 3).

Description of probabilities		
Descriptor	**Description**	**Values for analysis**
Highly improbable	Damage state almost certainly exceeded, but cannot be ruled out	0.000001
Improbable(remote)	Damage state only exceeded in exceptional circumstances	0.00001
Very unlikely	Damage state will only be exceeded in very unusual circumstances	0.001
Unlikely	Damage state may be exceeded, but would not be expected to occur under normal circumstances	0.001
Likely	Damage state expected to be exceeded	0.01
Very likely	Damage state almost certainly exceeded	0.1

Table 3. Damage state definition [55]

Based on the questionnaire results, fragility curves were produced which relate the flow volume to damage probabilities (Figures 9). It should be noted that in this study probabilites were derived based on the respondents experience only (qualitative data) with no statistical processing of damage observations or analytical/numerical modeling. The results were compared to known events in Scotland (UK) and the Republic of Korea. The major limitation of this method is the high degree of subjectivity, however it advances expert knowledge which might be in some cases the only/most appropriate source of information about damages caused by the impact of landslides.

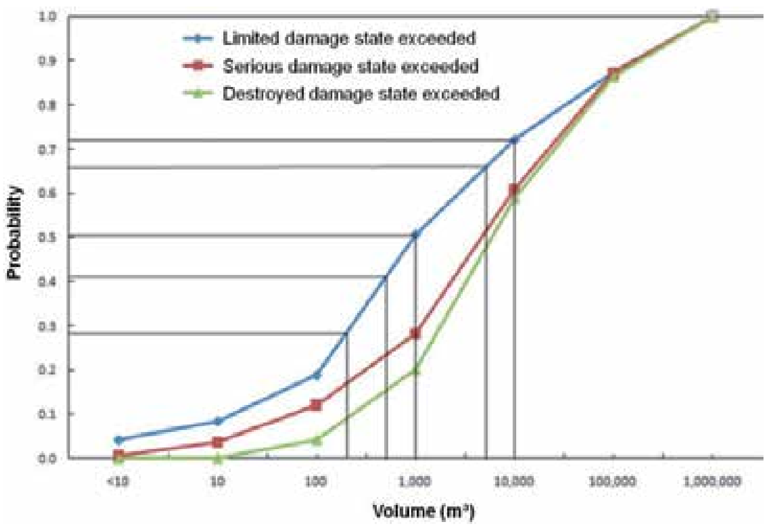

Figure 9. Fragility curves 'forced' to unity and manually extrapolated to the next order of magnitude for volume (local roads). The vertical lines are added at 200, 500, 1000, 5000 and 10000 m^3 (illustration only for 'limited damage' curves) [55]

In reference [53], the author performed a study of a well-documented debris flow event which occurred in the Austrian Alps (August, 1997) and derived vulnerability curves for buildings located on the fan of the torrent based on the intensity of the phenomenon and the damage ratio. The intensity was approximated by deposit height and the susceptibility of the element at risk (i.e. buildings) by material of construction (brick, masonry, and concrete). Figure 10 shows the curve produced together with other existing curves for comparison. The application of this vulnerability function is limited to process intensities expressed as deposit height ≤ 2.5 – 3 m which means that the curve is not relevant for intensities which exceed this value. Nevertheless, the authors argue that such high process intensities generally result in a total loss of the building since the reparation costs will exceed the expenditure necessary for a new construction [53].

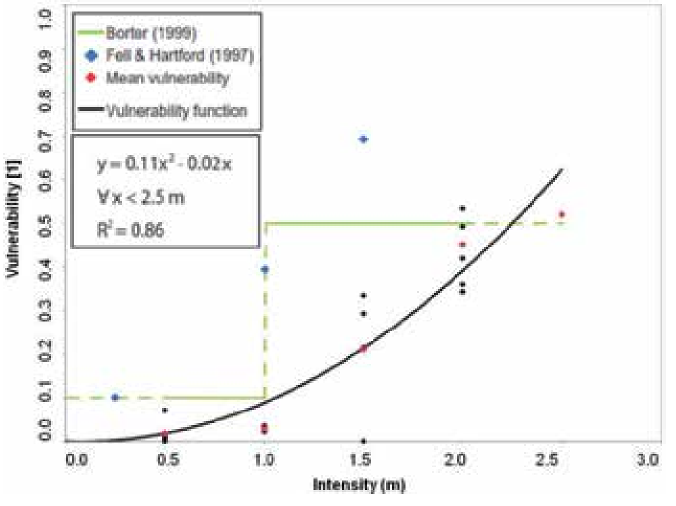

Figure 10. Relationship between debris flow intensity and vulnerability is expressed by a second order polynomial function for flow height > 2.5 m. Results from the study are indicated by black dots, the corresponding mean vulnerability is indicated by red dots [53]

In another study [51], a scenario-based method derived from a probabilistic approach to regional vulnerability assessment [56] was used. The authors defined vulnerability as a function of landslide intensity and the susceptibility of vulnerable elements (see Eq. 2).

$$V = I \bullet S \tag{2}$$

Susceptibility is defined as 'the lack of inherent capacity of the elements in the spatial extension under investigation to preserve their physical integrity and functionality in the course of the physical interaction with a generic sliding mass' and is independent of the characteristics of the landslide [51]. The susceptibility model is able to accommodate any factor dictated by the analyzed category of elements at risk. In this study, the susceptibility factors taken into account are: (a) resistance and state of maintenance for structures, and (b) persons in open space and vehicles, population density, income, age, and persons in structures, for individuals. For landslide intensity, a composite parameter is derived based on the kinetic – (related with the damage caused by the impact energy of the sliding mass) and kinematic (accounts for the effects of size-linked features of a reference landslide) characteristics of the interaction between the sliding mass and the reference area proposed. Models for quantification of susceptibility (Eq. 2) and intensity (Eq. 3) are illustrated below:

$$S = 1 - \prod_{i=1}^{ns} (1 - \vartheta i) \tag{3}$$

where,

ϑi is the i-th on ns susceptibility factor (each defined in the range) contributing to the category susceptibility

and,

$$I = ks \bullet (rK \bullet IK + rM \bullet IM) \tag{4}$$

where,

ks is the spatial impact ratio (equal to the ratio between the area pertaining to the category that is affected by the landslide and the total area pertaining to the category); rK and IK are kinetic factors and rM and IM are kinematic factors. The proposed methodology provided a framework for the quantification of uncertainties in vulnerability assessment.

3. Uncertainty in vulnerability analysis

In natural hazards risk management, decisions regarding the risk associated with a particular hazard are essentially enacted based on limited information and resources. In order to improve this process, experts started to investigate the effects of uncertainty on risk (and its determinants) qualitatively or quantitatively and communicate their results to decision-makers. This one-way approach toward finding solutions for advancing decision making proves out to be insufficient in contrast to the complexity of the problems at hand, especially when dealing with inherent uncertainties or unforeseen changes in the human-environmental system. Nevertheless, effort are being made to reduce the effects of uncertainty on vulnerability (and consequently, risk), particularly related with the data and models used. For example, representing hazard damage potential by only one parameter (e.g. for floods – depth of inundation) can result in overestimations of vulnerability and subsequently in un-economic investments in mitigation countermeasures. One possibility to overcome this problem would be to reduce the uncertainty in the input data by using data-mining approaches (e.g. tree-structured models) for the selection of the most important damage-influencing parameters [39]. Other examples would be the use of scenario analysis for seismic vulnerability and its probable damages in order to develop a hierarchy of effective factors in earthquake vulnerability [57] or testing the performance of different structures (reliability analysis) subjected to the impact of landslides with various intensities through the use of traditional methods like Monte Carlo Simulation (MCS), First Order Second Moment (FOSM), First Order - /Second Order Reliability Method (FORM/SORM). However, the selection of the most appropriate uncertainty modeling approach depends on the level of complexity required by the scope of analysis or the use of the final results.

Generally, uncertainties in decision and risk analysis can be divided into two categories [10]: those that stem from 'real' variability in known (or observable) processes or phenomena (e.g. height or the ethnicity of an arbitrary individual in a specified population or the distribution of velocities in a sliding mass, etc.) and those which reside from our limited knowledge about fundamental phenomena (e.g. the nature of some earthquake mechanism, the effect of water level fluctuation on clay slope stability, etc.). The former is known as aleatory (inherent or stochastic) uncertainty and cannot be reduced. The latter, epistemic uncertainty, includes measurement uncertainty, statistical uncertainty (due to limited information), and model uncertainty, which can be reduced, for example, by increasing the probing samples or by improving the measurement methods or modeling algorithms. Other types of classification systems, together with a review of methods and simulation techniques for uncertainty treatment are critically discussed and illustrated in a work performed by the Norwegian Geotechnical Institute (NGI), in [34]. Uncertainty can be addressed from (1) an integrative perspective, where vulnerability is registered by exposure to hazards but also resides in the resilience of the system experiencing the hazard [58] (bottom-up oriented vulnerability assessment). In this context, uncertainty is associated with future changes (in frequency and magnitude of hazards but also in climatic, environmental and socio-economic patterns) characterized by unknowable risks to which communities must learn to adapt. This approach is centered on the human systems' coping capacity and promotes vulnerability reduction through enhancing resilience to future change. Conversely, (2) a direct approach towards reduction of (epistemic) uncertainty is developed within the technical field (assimilated to deductive, top-down vulnerability assessments), where uncertainty models are defined for each component of vulnerability and the sources of uncertainty categorized [45]. Figure 11 shows how these two approaches of dealing with uncertainty can inform climate adaptation policy: one is (epistemic) uncertainty 'reducer' while the other is uncertainty 'accepting' (due to issues like, for example, timescale and planning horizons, the unit of analysis being considered and the development status of the region or country) [59].

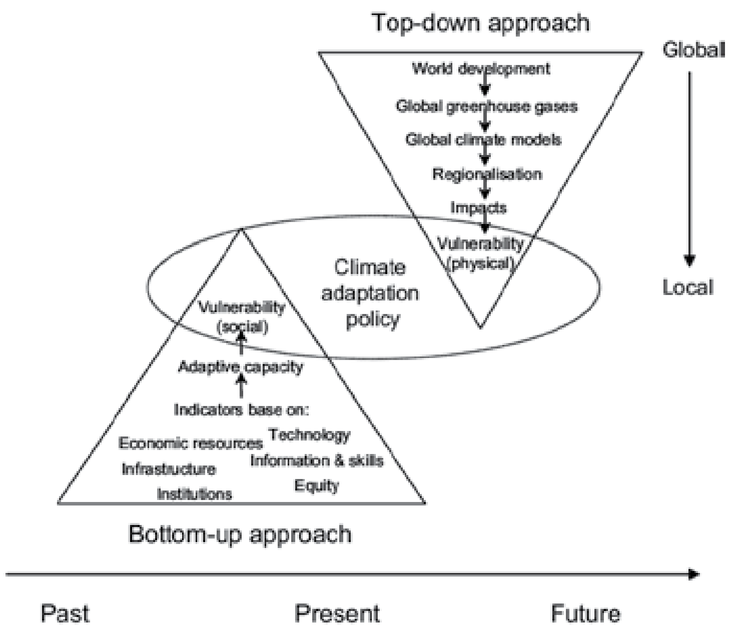

Figure 11. "Top-down" and "bottom-up" approaches used to inform adaptation to climate change [59]

Table 4 illustrates an example of uncertainty sources in physical vulnerability analysis of buildings. It is obvious that these will vary with the methodology used and the quality and quantity of data available.

Type	Source
Epistemic	Intensity assessment (using proxies e.g. depth of material, velocity, volume, impact pressure, etc.) Characterization of elements at risk (e.g. structural-morphological characteristics, state of maintenance, strategic relevance, etc.) Estimations of buildings' value and damage costs Vulnerability model (selection of parameters, mathematical model, calculation limitations) Expert judgement
Aleatory	Spatial variability of parameters* (e.g. landslide intensities, population density, etc.)
*also related with the scale of investigation	

Table 4. Sources of uncertainty in physical vulnerability to landslides (e.g. for buildings)

Within the general risk assessment framework, uncertainty propagates not only from one component of risk to another but also within the process stages of vulnerability analysis. This is schematically described in a classification system for vulnerability estimation proposed in [34] and represented in Figure 12.

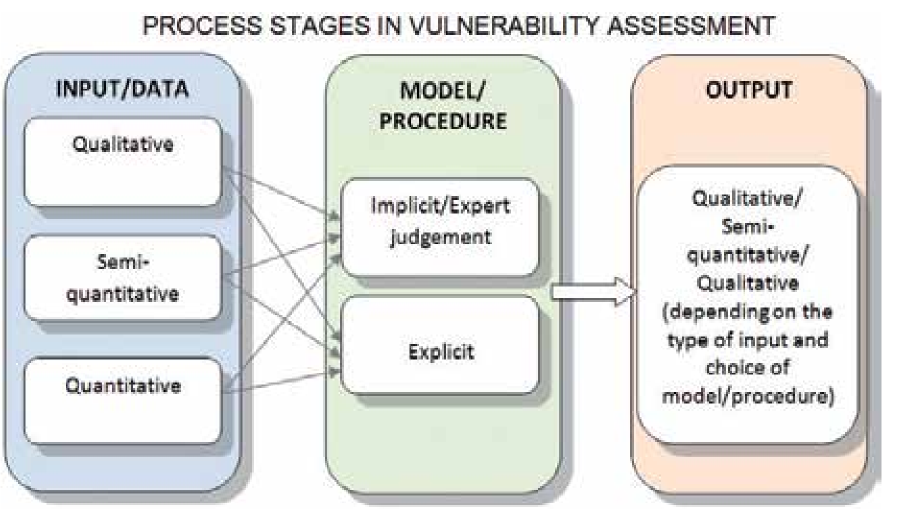

Figure 12. Classification system for vulnerability estimation. Uncertainty is associated with each process stage [34]

According to the authors, uncertainty associated with the input data (depending on the type, quantity and quality), propagates through the model, which also contains a degree of uncertainty due to, for example, expert judgment, mathematical model or basic assumptions. The uncertainty in the output depends on the two previous process stages as well as the uncertainty related with the interpretation of the results.

4. Conclusions

The most important goal in developing tools for measuring vulnerability is their use in natural hazards risk reduction strategies, thus applying them in decision making processes. In this context, it is necessary to know what is the objective of the assessment, what is the target group of any particular approach, who is using the results and what is their understanding of the outcome. The methods of vulnerability assessment presented herein are mere exemplification of the complexity and wide range of approaches that can be applied in natural hazards disaster risk management. However, based on these a number of observations may be formulated.

Vulnerability defined considering physical exposure or social-economical determinants only cannot encompass the complexity of effects caused by the impact of a natural hazard on an element or group of elements at risk (especially for systems like urban developments, communities, etc.). In an editorial for vulnerability to natural hazards [60] addressed the question of integration between natural and social scientific approaches based on a number of research studies. Their findings show that, studies that are dedicated to different components of vulnerability (e.g. frequency and magnitude of a hazard, elements at risk, exposure, coping and adaptation capacities, etc.) and therefore use different methodological approaches, are relatively similar in scope. Hence it is important to clearly describe and define which components of risk and/or vulnerability assessment are considered in each individual case study. The aim is to communicate without losing the perspective either of the approaches advances. Thus, a step forward towards an integrative vulnerability assessment might be to strengthen the dialogue between different groups of experts in natural hazard vulnerability/risk assessment through exchange of views about definitions, concept and underlying worldviews and values [60].

In terms of vulnerability/risk assessment outcomes, there are three main types of methods (results) - quantitative, semi-quantitative and qualitative, all with benefits and drawbacks. The main difference between quantitative and qualitative methods lies in the fact that quantitative assessments provide a more explicit objective framework which may be conducive to improving decision making process. However, the most appropriate tool depends on the decision problem at hand (for example, qualitative vulnerability assessment can be more cost effective, less time consuming and easier to understand for non-technical stakeholders), the objective (including scale) of the analysis and the quality/quantity of available data. Hence there is no general preference for qualitative, semi-quantitative or quantitative approaches [61]. One must also acknowledge that there is no quantitative vulnerability/risk assessment totally devoid of expert judgment; quantitative vulnerability/risk analysis rather provides a framework for making systematic judgment [62]. It is the quality and quantity of subjectivity that affects the overall outcome of the analysis.

With regards to uncertainty in vulnerability analysis, Gall [63] emphasizes the importance of knowledge quality assessment - 'uncertainty and sensitivity analysis are mandatory for maximizing methodological transparency and soundness, and hence the acceptance of research findings; despite this demand, both analyses are often missing in vulnerability assessment'. However, progress has been done, for example, in the field of technical (structural) vulnerability (mostly, for hazards like floods and earthquakes), where empirical as well as statistical (probabilistic) methods aided by GIS and advanced computational models are used to estimate uncertainty in vulnerability and its components.

To allow for an improved decision making process through the treatment of uncertainty, first the joint effort between end-users and experts must shift towards a more transparent, participative and open process. The role of the scientist seen as 'speaking truth to power' is defective as it implies that all uncertainties can be treated. Conversely, experts should clearly communicate the limitations of their findings as well as continue to investigate the effects of uncertainty on risk and its determinants in order support the community to face future challenges in dealing with natural hazards and risk and global change.

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Chapter 2

Disaster Management Discourse in Bangladesh: A Shift from Post-Event Response to the Preparedness and Mitigation Approach Through Institutional Partnerships

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Additional information is available at the end of the chapter

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1. Introduction

The discourse of disaster management has undergone significant changes in recent decades and their effects have been profoundly felt in the developing world, particularly in terms of reduction in the loss of human lives. In this chapter, we concentrate on the evolution of disaster management approaches in Bangladesh and the method of their implementation by mobilizing institutions as a case in the developing world. The geographical location of Bangladesh in South Asia, at the confluence of three large river systems – the Brahmaputra, the Ganges, and the Meghna – and north of the Bay of Bengal, renders it one of the most vulnerable places to floods and cyclones. Human-induced climate change exacerbates the problem, with its already manifested effects and the predicted rise in sea level of 0.3 m to 0.5 m by 2050 [1, 2, 3]. Climate models have revealed that the effects of climate change are not only affecting individual countries, but resulting in increased climate variations at regional levels [4]. Bangladesh, as part of South Asia, is likely to experience more variations in climate regimes, as well as more extreme weather events.

Bangladesh is the most densely populated country in the world, except city states, with more than 1,000 people per sq km [5]. Agriculture, which provides a quarter of the gross domestic product (GDP), depends largely on timely monsoon rainfall and regularity in seasonal fluctuations. In the period 1970–2004, about 0.7 million people lost their lives due to natural disasters, and economic losses totaled about US $5.5 billion [6, 7, 8, 9]. The cyclone of 1970, in the coastal areas of what was then East Pakistan, alone claimed over half a million lives. Again, the 1991 and 2007 cyclones caused the loss of about 149,000 and 3,406 people respectively. In recent years, the frequency of extreme floods has increased, as has the corresponding economic loss. The flood in

July 2004 was the most devastating – with an economic loss of about US $2.2 billion [5]. In terms of GDP, this loss was less than what the world's poorest countries faced during the 1985–99 disasters – a loss of 13.4% of combined GDP [10]. But the loss in Bangladesh amounted to an immense step backwards in development efforts. The floods in 2007 inundated about 36% of the total area in 57 out of 64 districts [11] and affected at least 4.5 million people [12].

Because of the extreme vulnerability of the people in general and of the economy to natural disasters, various regimes of the government of Bangladesh (pre- and post-independence) have developed an institutional infrastructure to deal with natural hazards and their potential losses [13, 14]. Traditionally, the disaster management approach in the country has been to respond to disaster in the aftermath of the events. Nonetheless, the ever-increasing human and economic costs have raised serious questions about such approaches. Also, flood-disaster management has relied heavily on structural engineering and post-flood relief operations. Overall, such a post-facto approach has failed to effectively deal with the problems of disaster loss.

In recent years, there has been a shift to recognize the critical roles of non-structural measures as well as pre-disaster mitigation and preparedness. These initiatives recognize the roles of different stakeholders. For example, the Disaster Management Act of 1998 acknowledges the capacity of affected populations [15]: "An event, natural or man-made, sudden or progressive, that seriously disrupts the functioning of a society, causing … such severity that the affected community has to respond by taking exceptional measures and is on a scale that exceeds the ability of the affected people to cope with using only its own resources." Disaster management warrants more than relief and recovery: it should be part of development planning, without which the loss of life and property is likely to intensify. It is recognized that institutional partnerships can be effective when they involve all stakeholders – government, local communities, NGO/CBOs, media, the private sector, academia, neighboring countries, and donor communities.

In this study, we examine the extent and effectiveness of institutional partnership from the perspective of a shift from a managerial approach to an approach using participatory, collective decision-making and resource-sharing to manage disaster risk. Since community members are the direct and most seriously affected victims, effective and sustainable partnership requires a change from a partnership approach based on equality to a focus on the community [16]. Our central concerns are to assess who decides, at what level, and how. There has been only very limited analysis of the shifting approaches and of how institutions at different levels are presently functioning in Bangladesh. Is this mechanism based on partnership, with collective decision-making? Is a culture of working together on a national cause such as disaster management evolving? How functional are these elaborate institutional mechanisms? What is the role of the private sector or the knowledge stakeholders? How can an effective partnership be built into disaster management? These are questions we examine in this chapter.

2. Methodology

Our research examines whether the elaborate institutional mechanisms of disaster management in Bangladesh reflect the partnership of stakeholders. For this purpose, social science policy analysis seemed useful. Obtaining reliable quantitative data on activities of both government and NGOs is a chronic problem in Bangladesh; our research therefore applied qualitative, rather than quantitative, tools and techniques.

Both primary and secondary data sources were used for empirical investigation and policy analysis. To collect the primary data from local communities, we applied a case study approach which employed participatory rural appraisal tools, such as focus group discussions (FGDs), household interviews and key informant interviews, in two coastal communities of Bangladesh severely affected by Cyclone Sidr. We analyzed data procured from a total of 162 households distributed across eight villages, which were randomly selected to conduct the interviews and FGDs. We received 100% response from the targeted households for household interview. A random sampling procedure was followed to select households from the complete list of households in the selected villages for interview. Households were proportionately selected according to the size of the villages, and household heads were interviewed. Eight FGDs were carried out by administering a semi-structured questionnaire to each village.

For policy analysis, we relied chiefly on secondary data, which were supplemented by primary data. Because Bangladesh has experienced numerous devastating cyclones, as well as long-lasting floods that have caused immense suffering to people and damage to properties in recent decades, we relied on secondary data on the relevant disaster response and management policies. Official documents from the government and donors, study reports from NGOs and other organizations, journal articles, newspaper clippings, TV reports and documentaries, and internet resources from reliable and responsible sources provided additional information for our analysis. To ensure openness in discussing sensitive issues, we used informal discussions with stakeholders at different levels. Through personal contacts and over the internet we collected reports and documents from government agencies, NGOs, and donors in Bangladesh, such as the Bangladesh Disaster Preparedness Centre (BDPC), the Disaster Forum, the Disaster Management Bureau, the Sustainable Development Resource Centre, and the United Nations Development Program (UNDP).

3. Shifting approaches in disaster management

In recent decades, government agencies, non-governmental organizations (NGOs) and local communities in Bangladesh have undertaken various measures to mitigate the impacts of natural disasters, including floods and cyclones, on the people, economy and society. The concept of developing national preparedness, as opposed to post-event response, to disasters like floods and cyclones evolved after the floods of 1988 and the devastating cyclone of 1991. The main argument behind this shift was that if people were well prepared for frequent disasters they would minimize their impacts, resulting in a reduced need for relief and rehabilitation. It was also strongly felt by the public institutions that if disaster preparedness could be integrated in the socio-economic development process at household, community, regional and national levels, it would build the long-term capacity of the community to mitigate risk and vulnerability to disasters [17]. The aim of the shift also included changing disaster management approaches and measures from structural engineering interventions to the social dimensions and community partnerships.

The stated significant change in emergency and disaster management approaches demanded institutional restructuring in the governance portfolios. Consequently, the government of Bangladesh, led by the Ministry of Disaster Management and Relief, has undertaken various steps in the form of policy, strategy and programs considering the concept of disaster management through mitigation, preparedness, recovery and rehabilitation. The government established the Disaster Management Bureau (DMB) under the Ministry of Disaster Management in 1993 to promote disaster prevention, mitigation and preparedness; to provide guidelines; and to organize training and awareness for the concerned people and stakeholders to mitigate the impacts of disasters. Currently, the DMB has focused on risk reduction through community mobilization, capacity-building and linking risk reduction with the socio-economic development of the poor and vulnerable groups and with developing the DMB's partnership with other government agencies, NGOs and international organizations.

Alongside the development thinkers, international development partners (such as UNDP, DFID, Oxfam GB, USAID, Care International, Caritas) and local NGOs which are concerned with, and are experienced in, disaster management in Bangladesh, the government has promoted the approach of capacity-building and disaster preparedness at all levels. A call for institutional partnerships therefore stemmed from both the government as well as non-governmental and civil society organizations. A few key policy planners and senior government officials have also favored this new thinking and reflected this through the renaming of the Ministry of Relief and Rehabilitation to the Ministry of Disaster Management and Relief. In 1993, the Ministry of Disaster Management then established the Disaster Management Bureau (DMB) and the government set up a national council and various committees at national, district, *upazila* (sub-district) and union (local council) levels, for overall disaster management preparedness [17]. The implications of this institutional restructuring were manifold, and evolved through a sequence of placing increasing emphasis on institutional partnership and community-based disaster management (CBDM).

3.1. Institutional Restructuring to Reflect a Shift in Disaster Management

In order to manage the consequences of natural disasters, formal public policymaking institutions in Bangladesh have formulated a well-developed mechanism (Figure 1) at national and field levels. The factors that led to such a development can be explained as follows:

a. the severity of the consequent casualties has led to motivations at local, national and international levels to address the issue;

b. the recurrent disasters created serious development setbacks: loss in the production and infrastructure sectors set back the affected regions and the country; and

c. in order to attract external investment, the minimization of disaster risks and vulnerabilities warranted intervention at the policy level.

In Bangladesh, at the national level, four high-profile bodies were established for the multi-sectoral coordination of emergencies associated with environmental disasters as well as disaster management in general: the National Disaster Management Council (NDMC), headed by the prime minister; the Inter-Ministerial Disaster Management Coordination Committee (IMDMCC), led by the minister of food and disaster management; the National Disaster Management Advisory Committee (NDMAC), headed by a specialist nominated by the prime minister; and a Parliamentary Standing Committee on Disaster Management to supervise national policies and programs. The common missions of these bodies have been to provide policy and management guidance and the macro-coordination of activities, particularly relief and rehabilitation.

Presently, the lead actor in disaster management is the Ministry of Disaster Management and Relief (MoDMR) until 2002. It has the role of inter-ministerial planning of disaster management and coordination and of responding in the event of a disaster. Under the MoDMR, there are two line agencies, the Disaster Management Bureau (DMB) and the Directorate of Relief and Rehabilitation (DRR). The DMB is a small professional unit at the national level that performs specialist functions, working with district and *upazila* (sub-district) administrations and line ministries under the overall guidance of the IMDMCC. It is a catalyst for planning, for arranging public education, and for organizing the systematic training of government officers and other personnel from the national down to the union (local council) or community level. The DRR manages the post-disaster provision of relief and rehabilitation. At present, it leads risk reduction at the local community level.

Among all the other ministries, the Ministry of Water Resources (MoWR) plays a vital role in flood management. It is involved in the planning of water resources, including planning for water-related natural disasters such as cyclone protection, flood proofing, riverbank erosion control and drought management, although the mitigation of disasters remains beyond their mandate. The Flood Forecasting and Warning Center (FFWC), under the Bangladesh Water Development Board (BWDB) of the MoWR, plays an important role in providing early warning about impending floods to the agencies involved.

In the areas of both cyclone and flood hazards, the Bangladesh Red Crescent Society (BRCS) and various donor agencies play important roles. The Cyclone Preparedness Program (CPP) was established in 1972 following the devastating cyclone of 1970, under an agreement between the BRCS and the government of Bangladesh, with an aim to undertake effective cyclone preparedness measures in the coastal areas. CPP, under the BRCS, has a joint management structure, with two committees, *viz.* a 7-member Policy Committee headed by the Minister of MoFDM, and a 15-member Implementation Board led by the Secretary of the MoFDM. Now the CPP has about 33,120 trained volunteers, including 5,520 women [18].

Besides, the government has a "standing order" for natural disasters (mainly for floods and cyclones), which was last updated in August 1999. The standing orders are followed by all ministries, divisions/departments and government agencies during normal times, precautionary and warning stages, the disaster stage and the post-disaster stage.

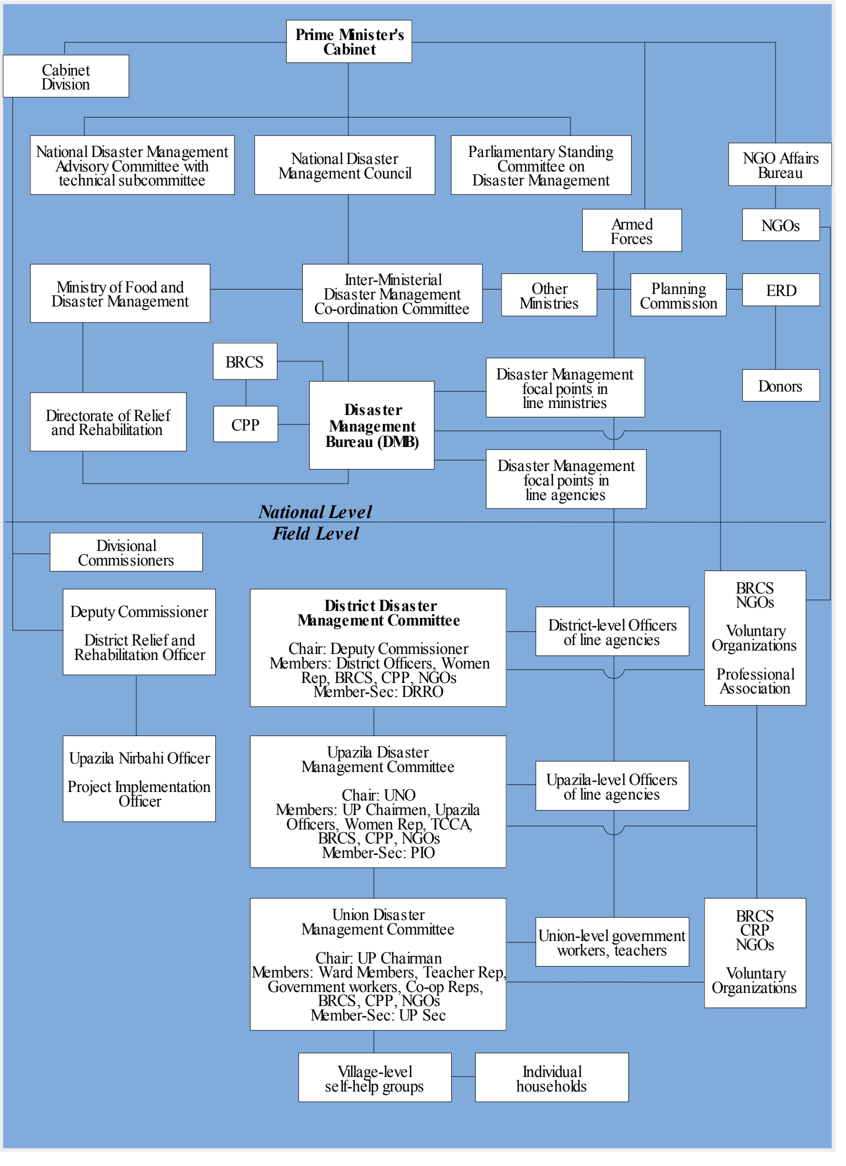

Figure 1. Organizational structure and institutional arrangements for disaster management at the national level and field level

The National Water Management Plan also underlines the importance of implementing effective non-structural measures to reduce the impact of floods and erosion. Thus, as opposed to the structural measures against floods (like dams, river embankments, and flood control and drainage projects) and riverbank erosion control projects (like the building of hard points, canalization and revetment), the recent policies and plans have recognized the importance of participatory planning that focuses on sustaining people's livelihoods.

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At the field level (Figure 1), disaster management and related mechanisms start with the district administrations covering all 64 districts of Bangladesh. The District Disaster Management Committee (DDMC) is chaired by the deputy commissioner, the chief civil administrator of the district. The members of the committee include departmental officers and NGO, BRCS and CPP and women's representatives. Likewise, below the district level, there are the *upazila*, union and village tiers of the disaster management committees. These local-level committees include representatives from almost all relevant interest groups in society (Figure 1). An examination of how these committees function appears in succeeding sections.

3.2. Increasing roles and responsibilities of NGOs

The Disaster Management Bureau (DMB) has been assigned the role of coordinating the activities of NGOs. The NGOs constitute a vibrant sector in Bangladesh, and have been acclaimed worldwide. NGOs and CBOs are actively involved, among others, in disaster management, micro-credits, family planning, and human rights protection. As a matter of fact, the advent of NGO activities in Bangladesh owes its origin to the rehabilitation works immediately after the devastating war of independence in 1971. Currently, about a quarter of foreign assistance to Bangladesh is channeled through the NGOs. Therefore, their contributions, particularly to the social service sector and the mobilization of the poor, are quite prominent. This has been acclaimed by the international community. NGOs like the Grameen Bank and Bangladesh Rural Advancement Committee (BRAC) have extended their development and disaster management programs at the international level as well.

NGOs such as CARE-Bangladesh, OXFAM-Bangladesh, Action Aid, Intermediate Technology Development Group-Bangladesh, Bangladesh Disaster Preparedness Center (BDPC) and Disaster Forum are particularly involved in various pre-, during and post-disaster activities. Pre-disaster activities include advocacy, public education campaigns and training programs for personnel involved in disaster management from the national down to the union or local community level. NGOs also are active in emergency evacuation and in taking people to shelters. The post-disaster activities include offering new micro-credits or rescheduling their loan payment programs for rehabilitation.

3.3. Developments in the Institutional Framework: Introduction to the Comprehensive Disaster Management Plan (CDMP)

Besides the Cyclone Preparedness Program (CPP) and the standing orders, the government of Bangladesh adopted a Corporate Plan (2005-2009) called "Comprehensive Disaster Management: A Framework for Action." The US $15 million Comprehensive Disaster Management Plan (CDMP, Table 1) was funded by DFID and UNDP. It aimed "to reduce the level of community vulnerability to natural and human-induced hazards and risks to manageable and humanitarian levels." This program was supposed to be implemented through a "program-based approach" that encompassed all aspects of risk management. The approach comprehended a transition from a single agency response and relief system to a holistic strategy involving the entire development planning process of the government. CDMP Phase II was launched in 2010 to institutionalize the adoption of risk reduction approaches, and to channel support through government and velopment partners, civil society and NGOs into a people-oriented disaster management and risk reduction partnership. The project period will be 2010-20114.

Strategic Directions	Sub-programs	Target Area/ Group	Key Outputs	Responsible Agencies
Raising the level of expertise of the Disaster Management Systems	Capacity-building	MDMR and Implementing Agency	1. PPDU established and effectively executing its key functions. 2. New MDMR allocation of business and organogram reflecting broader responsibilities in disaster risk management 3. Professional skill enhancement program developed and implemented 4. Professional training institutionalized 5. Phase II program identified	MDMR/ UNOPS
Mainstreaming Disaster Risk Management Programming	Partnership Development	National, District and Upazila level officials	1. High level advocacy program established and implemented 2. Review of the development project appraisal processes and integration of disaster risk management 3. Training for national, district and upazila officials implemented	MDMR/ DMB/ NGO MDMR/ DMB
Strengthening Community Institutional Mechanisms	Community Empowerment	Union, Ward and Community levels	1. Inventory of existing programs developed and gaps identified 2. Community risk management programs based on formal hazard analysis 3. The Local Risk Reduction Fund is supporting community risk reduction efforts	UNOPS DRR UNOPS
Expand Preparedness Programs across a broad range of hazards	Research, Information and Management	Dhaka and selected cities	1. Urban search and rescue pilot for Dhaka fire services based on earthquake threat 2. Establishing an integrated approach to climate change risk management at national and local levels	MDMR/Fire Service MoEF/ DoE
Operationalizing Response Systems	Response Management	Whole country	1. Upgrading the capacity in information management during normal and emergency periods 2. Regional networks strengthened 3. Timely deployment of resources 4. Operational response capacities strengthened	MDMR

Table 1. Sub-programs, outputs, target area/group and implementing agencies of CDMP. Adapted from [19].

The Corporate Plan (2005-09; 2010-14) acknowledged the need for pre-disaster mitigation and preparedness of the people as opposed to the earlier concepts of responding after a disaster had taken place. Priority was accorded to focus on community-level preparedness, response, recovery and rehabilitation. Programs to train people living in disaster-prone areas were emphasized to improve their capability to cope with natural disasters. The Corporate Plan emphasized a series of broad-based strategies: First, disaster management involved the *management of both risks and consequences* of disasters, which included prevention, emergency response and post-disaster recovery. Second, *community involvement* was a major focus for preparedness programs to protect lives and properties. The involvement of local government bodies was an essential part of the strategy. Self-reliance was the key for preparedness, response and recovery. Third, *non-structural mitigation measures*, such as community disaster preparedness, training, advocacy and public awareness, were given a high priority; this required the integration of structural mitigation with non-structural measures.

The strategic focus of the CDMP was to lay the foundation for the shift in principle from a post-disaster relief and response strategy towards a comprehensive risk minimization culture that encouraged disaster-resilience initiatives. This approach was to be realized through a series of interconnected strategic directives:

1. Raising the level of expertise of the disaster management systems,
2. Mainstreaming disaster risk management programming,
3. Strengthening community institutional mechanisms,
4. Expanding preparedness programs across a broad range of hazards, and
5. Putting the response systems into operation.

Based on these directives, the major sub-programs of CDMP included: (1) Capacity-building, (2) Partnership Development, (3) Community Empowerment, (4) Research and Information Management, and (5) Response Management. Under the sub-program of *Partnership Development*, the government actively sought to achieve a multi-agency approach that encompassed the institutions of the government, NGOs and private sector in a collaborative strategy for the alleviation of disaster-induced poverty. This enhanced co-ordination and information-sharing among the various actors and thus maximized the efficacy of resource use for effective risk reduction. Under the *Community Empowerment* sub-program, the government planned to further consolidate the empowerment process by expanding the program and by realizing community capacity-building through awareness and skill development and by expanding disaster management studies within the school system and staff training academies.

Besides these, disaster risk reduction was incorporated as a component into the Poverty Reduction Strategy Paper (PRSP) of Bangladesh as Annex-9 of Disaster Vulnerability and Risk Management [14]. The preparation of the PRSP, funded by the World Bank, acknowledged a holistic approach to disaster management.

4. Shift from relief and response to disaster risk management

In the last few decades, disasters have typically been viewed by the public institutions as numerous individual extreme events, and the responses included top-down-oriented government policies and efforts by local and international relief agencies that did not take into simultaneous account the social and economic implications and causes of these events. With the significant advancement in the understanding of the natural processes that underlie the hazardous events, a more technocratic paradigm came into existence which conceded that the only way to deal with disasters was by the public policy application of geophysical and engineering knowledge and the associated interventions. These approaches treated disasters as exceptional or "abnormal" events, not related to the ongoing social and developmental processes. Gradually, with recognition of the fact that these are not "natural events" per se, but directly linked with social structures and their dynamics [20], this structural engineering, technocratic approach shifted to an emphasis on preparedness measures, such as stockpiling of relief goods, preparedness plans and a growing role for relief agencies such as the Red Crescent [21]. This evolution of public policy approach from "relief and response" to "risk management" has begun to influence the way disaster management programs are planned and financed. Initiatives have been aimed more and more at reducing social and economic vulnerability and at investing in long-term mitigation activities.

Community-Based Disaster Management (CBDM)

Recognizing the need for vulnerability reduction for effective disaster management, the failures of a top-down management approach have become evident. This approach has been unsuccessful in addressing the needs of vulnerable communities. A better understanding of disasters and losses also brings to light the fact that the increased occurrence of disasters and disaster-related loss has been due to the exponential increase in the occurrence of small- and medium-scale disasters. As a result, numerous scholars and stakeholders feel that it is important to adopt a new strategy that directly involves vulnerable people in the planning and implementation of mitigation, preparedness, response, and recovery measures. This bottom-up approach has received wide acceptance because it considers communities as the best judges of their own vulnerability and capable of making the best decisions regarding their well-being. The search for the newer approach led to the formulation of the Community-Based Disaster Management (CBDM) strategy.

The aim of CBDM is to reduce vulnerabilities and to strengthen people's capacity to deal with hazards and cope with disasters. A thorough assessment of a community's exposure to hazards and an analysis of their specific vulnerabilities and capacities is the basis for activities, projects and programs that can reduce disaster risks. Because a community is involved in the whole process, their real and felt needs, as well as their inherent resources, are considered. Therefore, there is a greater likelihood that problems will be addressed with appropriate interventions. People's participation is not only focused on processes but also on the contents. It is anticipated that the local community should be able to gain directly from improved disaster risk management. This in turn will contribute to a progression toward safer conditions and to the improved security of livelihoods and sustainable development. This underlines the point that the local community is not only the primary actor but also the beneficiary of the risk reduction and development process [21].

The implementation of CBDM requires consideration of many essential features. Following Yodmani (2001), [21], the primary ones could be identified as:

a. The local community has a central role in long-term and short-term disaster management and therefore the focus of attention in disaster management must be on the local community.

b. Disaster risk or vulnerability reduction is the foundation of CBDM; the primary content of disaster management activities revolves around reducing vulnerable conditions and the root causes of vulnerability. The primary strategy for vulnerability reduction is by increasing a community's capacities and their resources, and by improving and strengthening coping strategies.

c. Disaster management must also establish linkages to the development process as disasters are viewed as unmanaged development risks and unresolved problems of the development process. CBDM should lead to a general improvement of the quality of life of the vast majority of the poor people and of the natural environment.

d. CBDM contributes to people's empowerment – to possess physical safety; to have more access to, and control of, resources; to participate in decision-making which affects their lives; to enjoy the benefits of a healthy environment.

e. As community is a key resource in disaster risk reduction, their role and interests must be recognized. The community is the key actor as well as the primary beneficiary of disaster risk reduction. Within the community, priority attention is given to the conditions of the most vulnerable, as well as to their mobilization in the disaster risk reduction. The community must directly participate in the whole process of disaster risk management -- from situational analysis to planning and to implementation.

f. A multi-sectoral and multi-disciplinary and trans-disciplinary approach must be applied. CBDM brings together the multitude of community stakeholders for disaster risk reduction, as well as to expand their resource base. The local community-level institutions link up with the intermediate and national levels and even up to the international level to address the complexity of vulnerability issues. A wide range of approaches to disaster risk reduction is employed.

g. The CBDM is an involving and dynamic framework, and therefore its implementation must be monitored, evaluated and adapted to incorporate newer elements. Lessons learned from practice continue to build into the theory of CBDM. The sharing of experiences, methodologies and tools by communities and CBDM practitioners continues to enrich practice.

5. Is the present framework based on a partnership approach?

As is evident from the institutional structure explained above, Bangladesh has developed quite an elaborate framework and disaster preparedness and response mechanism. Moreover, some policy and plan pronouncements in the recent past indicate that the government has begun to adopt an approach to disaster management that includes both risks and consequences. Some progress has been made in enhancing the disaster management capacities during the last decades. After the experiences of the devastating 1988 floods and 1991 cyclone, the concept of *disaster management* was introduced in place of *disaster control*. The ministry was renamed the Ministry of Disaster Management and Relief (MoDMR) in 1993 and then again renamed the Ministry of Food and Disaster Management (MoFDM) in 2002. After the formation a new government in 2008, this name of this ministry went back to its previous title as the Ministry of Disaster Management and Relief (MoDMR).

The primary function associated with disaster management is outlined in the government's Rules of Business which are undertaken by the DMB and the DRR. The Rules of Business have been revised to reflect the current MoDMR approach of comprehensive, community-based vulnerability reduction and risk management. The result is that though there has been a declining trend in loss of lives and property, particularly from cyclone disasters, flood damage has tended to rise because of the large spatial extent of floods, their increased frequency and the expanding economy.

Government documents and the NGO literature indicate that there is a wide recognition that effective disaster response at the local level is not possible by government agencies alone and that the cost of management needs to be shared by all stakeholders. Still, the major lacuna in the institutional framework continues to be a lack of functioning partnerships among the stakeholders. The massive flood of July 2004 showed that there were no partnerships functioning and there was little coordination. The Local Consultative Group (LCG) concluded that massive shortcomings existed in the forecasting, preparedness and coordinated response to the crisis [22]. As a result, the NGOs conducted relief and rehabilitation efforts largely without government directives and coordination. Initially, the government appeared confident to deal with the post-disaster recovery singlehandedly. When things were getting worse, it made a flash appeal on 17 August 2004 through the UNDP, Dhaka, for international assistance. Another report argues about the handling of 1998 floods, indicating that "limited evidence of government coordination was found in the recovery phase" [23]. Save the Children (USA) also proclaimed that "there was a general lack of coordination among actors" [24]. In the wake of the latest cyclone, Sidr in 2007, BBC reported, "Plenty of agencies, but not enough aid - too little, too late," and further quoted a professional working in an affected area, "The reason why these people are not receiving enough help is because there is no coordination between the government and aid agencies" [25].

A striking example of poor management and coordination is the following case. Southkhali village in Shoronkhola *upazila* of Bagerhat district was one the worst hit areas in Sidr. During a visit immediately after the event to the area, the Indian foreign minister pledged his country's intention to build all the houses in this and the surrounding villages. From then onwards, nominal government initiative was taken to give shelters to the affected people in this area, and a virtual official ban was put into effect on others, including NGOs and aid agencies, to build houses for the affected people. The pledged Indian support did not come in due time and even 100 days after the event people in this area were forced to live under the sky [26]. Perhaps this unfortunate decision arose from the lack of international/bilateral coordination, bureaucracy on both sides in Bangladesh and India, a lack of understanding of the gravity of not giving shelter to victims in time, or from the unnecessary exercise of power on the administration's part, even when in distress.

5.1. Empirical Investigation of Cyclone Sidr Victims at the Local Level: Vulnerability of the Poor

It is worth noting that the recent initiatives on community-based disaster risk management became subject to stern criticisms because of their general inadequacy in addressing the vulnerability of the poor to natural hazards and socioeconomic shocks. CBDM programs that aim at prevention and mitigation are few in low- and middle-income countries like Bangladesh and they are poorly funded and insignificant when compared to the financial capital spent by donors and development banks on humanitarian assistance, relief and post-disaster reconstruction. Another weakness of such initiatives was that they were often taken up in the formal sector of the economy, and therein bypassed the poor and the most vulnerable sections of society. As Maskrey (p. 86) points out, "in the year or so between the occurrence of a disaster and approved national reconstruction plans, many vulnerable communities revert to coping with risk, often in the same or worse conditions than before the disaster actually struck" [27]. Therefore, in the current paradigm of risk management approaches, there is more room than ever before for addressing the issues of risk reduction for the poor. This is also consonant with the paradigm shift in mainstream development practice, which is now characterized by a focus on good governance, accountability and greater emphasis on bottom-up approaches [21]. In light of the above perspective, the case of Cyclone Sidr can be examined.

Bangladesh has experienced several catastrophic environmental disasters during the last two decades; among these events, the April 1991 [28] and November 2007 major cyclones were the most catastrophic in terms of both physical and human dimensions [29]. Cyclone Sidr struck the coast of Bangladesh on 15 November 2007 and was the most powerful mega-cyclone to impact Bangladesh since 1991. However, the death toll (officially, 3,406 lives were lost) caused by Cyclone Sidr was significantly lower than comparable cyclones in previous years due to the improved warning system and evacuation. Nonetheless, the damage to crops and infrastructure was considerable across 30 districts, 200 *upazilas* and 1,950 unions. In total, more than 55,000 people were injured by the Cyclone Sidr event. The Joint Damage, Loss, and Needs Assessment (JDNLA) committee estimated that the total damage and losses caused by the cyclone were more than US $1.7 billion [30].

Our investigation along the coastal plains of Bangladesh revealed that the geographical location and patterns of settlement associated with low income populations were the most important determinants of vulnerability to tropical cyclones and related storm surges. Coastal and island people observed that the new, isolated, single-unit settlements were the most severely impacted by the cyclone and storm surge forces. The settlements near the coast and those which were in linear patterns along the coastal embankment suffered the most. This type of settlement, which was more susceptible to cyclonic storm surges, was inhabited primarily by the poor of the coastal zones. The fragmentation of families and the building of new settlements also contributed to high cyclone disaster loss. The soil of the new settlements was less cohesive, and in most cases, the properties had few or only very small trees. The houses of the linear settlements along the coastal and island embankment were made of straw, bamboo and other locally sourced materials. Apart from high winds and storm surges, these houses were also vulnerable to breaches of the embankment that occur in major cyclonic storms. In our survey, we registered that most of the houses constructed using straw, bamboo, jute stalk, and corrugated iron sheets alongside of the coastal embankment had faced the sea. Such positioning of the housing structures also made them more susceptible to severe damage by the cyclones. In contrast, houses located in the interior mainland were usually clustered in groups of six or seven houses called *Baris* in dense tropical forest. Several closely located *Baris* comprise a *Samaj*. This type of settlement is less susceptible to severe cyclonic wind and storm surges.

Landless families tend to occupy coastal embankments illegally, as there are no public housing or welfare programs in Bangladesh for the landless. The respondents of our survey asserted that because of easy access to both land areas and the sea, they preferred to live on the embankment despite the well-known risks related to both illegal settlement and tropical cyclones (Figure 2).

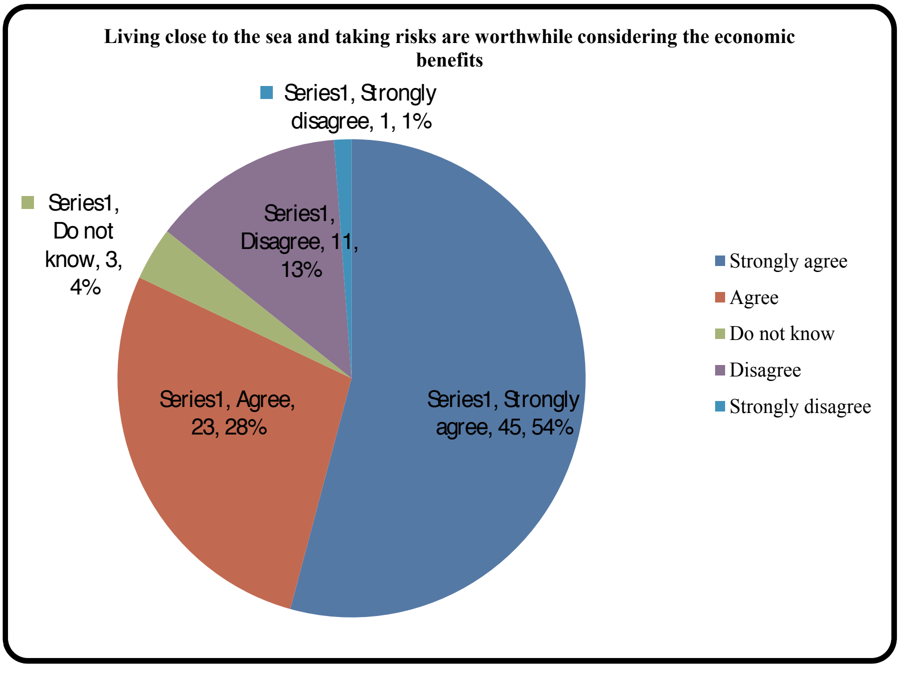

Figure 2. Consideration of villagers living close to the sea

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5.2. Cyclone preparedness at the local level

Cyclone preparedness programs that have been implemented in recent years in the coastal zones of Bangladesh have involved both non-structural and structural measures. Appropriate cyclone preparedness training and enhancement of awareness by campaigns and public education have been major tools for building a well-prepared and cyclone-resilient community. Our field investigation revealed that only 31% of the local community members have received cyclone preparedness training during non-cyclone periods. Such training was chiefly provided by the non-governmental organizations (NGOs) that were locally active (30% of the local community members received training from them); national and local government initiatives in this regard were nominal (only 1% received training from them) (Figure 3).

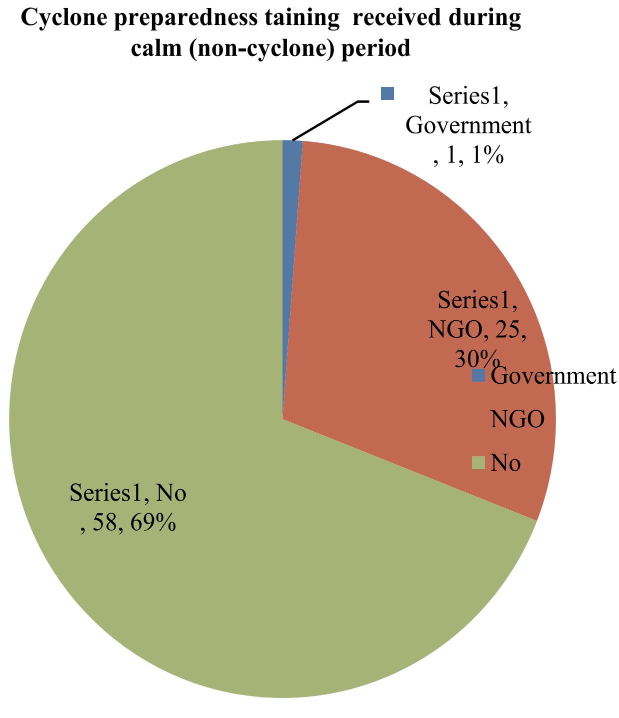

Figure 3. Training on cyclone preparedness

Among the structural engineering measures, the construction of cyclone shelters and raised mounds (locally known as *killa*) to provide refuge during the onset of cyclones were the principal ones. The expansion of coastal embankments and reforestation programs to protect settlements and properties from cyclone gusts and storm surges along the coast and estuary channels were among other significant structural measures. The majority (59%) of the community members took refuge in the designated cyclone shelters or in the masonry buildings of neighbors, friends, and relatives during the onset of Cyclone Sidr. About 41% stayed in their homes and opted not to go the cyclone shelters. Such behavior was attributed either to a strong belief that their lives were in the hands of *Allah* (i.e., strong presence of fatalism), a desire to save property from potential looting, the considerable distance of the shelters from their houses, or the unavailability of cyclone shelters in their locality.

The degree of variation in the number of people who took refuge per cyclone shelter among the localities was significant. Our field research calculated that there were 34 cyclone shelters for 631,138 people (according to the 2001 population census) in the Burguna Sadar *upazila*, under Burguna district, implying that each cyclone shelter would need to provide refuge to 18,563 people. In Kalapara *upazila*, under Patuakhali district, there were 113 cyclone shelters for 202,078 people, implying that each shelter would need to accommodate 1,788 people during the onset of a cyclone. Our exploration into why a considerable population did not use cyclone shelters during Cyclone Sidr provided a number of explanations. All cyclone shelters were being used as civic facilities (such as primary schools or community centers) during the non-cyclonic periods but lacked adequate drinking water supply infrastructure and toilets. A total of 87% of the cyclone shelter users identified low sanitation and inadequate drinking water facilities as major constraints to using these shelters. They also opined that low physical capacity (79%) and difficulty in maintaining privacy (47%) were other major problems in using the shelters (Table 2). The poor dispersion of cyclone shelters and the lack of road access were other major concerns about the cyclone shelters. The degree of satisfaction about the cyclone shelters was very low among the local community members (only 6% were satisfied). The examination of the use pattern of cyclone shelters at the local level revealed that although cyclone shelters saved many lives during Cyclone Sidr, many local people opted not to use them or they were simply unavailable in some localities. Clearly, these cyclone preparedness and mitigation measures are testimony of institutional partnerships at various levels of governance and public services.

Factors	Respondents (%) (n= 162)
Inadequate sanitation and drinking water facilities	87
Inadequate physical capacity	79
Hard to maintain privacy	47
Fragile structure	43
Unhygienic conditions	24
Absence of access road	14
Situated in a distant place	12
Do not know	5

Table 2. Problems in using cyclone shelters. Source: Field survey

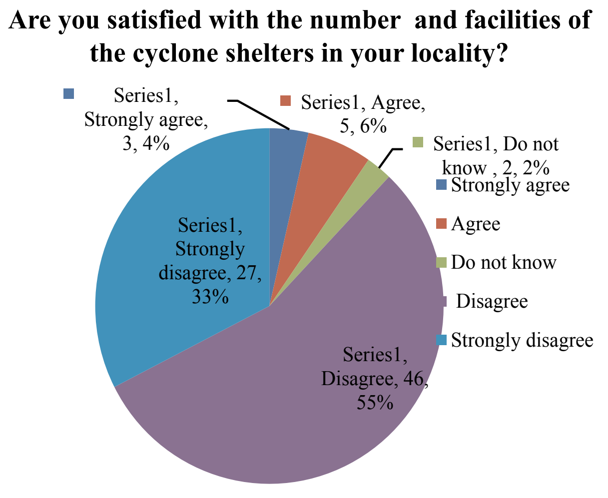

Figure 4. People's response on cyclone shelters and facilities

Over the last four decades, the Water Development Board, in collaboration with other ministries, has constructed about 5,333 km of embankments in the coastal districts to support agriculture and protect the lives and property of coastal residents during cyclones and storm surges. Reducing vulnerability via these structural measures has been quite effective in coastal Bangladesh. There is clear evidence that these embankments along the coastal areas provided an effective buffer during the storm surge associated with Cyclone Sidr. Lives were saved, and damages and property losses were much lower where embankment structures had been properly maintained. Some embankments did not fail even when the storm surge overtopped them. More than 90% of our survey respondents observed that coastal embankments had saved their lives and property from Cyclone Sidr. They also registered that coastal plantations were another major living structural feature that reduced the velocity of the wind and the speed of tidal surges along with the cyclone and, in turn, saved their lives and properties.

6. Conclusions

The findings of our study reveal that, officially and legislatively, the government of Bangladesh in recent years has taken a comprehensive and integrated approach to disaster management. Both preparedness and response capacity have increased as a result. However, in the absence of stable and transparent institutions, this strong institutional partnership approach remains largely on paper. Individual stakeholders continue to make significant contributions, but synergy and multiplier effects are still missing. Our analysis shows that no, or only a very limited, culture of partnership in disaster management has yet been established. Divisive partisan politics and the lack of good governance prevent partnerships among stakeholders.

Therefore, in the following section we propose a partnership framework that outlines new roles and responsibilities for major players. Implementation of the framework could lead to partnership in disaster management in Bangladesh. Government agencies, NGOs and policymakers need to understand the perspectives of local communities, the impacts of floods, and the levels of vulnerability to improve information, knowledge, resource support and services. For this, there is a need for more "action research" involving communities and scientists from different disciplines and greater awareness about the integration of floods, cyclones and other natural disasters and climatic events into the development process among key actors, particularly, government agencies.

Disaster management is a nationwide affair, involving each and every organization and citizen of the country. The government of any country cannot do it alone because of the resource constraints as well as the wide scope of the tasks involved. Therefore, a broad-based partnership involving all the stakeholders is a desirable and realistic approach to realizing the full potential at all stages of disaster management, namely, prevention, preparedness, response and recovery [31]. Experience that demonstrates the value of partnership in managing disasters is grounded in the mutual recognition of many different ideas and interests. The constituencies or interests associated with this partnership include the stakeholders, such as government ministries/agencies, National Parliament and the Parliamentary Standing Committee on Disaster Management, NGOs/CBOs, the private sector, the media, academia, donors and regional countries (Figure 5). The approach, involving multi-modal communication and interaction, proposes to integrate the activities of different stakeholders into a functional partnership framework. This outline describes how each stakeholder can be a loop in an integrated chain.

Ministry of Disaster Management and Relief (MoDMR)

This organization, directly supported by DMB and DRR, remains the pivot and is destined to channel and coordinate all communications and activities between and among all the partners in the loop. This coordinated process, particularly during non-crisis periods, is expected to result in the shift of focus from post-disaster to pre-disaster risk management. However, the MoDMR must ensure the transparency of its own and all other agencies involved in developing the partnership for disaster management. Public disclosure and documentation should be mandatory for all the stakeholders and must be published by this pivotal agency on a regular basis. The ultimate goal of the partnership is to enhance the investment and social capital for community empowerment against disaster risks.

From a partnership point of view, the following measures need to be initiated by the MoDMR:

1. Adoption of a comprehensive national disaster management policy, with clear guidelines for an effective partnership of all stakeholders.

2. Coordination of the functions of disaster management and climate change communities; this is likely to help integrate prevention with preparedness, response and recovery efforts, in both short-term and long-term perspectives; CDMP appears to be beginning in the right direction.

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3. Strengthening the capacity of the MoFDM and other disaster management-related agencies and committees at all levels, with particular emphasis on the district-level disaster management committees (DDMC). Each of the DDMC in the risk-prone areas can be equipped with a Geographic Information System (GIS) Cell as a planning tool for managing development and disaster reduction activities.

4. Large-scale training of staff at all levels, including the stakeholders, particularly from the media, NGOs and private sector, in team and motivational works and in how to prevent disasters; for the purpose, a Disaster Management Training Cell can be established at the DMB.

5. Activating the Disaster Management Committees (DMC) at all levels, including the national ones, through organizing meetings at regular intervals.

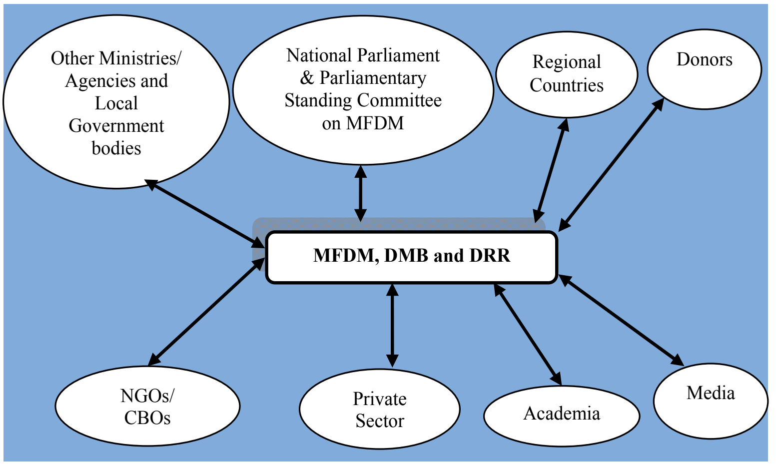

Figure 5. Proposed partnership framework for disaster management in Bangladesh

1. Strengthening the project monitoring and evaluation capacities at all levels, with the involvement of local stakeholders; the establishment of broad-based and inclusive monitoring and evaluation committees for projects will ensure transparency, accountability and therefore the delivery of intended results.

2. Decentralization of not only responsibilities, but also decision-making power, to DDMCs, led by the local governments with sufficient financial resources and autonomy.

3. Establishment of small teams at all levels of DMCs to better coordinate and integrate disaster management planning and activities from the national to local levels.

4. Finally, developing a network among the GOs, NGOs, researchers, academics, journalists and other professionals in order to enlist their potential roles and contributions in mitigating disaster-related problems. The MoDMR can act as the coordinating agency for building up this network.

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Chapter 3

Hazard Mitigation Planning in the United States: Historical Perspectives, Cultural Influences, and Current Challenges

Andrea M. Jackman and Mario G. Beruvides

Additional information is available at the end of the chapter

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1. Introduction

Planning for disasters at the federal, state, and local level is a relatively recent area of focus within the practice of emergency management in the United States. Historically, emergency management as a practice was focused on response to a disaster, with little attention paid to preparation, recovery, or overall and ongoing activities to reduce the effects of disasters. The theoretical framework and literature demonstrates the importance of planning as an activity which impacts the success of many other emergency management activities, yet practice has shown that planning is not always a valued or highly prioritized practice at the local level. The Disaster Mitigation Act of 2000 marked the first legislative emphasis on planning and mitigation and recent studies by the authors have shown mixed results for the implementation of planning laws. This chapter reviews in detail the historical developments in the theory and practice of planning with special emphasis on hazard mitigation planning; provides a theoretical framework based on the literature for understanding the importance of local level planning within the national system of emergency management, and the complexity that arises within that system; and discusses ongoing challenges in the successful completion of planning activities in the 21st century due to ongoing administrative and cultural challenges.

2. Hazard mitigation before and during the cold war

Understanding hazard mitigation in the United States first requires an understanding of how emergency management activities evolved historically. E. L. Quarantelli, one of the leaders in disaster sociology, described the beginnings of disaster research as "almost exclusively supported by the U.S.A. military organizations with very practical concerns about wartime situations" [1]. He notes that these "organized research activities [occurred] from about 1950 to 1965" and their primary goals were civil organization in wartime situations, under the assumption that "morale is the key to disaster control," and "effective disaster control includes the securing of conformity to emergency regulations" and "the reduction and control of panic reactions" [1]. The federal government took further action during the 1950s by undergoing several reorganizations within the Department of Defense (see [2]). Prior to, and during that time, the federal government was mainly concerned with civil defense, so that "private, voluntary agencies such as the American National Red Cross, the Salvation Army, and many others bore the primary responsibility for disaster relief; and state and local governments coped as best they could" [2]. Federal assistance was available as an absolute last resort by way of "special assistance acts passed by Congress" [2]. However this system had been operating essentially without change since 1803, and due to its reactive nature, there were "frequent delays before federal assistance reached impacted areas, and the nature of the assistance was designated only for selected purposes" [2].

Two interesting notes about the observations in [1] and [2]: first, the basis of government activity in emergency management emerged from a military and national defense perspective. The first "emergencies" in this regard were wars, or attacks from outside invaders. This militaristic approach – managing a disaster as enemy attack – would shape emergency management significantly in later years. Second, governmental activities in early years were largely reactive. Planning, particularly with an emphasis on mitigation, is not mentioned. A reactive war approach may seem antiquated outside of the Cold War context, but it is essential to understanding the development and decisions of current sentiments toward planning within local governments. As will be discussed in later sections, the defense mentality is still the dominant approach to loss prevention at the local level, and helps explain actions at all levels of government, in all modern aspects of emergency management.

3. The four phases of emergency management

In 1979, a report by the National Governor's Association was published on the topic of emergency management, and defined the general practice as:

A state's responsibility and capability for managing all types of emergencies and disasters by coordinating the actions of numerous agencies. The comprehensive aspect of [emergency management] includes all four phases of disaster or emergency activity: mitigation, preparedness, response, and recovery. It applies to all risks: attack, man-made, and natural, in a federal-state-local partnership (see Table 1).

The four phases listed- mitigation, preparedness, response, and recovery- serve as the current model of emergency management, are widely used among practitioners, and are considered the starting point for all policy and program design for all types of hazards at all levels of government. The NGA Report included only suggested actions for each phase, which were not operationally defined until 1985:

1. Mitigation- assessing the risk posed by a hazard or potential disaster and attempting to reduce the risk;
2. Preparedness- developing a response plan based upon the risk assessment, training response personnel, arranging for necessary resources, making arrangements with other jurisdictions for sharing of resources, clarifying jurisdictional responsibilities, and so on;
3. Response- implementing the plan, reducing the potential for secondary damage, and preparing for the recovery phase; and
4. Recovery- reestablishing life support systems, such as repairing electrical power networks, and providing temporary housing, food, and clothing. Recovery is assumed to stop short of reconstruction. [3]

In the years following the development of the NGA model, a number of scientific studies (summarized in Table 1) sought to define each phase in more detail. These definitions are still widely used today.

Author	Preparedness	Response	Recovery	Mitigation
NGA Report, 1979 [4]	Developing a response plan and training first responders to save lives and reduce disaster damage, including the identification of critical resources and the development of necessary agreements between responding agencies	Providing emergency aid and assistance, reducing the probability of secondary damage, and minimizing problems for recovery operations.	Providing immediate support during the early recovery period necessary to return vital life support systems to minimum operation levels, and continuing to provide support until the community returns to normal.	Deciding what to do where a risk to the health, safety, and welfare of society has been determined to exist; and implementing a risk reductive program
Petak, 1985 [3]	[D]eveloping a response plan based upon the risk assessment, training response personnel, arranging for necessary resources, making arrangements with other jurisdictions for sharing of resources, clarifying jurisdictional responsibilities, and so on.	Implementing the plan, reducing the potential for secondary damage, and preparing for the recovery phase	Reestablishing life support systems, such as repairing electrical power networks, and providing temporary housing, food, and clothing	Assessing the risk posed by a hazard or potential disaster and attempting to reduce the risk

Author	Preparedness	Response	Recovery	Mitigation
Comfort, 1985 [5]	Cities should review, exercise, and update their plans regularly based on staffing and past performance. Counties and states may review summarized local plans to identify resource needs and coordinate multijurisdictional exercises. FEMA may review state plans and adjust resources accordingly, as well as facilitate coordination between states.	Hierarchy proceeds from city, to county, to state, to federal. At the local level, responders make regular reports on status of life and property, assistance requests, at regular intervals. County, state, and federal designate aid, collect and analyze reports, summarize for next highest level and continue until basic systems are restored.	Assess damage and formulate short-term and long-term goals for rebuilding, including costs, needed equipment, and aid opportunities; ask for public input and improve rebuilt structures where possible; create schedule. All levels except city should identify and implement opportunities for inter-jurisdictional aid.	Conduct annual risk & vulnerability assessment with public involvement. Identify and formulate mitigation goals, and assign to appropriate agencies. County, state, and federal offices should monitor incoming reports and progress, allocate necessary resources, identify opportunities for inter-jurisdictional cooperation, and report to the next highest level.
Waugh, 1990 [6]	Activities that develop operational capabilities for responding to an emergency (e.g. emergency operations plans, warning systems, emergency operations centers, emergency communications networks, emergency public information, mutual agreements, resource management plans, and training and exercises for emergency personnel	Activities taken immediately before, during, or directly after an emergency that save lives, minimize property damage, or improve recovery; e.g., emergency management plan activation, activation of emergency systems, emergency instructions to the public, emergency medical assistance, manning EOCs, reception and care, shelter and evacuation, search and rescue	Short-term activities that restore vital life support systems to minimum operating standards and long-term activities that return life to normal; e.g., debris clearance, contamination control, disaster unemployment assistance, temporary housing, and facility restoration.	Activities that reduce the degree of long-term risk to human life and property from natural and man-made hazards, e.g., building codes, disaster insurance, land-use management, risk mapping, safety codes, and tax incentives and discentives.
FEMA, 2012 [7]	Actions that involve a combination of planning, resources, training, exercising, and organizing to build, sustain, and improve operational capabilities. Preparedness is the process of identifying the personnel, training, and equipment needed for a wide range of potential incidents, and developing jurisdiction-specific plans for delivering capabilities when needed for an incident.	Immediate actions to save lives, protect property and the environment, and meet basic human needs. Response also includes the execution of emergency plans and actions to support short-term recovery.	The development, coordination, and execution of service- and site-restoration plans; the reconstitution of government operations and services; individual, private-sector, nongovernmental, and public-assistance [housing and restoration] programs; long-term care and treatment of affected persons; [social, political, environmental, and economic restoration]; [identification of] lessons learned; postincident reporting; and development of [mitigation]initiatives	Activities providing a critical foundation in the effort to reduce the loss of life and property from natural and/or manmade disasters by avoiding or lessening the impact of a disaster and providing value to the public by creating safer communities… [F]ix the cycle of disaster damage, reconstruction, and repeated damage. These activities or actions… will have a long-term sustained effect.

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Author	Preparedness	Response	Recovery	Mitigation
Summary	*Threat assessment (TA) *Resource assessment & acquisition (RA&A) *Inter and intra-jurisdictional cooperation *Drills & Exercises (D&E) *Writing a plan (Plan)	*Activation of Emergency Protocol (AEP) *Medical assistance and first aid (EMS) *Shelter & Evacuation (S&E) *Search & Rescue (S&R) *Secondary Damage Reduction (SDR)	*Damage Assessment (DA) *Clean-up (De-con) *Restoration of critical systems & facilities (Restor) *Providing temporary basic needs (TBN) *Basic reconstruction (Recon I)	*Improved reconstruction (Recon II) *Legislative planning (LP) *Regularly scheduled vulnerability & risk assessments (VRA)

Table 1. Four Phase Model Definitions

The four phases are widely considered to be overlapping and cyclical (Figure 1). Mitigation activities occur in all phases of a disaster, and frequently are most evident during reconstruction, which has since been informally added by practitioners as a part of the long-term recovery phase. The ongoing, ubiquitous nature of mitigation activities makes this the hardest phase to clearly define with a beginning and end point. As reconstruction and recovery near completion, lessons learned from these phases are incorporated into preparedness activities with additional mitigation in mind, which in turn are set aside when a response becomes necessary. Hazard Mitigation Plans are easiest to study within the context of the Planning phase, instead of Mitigation. According to the federal policy described later, mitigation, recovery and even some response activities are directed by state and local Hazard Mitigation Plans. Although risk assessment, defined here to be part of the mitigation, is a critical step in authoring a HMP, the entire process will be grouped into the Preparedness phase for simplicity. This is also due to the complex nature of risk assessment as a separate activity, and a tolerance for imprecision in the HMP approval process. Within the context of the Four Phase model, Preparedness, and specifically plan creation, at each level of government is described in the next section.

3.1. Planning for disaster in federal, state, and local government

The role of local-level emergency planning within the national emergency management framework is one of great importance. Federal government provides direction and goals for local planners, but primarily serves as a financial supporter when governments are unable to meet these goals. Likewise, the state acts as a regional conduit between federal and local government, providing aid to its local jurisdictions as needed. This concept, known as shared governance, is a reflection of American attitudes about self-governance. In their book exploring policy implementation issues within the federal government, May and Williams [8] cited, as an example of this mindset, the Elementary and Secondary Education Act of 1965, which marked the first time in U.S. history that the federal government assumed a direct funding role in public education. Although American government was deliberately designed in this fashion, it can cause a dilemma:

On the one hand, federal officials have a strong stake in promoting hazard mitigation and preparedness but little direct control over the effectiveness of such efforts. On the other hand, in the aggregate, sub-national governments and individuals owning property in hazardous areas directly control the effectiveness of mitigation and preparedness policies, but for the most part actions consistent with such policies are low on their list of priorities. [8]

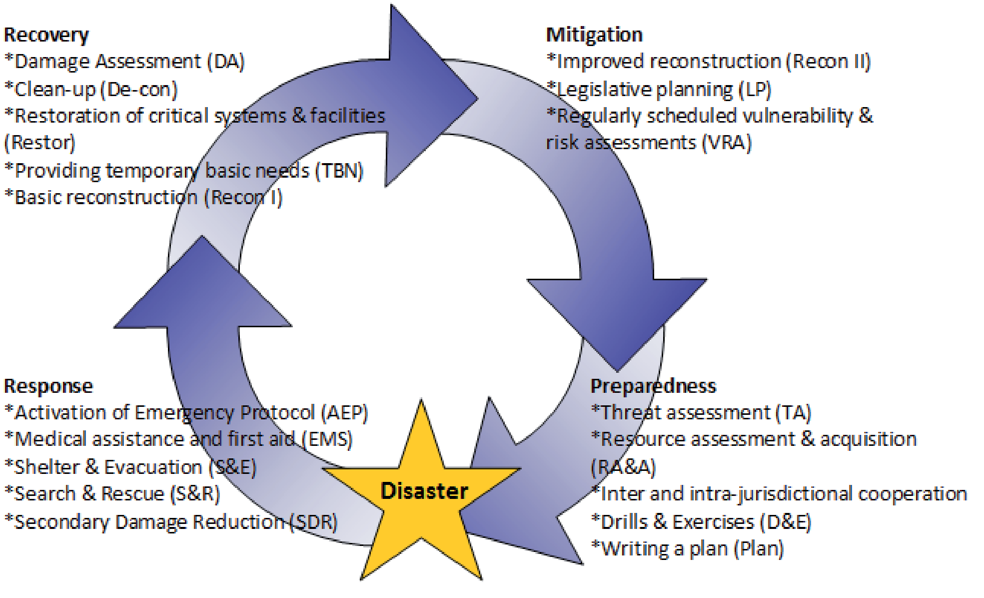

Figure 1. The cyclic nature of the Four Phase Model

In the following sections, emergency planning at each phase of government will be discussed, with particular emphasis on local response to the recent federal demands for Hazard Mitigation Plans.

3.2. What is a hazard mitigation plan?

Before discussing how Hazard Mitigation Plans are completed within the government, it is worth briefly considering: what exactly is a Hazard Mitigation Plan? The Disaster Mitigation Act of 2000 [9] only lists two requirements for local mitigation plans, stating that the plans "shall (1) describe actions to mitigate hazards, risks, and vulnerabilities identified under the plan; and (2) establish a strategy to implement those actions" [P.L. 106-390 § 322(b)]. FEMA's Interim Final Rule (The Rule) provides much more specific requirements based on these guidelines. In summary, a Hazard Mitigation Plan must include:

1. Documentation of the planning process;

2. A risk assessment, including: (i) a description of the type, location, and extent of all natural hazards that can affect the jurisdiction, including previous occurrences and (ii) a description of the jurisdictions vulnerability to the hazards. Vulnerability should be described in terms of: (A) types and numbers of existing infrastructure, (B) an estimate of potential dollar losses to vulnerable structures, and (C) a description of land uses and development trends. (iii) "For multi-jurisdictional plans, the risk assessment section must assess each jurisdiction's risks where they vary from the risks facing the entire planning area."

3. A mitigation strategy, including: (i) long-term mitigation goals, (ii) a description of specific actions for new and existing structures, and (iii) an action plan for how the above will be implemented, prioritized by cost-benefit analysis.

4. A plan maintenance process, including: (i) a description of maintenance for the plan on a five-year cycle, (ii) a process, if possible, to incorporate mitigation efforts into other aspects of local planning, and (iii) a discussion on continuing public maintenance of the plan.

5. Documentation that the plan has been formally adopted by all participating jurisdictions [44 CFR 201.6(c)].

Because the legal style of The Rule can be tedious and lacking examples, FEMA published a series of how-to guides for state and local mitigation planning [10]. The first four guides listed are considered the "Core Four" of HMPs, with the remaining guides available for those jurisdictions as applicable:

1. Getting started with the mitigation planning process, including important considerations for how you can organize your efforts to develop an effective mitigation plan (FEMA 386-1);

2. Identifying hazards and assessing losses to your community, State, or Tribe (FEMA 386-2);

3. Setting mitigation priorities and goals for your community, State, or Tribe and writing the plan (FEMA 386-3);

4. Implementing the mitigation plan, including project funding and maintaining a dynamic plan that changes to meet new developments (FEMA 386-4);

5. Evaluating potential mitigation actions through the use of benefit-cost review (FEMA 386-5);

6. Incorporating special considerations into hazard mitigation planning for historic properties and cultural resources, the topic of this how-to guide (FEMA 386-6);

7. Incorporating mitigation considerations for manmade hazards into hazard mitigation planning (FEMA 386-7);

8. Multi-Jurisdictional Mitigation Planning (FEMA 386-8); and

9. Finding and securing technical and financial resources for mitigation planning (FEMA 386-9).

All of the guides have a similar format of listing the specific subsection of The Rule, and then provide an explanation, a list of required activities, recommended activities, and examples for how to implement the specific part of The Rule in a clear, non-legal style.

The eighth volume of the How-To Guide, published in 2006 (386-8), is titled "Multi-Jurisdictional Mitigation Planning" and provides guidelines for this specific type of local plan authorship. Although there are many ways to organize a multi-jurisdictional plan, the guide recommends a specific structure to follow; the common portion of the plan may include the "process, common hazards, general mitigation goals, collaborative actions, and [plan] maintenance [schedule]." The items unique to each participating jurisdiction that may be included are: "geographically specific hazards, risks, specific [mitigation] goals, actions, participation, and adoption" [10]. In other words, the number of activities for which the costs would fall exclusively to a single jurisdiction has already been reduced.

If a plan is to be submitted as a multi-jurisdictional HMP, 386-8 provides specific requirements that must be met at each stage of the process. FEMA 386-8 makes recommendations for how to implement the requirements, and tips and examples for following the recommendations. Since the recommendations are not mandatory, and each jurisdiction is unique, the recommendations are not included in summary table. One critical component for multi-jurisdictional plans however, is "documentation" or "proof or adoption" is required from participating single jurisdictions. This refers to city or county resolutions that were passed in the individual jurisdictions to adopt the regional or multi-jurisdictional mitigation plan.

With regard to plan participation, the organization of multiple jurisdictions generally follows three models: Direct Representation, Authorized Representation, and a combination of the two. The first involves sending "direct representatives" to the plan author, who coordinates the creation of the plan. For the second, the individual jurisdictions will authorize the plan author to act on their behalf, usually through city or county resolution [10]. A combination of the two can also be created. Any or all of the models are acceptable, but may lead to different cost situations.

3.2.1. Planning at the federal and state level

As the U.S. exited the Cold War, emergency management at all levels of government continued to evolve and in 1974 with The Disaster Relief Act was enacted. The primary goal of the Disaster Relief Act was to update the federal response and relief system described earlier, and to grant more power to the federal government to provide aid in the immediate aftermath of a disaster. In 1979, following the Disaster Relief Act, the Federal Emergency Management Agency (FEMA) was formed. While FEMA remains the national organization for emergency management, past structuring of the federal bureaucracy has shown that these institutions are frequently replaced. Predecessors to FEMA include: The Office of Civil and Defense Mobilization (1958), the Office of Emergency Preparedness (1961), The Civil Defense Preparedness Agency (1972), and finally the Federal Emergency Management Agency

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in 1979 (see [2]). Each of these contained multiple sub-organizations concerned with different areas of emergency management, and operated within a wide range of government groups, from the Department of Defense (DOD) to Housing and Urban Development (HUD) [2]. As a result of the terrorist attacks on September 11, 2001, FEMA was brought under the auspices of the newly created Department of Homeland Security (DHS); and after a controversial response to Hurricane Katrina in 2005 CNN reported that a congressional committee was calling for the abolition of FEMA [11].

After the changes made at the federal level during 1970s, policy continued to evolve through amendments to the Disaster Relief Act of 1974 with the Robert T. Stafford Disaster Relief and Emergency Assistance Act (1988), and the Disaster Mitigation Act (2000). Each amendment encourages localities to "focus on individual and community infrastructures," unless the disaster is beyond their ability to manage [12]. Further, "if the disaster exceeds the state's capacity to respond … the state governor [is allowed] to request aid from the national government. FEMA evaluates the request, prepares material for presidential approval, and coordinates the federal response" [12]. Local and state governments now officially bore the responsibility for emergency planning, although federal response capacity had been expanded.

The Disaster Mitigation Act of 2000 was significant because by its own title was the first law to emphasize the mitigation and preparedness phases of the Four Phase model, rather than "relief" or "assistance" as before; this was achieved by expanding Section 404 of the Stafford Act, which authorized the Hazard Mitigation Grant Program (HMGP) as a means by which jurisdictions *that had received presidential declarations of disaster* could apply for and receive federal assistance for mitigation projects. An additional program, for Pre-Disaster Mitigation grants (PDMs), was instituted so that a presidential declaration was not a requirement to apply for funding directed at mitigation activity; however the application process is separate, nationally competitive, and less familiar than that of the HMGP; and often the amount of money made available for funding applications through presidential declarations is substantially higher. In amending Section 404 of the Stafford Act, Section 322(a) of the Disaster Mitigation Act required state and local mitigation plans to be in place before any applications were made to the HMGP:

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a condition of receipt of an increased Federal share for hazard mitigation measures…a State, local, or tribal government shall develop and submit for approval to the President a mitigation plan that outlines the processes for identifying the natural hazards, risks, and vulnerabilities of the area under the jurisdiction of the government.

The Disaster Mitigation Act provided a legal foundation for FEMA to author an Interim Final Rule under the Federal Register (44 CFR Parts 201 and 206). As discussed in the previous section, the Rule provides specific clarification, based on the Disaster Mitigation Act, for receiving funding through FEMA under the HMGP. Beginning at the state level, a state can either have a Standard or Enhanced Mitigation Plan that will result in a 15% or 20% increase in HMGP funding, respectively. The state is also allowed to use up to 7% of the HMGP funding to cover the expenses of writing state, local, or tribal plans. As of November 2007, 48 states had approved Standard Plans, and two states were waiting for approval on submitted plans. Seven of the 48 states with approved plans had also elevated their status to having approved Enhanced Plans, showing the state-level implementation of plans was highly successful. The Rule explicitly states that "[t]o be eligible to receive HMGP project grants, local governments must develop Local Mitigation Plans that include a risk assessment and mitigation strategy to reduce potential losses and target resources. Plans must be reviewed, revised, and submitted to us for approval every 5 years" (p. 8847). Local Mitigation Plans are also referred to as Hazard Mitigation Plans (HMPs), or Mitigation Action Plans, by FEMA and local planners alike. An important note for later discussions on the cultural influences in local planning, The Rule further specifies that "[m]ulti-jurisdictional plans may be accepted, as appropriate, as long as each jurisdiction has participated in the process and has officially adopted the plan. State-wide plans will not be accepted as multi-jurisdictional plans" [44 CFR § 201.6(3)].

To encourage a fast response to the new local-level planning requirements, The Rule originally set a deadline of November 1, 2003. Prior to that date, writing plans and applying for funding through the HMGP could be done simultaneously. In October 2003 the deadline was changed to November 1, 2004 with an amendment in the Federal Register, stating that "local governments must have an approved mitigation plan in order to receive project grants under any Notice of Funding Opportunity [including PDMs] issued after November 1, 2003 [fiscal year 2004 and later]" (p. 61368). Interestingly, this legislation used a limitation of access to federal grants to motivate local governments to create HMPs.

From this sequence of bureaucratic re-organization and policy implementation, it is clear that planning for disasters at the federal level has involved maintaining a reliable response and relief capacity, and passing the planning responsibilities to state and local government. This is not counterintuitive however, as local residents have a better understanding of their areas, and would be the first to respond during a disaster.

3.2.2. Planning at the local level

While federal and state governments are easily recognizable, it is worth considering the definitions of local government when considering the planning that occurs there. The U.S. Census Bureau provides rigorous definitions for city governments, and a certain set of criteria that must be met for a local government to be considered legitimate. FEMA accepts plans from a wide variety of local governments, including tribal governments and individual school districts. When conducting any analysis on HMPs, a distinction should be made for which types of governments are under consideration. Councils of governments are not defined by the census bureau, and may take a variety of forms depending on the needs of localities within a region. According to the National Association of Regional Councils (NARC), a regional council, or council of governments, is defined as:

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> …a multi-service entity with state and locally-defined boundaries that delivers a variety of federal, state and local programs while continuing its function as a planning organization, technical assistance provider and "visionary" to its member local governments. As such, they are accountable to local units of government and effective partners for state and federal governments [13].

In support of the notion within emergency management that inter-organizational cooperation is crucial, [13] believes "the role of the regional council has been shaped by the changing dynamics in federal, state and local government relations, and the growing recognition that the region is the arena in which local governments must work together to resolve social and environmental challenges."

As emergency management evolves and becomes more advanced, the earlier quotation from [8] becomes more relevant. Recall that:

> On the one hand, federal officials have a strong stake in promoting hazard mitigation and preparedness but little direct control over the effectiveness of such efforts. On the other hand, in the aggregate, sub-national governments and individuals owning property in hazardous areas directly control the effectiveness of mitigation and preparedness policies, but for the most part actions consistent with such policies are low on their list of priorities [8].

Because of increased globalization, a community that was once relatively isolated might now house critical facilities for a distant parent company. Sociologist Arjen Boin notes how deeply systemic and interlinked society as become, allowing the effects of disaster to spread and multiply more rapidly than in the past, and stressing the need for improved local disaster planning:

> First, Western societies become increasingly dependent on complex systems to deliver most basic tasks ranging from garbage collection to national defense. Second, the various subsystems become increasingly tightly coupled, which means that a disturbance in one system rapidly propagates toward another [14].

All levels of government participate in some way in all levels of emergency management, creating a complex system of interlinked activities. Ultimately though, the entire structure of emergency management in the United States, and within the Four Phase model, depends on preparedness at the local level. This concept is aptly publicized by the planning requirements within the Disaster Mitigation Act and FEMA's Interim Final Rule. Despite general consensus that local preparedness is essential, its execution has traditionally been of minimal quality, low priority, and host to a multitude of administrative problems. These are discussed in the following sections.

3.2.2.1. What constitutes preparedness?

Returning to the Four Phase model of emergency management proposed in 1979 by the NGA, the report failed to provide definitions for the phases; instead, suggested activities were included. For the preparedness phase, the NGA recommended:

Developing a response plan and training first responders to save lives and reduce disaster damage, including the identification of critical resources and the development of necessary agreements among responding agencies, both within the jurisdiction and with other jurisdictions [6].

Six years later, the NGA was better able to define each phase (see Table 1). Preparedness was defined as:

Developing a response plan based upon the risk assessment, training response personnel, arranging for necessary resources, making arrangements with other jurisdictions for sharing of resources, clarifying jurisdictional responsibilities, and so on. [14]

An interesting similarity between both definitions is that they encourage cooperation with other jurisdictions. Although this cooperation has appeared low on the list of priorities of local planners for reasons discussed later, recent research has shown multi-jurisdictional cooperation to be almost exclusively responsible for the creation of HMPs [15].

As the understanding of emergency planning and hazards progressed, a number of researchers would recommend activities that led to an increased state of preparedness for local emergency managers (see [16]). After the terrorist attacks of September 11, 2001, [16] revisited these activities, summarized and combined the work that had been done previously, and suggested ten guidelines for increased preparedness within the newfound context of terrorism as a viable threat. In summary, the ten steps are:

1. Base planning activities "upon accurate knowledge of the threat and of likely human responses;"

2. encourage an appropriate, rather than quick or impulsive, response;

3. emphasize "response flexibility so that those involved in operations can adjust to changing disaster demands;"

4. address inter-organizational coordination;

5. "integrate plans for each individual community hazard managed into a comprehensive approach for multi-hazard management;"

6. include a training program so that all involved parties are familiar with the plan, including elected officials and the general public;

7. test the plan with drills and exercises;
8. recognize that "planning is a continuing process;"
9. recognize that due to the nature of local government culture [see Section 2.2.3.2.3], "emergency planning… is almost always conducted in the face of conflict and resistance;" and
10. 1recognize that a plan is only ever truly tested and improved upon "with its implementation in an emergency" (adapted from [16]).

The authors note that "often, there is a tendency to equate emergency planning with the presence of a written plan and similarly believe that a written plan is evidence of jurisdictional preparedness" [16]. In fact, as demonstrated in the ten guidelines, planning is a dynamic process. Emphasizing a written plan may not be a bad idea, given the requirements of the Hazard Mitigation Grant Program; however a possible future task for policy might be to highlight the process rather than the written document.

Combining the definitions of the NGA Four Phase model with [4] and [16], preparedness within the context of emergency management is best thought of as a cyclic process, much like the Four Phase model, which consists of threat assessment, resource assessment and acquisition, inter- and intra-jurisdictional cooperation, drills and exercises, and finally writing a plan (see Figure 1). As previously discussed, a preliminary examination of FEMA data on Hazard Mitigation Plan completion has shown that over 90% of the "plan writing" phase of preparedness has occurred at the multi-jurisdictional level, especially within counties and COGs [15]. It would appear that these five activities within preparedness can occur with varying success at different levels of local government. The history of multi-government bodies in emergency management is discussed in the next section.

3.2.2.2. The role of counties and councils of governments

With rare exception, emergency management literature has followed the governmental design of the NGA model to the letter; the four phases are to be carried out at the federal, state, and local level. However, in the NGA report and subsequent literature, local government is seldom defined and assumed to mean primarily city, or occasionally, county government. Very little literature exists on the role of councils of governments in the preparedness phase.

An important note from the literature in emergency management is that "inter-organizational" or "multi-jurisdictional" coordination is considered essential among disaster researchers; even if the terms are broad, encompass many types of coordination, and refer almost exclusively to the response phase of emergency management. Like [14], Louise Comfort argues that due to the increasing complexity of society, not only are effective local responses critical, but are also "necessarily inter-organizational and interdisciplinary" [17]. Comfort had previously proposed specific roles for county emergency management within the preparedness phase. In summary, Comfort lists the county's responsibilities as:

1. Review individual city emergency plans and enter their data into a resource database;

2. Summarize database into county-wide profile of responsibilities and capabilities, and return this report to city governments for review;
3. Conduct drills and exercises that bring multiple organizations together; 4) evaluate the performance of the cities in these drills;
4. improve preparedness at the county level and "seek assistance…from inter-jurisdictional sources;"
5. schedule, monitor and evaluate preparedness activities; and
6. submit an annual report of these activities to the state (adapted from [17]).

Two important factors in Comfort's guidelines are that first, she recognizes the importance of a coordinating government to act between the city and state levels, but she also relies on the assumption that individual cities will author their own plans.

In 1994, William Waugh expanded on Comfort's role for county government. Waugh argued that counties should be the exclusive home of local emergency management, because county offices generally:

1. are geographically close to environmental problems,
2. have larger resource bases than municipalities,
3. have ambiguous administrative structures that encourage inter- and intra-organizational cooperation,
4. are local agents of state administration,
5. have close administrative ties to state agencies,
6. provide forums for local-local cooperation, and
7. serve as general-purpose governments representing local interests and have strong local identification (adapted from [3]).

Waugh's reasoning may provide some insight into why the success rates for Hazard Mitigation Plan authorship are so high for counties and COGs. Yet in many rural areas, counties only encompass a small number of sparsely populated municipalities, which raises the question of when county governments or COGs are more appropriate in the planning process.

Only one example of a successful COG exists in the literature, and it receives a brief mention in a report by Thomas Drabek [18]. In 1990, Drabek published the results of a study of twelve highly successful local emergency managers. From what he learned through personal visits and interviews, Drabek extracted fifteen qualities that all of the managers shared; one of which was the formation of "mergers." While this generally meant the cooperation between public and private organizations, or inter-departmental cooperation, Drabek found that Donald Herrick of Davidson County, South Dakota founded the James Valley Emergency and Disaster Service District- "a four county emergency services unit" [18].

Undoubtedly the academic aspect of emergency management recognizes the usefulness of regionalized government, especially counties and within the response phase of a disaster. In practice at the local level however, both the preparedness phase of emergency management and the concept of shared governance even at a regional level is resisted and viewed with suspicion and disdain. Despite its apparent benefits, the difficulty in implementing multi-jurisdictional cooperation is discussed next.

3.2.2.3. Cultural issues in local government

Planning for disaster in local government has traditionally been a neglected and misunderstood part of emergency management. The reasons, summarized and listed in [19], include:

…diversity of hazards, low issue salience, resistance to regulatory efforts, resistance to planning efforts, lack of a strong political constituency, lack of a strong administrative constituency, problems with measuring the effectiveness of programs, the technical complexity of many emergency management efforts, vertical fragmentation of federal systems, horizontal fragmentation of governments and communities, current political and economic milieu, and state and local capacity [19].

In other words, emergency management is not a simple matter. The complex and infrequent nature of disasters compared with more familiar problems places them low on the list of priorities for many planners. This lack of enthusiasm is compounded by local politics, turf protection, and ambiguity caused by shared governance. These reasons for resistance to planning efforts can cause both vertical and horizontal fragmentation of government.

Documenting this type of cultural phenomenon poses a challenge of a sociological nature. Presented below are the results of preliminary studies that have begun quantifying these barriers to success. The results indicate that an aversion to planning is frequently present among local government officials. The reason is twofold: the process itself is ongoing, expensive, and time-consuming, and the background of many professionals in emergency management is one of trained rapid response. By asking city planners to rate their own successes in the formation of mandated local toxic chemical emergency planning committees (LEPCs) under SARA Title III, five years after the policy went into effect in the state of Michigan, M. Lindell [20] found that:

On average, LEPCs had completed 31% of the task of conducting hazard analyses, 26% of the task of developing site-specific emergency plans, and 15% of the task of training emergency responders. Moreover, they rated the quality of their LEPCs work (on a scale of 1-5, 5 is very high quality) at 2.88 for organizing and administering the LEPC, 2.46 for conducting hazard analyses, 2.55 for developing site specific plans, 1.71 for training emergency responders, 2.02 for conducting drills and exercises, and 2.64 for filing hazard data [20].

Lindell's results indicate that not only are planners reluctant to take action, but willingly rank themselves as such. In a follow-up study [21], Lindell found that the largest contributors to the time commitments needed for plan completion were: committee member input, available planning resources, and community support. Staffing and structure within the government and the city's vulnerability to hazards were not found to be significant (see [21]).

Lindell's findings [20, 21] were supported by two recent papers (see Buckle et al. [22]; and Stuart-Black et al. [23]). Buckle et al. found that the unfamiliar nature of hazards made them less appealing for planners, and that good communication between local government and community led to better planning [22]. The second study [23] surveyed local emergency managers to determine the composition of the field with regard to education, background, age, sex, and previous job experience. The results demonstrated a lack of value placed on education or academic training, with preferences given to practical experience in defense or response-oriented jobs. One of the motivations for the study was what the authors described as an informal "notion…that those doing the job were older men from a military or emergency services background, who having retired from their service were embarking on a second career in order to boost their pensions" [23]. In the United Kingdom, the study found that 76% of local planners looking to hire a new emergency manager were not even considering recent graduates or degree holders [23]. The planners estimated they would fill their positions using employees with significant experience or those looking for a transition into retirement. When asked where they expected to find potential candidates, the planners responded that they "expected to recruit from the local government sector (63%), first response (37%), and/or retired military (34%)," with percentages including responses where multiple sectors were chosen as potential hiring pools. The surveys also asked why these sectors where chosen, and "the overwhelming answer was that age and experience were paramount to the job, and younger applicants were not always able to bring the necessary authority that was needed in dealing with senior officers and elected council members." In regard to this "overwhelming" response, the authors commented that "clearly the emergency planners are by their own actions and beliefs perpetuating the myth." Though the "notion" that prompted surveys in [23] was informal and not fully documented, it certainly is supported by the data collected.

Local emergency managers appear to subscribe to the war-oriented approach described by [1] above. Often police and fire departments closely resemble the military in structure, training, and operation, with all groups placing high emphasis on the ability to act rationally and maintain order in emergency situations. As indicated by [23], this leads directly to hiring preferences that value the experienced responder above all other candidates. It also leads to a second inhibitor to local planning: the difficulties of implementing inter-jurisdictional cooperation.

Policy research has shown that because of differing priorities of various agencies, such as police and fire, "bureaucrats tend to avoid communication with their counterparts in other agencies, even when their responsibilities clearly overlap or interface… In general, the more coordination required to implement a policy, the less chances of its success" (Edwards, 1978, as quoted in [24]). Kartez and Kelley [25] supported this finding with their own survey of local emergency planners. The planners were asked to rank seven strategies for implementing preparedness policy, based on perceived likelihood of adoption, perceived benefits of strategy, and perceived effort of adoption. Among other strategies, such as citizen education and creating a media information center, inter-jurisdictional forums ranked third and second respectively in benefit and effort, but dropped to fourth for the likelihood of adoption [25]. The authors surmised that the planners recognized the benefit of inter-jurisdictional collaboration, but deemed it too difficult to execute.

Drabek's study [18] of successful emergency managers also supported these conclusions, highlighting the political reasons for avoiding working with other jurisdictions and even departments within their single jurisdiction. Drabek sited "turf defense" as a major barricade to what he called the "sensitive ground" of "coalition building" [18]. Drabek specifically cited an emergency manager that had tried to start a smoke detector and fire extinguisher campaign in his jurisdiction, much to the irritation of the fire department, who felt such a campaign was their responsibility and resented the emergency manager for making them look unconcerned about prevention.

3.2.3. *Summary of planning for disaster in federal, state, and local government*

The previous sections provided a history of the planning subsection of the preparedness phase of emergency management. Planning at the federal level is limited; federal government is primarily a financier and supporting partner of response, recovery, and mitigation efforts. The most recent federal policy, the Disaster Mitigation Act of 2000 and FEMA's subsequent Interim Final Rule (44 CFR Parts 201 and 206) have required that all local jurisdictions have an approved Hazard Mitigation Plan in order to be eligible for any federal funding opportunities.

The states play intermediate roles in transferring information between local and federal governments, and the local governments are responsible for their own planning. Using the five aspects of preparedness [4, 16], Table 2 shows how some roles within the Preparedness phase can be checked off by definition, while others remain poorly understood. To carry out any of the activities listed at the regional level, without the knowledge or cooperation of the city level, would be extremely poor planning. Similarly, inter- and intra-jurisdictional cooperation requires the participation of multiple jurisdictions by definition. The remaining roles however, are poorly understood within the literature. For instance, what is the role of a council of governments in drills and exercises? Are they activities that require maximum cooperation, or are counties better suited to perform this task so as to avoid over-complication? This chapter focused on planning at the city, county, and COG level (Table 2) but certainly more research is needed in the other areas of the Preparedness phase.

COG	?	?	?	+	?
County	?	?	?	+	?
City	+	+	+	+	+
	Plan	TA	RAA	IJC	D&E

Table 2. The Roles of Local Government within the Preparedness Phase

Although placing responsibility for planning at the local level is logical, considering locals know their areas the best and are the first to respond to a disaster, literature shows that in practice there are many more factors at play. First, writing a plan on paper is only a small portion of preparedness as a whole. Second, the individual government success rate for Hazard Mitigation Plans is minute compared to that for multi-jurisdictional bodies; even though the latter is not well understood in the literature. Finally, a political, response-based culture at the local level has consistently made multi-jurisdictional cooperation difficult.

Returning to planning and preparedness within the context of a national emergency management system, recall that emergency management follows a four-phase model developed in 1979 by the National Governor's Association. The four phases are: preparedness, response, recovery, and mitigation. They are accepted as standard among practitioners of emergency management, and are widely considered to be overlapping and cyclical (Figure 1). All four phases contain component activities as demonstrated in the literature (Table 1). Due to the complexity of actual disasters, it is likely that even more activities and sub-categories exist within these divisions, but they have yet to be formally established by the literature.

As defined by the NGA model, the four phases of emergency management can be extended to all levels of government (Figure 2). A typical assumption in emergency management literature is that government in the United States is divided into local, state, and federal levels. However local government can be further subdivided into municipality/town, county, and COG. The activities that comprise the four phases of emergency management may be carried out at all levels of government.

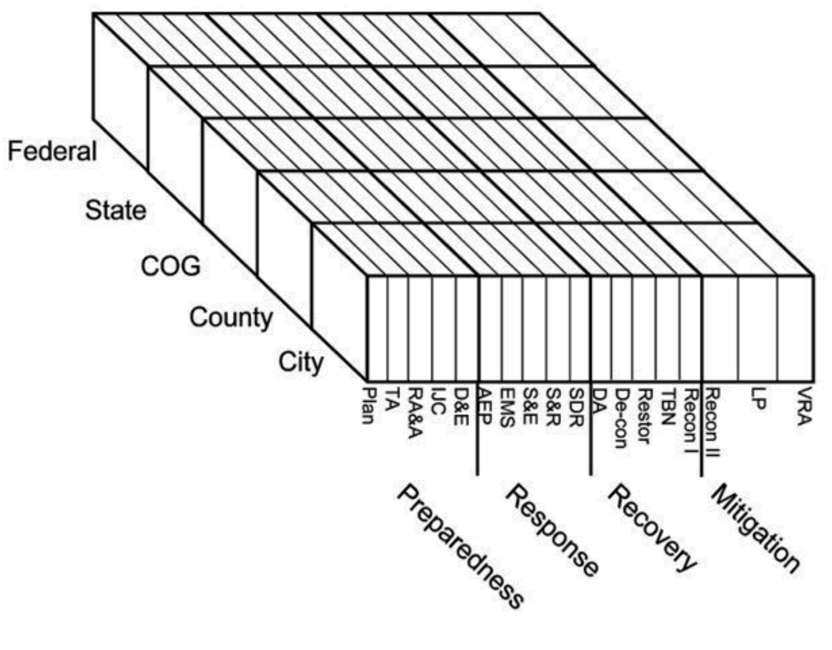

Figure 2. Four phases of emergency management at all levels of government

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However a third dimension may be added to the model to show what aspects of emergency management can influence the activities within certain areas of government. Three factors were found to have a significant effect on organizing emergency management activities within a government by [21] as discussed earlier: available resources, committee input, and community support. It is likely that there are many more factors that influence preparedness and cooperation in local emergency planning, but these have yet to be documented in the literature. In addition to influencing emergency management activities, these three factors also provide frameworks for measuring the activities. A pictorial representation (Figure 3) provides a visual summary of the Four Phase Model, extended to all levels of government, and within the contexts for action identified by [21], and clearly shows the complexity faced by local planners.

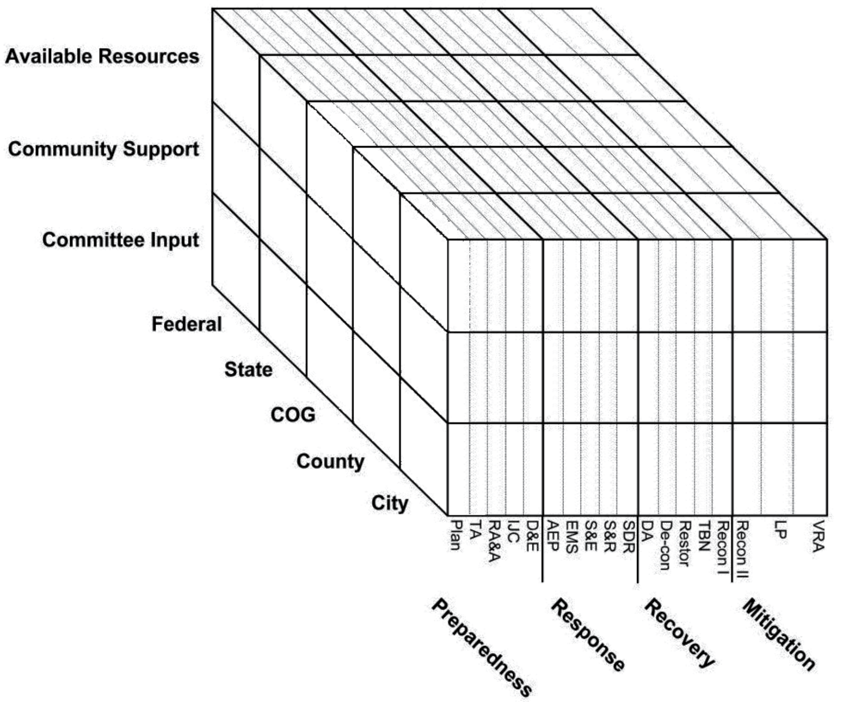

Figure 3. A Conceptual Model of the National Emergency Management System. Copyright © 2008 Andrea M. Jackman & Mario G. Beruvides

3.3. Hazard mitigation planning as part of a national emergency management system

Most of the emergency management literature in this chapter is presented within the context of planning, specifically for hazard mitigation in a local community. However based on Table 1, the findings of [21], and the established structure of American government, it is not unreasonable to begin imagining the complexity of our national emergency management system as illustrated in Figure 3. Certainly there is more research to be done; more activities may be added to the subdivisions of the Four Phase Model as our national approach to emergency management grows and evolves, and further motivating factors for each activity will likely be discovered beyond those in [21] that were found to influence planning.

However one aspect of Figure 3 cannot be disputed: the complexity of our national emergency management system will not get any simpler. Even the introductory overview of literature provided in this chapter is able to justify an 18 x 5 x 3 conceptual diagram – equaling a minimum of 270 individual components that make up the national system of emergency management. Recalling the words of sociologist Arjen Boin from earlier:

First, Western societies become increasingly dependent on complex systems to deliver most basic tasks ranging from garbage collection to national defense. Second, the various subsystems become increasingly tightly coupled, which means that a disturbance in one system rapidly propagates toward another [14].

Hazard mitigation planning is a small component of emergency management. Even expanded to all possible levels of government, it is only one type of plan among many, and planning is only one type of activity in overall preparedness. Yet one might question, how "tightly coupled" is it with other aspects of emergency management? How rapidly will one action within a HMP propagate to other subsystems within emergency management as a whole? A simple HMP may be comprised of a community risk assessment and one or two mitigative actions to reduce those risks. But the risk assessment is likely based on past disasters in the community. The lessons learned and recommended actions from those disasters in turn influence future responses, which influence future recovery efforts, which will drive mitigation planning and risk assessments in later years. Through Figure 3 we see how one activity affects many others within the system. At first glance, local hazard mitigation planning seems distant and unrelated to decontamination efforts managed by the federal government. However an effective mitigation strategy put in to place today through the HMP process may significantly reduce the need for decontamination or any federal involvement at all. As another example, the after-action report of a state-level search and rescue team could directly impact risk assessments, planning, and mitigation strategy following a major disaster.

Hazard mitigation planning at the local and COG level, studied from all possible planning contexts, only comprises (at most) 9 out of 270 subsections of Figure 3, or 3%. This estimate does not include the further breakdown of different kinds of plans in addition to HMPs, yet was shown to influence many other subsections of Figure 3. This illustrates not only the importance of understanding hazard mitigation plans, but the impact of *any legislative action* taken in emergency management. The true impact of a single act can have vast, sometimes unpredictable consequences, especially in a system such as emergency management where current practices and scientific research are still relatively

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new. An understanding of the implementation of the HMGP policy is critical for this reason, and is discussed in the next section.

4. Hazard mitigation planning in the 21st century

The HMGP policy that led to HMPs as a requirement was put into place in November, 2004. Based on the material covered in the previous sections, two questions naturally arise: first, how many local jurisdictions have completed HMPs since the original deadline? Second, for those localities with an approved HMP, how did they manage given all the documented cultural aversions to planning at the local level?

These questions were answered in part by a recent series of studies [15, 26]. An initial study [15] found that in 2008, 67% of the country's active local governments were without an approved Hazard Mitigation Plan (Figure 4).

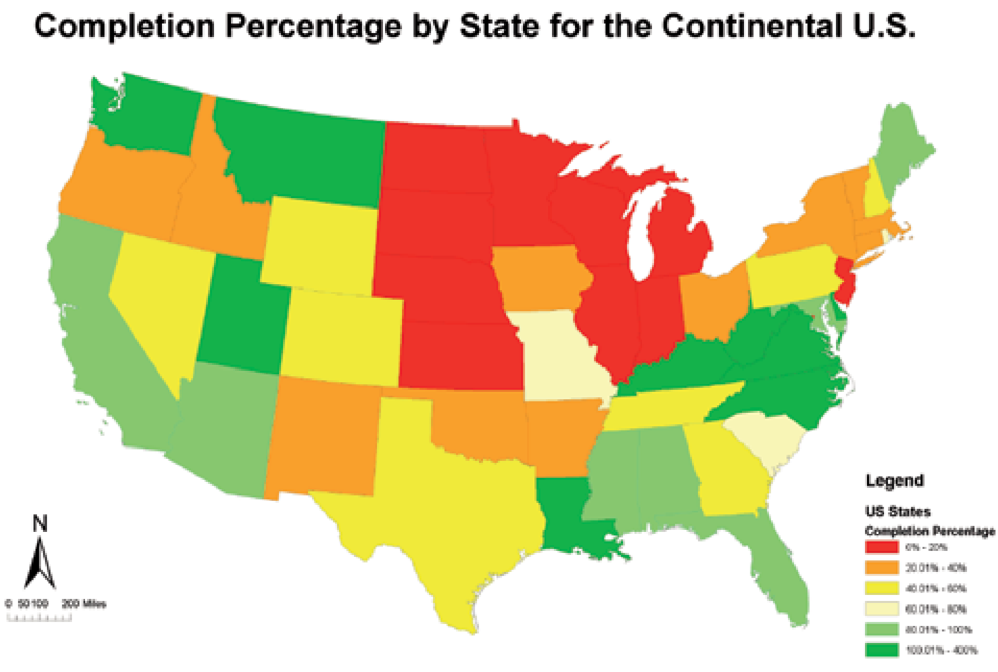

Figure 4. Map of Hazard Mitigation Plan Completion Percentage for the Continental United States in 2008 [15]

A follow up examination in 2009 [15] of the eight states with the lowest completion percentages did not indicate significant improvement following the initial study, and revealed inconsistencies in plan completion data over time. The completion percentage varied greatly by state, and did not appear to follow any expected pattern such as wealth or hazard vulnerability that might encourage prompt completion of a plan. Further, the results indicated that approximately 92% of the approved plans were completed by multi-jurisdictional entities, which suggests single governments seldom complete and gain approval for plans. This is directly opposed to expectations set by literature documenting cultural barriers to multi-jurisdictional collaboration, and presents a number of opportunities for further research.

The study was conducted for the initial three year period of the HMGP from 2004 to 2007, and given the results, it is important to note that federal policy such as the HMP requirements can change quickly and often. Strategic directions, policy, and guidance can change regularly, and is always expected at the federal level following a change in administration. The completion percentages demonstrated in this study represent an important step in understanding how long it takes for jurisdictions to react to policy changes and take necessary steps to become compliant, especially given the systemic complexity demonstrated in Figure 3.

A second study [26] examined HMP completion within the context of "available resources" from Figure 3; namely, cost. It was found that the cost of a HMP varied significantly based on the frequency of natural hazards experienced by the authoring jurisdiction, the number of participating jurisdictions in the plan, population, and population density. Similarly, multi-jurisdictional plans were found to be significantly cheaper unless a jurisdiction experienced, on average, more than 6.5 events requiring some kind of emergency response per year (see [26]). This would provide a financial incentive for jurisdictions to override some of the cultural barriers mentioned earlier, and proceed with a multi-jurisdictional plan. In view of the realities presented thus far and the sheer complexity of the US emergency management system, future research might benefit from a systems analysis and systems dynamic modeling to assist in shaping our national emergency management policy.

Where will hazard mitigation planning go from here? The importance of having at least some level of understanding of the possible impacts of any new emergency management policy were illustrated by Figure 3, and this section demonstrates that for the example of hazard mitigation planning, relatively little is known about its implementation, success, and longevity. Planning in general was shown by the literature to be valued by policymakers and theorists, but difficult to execute in practice for a variety of reasons. Due to the far-reaching consequences of good mitigation and mitigation planning, continued research in this area is critical to a better understanding of our entire national emergency management system.

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Section 2

Managing Information for Disaster Management

Chapter 4

Improved Disaster Management Using Data Assimilation

Paul R. Houser

Additional information is available at the end of the chapter

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1. Introduction

Decision makers must have timely and actionable information to guide their response to emergency situations. For environmental problems, this information is often produced using decision support systems (DSS), which is usually a computer-based, environmental simulation and prediction model that emphasizes access and manipulation of data and algorithms. Using historical time series data, current conditions, and physically-based algorithms the DSS can predict the potential outcomes for various decision scenarios, and may also provide the decision maker with uncertainty and risk estimates. In this way, the DSS can improve decision making efficiency and accuracy, facilitate decision maker exploration and discovery, communication and information organization, and outreach and education.

An important component of advanced decision support tools is data assimilation. Data assimilation is the application of recursive Bayesian estimation to combine current and past data in an explicit dynamical model, using the model's prognostic equations to provide time continuity and dynamic coupling amongst the fields. Data assimilation aims to utilize both our knowledge of physical processes as embodied in a numerical process model, and information that can be gained from observations, to produce an improved, continuous system state estimate in space and time. When implemented in near-real time, data assimilation can objectively provide decision makers with the timeliest information, as well as provide superior initializations for short term scenario predictions. Data assimilation can also act as a parameter estimation method to help reduce DSS bias and uncertainty.

This chapter will provide an overview of data assimilation theory and its application to decision support tools, and then provide a review of current data assimilation applications in disaster management.

2. Background

Information about environmental conditions is of critical importance to real-world applications such as agricultural production, water resource management, flood prediction, water supply, weather and climate forecasting, and environmental preservation. Improved estimates about current environmental conditions useful for agriculture, ecology, civil engineering, water resources management, rainfall-runoff prediction, atmospheric process studies, climate and weather/climate prediction, and radiation management [1,2].

This information is usually provided to decision makers through Decision Support Systems (DSS). DSS's are generally defined as interactive software-based systems that help to assemble useful information from raw data, documents, knowledge, and models to identify and resolve problems and make decisions. A model-driven DSS emphasizes access to and operation of a statistical, financial, optimization or physical simulation model. A data-driven DSS emphasizes access to and manipulation of a time-series of data and information. Data-driven DSS's combined with analytical model processing provide the highest level of functionality and decision support that is linked to analysis of large collections of historical data.

Physically-based environmental models are often at the heart of powerful DSSs. They rely on a set of well-established physical principles to make current condition assessments and future projections. Physical model simulations are performed on powerful computer platforms, dividing the area of interest into elements in which fluxes and storages are calculated. Environmental parameters are provided by connected databases of observational and calibration data.

Observations are important components of DSSs, providing critical information that mitigates the risk of loss of life and damage to property. Environmental observations are sourced from the numerous disconnected observational networks and systems that have a wide variety of characteristics (Figure 1). Basic monthly, seasonal and annual summaries of temperature, rainfall and other climate elements provide an essential resource for planning endeavors in areas such as agriculture, water resources, emergency management, urban design, insurance, energy supply and demand management and construction.

While ground-based observational networks are improving, the only practical way to observe the environment on continental to global scales is via satellites. Remote sensing can make spatially comprehensive measurements of various components of the environment, but it cannot provide information on the entire system, and the observations represent only an instant in time. Environmental process models may be used to predict the temporal and spatial state variations, but these predictions are often poor, due to model initialization, parameter and forcing, and physics errors. Therefore, an attractive prospect is to combine the strengths of environmental models contained within DSSs and observations and minimize the weaknesses to provide a superior environmental state estimate. This is the goal of data assimilation.

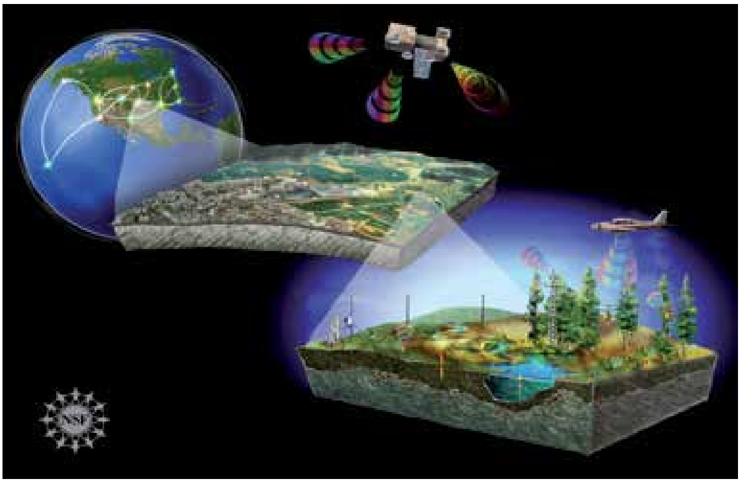

Figure 1. Illustration of an integrated environmental observation network. The network illustrated is the National Science Foundation (NSF) National Ecological Observatory Network (NEON).

Data assimilation combines observations into a dynamical model, using the model's equations to provide time continuity and coupling between the estimated fields. Data assimilation aims to utilize both our environmental process knowledge, as embodied in a numerical computer model, and information that can be gained from observations. Both model predictions and observations are imperfect and we wish to use both synergistically to obtain a more accurate result. Moreover, both contain different kinds of information, that when used together, provide an accuracy level that cannot be obtained individually.

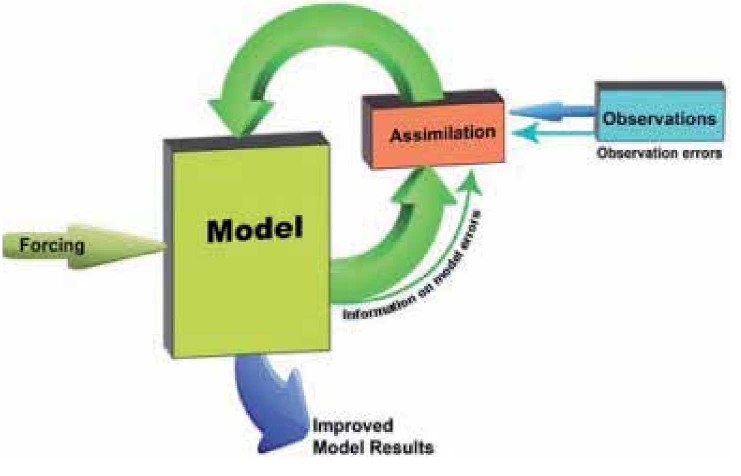

Figure 2. Numerical models contain errors that increase with time due to model imperfections and uncertainties in initial and boundary conditions. Data assimilation minimizes these errors by correcting the model stats using new observations (from http://www.hzg.de/institute/coastal_research/cosyna).

The data assimilation challenge is to merge the spatially comprehensive observations with the dynamically complete but typically poor predictions of an environmental model to yield the best possible system state estimation (Figure 2). In this illustration, the model represents any environmental model that simulates system states. Model biases can be mitigated using a complementary calibration and parameterization process. However, model imperfections will always remain and will be exasperated by uncertain initial and boundary (forcing) conditions. Data assimilation techniques can be used to continuously partially reinitialize the model with information provided by observations. This reinitialization can be constrained by the model physics to assure that it is physically and dynamically realistic. Limited point measurements are often used to calibrate the model(s) and validate the assimilation results [3].

3. Data assimilation

Charney *et al.* (1969) first suggested combining current and past data in an explicit dynamical model, using the model's prognostic equations to provide time continuity and dynamic coupling amongst the fields [4]. This concept has evolved into a family of techniques known as data assimilation. In essence, data assimilation aims to utilize both our physical process knowledge as embodied in an environmental model, and information that can be gained from observations. Both model predictions and observations are imperfect and we wish to use both synergistically to obtain a more accurate result. Moreover, both contain different kinds of information, that when used together, provide an accuracy level that cannot be obtained when used separately.

Data assimilation techniques were established by meteorologists [5] and have been used very successfully to improve operational weather forecasts. Data assimilation has also been successfully used in oceanography[6] for improving ocean dynamics prediction. Houser et al., (2010) gave an overview of hydrological data assimilation, discussing different data assimilation methods and several case studies in hydrology [7].

Data assimilation was meant for state estimation, but in the broadest sense, data assimilation refers to any use of observational information to improve a model [8]. Basically, there are four methods for "model updating", as follows:

- *Input:* corrects model input forcing errors or replaces model-based forcing with observations, thereby improving the model's predictions;
- *State:* corrects the state or storages of the model so that it comes closer to the observations (state estimation, data assimilation in the narrow sense);
- *Parameter:* corrects or replaces model parameters with observational information (parameter estimation, calibration);
- *Error correction:* correct the model predictions or state variables by an observed time-integrated error term in order to reduce systematic model bias (*e.g.* bias correction).

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State updating can be justified by lack of knowledge about the model's initial conditions, but with unconstrained state updating, the model logic is foregone, while this is exactly the main strength of dynamic assimilation and modelling. If an intensive update of the state is needed for good results, the model may simply not be able to produce correct state or flux values. In such cases, assimilation for parameter estimation is better advised. The static parameters obtained through off-line calibration, prior to the actual forecast simulations, may not always result in a proper model definition, because of the state and time dependency of parameters or problems in the model structure or input. Often the model validation residuals show the presence of bias, variation in error and a correlation structure.

The data assimilation challenge is: given a (noisy) model of the system dynamics, find the best estimates of system states $\hat{x}$ from (noisy) observations y. Most current approaches to this problem are derived from either the direct observer (*i.e.*, sequential filter) or dynamic observer (*i.e.*, variational through time) techniques (Figure 3).

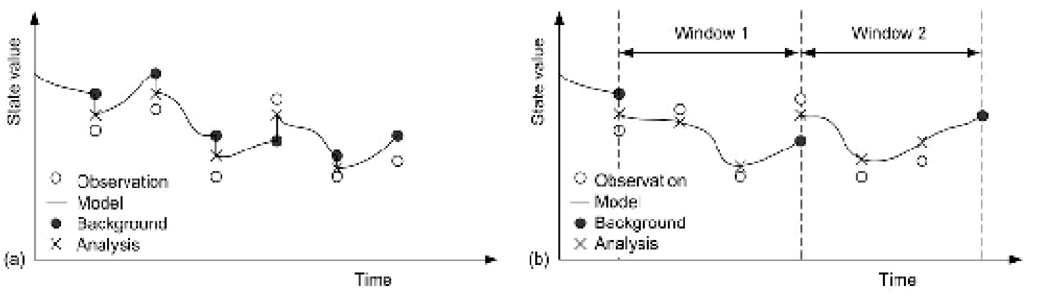

Figure 3. Schematic of the (a) direct observer and (b) dynamic observer assimilation approaches [7].

3.1. Direct observer assimilation

Direct observer techniques sequentially update the model forecast $\hat{x}_k^b$ (*a priori* simulation result), using the difference between observation y_k and model predicted observation $\hat{y}_k$, known as the "innovation", whenever observations are available. The predicted observation is calculated from the model predicted or "background" states, indicated by the superscript b. The correction, or analysis increment, added to the background state vector is the innovation multiplied by a weighting factor or gain **K**. The resulting estimate of the state vector is known as the "analysis", as indicated by the superscript a.

$$\hat{\mathbf{x}}_k^a = \hat{\mathbf{x}}_k^b + \mathbf{K}_k\left(\mathbf{y}_k - \hat{\mathbf{y}}_k\right) \tag{1}$$

The subscript k refers to the time of the update. For particular assimilation techniques, like the Kalman filter, the gain represents the relative uncertainty in the observation and model variances, and is a number between 0 and 1 in the scalar case. If the uncertainty of the predicted observation (as calculated from the background states and their uncertainty) is large relative to the uncertainty of the actual observation, then the analysis state vector takes on values that will closely yield the actual observation. Conversely, if the uncertainty of the predicted observation is small relative to the uncertainty of the actual observation, then the analysis state vector is unchanged from the original background value. The commonly used direct observer methods are: (i) direct insertion; (ii) statistical correction; (iii) successive correction; (iv) analysis correction; (v) nudging; (vi) optimal interpolation/statistical interpolation; (vii) 3-D variational, 3D-Var; and (viii) Kalman filter and variants [7].

While approaches like direct insertion, nudging and optimal interpolation are computationally efficient and easy to implement, the updates do not account for observation uncertainty or utilize system dynamics in estimating model background state uncertainty, and information on estimation uncertainty is limited. The Kalman filter, while computationally demanding in its pure form, can be adapted for near-real-time application and provides information on estimation uncertainty. However, it has only limited capability to deal with different types of model errors, and necessary linearization approximations can lead to unstable solutions. The Ensemble Kalman filter (EnKF), while it can be computationally demanding (depending on the size of the ensemble) is well suited for near-real-time applications without any need for linearization, is robust, very flexible and easy to use, and is able to accommodate a wide range of model error descriptions.

Direct insertion. One of the earliest and most simplistic approaches to data assimilation is direct insertion. As the name suggests, the forecast model states are directly replaced with the observations by assuming that $\mathbf{K} = \mathbf{I}$, the unity matrix. This approach makes the explicit assumption that the model is wrong (has no useful information) and that the observations are right, which both disregards important information provided by the model and preserves observational errors. The risk of this approach is that unbalanced state estimates may result, which causes model shocks: the model will attempt to restore the dynamic balance that would have existed without insertion. A further key disadvantage of this approach is that model physics are solely relied upon to propagate the information to unobserved parts of the system [9,10].

Statistical correction. A derivative of the direct insertion approach is the statistical correction approach, which adjusts the mean and variance of the model states to match those of the observations. This approach assumes the model pattern is correct but contains a non-uniform bias. First, the predicted observations are scaled by the ratio of observational field standard deviation to predicted field standard deviation. Second, the scaled predicted observational field is given a block shift by the difference between the means of the predicted observational field and the observational field [9]. This approach also relies upon the model physics to propagate the information to unobserved parts of the system.

Successive correction. The successive corrections method (SCM) [5,11-13] is also known as observation nudging. The scheme begins with an *a priori* state estimate (background field) for an individual (scalar) variable, which is successively adjusted by nearby observations in a series of scans (iterations, n) through the data. The advantage of this method lies in its simplicity. However, in case of observational error or different sources (and accuracies) of observations, this scheme is not a good option for assimilation, since information on the observational accuracy is not accounted for. Mostly, this approach assumes that the observations are more accurate than model forecasts, with the observations fitted as closely as is consistent. Furthermore, the radii of influence are user-defined and should be determined by trial and error or more sophisticated methods that reduce the advantage of its simplicity. The weighting functions are empirically chosen and are not derived based on physical or statistical properties. Obviously, this method is not effective in data sparse regions.

Analysis correction. This is a modification to the successive correction approach that is applied consecutively to each observation [14]. In practice, the observation update is mostly neglected and further assumptions make the update equation equivalent to that for optimal interpolation [15].

Nudging. Nudging or Newtonian relaxation consists of adding a term to the prognostic model equations that causes the solution to be gradually relaxed towards the observations. Nudging is very similar to the successive corrections technique and only differs in the fact that through the numerical model the time dimension is included. Two distinct approaches have been developed [16]. In analysis nudging, the nudging term for a given variable is proportional to the difference between the model simulation at a given grid point and an “analysis” of observations (*i.e.*, processed observations) calculated at the corresponding grid point. For observation nudging, the difference between the model simulation and the observed state is calculated at the observation locations.

Optimal interpolation The optimal interpolation (OI) approach, sometimes referred to as statistical interpolation, is a minimum variance method that is closely related to kriging. OI approximates the “optimal” solution often with a “fixed” structure for all time steps, given by prescribed variances and a correlation function determined only by distance [17]. Sometimes, the variances are allowed to evolve in time, while keeping the correlation structure time-invariant.

3-D variational. This approach directly solves the iterative minimization problem given [18]. The same approximation for the background covariance matrix as in the optimal interpolation approach is typically used.

Kalman filter. The optimal analysis state estimate for linear or linearized systems (Kalman or Extended Kalman filter, EKF) can be found through a linear update equation with a Kalman gain that aims at minimizing the analysis error (co)variance of the analysis state estimate [19]. The essential feature which distinguishes the family of Kalman filter approaches from more static techniques, like optimal interpolation, is the dynamic updating of the forecast (background) error covariance through time. In the traditional Kalman filter (KF) approach this is achieved by application of standard error propagation theory, using a (tangent) linear model. (The only difference between the Kalman filter and the Extended Kalman filter is that the forecast model is linearized using a Taylor series expansion in the latter; the same forecast and update equations are used for each approach.)

A further approach to estimating the state covariance matrix is the Ensemble Kalman filter (EnKF). As the name suggests, the covariances are calculated from an ensemble of state forecasts using the Monte Carlo approach rather than a single discrete forecast of covariances [20].

3.2. Dynamic observer assimilation

The dynamic observer techniques find the best fit between the forecast model state and the observations, subject to the initial state vector uncertainty and observation uncertainty, by minimizing over space and time an objective or penalty function, including a background and observation penalty term. To minimize the objective function over time, an assimilation time "window" is defined and an "adjoint" model is typically used to find the derivatives of the objective function with respect to the initial model state vector. The adjoint is a mathematical operator that allows one to determine the sensitivity of the objective function to changes in the solution of the state equations by a single forward and backward pass over the assimilation window. While an adjoint is not strictly required (*i.e.*, a number of forward passes can be used to numerically approximate the objective function derivatives with respect to each state), it makes the problem computationally tractable. The dynamic observer techniques can be considered simply as an optimization or calibration problem, where the state vector – not the model parameters – at the beginning of each assimilation window is "calibrated" to the observations over that time period. The dynamic observer techniques can be formulated with: (i) strong constraint (variational); (ii) weak constraint (dual variational or representer methods).

Dynamic observer methods are well suited for smoothing problems, but provide information on estimation accuracy only at considerable computational cost. Moreover, adjoints are not available for many existing environmental models, and the development of robust adjoint models is difficult due to the non-linear nature of environmental processes.

4D-Var. In its pure form, the 4-D (3-D in space, 1-D in time) "variational" (otherwise known as Gauss-Markov) dynamic observer assimilation methods use an adjoint to efficiently compute the derivatives of the objective function with respect to each of the initial state vector values. Solution to the variational problem is then achieved by minimization and iteration. In practical applications the number of iterations is usually constrained to a small number.

Given a model integration with finite time interval, and assuming a perfect model, 4D-Var and the Kalman filter yield the same result at the end of the assimilation time interval. Inside the time interval, 4D-Var is more optimal, because it uses all observations at once (before and after the time step of analysis), *i.e.*, it is a smoother. A disadvantage of sequential methods is the discontinuity in the corrections, which causes model shocks. Through variational methods, there is a larger potential for dynamically based balanced analyses, which will always be situated within the model climatology. Operational 4D-Var assumes a perfect model: no model error can be included. With the inclusion of model error, coupled equations are to be solved for minimization. Through Kalman filtering it is in general simpler to account for model error.

Both the Kalman filter and 3D/4D-Var rely on the validity of the linearity assumption. Adjoints depend on this assumption and incremental 4D-Var is even more sensitive to linearity. Uncertainty estimates via the Hessian are critically dependent on a valid linearization. Furthermore, with variational assimilation it is more difficult to obtain an estimate of the quality of the analysis or of the state's uncertainty after updating. In the framework of estimation theory, the goal of variational assimilation is the estimation of the conditional mode

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(maximum *a posteriori* probability) estimate, while for the Kalman filter the conditional mean (minimum variance) estimate is sought.

Hybrid assimilation methods have been explored in which a sequential method is used to produce the *a priori* state error or background error covariance for variational assimilation [7].

4. Review of current data assimilation applications in disaster management

4.1. Weather forecasting

During the last three decades, data assimilation has gradually reached a mature center stage position at operational numerical weather prediction centers, and are largely responsible for the significant advances in weather forecast accuracy [21]. Improved weather forecasts are critical for better informing the public and decision makers about impending severe weather events such as tropical storms, tornados, frozen precipitation events, wind hazards, droughts, and flooding.

The basis for improved weather prediction using data assimilation is to improve the initial state, which results in an improved forecast. Initial work was based on hand interpolations that combined present and past observations with model results [22-24]. This tedious procedure was replaced by automatic objective analysis [12, 25-27].

Currently, data assimilation is available and implemented worldwide at operational numerical weather prediction centers. The impact of adopting data assimilation in numerical weather prediction was qualified as a substantial, resulting in an improvement in NWP quality and accuracy [28]. Combined with improvement in error specifications and with a large increase in a variety of observations has led to improvements in NWP accuracy [29].

The development of the global positioning system (GPS) satellites has facilitated the use of radio occultation (RO) techniques for sounding the earth's atmosphere. RO is a remote sensing technique that relies on the detection of a change or refraction in a radio signal as it passes through the atmosphere. The degree of refraction depends on the gradients of density and the water vapor. These global measurements are actually commensurable with radiosonde soundings in accuracy [30]. Assimilations of the RO retrieved data have exhibited promising impact on regional as well as global weather predictions [31,32].

The impact of GPS radio occultation data assimilation on severe weather predictions was demonstrated in East Asia [33]. These observations were assimilated in the Weather Research and Forecasting (WRF) model's using a three-dimensional variational (3DVAR) data assimilation system to improve the initial analysis of the model. The GPS RO data assimilation may improve prediction of severe weather such as typhoons. These positive impacts are seen not only in typhoon track prediction but also in prediction of local heavy rainfall associated with severe weather over Taiwan. From a successive evaluation of skill scores for real-time forecasts on frontal systems operationally conducted over a longer period and predictions of six typhoons in 2008, assimilation of GPS RO data appears to have some positive impact on regional weather predictions, on top of existent assimilation with all other observations.

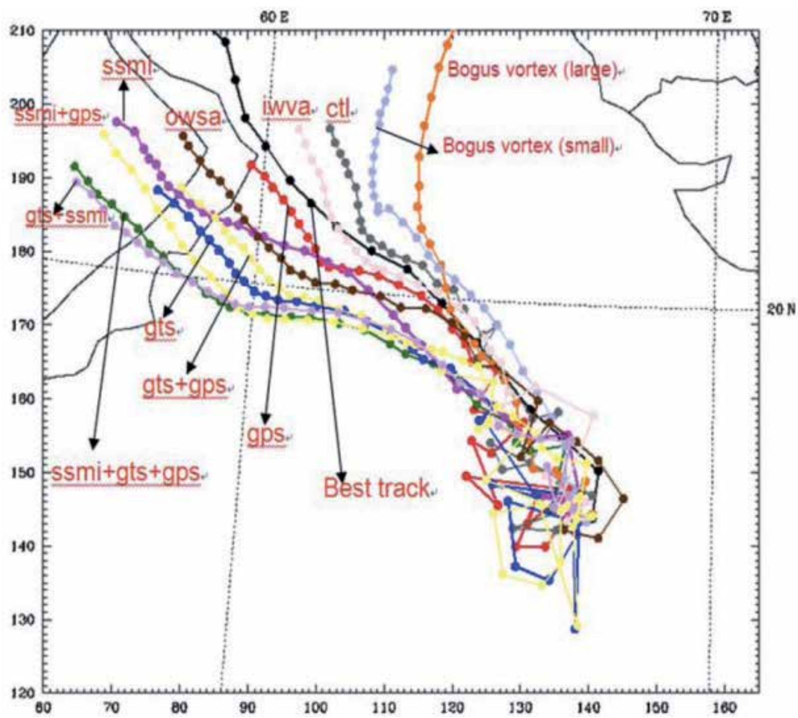

Figure 4. The best track from JTWC (black line) for Cyclone Gonu (2007) and simulated tracks for experiments CTL and GPS without and with the RO data assimilated, respectively, and other experiments with different data, GTS (radiosondes), SSMI (SSM/I retrieved oceanic near-surface wind speed OWS and integrated precipitable water PW, denoted as OWSA an IWVA, respectively), bogus vortex 1 (large vortex) and bogus vortex2 (small vortex) [33].

The impact of GPS RO assimilation on Tropical Cyclone Gonu (2007) was studied over the western Indian Ocean [33]. Gonu was one of the most intense in regional history and had asevere impact. The positive impact of GPS RO data on track prediction is clearly seen in Figure 4. It is surprisingly found that assimilations with all other data (including SSM/I, GTS and their combinations) do not outperform the run with GTS+GPS or even the run with GPS RO data only.

4.2. Flood management: early warning, monitoring, and damage assessments

Flood forecasting using numerical models and data assimilation techniques provides extended lead-time and improved accuracy for flood information useful for residents, local authorities and emergency services. The use of data assimilation in operational hydrologic forecasting predates its use in weather forecasting and oceanography. Examples include updating of snow model states and the use of observed streamflow to make short-term adjustments to the simulated streamflow. However, despite its early adoption, more advanced methods of data assimilation (i.e. Kalman filtering) has yet to take firm root in operational hydrologic forecasting.

Operational hydrologic data assimilation typically uses telemetered, near real-time measurements of river levels and flows, and raingauge or Doppler radar precipitation estimates as inputs to a computer-based flood forecasting system. Model outputs include minute to several

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day forecasts for river levels, river flows, and reservoir and lake levels. Forecasts can be extended further using weather forecasts, and can include snowmelt processes and river control operations.

Hydrologic rainfall-runoff models are used to estimate river flows from rainfall observations and forecasts. These models may take into account local catchment topography, soils, vegetation, temperature, river flow hydrodynamics, and structure operations and backwater effects. These models are enhanced using data assimilation methods such as error prediction, state updating, and parameter updating techniques. Forecast uncertainties can arise and propagate through the modeling network from errors in model parameters, initial conditions, boundary conditions, data inputs and model physics.

As part of the European Union near real time flood forecasting, warning and management "FloodMan" project data-assimilation techniques were developed, demonstrated and validated for integrated hydrological and hydraulic models in a pilot study of the Rhine River [34]. The model combines a hydraulic model (SOBEK) representing the Rhine River between Andernach and Düsseldorf with a hydrological model (HBV) for the Sieg tributary. To increase the accuracy of flood forecasts, data assimilation is applied, using measured water levels at Bonn and Cologne to adapt bed roughness and lateral discharges until the calculated water levels agree with the measured water levels.

The data-assimilation technique computes model corrections based on the assumption that the uncertainties in model output and observations are known and are normally distributed. The data-assimilation algorithm compares the observed value with the calculated value, and makes corrections to the parameters. The changes are made taking into consideration the uncertainty of the parameters and measured data. For example, a mean water level measurement is accurate compared to calculated water levels. Therefore the water level calculated with data-assimilation will be closer to the measured water level than the calculated without data-assimilation.

The data-assimilation algorithm is applied to the flood of December 1993 (Figure 5). The data-assimilation improves the water level forecast. The small differences between forecast and measured data are due to the perfect forecast for the input at Andernach. The adaptations by the data-assimilation on the model parameters were small indication a well calibrated hydraulic model for 1993 flood and that robust data assimilation procedure.

4.3. Drought management

Droughts are environmental disasters that occur in virtually all climates, and are generally related to reduced precipitation for an extended period of time. High temperature, high wind, low humidity; rainfall timing, intensity and duration, also play a significant role in droughts [35]. Aridity is a permanent feature of climate related to low rainfall areas [36], while drought is a temporary anomaly, lasting from months to several years. Population growth, agricultural and industrial expansion, energy demands for water, climate change, and water contamination further amplify the effects of drought and water scarcity.

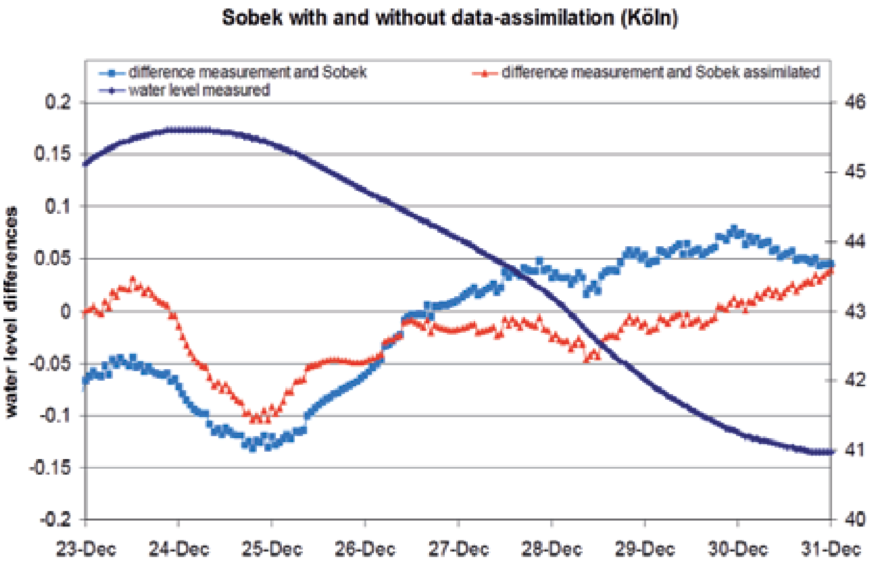

Figure 5. Streamflow forecasts using data assimilation. The blue line depicts the difference between forecast and measured water levels without data-assimilation, the red line the differences with data-assimilation [34].

Droughts impact both surface and groundwater, leading to reduced water supply and quality, crop failure, reduced livestock range, reduced power supply, disturbed riparian habitat, and deferred recreation [37]. Therefore, droughts are of great importance in the planning and management of water resources.

Droughts rank first among all natural hazards when measured in terms of the number of people affected [38]. Hazard events were ranked based on the degree of severity, the length of event, total areal extent, total loss of life, total economic loss, social effect, long-term impact, suddenness, and occurrence of associated hazards [39]. It was found that drought stood first based on most of the hazard characteristics. Other natural hazards, which followed droughts in terms of their rank, are tropical cyclones, regional floods, earthquakes, and volcanoes.

The Gravity Recovery and Climate Experiment (GRACE) satellite mission, launched in 2002 measures monthly changes in total water storage over large areas, which can help to assess change in water supply on and beneath the land surface. However, the coarse spatial and temporal resolutions of GRACE, and its lack of information on the vertical distribution of the observed mass changes limits its utility unless it is combined with other sources of information. In order to increase the resolution, eliminate the time lag, and isolate groundwater and other components from total terrestrial water storage, the GRACE data was integrated with other ground- and space-based meteorological observations (precipitation, solar radiation, etc.) within the Catchment Land Surface Model, using Ensemble Kalman smoother type data assimilation [40]. The resulting fields of soil moisture and groundwater storage variations are then used to generate drought indicators based on the cumulative distribution function of wetness conditions during 1948-2009 simulated by the Catchment model [41] (Figure 6).

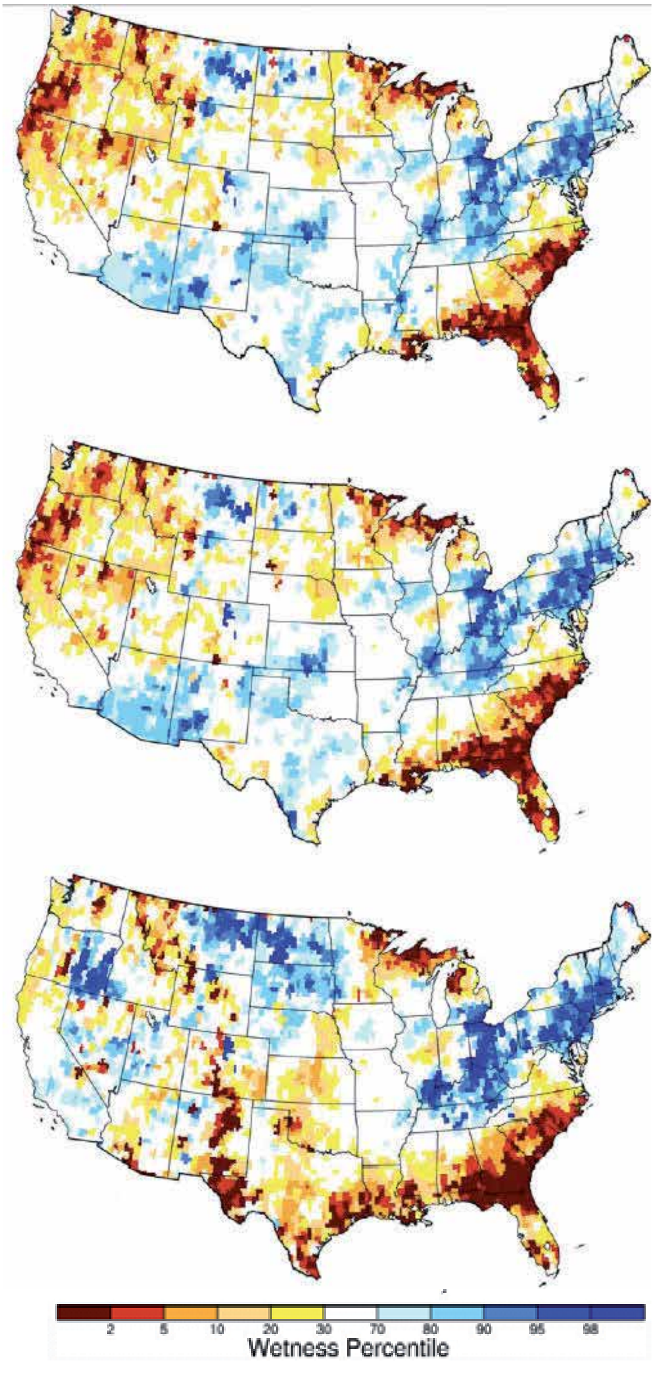

Figure 6. GRACE data assimilation based drought indicators for surface (top) and root zone (middle) soil moisture and groundwater (bottom) for 26 December 2011, expressed as percentiles relative to conditions during the 1948-2011 simulated record [41].

There are several aquifers in the U.S. that have been depleted in that way over the past century, such as the southern half of the High Plains aquifer in the central U.S. If the groundwater drought indicator map accounted for human-induced depletion, such regions would be red all the time, which would not be useful for evaluating current wetness conditions relative to previous conditions. On time scales of weeks to ten years, we expect that these maps will be reasonably well correlated with measured water table variations over spatial scales of 25 km (16 miles) or more. However, users should not assume a direct correspondence between these groundwater percentiles and measured groundwater levels over multiple decades. The color-coded maps show how much water is stored now as a probability of occurrence in the record from 1948 to the present.

4.4. Radiation guidance and monitoring

Decision makers must have the information needed to react in a rapid and appropriate manner before, during and immediately after an accidental or intentional contamination of the environment. Decision support systems are needed to estimate the likely evolution of the environmental contamination. The primary goal is to determine the area likely to be affected by a possible release and to obtain an estimate of the potential maximum environmental consequences. In the early phases of an accident the main goal is to provide a forecast of the magnitude and geographical coverage of the potential environmental consequences. It is important to know the prevailing and forecasted meteorological conditions in the local area. Also the status of the source should be known in detail. Depending on the meteorological situation and the model used, trajectories may be calculated first to give a rough estimation of the plume transport.

Dispersion models driven with weather data and best-estimate source information can be used. When results of radiological measurements are available they can be used to improve model calculations by data assimilation. Atmospheric dispersion modeling of radioactive material in radiological risk assessment and emergency response has evolved significantly over the past 50 years. The three types of dispersion models are the Gaussian plume, Lagrangian-puff and particle random walk, and computational fluid dynamic models. When data from radiological measurements are available, they should be taken into account in the consequence assessment and used to correct and update model calculation results (data assimilation). Because observations are often sparse in emergency situations, data assimilation procedures should be designed to handle cases with only a few measurements. Even simple dispersion models would benefit from data assimilation, and may also run faster to provide critical time-sensitive information to decision makers [42].

Rojas-Palma et al., (2005) describe an in-depth effort to integrate a suite of computer codes, with different degrees of complexity, into a European real-time, on-line decision support system for off-site management of nuclear emergencies (the RODOS system) [42]. The resulting modeling system describes the transport and dispersion of radionuclides in both atmospheric and aquatic systems, as well as their impact on the food chain.

RODOS predicts the values of many quantities that are likely to be of interest to decision makers after an accident (e.g. activity concentration in air, deposition, concentration in foods, external dose rates, concentrations in water bodies). The predictions will not exactly reflect the situation after an accident, as the models use a number of assumptions that are appropriate to the average situation across large areas of Europe, rather than to the particular conditions of the area affected by the accident. In the period immediately after the accident there will be a limited amount of information available from monitoring programs. To make the best use of this information, it is necessary to correct the RODOS predictions in light of the available measurements.

A 2 km RODOS test case was generated with a release point at Risø, Denmark, and 23 detector points surrounding Risø (Figure 7,8). The meteorological situation was a 7m/s westerly wind at 60 m above ground with neutral stability, and no rain.

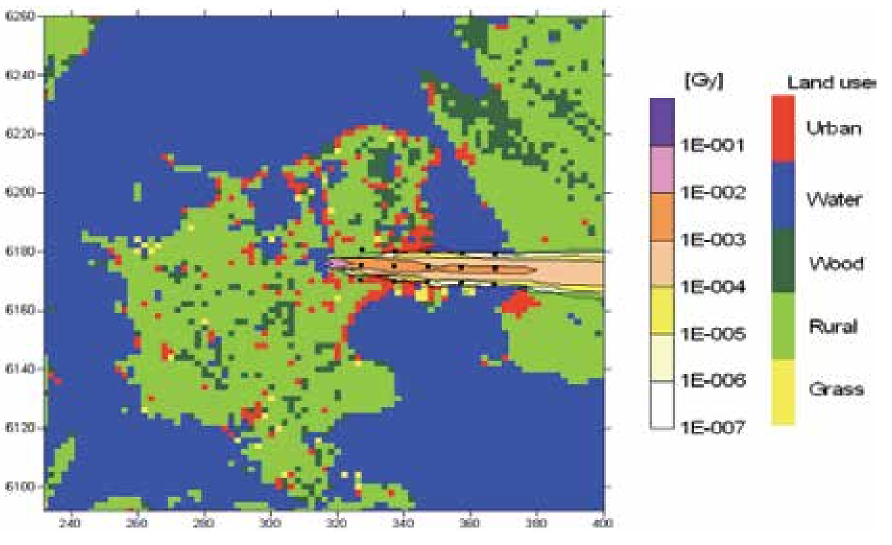

Figure 7. Gamma dose field from puffs in measurement generating run. The 15 detector points 10 to 50 km east of the release point are seen as black squares, the 8 points surrounding the release point are not marked. The background picture is the land use map [42].

In general, in off-site emergency management, data assimilation will prove useful throughout the different stages of the accident. In the assessment of the consequences during the early phase, in the improvement of prior assumptions based solely on expert judgement, and when there is a clear need for longer-term predictions to assess the radiological impact on the food chain.

4.5. Tsunami warnings and forecasts

A tsunami is a series of waves that can move on shore rapidly, but last for several hours and flood coastal communities with little warning. Tsunamis can be triggered by a variety of geological processes such as earthquakes, landslides, volcanic eruptions, or meteorite impacts. Throughout history, Tsunami's have taken many lives in coastal regions around the world. In

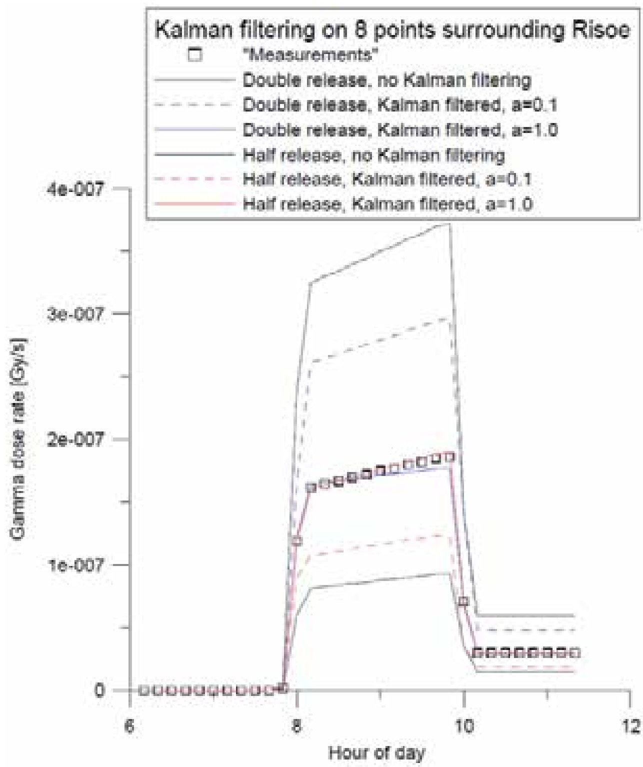

Figure 8. Gamma dose rates 50 km from the release point, right below the plume. Kalman filtering applied in runs with the release doubled and halved relative to that having generated the "measurements", and with different release rate uncertainties "a" [42].

the wake of the catastrophic 2004 Indian Ocean tsunami, which caused over 200,000 deaths and widespread destruction, many governmental organizations have increased their efforts to diminish the potential impacts of a tsunami by strengthening tsunami detection, warning, education and preparedness efforts [43].

In contrast to forecasting other natural hazards such as hurricanes or floods, near-real-time tsunami forecast models must produce predictions after a seismic event has been detected, but before the event arrive at the coast. These forecasts provide emergency managers near-realtime information about the time of first impact as well as the sizes and duration of the tsunami waves, and give an estimate of the area of inundation. The entire forecasting process has to be completed very quickly, to allow time for evacuation efforts. The entire forecast, including data acquisition, data assimilation and inundation projections, must take place within a few hours [44].

Titov et al., (2003) presented a method for tsunami forecasting that combining real-time data from tsunameters with numerical model estimates to provide site- and event-specific fore-casts for tsunamis in real time [45]. Observational networks will never be sufficiently dense because the ocean is vast. Establishing and maintaining monitoring stations is costly and difficult, especially in deep water. Numerical model accuracy is inherently limited by errors in bathymetry and topography and uncertainties in the generating mechanism. But combined, these techniques can provide reliable tsunami forecasts, as is demonstrated in the Short-term Inundation Forecasting (SIFT) system. The Method of Splitting Tsunamis (MOST) numerical model is run in two steps or modes. In the data assimilation mode, the model is adjusted "on-the-fly" by a real-time data stream to provide the best fit to the data. In the forecast mode, the model uses the simulation scenario obtained in the first step and extends the simulation to locations where measured data is not available, providing the forecast. An effective implementation of the inversion is achieved by using a discrete set of Green's functions to form a model source. The algorithm chooses the best fit to a given tsunameter data among a limited number of unit solution combinations by direct sorting, using a choice of misfit functions (Figure 9).

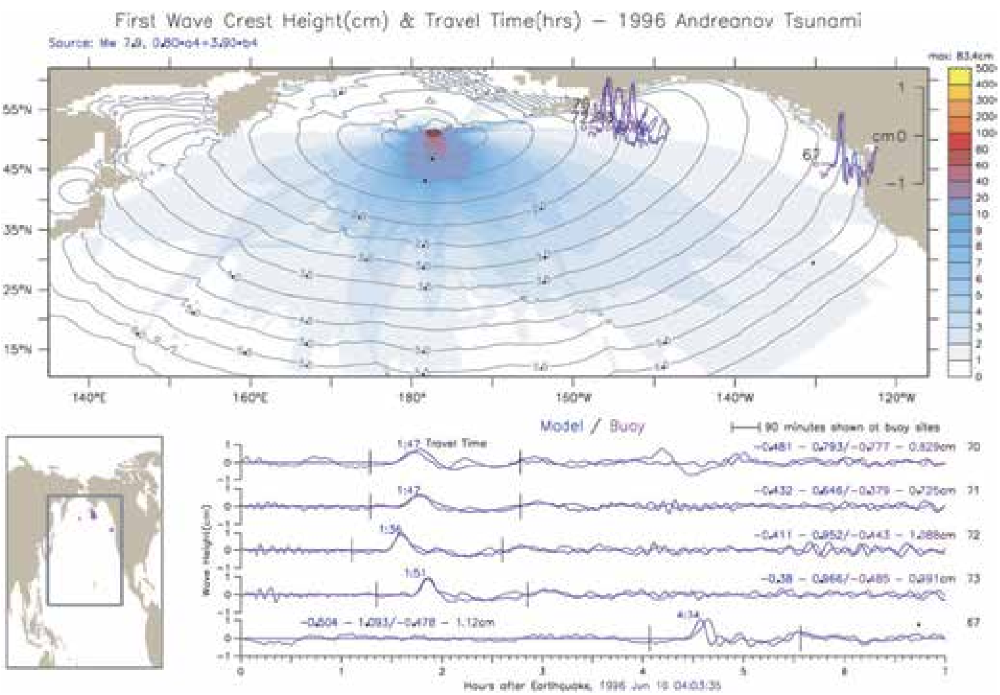

Figure 9. Results of MOST data assimilation for 1996 Anderanov Island tsunami [45]. Top frame shows the source inferred by the data assimilation (black rectangles show unit sources' fault plains), maximum computed amplitudes of tsunami from this source (filled colored contours), travel time contours in hours after earthquake (solid lines), and locations of the bottom pressure recorders. Bottom frame shows a reference map (left) and comparison of the model (blue) and bottom pressure recorder data (magenta).

5. Conclusions

This chapter provided an overview of data assimilation theory and its application to decision support tools, and provided 5 examples of operational data assimilation applications in disaster management. These included tsunami warning, radiation guidance and monitoring, flood and drought management, and weather forecasting.

Information about environmental conditions is of critical importance to real-world applications disaster management in areas such as agricultural production, water resource management, flood prediction, water supply, weather and climate forecasting, and environmental preservation. This information is usually provided to decision makers through Decision Support Systems (DSS). Observations are important components of DSSs, providing critical information that mitigate the risk of loss of life and damage to property. Environmental process models are used in DSSs to predict the temporal and spatial state variations, but these predictions are often poor, due to model initialization, parameter and forcing, and physics errors. Therefore, we must combine the strengths of environmental models contained within DSSs and observations and minimize the weaknesses to provide a superior environmental state estimate – data assimilation.

Data assimilation merges the spatially comprehensive observations with the dynamically complete but typically poor predictions of an environmental model to yield the best possible system state estimation. Data assimilation aims to utilize both our knowledge of physical processes as embodied in a numerical process model, and information that can be gained from observations, to produce an improved, continuous system state estimate in space and time. When implemented in near-real time, data assimilation can objectively provide decision makers with the timeliest information, as well as provide superior initializations for short term scenario predictions. Data assimilation can also act as a parameter estimation method to help reduce DSS bias and uncertainty.

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Chapter 5

Visualization for Hurricane Storm Surge Risk Awareness and Emergency Communication

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Additional information is available at the end of the chapter

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1. Introduction

1.1. The impetus for hurricane storm surge visualization

Visualizations of storm surge forecasts offer opportunities to improve risk awareness and communication of impending disaster in emergency situations such as a hurricane evacuation. A continuum of potential visualizations ranges from static maps, animated model output, to 3-D, immersive, and multimedia. In addition to risk communication for the public high-quality photorealistic geovisualizations might allow managers to investigate and explore forecasted surges and could reveal vulnerabilities and improve preparedness and response. Visualization can reveal three-dimensional space-time dynamics and provide insights for practical applications [1,2]. Scientific and visual analytic applications, for example, might include representations of model uncertainty or instability, such as "quality flags" symbolized on the model mesh or grid. With a focus on spatial and specifically "place-based" site and situation, geovisualization encourages analysis for multiple purposes and users, for interpreting spatial patterns, and using new multimedia and communications in a broader, informed way among academics, government managers, and stakeholders [3]. Hence, the challenge is to develop accessible technology that will provide proven and robust improvements to risk awareness and communication.

This chapter aims to evaluate existing storm surge models such as Sea, Lake, and Overland Surges from Hurricanes (SLOSH) and ADvanced CIRCulation (ADCIRC) models (described below) in order to identify constraints to their application for risk communication and to explore their potential for diverse forms of geovisualization. This chapter reviews some of the physical and computational limitations of surge models, the factors inhibiting spatial representation and visualization, and the applications of and hurdles for GIS post-processing and cartographic analysis and communication. A subset of computational techniques and geovisualizations are demonstrated that could improve upon the limitations inherent in the status quo approaches to representing surge and inundation model output. Applications and case studies that employ enhanced spatial resolution (down-scaled) grid output, enforcement of hydrologic connectivity in spatial models of inundation, and web-based, interactive cartography (2-D and 3-D) and 3-D, animated, and interactive-immersive geovisualization are described. Enhanced visualizations that provide better "on the ground" resolution of potential flooding events play an increasingly critical role in surge management and response, particularly in urban centers with dense population and infrastructure. While storm tracks, intensity forecasts, and tabular metrics have become ubiquitous, they do little to convey the highly localized effects of potential flooding at municipal or facility scales. The chapter concludes with a case study, reflects upon the constraints and limitations, and makes suggestions for avenues of future research.

1.2. General approaches to modeling water surfaces

Users of storm surge model output should realize that the surface of the storm tide is not flat. It has relief. In addition, local short-term variation in sea surface height results mostly from tidal forces and atmospheric conditions and is less influenced by large-scale ocean and estuarine circulation, or even gravitational anomalies. NOAA has defined three broad categories within which most storm surge models may be classified: modeled water surfaces, interpolated water surfaces, and single-value water surfaces [4].

Modeled water surfaces typically comprise inundation grids that are based on output from either a single hydrodynamic model, or a combination of hydrodynamic and wave models. Both the SLOSH and ADCIRC models provide modeled water-surface outputs. Water surface models may consider variables such as winds, atmospheric pressure, tides, storm duration, basin circulation, terrestrial obstructions, and other factors. Increased output accuracy of modeled water surfaces is the primary benefit that results from accounting for this diversity of variables. However, the models used to produce these surfaces require significant amounts of *a priori* information and often require expert-level knowledge of one or more modeling applications.

Interpolated water surfaces may be preferred when only a few water level observations exist for an area of interest. In such cases, the modeler must interpolate water level values between actual water level measurements within the study area. This method is often used and best employed for post-event analysis when modelers employ observed high-water data (e.g., high water marks or tide gauges) to reconstruct flood levels for a storm. This approach for predictive surge modeling may have limited value due to the need for observational input. Input of a relatively small set of observational data may also result in a coarse resolution representation of the water surface height that does not adequately reflect variations due to terrestrial topography and other factors. However, the variety and complexity of interpolation methods benefits greatly from analyst experience in spatial statistical techniques.

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Single-value water surface models create water surfaces representations based on a single numerical water level value that is draped over a study area. These models are often known as "bathtub" models as they simply raise the water surface evenly and consistently over an entire region. Single-value water surface models may be the best alternative where only one water level observation is available and other modeling techniques are impractical [4]. Static models such as these are also frequently developed as second-tier models that use the output from modeled water surfaces (SLOSH, ADCIRC) as input parameters. The case study explored later in this chapter makes use of this technique. Single-value models require minimal modeling expertise and for this reason are often employed by small organizations with limited resources. NOAA suggests that modeled and interpolated surfaces are generally preferred to the single-value method for better accuracy and more realistic depictions [4].

2. Spatial modeling of hurricane surge inundation

Storm surge models are often developed by coastal modelers who only give secondary consideration to visualization or the potential for integration into GIS and other decision-support systems. There are many advantages to incorporation of such model output into decision-support systems. Other data layers, such as evacuation routes, critical infrastructure, and vulnerable populations, can be analyzed in conjunction with the model results. The SLOSH model is the model that most emergency managers use for evacuation decision-making as well as for post-landfall guidance regarding the areas of likely inundation impacts and for disaster-response planning [5]. The model output is spatially coarse and provides limited assistance to site-specific operational preparedness, but rather produces a first-order estimate of storm surge potential.

A GIS model has been created to downscale the resolution of the SLOSH output, and to provide a more representative estimation of inundation. The downscaling of the SLOSH output uses a variety of elevation layers to illustrate the model's flexibility. The downscaled SLOSH outputs, shown in experimental form throughout this chapter, are compared to the other currently available SLOSH data products available in the State of North Carolina's geospatial clearinghouse, NC OneMap [6], to determine the best mapping, interpolation, and visualization techniques to represent a slow-moving Saffir-Simpson category 3 storm. Other comparisons that will be discussed include the areal extent of inundation produced by each model, the discrepancies of impacted critical infrastructure in the output and the measures of size and vulnerabilities of affected at-risk populations based on coarse- and fine-scale data.

2.1. Slosh

The SLOSH model was originally developed by the Techniques Development Laboratory of the National Weather Service (NWS) as a real-time operational surge forecast that could be run once the appropriate tropical cyclone track and pressure data became available. The networks of grid points comprising model domains are called SLOSH basins, and have been created for the Atlantic coast, Gulf Coast, Bahamas, Virgin Islands, Puerto Rico, as well as for parts of China and India. Each grid cell in a SLOSH basin has either topographic or bathymetric data associated with it. Updates are released as new elevation and bathymetry data for particular basins are provided by the U.S. Geological Survey (USGS) and the National Geophysical Data Center (NGDC). SLOSH basins are individually designed for the geography of a given coastal segment. Depending on the size and location of the particular area of interest, one might choose from an assortment of telescoping grids. The telescoping grid allows for higher resolution in coastal areas and less detail of open ocean. This reduces computing requirements compared to structured grids with uniform cells across a model's domain.

To obtain the surge levels, the SLOSH model requires several fairly simple meteorological parameters, at specified time intervals. The calculations use the latitude and longitude of the storm's eye, central atmospheric pressure, the radius of the maximum winds (RMW), storm track and speed [7]. Surface wind speed is not an input parameter in the SLOSH model [8], but rather "water levels are forced by an idealized wind field that depends upon the pressure deficit (Δp) and the radius of maximum wind (RMW) from the storm center" [5]. Houston and Powell [5] note that the calculations consider topography and bathymetry, but not astronomical tides, waves or rainfall flooding.

Every model, whether forecast model or numerical model, requires assumptions. Different models are designed to operate and handle these inaccuracies and assumptions in different ways depending on the end-product and the end-user. SLOSH has its own series of issues and limitations. One issue relevant to local application stems from the grid structure and basin formation. While the telescoping grids are efficient with regard to computational resources, they can fall short of local managers' desires when used to model inundation and surge to inform decision-making. For example, if the area of interest is a section of hurricane-prone Dare County, North Carolina, USA, the size of the cell is often too coarse to distinguish either surge on sound-side or back-barrier sites versus open-ocean shorelines, or the direction and interaction of both source area surges. Coarse resolution in this region occurs as a result of distance from the central arc of the SLOSH grid origin. Figure 1 illustrates how the cell size increases with the distance along an axis of the telescoping grid for an area of the Pamlico Sound SLOSH basin, and shows ambiguities of source-cell inundation (shown in hachures of selected grid cells overlaid on a greyscale of Light Detection and Ranging (LiDAR) elevation grids for the peninsular mainland and Outer Banks barrier islands). One solution for disambiguating the potential surge for finer-scale, local hurricane emergency management is to downscale the SLOSH surge forecast and incorporate finer elevation data and hydrologic modeling techniques in a GIS. To do so opens up a new set of issues and subject matter for research and geovisualization, but also new concerns for miscommunication and the mistaken assumption of precision as opposed to model forecast accuracy.

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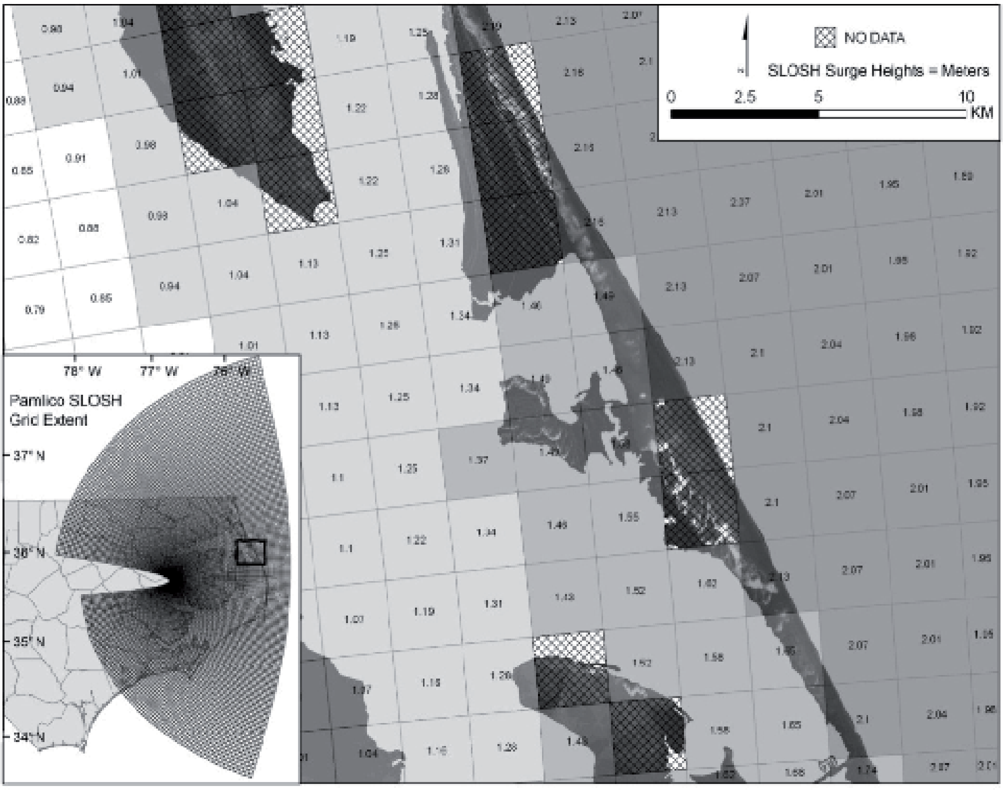

Figure 1. SLOSH surge model grid for Pamlico Sound Basin, North Carolina (inset) and a subset of the northern Outer Banks, illustrating telescoping grid scale, overlapping sound and ocean cells. Background shading of elevation corresponds to high resolution airborne LiDAR elevation values. Grid cells symbolize SLOSH forecast surge heights (meters) for a Category 2 slow-moving storm (Maximum-of-Maximums scenario) with hachured grid cells denoting ambiguities of source inundation (ocean vs. estuarine grid cells).

2.2. Surge visualization for emergency management

Coastal emergency managers have begun using visualizations in graphical programs to portray potential changes of ground-level inundation from floods and surges with photo-realism and software applications such as *CanVis* [9,10]. Technologies such as webmap services and GIS portals are now ubiquitous and able to distribute storm surge models such as ADCIRC output and related maps and animations produced using real-time forecasting [11]. The Louisiana Geographic Information Center's 2009 Hurricane Response Mapping is one example that has linked the National Hurricane Center (NHC) products with custom-developed Internet map servers [12], while the NC Coastal Hazards Portal (NC COHAZ) is an experimental platform that integrates multiple hazard layers in separate thematic map interfaces (e.g., coastal erosion, surges, and real-time hazards) [13]. In addition, local emergency managers have GIS resources and personnel who can employ the GIS products like SLOSH from the NHC. Some may already be using GIS software, such as FEMA HAZUS for loss estimation, in their operations [14]. Output generated by HAZUS may include coastal flood models corresponding to 100-year return interval flood events, based on FEMA flood modeling. These output data can be rendered in a desktop GIS and even draped onto high resolution LiDAR DEMs with building footprints rendered in 3-D (Figure 2). The outputs of generic inundation or hydrologic models are often erroneously applied to a specific, approaching hurricane to meet the desire of emergency management officials for data and forecasts specific to the potential track, intensity, and other factors of their storm. The result can be very inaccurate and grossly erroneous visuals. Therefore, anyone desiring to visualize forecast surges from hydrodynamic models must first select the most appropriate surge model output data and cross-reference this to the spatial context, resolution, and time-delimited needs of emergency managers. SLOSH Maximum Envelope of Water (MEOW) and Maximum of Maximum (MOM) of MEOW files are provided with the SLOSH Display System [15] and are exportable to ESRI shapefile format for GIS analysis. The SLOSH Display System provides access to a library of pre-run simulations, including a graphical user interface (GUI) to query and extract appropriate MEOW or MOM files. The system can be used as a stand-alone decision support tool or in conjunction with other software (such as FEMA's HAZUS-MH [16], Sea Island Software and FEMA-funded HURREVAC [17], PC Weather Products' HURRTRAK tracking software [18], or within a GIS). In general, the MOMs provide forecast guidance for up to 5 days of pre-landfall operations and decision-making. MEOW surge files, depending upon the local evacuation dimensions, routing issues, and congestion factors, can be used to guide decision-making closer to the actual critical decision time. A minimum clearance time of 24 to 48 hours is typically desired, and this often prompts the use of MOM and MEOW surge estimates for guidance. Prior to landfall, hurricane track and intensity forecasts are usually inadequate to judiciously postpone a decision, unless tropical storm-force winds arrive during an evacuation. Furthermore, antecedent rainfall and forecasts from the NWS's Hydrometeorological Prediction Center [19], time of day, tides, and local logistical factors are also used in response decisions and the selection of surge guidance.

The MEOW output characterizes maximum surge level associated with a hypothetical storm at any time for every grid cell in a SLOSH Basin. The MEOW represents the worst-case flooding scenario possible from a threatening hurricane of a given category, size, and particular track direction [20]. MEOW files do not directly incorporate tidal conditions, but these may be generalized and either added or subtracted in software like the SLOSH Display System.

A MOM is the maximum of a set of MEOWs, forming a composite of the maximum water levels at every grid cell for all hurricanes of a given category and for water from all directions. There are only 5 MOMs for each SLOSH model basin, each representing a single storm category. As with MEOWs, the MOM does not factor in tides. However, the SLOSH Display System provides easy access to the library of pre-run simulations, and to a GUI to query and extract appropriate MEOW or MOM files and to incorporate approximate tidal conditions at landfall (low, mean, or high).

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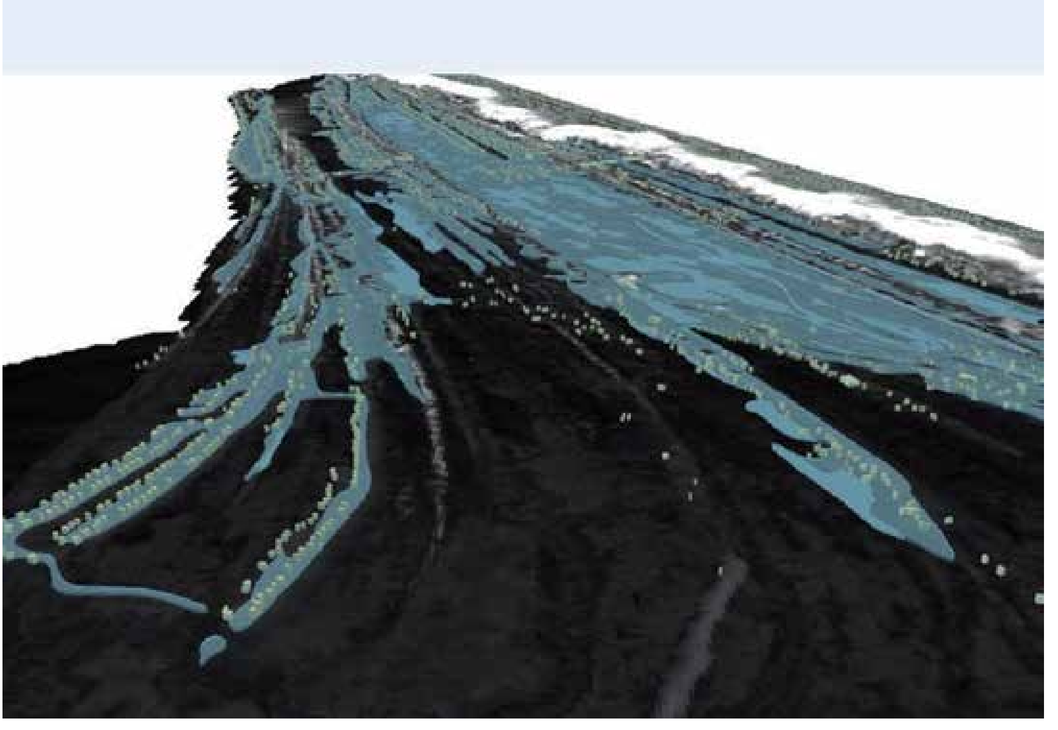

Figure 2. Orthoperspective of SLOSH surge model for northern Outer Banks (Kitty Hawk, Southern Shores, and Duck) illustrating digitized inundation contours for a SLOSH MOM category 2 slow-moving storm, superimposed over elevation with building model footprints extruded in 3-D. Lighter tones on the background DEM depict high dunes (upper right) and beach ridges for the relict Kitty Hawk Woods coastal spit (foreground.)

2.3. Surge modeling limitations

Every model, whether forecast model or numerical model, produces errors, uncertainties, and contains assumptions. Models are designed to handle some of these factors in different ways that depend upon the end-product and the end-user. SLOSH is no exception to this. It has its own series of issues and limitations. The limitations of concern here are primarily associated with grid-type, basin, and environmental parameters.

2.3.1. Grid spatial resolution

The first issue to be addressed is grid-type and basin geography. While the telescoping grids are designed to limit computational resources needed to run the model, they can fall short for surge inundation visualization. For example, if the area of interest is a section of Dare County, North Carolina, a highly hurricane-prone area, the size of the native SLOSH cell is too coarse for a site-specific visualization of surge, primarily because cell size increases with distance from the central arc of the origin of the grid. This limits the effectiveness of inundation forecasts for an emergency manager depending upon SLOSH output to identify problem areas, site vulnerabilities, relief staging areas, evacuation orders, shelters of last resort, or rapid response, reentry, and recovery operations. Later in this chapter, a method to down-scale and visualize some of these sensitivities is evaluated.

2.3.2. Forecast storm track uncertainty, waves, and tides

Limitations of the model remain a concern, particularly of concern is the need to simultaneously account for wave heights, astronomical tides and the forcings created by river-water levels that are not included in the model. Nonetheless, a set of MEOW grids are derived from hundreds of storm-track scenarios (based on varying the direction of landfall), forward-speed scenarios and tides scenarios (mean and high). Forward-speed scenarios predict surge variation according to increments of 5, 10, or 15 mph (8, 16, or 24 kph), which improves the earlier "slow" (<18mph, 29kph) and "fast" (>18mph or 29kph) scenarios. Emergency planning also benefits from the simpler derivation of MOM files, which characterize the maximum of MEOWs and provide a consistent worst-case picture of storm surges at specific intensities (Saffir-Simpson category 1-2, 3, and 4-5 are aggregated in traditional inundation contour maps), notwithstanding the limitations of antecedent precipitation and river-flow input, astronomical tides and waves.

Physical processes are fully represented in SLOSH. Temporal considerations dictate the use of pre-run models for 'worst case' estimates or reliance on single-run deterministic track runs (dependent and highly sensitive to track or intensity forecast errors). Thus, while SLOSH remains the NWS's *de facto* standard and operational model, it is also more often used in conjunction with forecasts from ADCIRC based on deterministic runs within approximately 24 hours of hurricane landfall. The model's limitations remain a concern. Nonetheless, a set of MEOWs output grids are derived from hundreds of storm-track, forward-speeds and tidal scenarios.

2.3.3. Currency and near-real-time utility

Real-time wind-field predictions or measurements are also lacking in SLOSH output. The wind models used by SLOSH can vary greatly from a storm's actual wind field in time, space, and magnitude. This was the case for hurricane Emily in 1993 when the eye wall crossed eastern Pamlico Sound in North Carolina causing very strong surface winds, and the SLOSH model "…significantly underestimated the surface winds and resulting storm surge observed on the Pamlico Sound side of Cape Hatteras" [5]. In further comparisons of SLOSH-model wind fields with observed winds, it was concluded that the use of the NOAA Hurricane Research Division's real-time wind-field data could be used to improve the SLOSH model's estimated values.

2.3.4. Surge uncertainty and elevation

The accuracy of SLOSH is also limited by elevation data accuracy and resolution. Surge heights are represented by a +/- 20% accuracy of predicted maximum surge height [21]. For instance, a prediction of 15-foot surge (4.57 m) might actually produce a range of prediction from only 8 to 12 feet (2.44 to 3.66 m). Since SLOSH computes storm tide elevations in National Geodetic Vertical Datum 1929, it is at least cumbersome to recalculate values to match extensive LiDAR DEMs in vertical meters and North American Vertical Datum 1988 (feet or meters). By design, SLOSH does not incorporate fine-scale landform features and potential inundation thresholds (such as the breaching of inlets in barrier islands, dunes, or engineered features such as levee). The grid resolution of SLOSH is variable and relatively coarse scale, with most cells on the order of 1 mile x 1 mile (1.6 km x 1.6 km). Elevations for grid cells are based on the averages of underlying DEMs, so the actual cell may really possess a non-normal distribution of elevation. Levee areas or areas protected by natural ridges may be overgeneralized. Furthermore, flooding in SLOSH cells is considered aspatially, wherein each cell is flooded as if it was inundated irrespective of the direction of flooding.

To assess the impacts of errors in elevation models as they relate to downscaling of SLOSH values to a finer grid, a Monte Carlo simulation was conducted. The primary goal of the downscaling model is to predict the area of inundation by utilizing the SLOSH model output and a DEM. The degree of positional error is related to the uncertainty in vertical and horizontal measurements and issues surrounding datum conversion, projections, and interpolation methods. If using high resolution airborne LiDAR, the dense sampling of LiDAR points reduces projection and interpolation errors to practically negligible for shorelines [22]. Airborne topographic LiDAR is increasingly available with a horizontal accuracy of +/-2.0 m and a vertical accuracy of +/-0.30 m (even as fine as +/- 5 to 10 cm). This amount of potential error may cause the position of the inundation zone to fluctuate either landward or seaward, but far less than any other modeling approach. Liu et al. [22] note that "the error inflation factor is determined by the foreshore slope. For each beach with a gentle surface slope, a slight vertical error will be amplified and translated to a larger error" [22]. Nonetheless, larger spatial error could result in poor decision making in the face of an extreme coastal event. The Norfolk, Virginia case study provides some insight into urban facility managers' concerns and the possible ramifications of error.

3. Geovisualization

The experimental demonstrations below primarily analyzed SLOSH and North Carolina LiDAR elevation data. The SLOSH data were obtained from two sources, the SLOSH Display Package [15] distributed by NOAA NHC and the NC Center for Geographic Information and Analysis (NCCGIA) data from NC OneMap online GIS repository [6]. The SLOSH data from NOAA are used in the downscaling model, and input as either MEOW or MOM file. The SLOSH MOM data are a "worst case" scenario, in which multiple hurricane tracks are used and landfall can occur from multiple directions for a given storm category and speed [15]. Elevation data were obtained from the North Carolina Flood Plain Mapping program in a variety of spatial resolutions (NC Floodplain Mapping Program uses 50 feet (15.24 m), 20 feet (6.1 m), and 10 feet (3.0 m) resampled elevation grids).

3.1. Downscaling and spatial analysis

The spatial modeling methods employed here include a combination of vector- and raster-based analysis, as well as automation using ArcGIS Model Builder. The downscaling model has the flexibility of incorporating a user-defined elevation grid and allows future iterations of the model to estimate inundation as new data become available. This is a substantial improvement over the traditional method of producing downscaled inundation maps, which were created with hand- digitized USGS topographic maps. The model also allows for the input of deterministic SLOSH model output from the NHC in the event of an actual storm, giving emergency managers more accurate predictions of area inundation, the affected populations and evacuations routes.

Most inundation models allow for the flooding of interior sections of land as water levels rise, that are, in reality, disconnected from water sources (either a bay or the ocean), an issue known as hydro-connectivity. This is typically referred to as a "bathtub model" and provides inaccurate representations. Hydro-connectivity is established in the model applied here by using a cost-distance function that allows inundation only from a source raster of water (i.e., a bay or the ocean). This generates better results than those produced using single-pixel or contour-based bathtub inundation.

The output from the SLOSH downscaling model is a raster grid. Once the downscaling has been computed, map algebra calculations are used to compare differences in inundation between the three elevation resolutions, and ultimately to a rasterized NCCGIA data. The analysis will be conducted for Dare County, North Carolina, with a special focus on Roanoke Island and the city of Nags Head. In subsequent geovisualization techniques, the LiDAR-based and SLOSH-downscaled surge inundation calculations are used.

3.2. 3-D Geovisualization

In addition to official updates from the NWS, other groups have worked with model output to refine the resolution for better visualization and more accurate representation of inundation. The size of the cells to the south of Kitty Hawk, North Carolina, for example, is not always appropriate for visualization. Figure 1 shows that single SLOSH cells may cover an entire swath of barrier island and in the current example (SLOSH category 2, fast-moving MOM) that stretch of barrier island would be inundated with between 1 and 2 meters of water.

The NCCGIA inundation and SLOSH inundation polygons are aggregated using the available 1:24,000 USGS topographic maps (approximately 5-foot or 1.5-meter contour interval). Areal interpolation was used to create an overlay to delimit inundation according to lumped categories 1 and 2, category 3, and categories 4 and 5 hurricanes. The result was a polygon file that exhibits inundation with relatively fine detail (Figure 2). These elevation data, however, have been vastly eclipsed by LiDAR bare-earth models with 15-cm vertical accuracy and 5- to 20-m spatial resolution.

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3.3. Monte Carlo error modeling

The procedure used in the assessment of accuracy errors in the prediction of inundation area was similar to those used by Liu. First, the levels of error and uncertainty (bound of potential error) of the source elevation model were determined. Then using a pseudo-random number generator and the bound of potential error, 30 random permutations were created. All 30 had similar means and standard deviations and were therefore determined to be within the realm of possible error. The inundation model was run on each permutation and their differences were recorded.

3.4. Case study: Hurricane Irene 2011 urban storm surge in Norfolk, Virginia, USA

In August 2011, Hurricane Irene drew close to the southeastern U.S. coast (Figure 3), eventually making landfall at Cape Lookout, North Carolina at 8 a.m. EDT, August 25, 2011 as a category one hurricane with maximum sustained winds near 85 mph. The storm moved more slowly than expected over North Carolina, with its center crossing over Norfolk and southeastern Virginia on August 27.

The path of Hurricane Irene was accurately predicted more than four days in advance by NOAA's NHC [23]. As the storm approached, the Emergency Management team at Old Dominion University (ODU) in Norfolk, Virginia began creating impact scenarios and making contingency plans. Potential flooding was of critical concern for a number of reasons. The university's population of 25,000 students has become more residential over the last few years and includes a large number of international students that have no other permanent U.S. residences to serve as temporary shelter. ODU is in a highly urbanized, mixed-use setting within Norfolk, is adjacent to several tidally influenced surge-prone water bodies (Chesapeake Bay, the Elizabeth River, and the Lafayette River) and has restricted transportation routes and limited evacuation corridors. A 2007 surge study in Norfolk revealed that census blocks near the university had some of the highest vulnerability to hurricane storm surge in the region [24].

The inherent challenges related to impending surge from an oncoming storm were exacerbated by Irene's timing as she was expected to pass over ODU during the "move-in" weekend for residential students. University administrators were faced with decisions such as: *Should students be allowed to move in prior to the storm? Do we evacuate residents and, if so, to where? What critical infrastructure is likely to be exposed to flooding? Should assets be relocated to mitigate damage? Which areas require temporary storm protection (sand bagging, etc.)? Which areas may be isolated during the flooding?* The best available information regarding potential storm surge flooding was required to confidently answer these questions. In June 2011, the Hampton Roads Planning District Commission (HRPDC) had compiled a report addressing storm-surge vulnerability in southeastern Virginia [25]. While this report estimated that over 100,000 people may be displaced by a Category 1 storm, regional surge maps were not of sufficient resolution to be useful at neighborhood or facility scales. To remedy this scale issue, independent GIS modeling and analysis of the surge potential associated with Irene was performed at the university.

Figure 3. NOAA GOES-13 satellite showing Hurricane Irene on August 25, 2011 at 10:10 a.m. EDT.

Localized surge inundation models were created for the ODU campus following three basic steps outlined by NOAA: 1) obtain and prepare elevation data, 2) determine water levels, 3) create MEOW inundation maps for the study area from the SLOSH display package. At the time of Irene's approach, ODU already possessed the best available high resolution (1-foot or 0.3-m grid) LiDAR-derived elevation data having an accuracy of +/-.30 m, referenced to the National Geodetic Vertical Datum 1929 (NAVD29). Horizontal and vertical datums (reference heights) must match when creating and overlaying elevation surfaces. If they do not, error will be introduced into the flood model elevation surface [4].

Since its inception, the SLOSH model has been used successfully by numerous emergency management agencies and forecasters to predict storm surge and assess flood potential [26]. Given the longevity and widespread use of the SLOSH model, ODU elected to use SLOSH model water level output and to evaluate the probabilistic SLOSH forecasts [27] for a "bathtub" campus flooding model. In this hybrid approach, iterative flood surfaces were developed from the most current storm track and intensity forecasts provided the NWS and NHC. Immediately prior to Irene's landfall, the most likely storm parameters were: a category 2 storm bearing NNE at 14 mph (22.5 kph) during mid-tide with the tide rising. Thus, this case using SLOSH, local LiDAR and 3-D GIS data provides insight into fine-resolution, urban applications of these modeling and geovisualization techniques.

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4. Results and discussion

4.1. Downscaling and spatial analysis

To exploit the available LiDAR DEMs, the model used accepts either raw MEOW/MOM data or deterministic runs when available and it outputs similar results. This dataset adds the option of including high accuracy LIDAR DEMs as they become available and using deterministic runs when they are made available by the NWS. The model inputs SLOSH, LiDAR DEMs, and water raster data and computes a cost-distance function with enforced hydro-connectivity to the bay or the ocean. The inundation can only originate from open-water sources and this eliminates the non-connected inundation polygons associated with "bathtub" models. Model output from three different elevation grids (2.4, 6.1, and 3.0 m resolution) generated similar results. The inundation grids from the 20-foot resolution (6.0 m) downscaled inundation model were overlaid with the NCCGIA interpolated contour-based flood prediction (Figure 4). The contour-based surge model expects more inundation on the Outer Banks relative to data indicated in LiDAR DEMs.

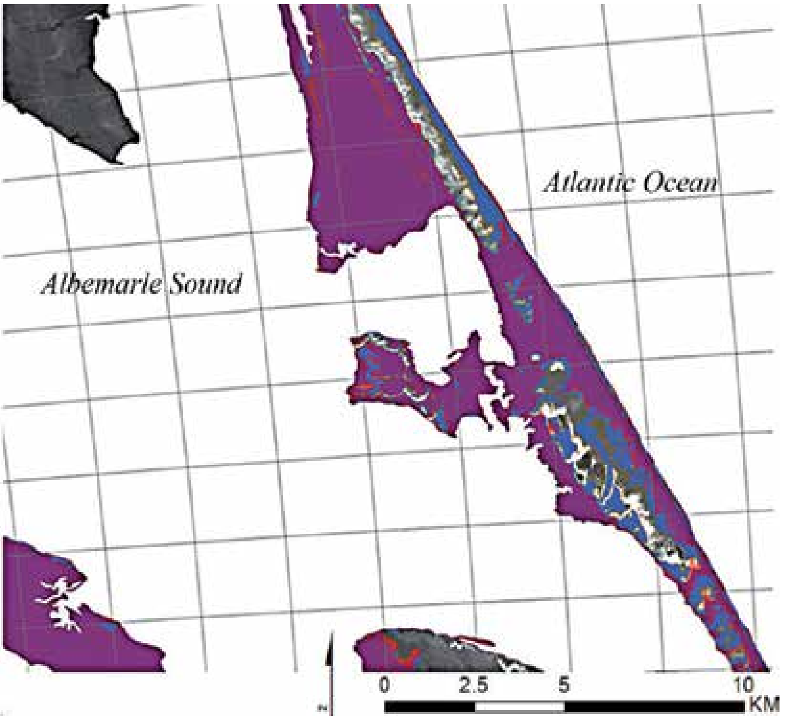

Figure 4. The comparison of results of inundation grids from the 20-foot resolution (6.0 m) downscaled inundation model and the NCCGIA interpolated contour-based flood prediction model from USGS 30 m DEMs (red-only), areas of agreement (purple), and areas of LiDAR-based potential inundation (blue-only) for a subset area of the Outer Banks and northern tip of Roanoke Island (at bottom). Shades of light grey surrounded by surge areas are relict medaño dunes and, in Jockey's Ridge State Park, a star dune.

4.2. Geovisualization

An experimental program to visualize and communicate storm surge risk and raise awareness to the hazard prompted the development of 3-D models and a series of photorealistic, interactive, and animated geovisualizations. In cooperation with Dare County (North Carolina) Office of Emergency Management, the Renaissance Computing Institute (RENCI) East Carolina Engagement Center [28] developed 3-D building models using Google Sketchup software. Seventeen prominent landmarks were selected in consultation with the emergency manager and community leaders. In addition, building footprints and heights were incorporated within surrounding 1-km buffers of the landmarks from the county's GIS database and extruded in 3-D using ESRI ArcScene software. SLOSH MOMs were also incorporated and matched to the elevation datum used in Google Earth. All landmarks were evaluated for availability on the Google 3-D Community Warehouse so that users examining existing building models would see the correct objects. For each focal landmark, a visualization was created and included: 1) a 3-D ortho-perspective view for use as representative graphic in presentations and briefings; 2) prerecorded video for download or playback on the Internet (e.g., a Windows Media Player (.wmv) file or FLASH); and 3) an interactive, downloadable master Keyhole Markup Language (.kmz) file with embedded 3-D inundation, landmark and building objects. All data were organized into a library hosted on the RENCI SurgeViz 2010 website [29].

These products were used in diverse venues, displayed to different audiences and employed in several activities which enabled a qualitative evaluation of their utility. Presentations and interactive educational use was facilitated in public school presentations to elementary, middle- and high school students on the Outer Banks to inform them of their local storm-surge potential. The library of graphics was compiled into a set of Microsoft Office Powerpoint slide presentations for use by emergency managers and forecasters for briefings and training exercises. These presentation graphics are organized by SLOSH MOM category and geography allowing for quick selection of appropriate surge levels and for specific sites during an emergency. Animations of short 3-D fly-throughs for each location and each MOM category provide snapshots of potential inundation regionally and are useful for risk communication. Finally, the interactive 3-D content of the.kmz files enabled public download and private exploration. All of these products could also be used in hurricane exercises and drills, and in June 2010 each product was demonstrated in a mock "tabletop" exercise for the Dare County Control Board using a hypothetical Hurricane Felix, a MOM category 2, fast-moving storm striking near the North Carolina-Virginia border. Each of these uses was deemed successful by their audiences (Figure 5).

Although qualitative successes of these geovisualization applications are difficult to quantify, particularly in a real emergency, it is possible to identify several problems that occurred in their production and delivery. First, the integration of local building data, storm surges, Google imagery and elevation data created some asynchrony and error. For instance, a custom building model in Sketchup was incorrectly located on the Google Imagery on a street opposite its true location. The model was submitted to the Google 3-D Warehouse and accepted, eventually also appearing in Google's building database for Google Earth users.

However, the placement error was only discovered later and took some months to correct. Additionally, very high spatial resolution aerial imagery in the Google Earth image database sometimes did not coincide with building footprints and surge data. In some cases, dynamic changes (e.g., dune construction or destruction) on the barrier island actually altered potential surge patterns. In other cases, edges and misalignments between the aerial imagery and building data were revealed that may indicate that there was either geometric error in the aerial data or positioning error in the mapped buildings. Nonetheless, the graphics seldom failed to impress emergency managers and oftentimes generated requests for similar products for other municipalities.

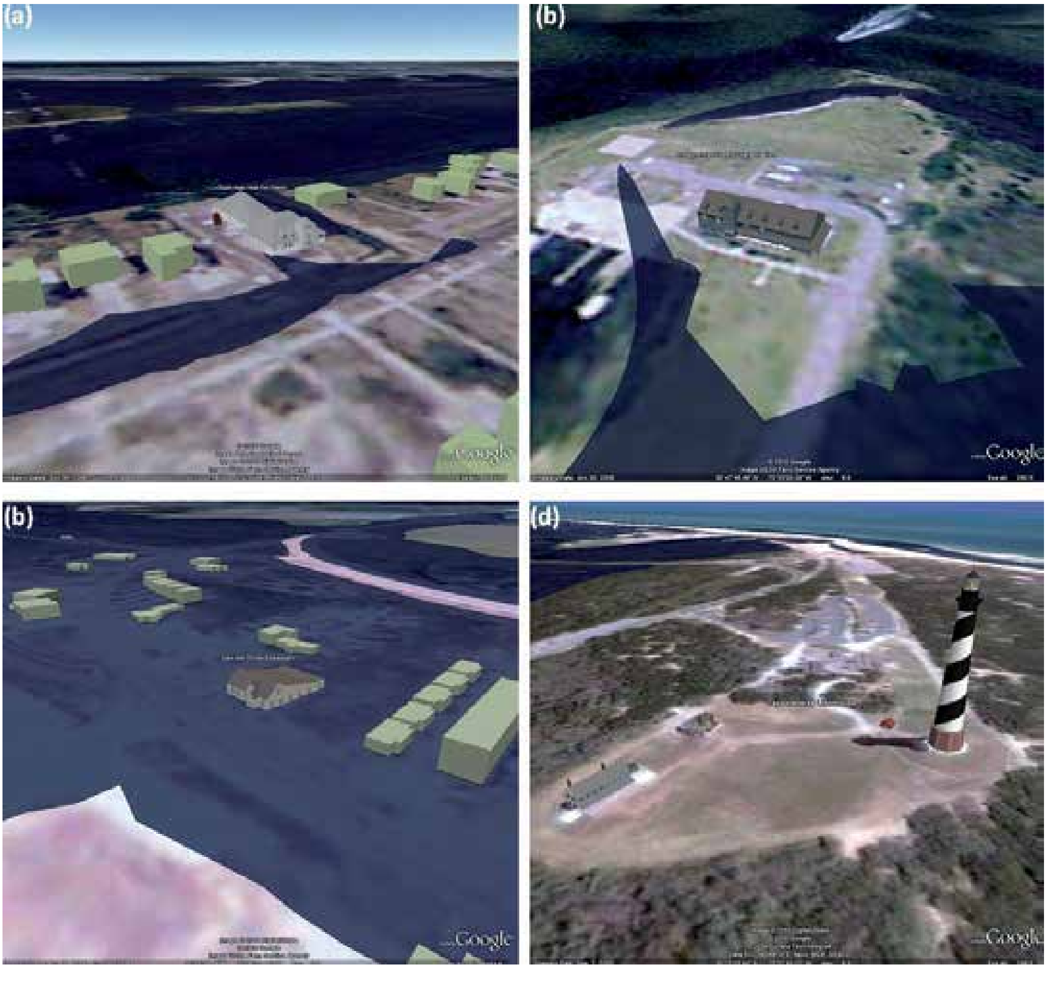

Figure 5. Screenshots of customized.kmz files with building footprint models, landmark 3-D buildings, and SLOSH MOM output storm surge inundation layers superimposed over Google imagery for a category 2 storm affecting the Outer Banks, North Carolina, (a) South Nags Head fire station, (b) US Coast Guard Oregon Inlet station, (c) Sam & Omie's Restaurant at Whalebone Junction, South Nags Head, and (d) Cape Hatteras Lighthouse, Buxton.

The static, apparently non-destructive impact of surges evident in the geovisualizations generated suggestions for future improvements to reinforce that these are downscaled surge models and only approximations of potential worst-case scenarios of SLOSH MOMs. They may not occur at all of these locations and they also carry the limitations of the SLOSH model with respect to accuracy and accurate portrayal of wave energy impacts. To scientifically and visually evaluate the potential error also found in the elevation data, a Monte Carlo error model was also applied.

4.3. Monte Carlo error modeling

The initial Monte Carlo simulation of error in the DEM focused on results around the Town of Manteo, Roanoke Island (Figure 6). Individual cells of the DEM were randomly perturbed by error following the Gaussian error distribution for +/-15 cm vertical error. For each new DEM, the downscaled SLOSH inundation model was run to delineate possible alternative inundation zones. The analysis reveals that in a minority of cases in the simulation, a depression in the study area is inundated (that is *not* delineated in the original DEM.) This result prompted further analysis and exploration of cartographic representation.)

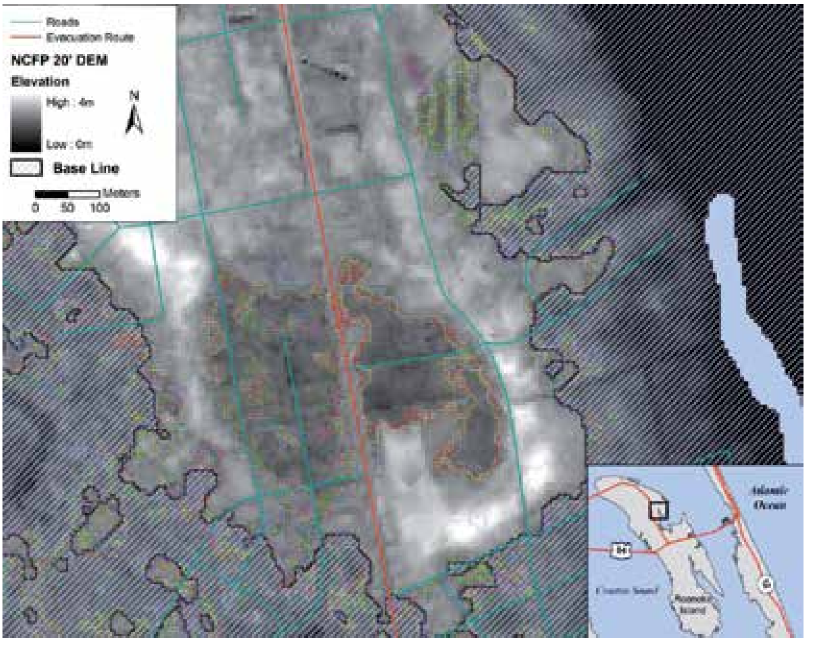

Figure 6. Prototype of Monte Carlo simulation analysis of inundation sensitivity, showing original storm surge inundation model with existing 20-foot (6-m) DEM (hachures and bold boundary line) and iterative results from the perturbed error modeling in alternate color polylines for an intensive study area of the Town of Manteo, North Carolina. This shows 30 possible inundation zones, each is shown in a different color (and the original outline in bold with a hachured inundation zone). The dark tone area of the DEM at center illustrates a low zone, bisected by a major road, of low-lying ground that the current DEM does not inundate but that several runs of the Monte Carlo simulation found to be inundated.

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To further evaluate the technique for evaluating sensitivity of inundation confidence, the analysis applied variable transparency and shading to more precisely identify uncertain areas in the DEM in a low-lying shore area (Figure 7) and on a barrier island segment (Figure 8). The cumulative confidence of inundation for 30 simulations was calculated by tallying the number of runs that resulted in each cell being inundated. The cells were shaded in proportion to the number of simulations that produced flooding. Results of this symbolization allow more precise delineation of potential DEM error and flood vulnerability. On the island, there seemed to be more inundation agreement, except in the boundaries around dunes and the upper beach berm zone. However, the zone of inundation appearing over water (in the later orthophoto) also underscores the potential for temporal asynchrony (the DEM for Figure 8 is from 2002 whereas the aerial orthophoto is from 2010) or error. Beach erosion at this location is not reflected in either the DEM or in the downscaling inundation model.

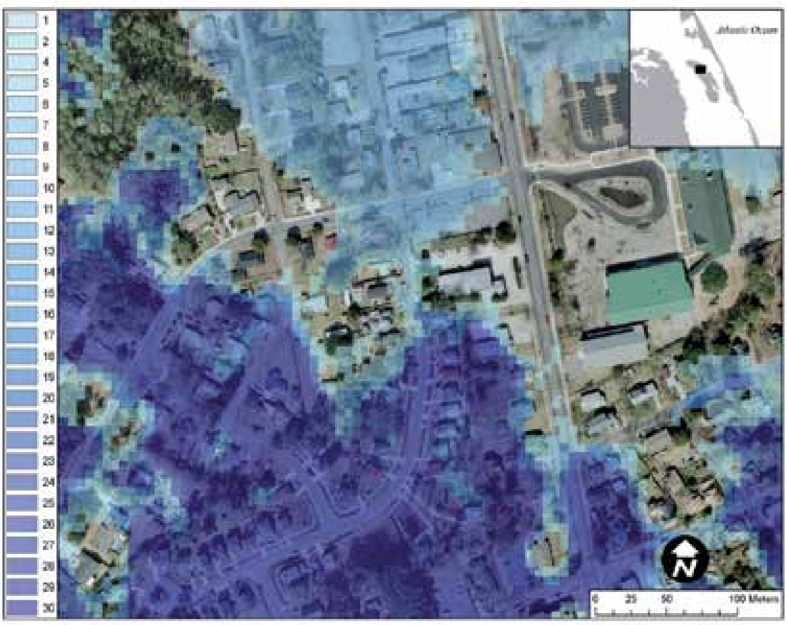

Figure 7. Sensitivity analysis of DEM inundation potential for a category 2 SLOSH MOM surge in Manteo by tallying inundation of Monte Carlo simulation runs. Transparency and saturation are proportionately modulated to the number of model runs that predicted flooding.

Over most of the tested portions of Roanoke Island and Cape Hatteras, there is marginal spatial variation in the inundation area. However, some surprising patterns are evident where there is likely to be an underlying representation limit. In low-relief coastal plain landscapes and barrier islands, features such as salt marshes, shrub and maritime forests, canals and drainage ditches and narrow features such as dune crests impart variable elevation error, even in LiDAR DEMs, and these may restrict the accuracy of inundation models of any kind. In our study area, one area exhibited a drastically different inundation zonation in the simulation. In Manteo (Figure 7), an extensive area was predicted to flood in several simulation runs but not based on the original DEM. This highlights the need for future floodplain-delineation sensitivity research and a need to better understand downscaling and surge inundation modeling error to address the propagation of inherent versus processing error.

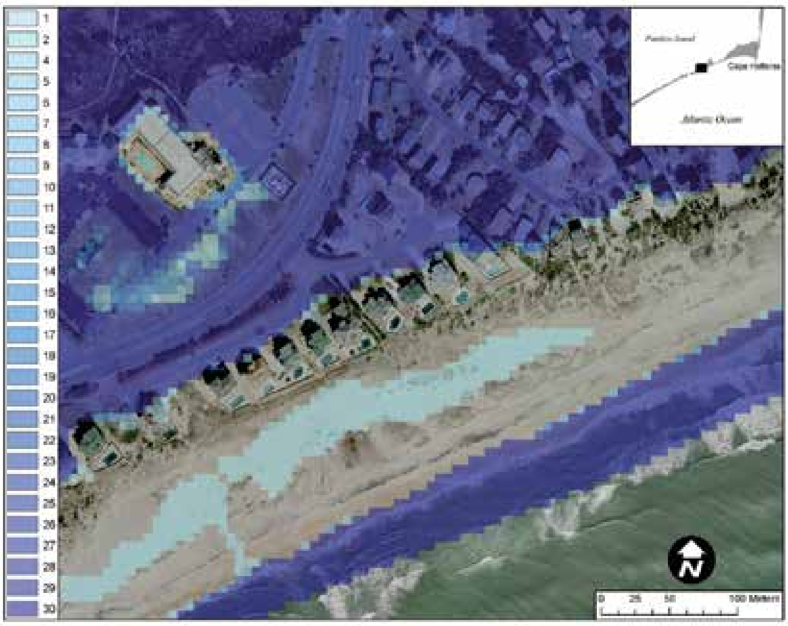

Figure 8. Results for Monte Carlo error analysis for a SLOSH category 2 MOM surge potential for southern Hatteras Island.

4.4. Hurricane Irene in Norfolk case study

The SLOSH model was run using these inputs to create a modeled water surface for the operational analysis of impacts from Hurricane Irene (Figure 9). SLOSH model runs predicted a storm surge of approximately 6.4 feet (2 m), referenced to NGVD29 vertical datum. However, the SLOSH model does not include precipitation, wave action, and the effects of tidal phases (spring/neap), each of which can have a significant impact on flooding. As Irene's landfall coincided with a spring tide and heavy rains were expected, 1.5 feet (0.5 m) of additional urban flooding was added evenly across the modeled surface. A raster surface approximating an 8-foot (2.4-m) water level was draped uniformly upon both 2-D and 3-D representations of ODU. Two-dimensional maps, graphics and GIS overlay-analysis proved valuable for determining the buildings and assets that required the most pre-storm intervention and flood-mitigation effort.

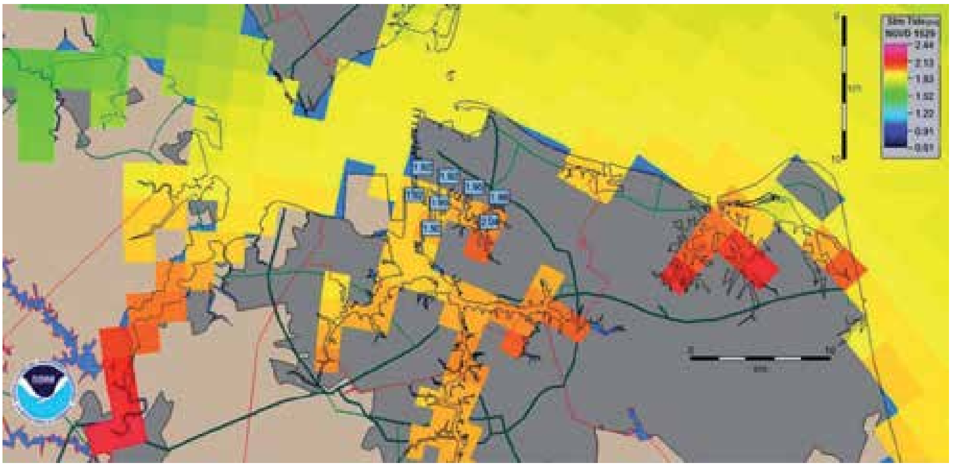

Figure 9. SLOSH model for Hurricane Irene with storm surge values flagged near ODU campus.

The 2-D portrayal of LiDAR estimated inundation reveals the surge following the low topography of an historic creek through the middle of campus (Figure 10). Water backing up the tributary is forced overbank onto streets, in many instances using streets as flood channels. Figure 10 also demonstrates the simultaneous, multivariate mapping of flood inundation depth (level of water above the ground surface) and the heights of the bases of building, important for protecting facilities and planning for emergency services. Flooded streets and impediments to vehicular or pedestrian traffic are also incorporated into this cartography. Three-dimensional visualizations employing enhanced cartographic techniques were more instructive to emergency management personnel for visualization of potential high-flood storm conditions (Figures 11 and 12).

Based upon the flood surfaces depicted in these visualizations, emergency management and facilities staff at the university were able to prioritize their efforts, spending time and resources more effectively. Non-fixed assets in the two residence halls predicted to be most severely impacted by flooding were relocated or elevated. Sand bags were deployed at critical seepage points for several structures. Several parking lots were also cleared based on the indication that they would experience flooding of 2 feet (0.6 m) or more. Ultimately, Irene weakened and turned towards the northwest as it passed through the Norfolk area, resulting in flood heights of approximately 2 to 3 feet (0.6 to 0.9 m) which was lower than predicted by all surge forecasts.

With all storms, the amount of flooding depends on hurricane intensity, tidal phase, rainfall, wind-driven waves, storm speed and duration, prior precipitation, and other factors [21]. ODU and southeastern Virginia were fortunate, as the northeast quadrant of the storm which always has stronger winds and higher surge, moved off the coast rather than inland. Despite the discrepancy between predicted and actual flooding, ODU's modeling and visualization of Irene's surge potential are viewed as having been a valuable resource and is now incorporated as standard operating procedure for future hurricanes.

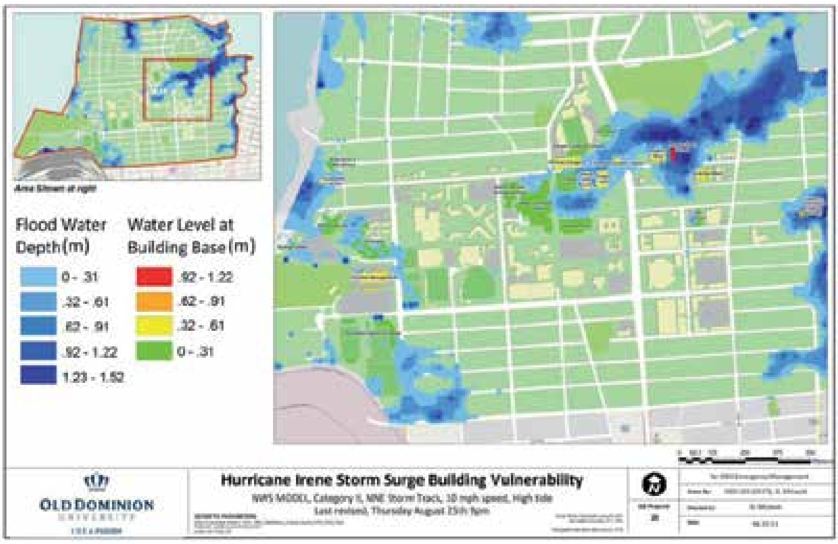

Figure 10. Map of depths of flooding encroaching on campus from the Lafayette River based on maximum storm tide for SLOSH MEOW scenario for Hurricane Irene, with depths of inundation based on cell by cell calculation from LiDAR DEM data for high tide.

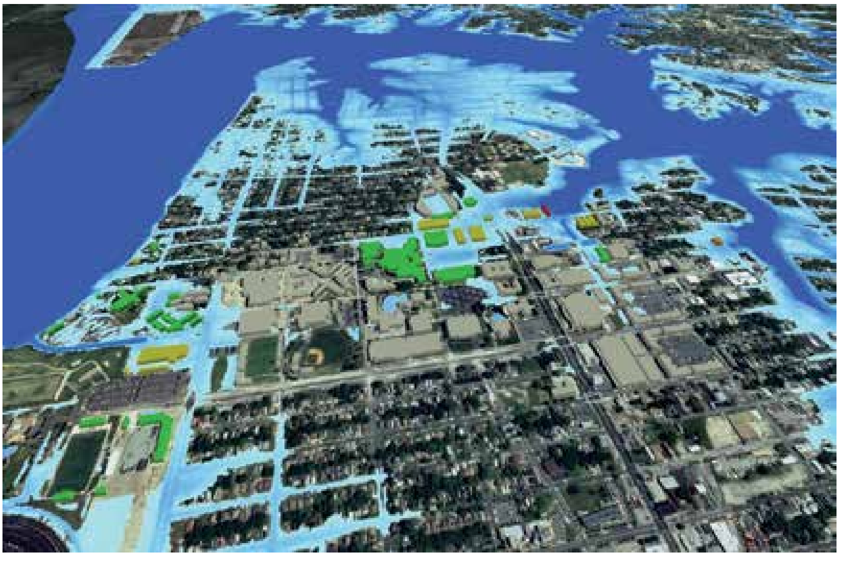

Figure 11. A 3-D ortho-perspective of Hurricane Irene maximum flooding at ODU campus. Map depicts inundation depth superimposed over 3-D buildings and orthophotography draped on a LiDAR DEM. View north toward Lafayette River at top and Elizabeth River at left. Inundated areas shown in blue shades connote inundation depths (as described in Figure 5). Building hues denote water level at first floor base height of building.

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Figure 12. D ortho-perspective of Irene-generated flooding focused on ODU with 3-D building models extruded for perspective. Blue shades depict inundation depth (as described in Figure 5).

5. Conclusion

This review and exploratory geovisualization research found variable results when comparing traditional coastal elevation to modern LiDAR DEM elevation and in residual fine-scale error in digital inundation models. Discrepancies in inundation predictions when using traditional contour-based surge maps compared to contemporary digital LiDAR-based inundation models were significant, highlighting the underestimation of potential surges in coarser coastal topographic data. Forecasters and emergency managers should be aware of their data sources and the potential error in maps used to make decisions. Incorrect results are produced not only by operational and observational errors in computer models but also by ignoring the errors inherent in elevation data sources. Future accuracy assessments should be made for downscaled inundation models to increase realistic representation of the extent of flooding. Even though the agreement of the areas of inundation produced by the two models is close to 95%, three main advantages of the more recent GIS-based model have been identified, all relate to model flexibility. The downscaling and fine-resolution error modeling of the Monte Carlo simulation methods also highlight the existence of error even in our modern, fine-scale LiDAR DEMs. Simulation runs showed that there is spatial variation in DEM error that may propagate underestimates of areal flooding in surges. Thus, floodplain mapping and emergency managers should cautiously interpret single inundation models, as underlying error in fine-scale topographic features (a levee, for instance) could mask the potential in some likely to be surge-affected areas. Cartographic techniques such as transparency and variable shading demonstrated in our chapter could also illuminate such weaknesses and errors in the DEMs or downscaled inundation model maps.

In the event of an actual hurricane landfall, the SLOSH deterministic runs could be input to the model resulting in a more realistic representation, rather than using inundation zones generated by the SLOSH MOM output. Doing this would provide a clear advantage over a static, "worst case" scenario map, and would allow emergency managers to pinpoint areas and infrastructure that would be effected in the event of specific storm parameters and track. Another advantage of the GIS-based model is its easy incorporation of newly available elevation data. In addition, digital elevation models do not typically incorporate features such as ditches and water-control canals that can greatly alter the spatial patterns of inundation, so DEM-processing techniques such as "stream burning" or "hydro-correction" to improve and enforce hydrologic representation in both runoff and inundation would help to improve the accuracy of surge visualizations.

This chapter also focused on the use of SLOSH model MEOW and MOM data for the time-delimited preparedness and response operations (particularly evacuation) of emergency management. In the future, the ability for modeling to produce a variety of inundation model output will expand and reduce uncertainty. Experimental runs are being conducted to make use of output from the ADCIRC model, and these will be enhanced by improvement of storm-track and intensity forecasts within the closing hours of landfall. The ADCIRC model is better than the SLOSH model in many ways, but still has some of the same visualization issues. In sum, the downscaling GIS SLOSH model produces results similar to previous contouring and manual-digitizing techniques but has better accuracy and tends to not overgeneralize. Although Monte Carlo analysis of inundation variability using error modeling suggests broad fidelity of inundation zones, there are still areas of moderate uncertainty. More work is needed to assess the accuracy of these downscaling models using actual storm data and hind-casting. Nonetheless, the GIS model has many advantages; they are primarily the model's flexible acceptance of inputs and its cartography. With more work, emergency managers and the public will be able to improve risk awareness and risk communication.

The array of geovisual products developed for education, public awareness, and emergency exercises have been welcomed by communities to whom they have been presented. Photorealism and 3-D building models are demonstrably versatile, providing visual communication in static graphics, libraries of surge visualizations, animated fly-throughs, and interactive 3-D digital globe data (such as Google Earth). The algorithms to downscale and visualize SLOSH or other surge model forecasts at the neighborhood or finer scale have fulfilled a need in local emergency management. The ODU case study demonstrated the integration of surge forecast inundation, fine-scale orthophotography and cartographic symbolization of building planimetrics, and accessibility for operational use during an emergency. Such applications require cautious and informed use of disparate data (meteorological, geospatial, and infrastructural). The spatial accuracy, scale, and temporal and physical uncertainties of a phenomenon as complex as storm surge suggest the need for advanced training and judicious exercising of the use of GIS and geovisualization. Hence, academics and practitioner communities comprising geographers, coastal modelers and engineers, emergency manag-

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ers, and decision-makers must continue to collaborate in the development of scientific approaches and robust tools to further refine and expand these advances for coastal disaster management.

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Chapter 6

The Role of Earthquake Information Management System to Reduce Destruction in Disasters with Earthquake Approach

Sima Ajami

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/53612

1. Introduction

Iran, because of extent, geographical situation and climatic variety, is one of the disaster-prone countries of the world. [1] Natural disasters, for example earthquake, are an unexpected event that cause damage and destruction to human life and health, and the injured persons without others assistance are not able to meet their need. Earthquakes in Iran and neighboring regions (e.g., India, Turkey and Afghanistan) are closely connected to their position within the geologically active Alpine-Himalayan belt (Table 1). [2-5] Earthquake crises disrupt all daily affairs of society, such as economic activities, city services, communication systems and community services and public health. [6] An Earthquake Information Management System (EIMS) is a system that records, collects, keeps, retrieves and analyzes inputs, produces reports and required earthquake information (EI) and renders them to the right people and organizations to manage earthquake response activities. [7] EI is not an end in itself, but it helps to make better decisions in designing policies, response planning, management of disasters, monitoring and evaluating disaster programs and services, and reducing damages. [8]

2. Problem statement

Unfortunately, information systems in most countries are inadequate to provide the needed management support. Earthquake loss estimates are forecasts of damage as well as human and economics impacts that may result from future earthquakes. These estimates are based on current scientific and engineering knowledge. [9] The “earthquake loss estimation methodology" is a system that uses mathematical formulae and information about building stock, local geology and the location and size of earthquake risk, economic data and other information to estimate losses from a potential earthquake. The EIMS uses ArcGIS (geographical information system) to map and display ground shaking, the pattern of building damage and demographic information about a community. Once the location and size of a hypothetical earthquake are established, EIMS will estimate the distribution of the amounts of the following: ground shaking, buildings damaged, injured persons, damage to transportation systems, disruption of electrical and water utilities, displacement of populations and cost of repair of likely damage. [10-13]

Deadliest earthquake				
Year	**Date**	**Magnitude**	**Fatalities**	**Region**
2005	03/28	8.7	1313	Northern Sumatra, Indonesia
2004	12/26	9.0	283,106	Off the west coast of Northern Sumatra
2003	12/26	6.6	31,000	Southeastern Iran
2002	03/25	6.1	1000	Hindu Kush region, Afghanistan
2001	01/26	7.7	20,023	India
2000	06/04	7.9	103	Southern Sumatera, Indonesia
1999	08/17	7.6	17,118	Turkey
1998	05/30	6.6	4000	Afghanistan–Tajikistan border region
1997	05/10	7.3	1572	Northern Iran
1996	02/03	6.6	322	Yunnan, China
1995	01/16	6.9	5530	Kobe, Japan

Table 1. Deadliest earthquakes by year, 1995–2005

Estimation of losses from future earthquakes is essential for preparation for disasters and it facilitates better decision making at local, regional, provincial and national levels of government. An EIMS can estimate earthquake losses to support land-use planning and facility site decisions (e.g., a map-based analysis of the potential intensity of ground shaking from a postulated earthquake that identifies those parts of the community that will experience the most violent shaking and the buildings at greatest risk of damage); prioritization of retrofit or abatement programs (e.g., an estimate of building damage that provides the basis for establishing programs to mitigate or strengthen buildings that may collapse in earthquakes by providing estimates of damages and casualties); regional, provincial and local emergency response and contingency planning (e.g., estimates of casualties and of damage to buildings and utilities); medical and relief agency preparedness and response (e.g., estimates of casualties and homelessness); and assistance planning. [11]

In this research, I seek to answer five important questions: When are EIMS useful? What are the essential substructures in an EIMS? What are the important functions of an EIMS? What are the steps taken to create an EIMS? and How is an EIMS used to prepare for earthquakes?

3. Aim

In this study, the information management networks related to earthquakes in India, Afghanistan, Japan, and Turkey were compared to Iran to rationally determine the relative strength of the EIMS in each country. Their weaknesses and strengths were determined. And several recommendations and a model were developed to eliminate weaknesses, improve the efficiency of EIMS, reduce damages and losses and expedite relief to victims after earthquakes.

4. Methodology

This research is empirical and the study was an analytical comparison. The data consisted of the population of EIMS employed in India, Afghanistan, Japan, and Turkey and Iran. These countries were chosen because they are among the countries with the most experience with extreme events in Asia, and they all experience devastating earthquakes (Table 1).

To perform this study, I developed forms and questionnaires for data collection through interviews and observations. The forms were developed to define standard characteristics of an information management system by extracting guidelines from the Joint Commission on Accreditation of Healthcare Organization (JCAHO), the American Health Information Management Association (AHIMA) and Canadian Council on Health Services Accreditation (CCHSA) [14] and synthesizing the information. The questionnaire was designed to acquire the opinions of experts to enable the weighting of each characteristic of an EIMS. In the first phase of data collection, the forms were validated and the questionnaire was approved. Internet sources, professional personnel, documents, journals and books were consulted to develop the data which included EI sources, methods of recording, storing, retrieving, analyzing, interpreting, and distributing EI, national and international usage of EI, and so on. The Criteria Rating Technique [15] and the descriptive method were used to analyze findings. Standard characteristics of information management systems were selected as criteria.

To compare the importance of the characteristics of EIMS, experts were asked to set weights (from 1, of low importance, to 10, of high importance) by brainstorm. The means of the experts' opinions of the weight of each criterion were calculated (Table 2 and 3). Ratings were established (ratio = weight of each criteria divided by sum) and scales (positive = 4, moderate = 3, not access = 2, negative = 1) and scores (score = ratio*scale) for selected countries were calculated.

Criteria/country	Weight	Ratio	India		Afghanistan		Iran	
			Scale	Score	Scale	Score	Scale	Score
1) Information sources are existed	8	0.11	4	0.44	4	0.44	3	0.33
2) Users of EI are specified	6	0.08	4	0.32	3	0.24	3	0.24
3) System has security process	6	0.08	4	0.32	2	0.16	2	0.16
4) EI is recorded and stored systematically	7	0.09	4	0.36	4	0.36	1	0.09
5) EI is retrieved, analyzed and interpreted systematically	9	0.12	4	0.48	2	0.24	3	0.36
6) Administrators are specified in various functions	9	0.12	4	0.48	4	0.48	3	0.36
7) No parallel and repeated activities by various organizations	5	0.07	4	0.28	4	0.28	1	0.07
8) EI is distributed and used in national and international levels	6	0.08	4	0.32	4	0.32	3	0.24
9) EIMS has feedback	9	0.12	4	0.48	4	0.48	3	0.36
10) Accessibility of EI is easy and fast	8	0.11	4	0.44	3	0.33	1	0.11
Sum	73	1		4		3.3		2.32

Table 2. The EIMS characteristics evaluating in selected countries

Criteria/country	Weight	Ratio	Japan		Turkey		Iran	
			Scale	Score	Scale	Score	Scale	Score
1) Information sources are exist ed.	8	0.11	4	0.44	4	0.44	3	0.33
2) Users of E.I. are specified.	6	0.08	4	0.33	4	0.33	3	0.25
3) System has security process.	6	0.08	2	0.16	4	0.33	2	0.16
4) E.I. is recorded and stored systematically	7	0.09	4	0.38	4	0.38	1	0.09
5) E.I. is retrieved, analyzed and interpreted systematically.	9	0.12	4	0.49	4	0.49	3	0.37
6) Administrators are specified in various functions.	9	0.12	4	0.49	4	0.49	3	0.37
7) No parallel and repeated activities by various organizations.	5	0.07	4	0.27	4	0.27	1	0.07
8) E.I. is distributed and used in national & international levels.	6	0.08	4	0.33	4	0.33	3	0.25
9) EIMS has feedback.	9	0.12	4	0.44	4	0.49	3	0.37
10) Accessibility of E.I. is easy and fast.	8	0.11	4	0.44	4	0.44	1	0.11
Sum	73	1		3.77		4		2.37

Earthquake Information= EI; Ratio = weight of each criteria/sum; Score = ratio*scale

Scales: Positive = 4, moderate = 3, negative = 1, not access = 2

Range of ranks: 1–1.6: Very weak; 1.7–2.2: Weak; 2.3–2.8: Moderate; 2.9–3.4: Good; 3.5–4: Very good

Table 3. The EIMS characteristics evaluating in selected countries (continued)

5. Results

The results of the data collection provide answers to the five research questions. Each answer is described briefly below.

When are EIMS useful? There are four conditions that make EIMS more useful: when information users and addressers are specified; when time, form and the mechanism of information distribution are specified; when the EI is valid and reliable; and when there is fast access to EI. Furthermore, the data received are often not helpful for management decision making because they are incomplete, inaccurate, untimely and unrelated to the priority tasks and functions of crisis management.

What are the essential sub-structures of an EIMS? The information compiled and surveys indicate that the essential sub-structures that must be addressed or included in an EIMS are the nature of: crisis management, information technology, the geographic information system, the earthquake information system, mass media communication, cell phone communication, capital and human resources.

What are the important functions of an EIMS? This study finds that EIMS are needed: for fast and easy retrieval of information, which is very difficult; for extraction and access of information for managers and related users; for integrating data from different sources; for reduction of parallel and redundant activities by responding organizations; to decrease cost and time; for assessment and monitoring of plans before and after earthquakes; to identify training and function needs; and to formulate prevention, action and rehabilitation actions.

What are the steps taken to create an EIMS? The following steps are usually taken: establish a joint commission of governmental and non-governmental sectors and organizations; determine the primary participants in earthquake management; determine and formulate a plan for a system based on general principles and goals; identify the data needed for the system; identify the sources for the system's informatics; identify registration, collection and storage methods of and administrators for the system; determine the retrieval and analytical methods of and administrators for the system; establish the information methods and distribute them to the administrators of the system; establish methods of systematic communication among the administrators; create a mechanism to render feedback for system improvement; and ensure that the system and its plans and functions are dynamic and flexible.

How is an EIMS used to prepare for earthquakes? The first step in preparing for a disaster is estimate and assess its potential impact. These estimations and assessment can provide the basis for developing mitigation policy, developing and testing emergency preparedness and responsing for post-disaster, and reliefing negative outcomes. [16] Reducing earthquake loss begins before the earthquake. Loss estimates provide public and private sector agencies with a basis for planning, zoning, building codes and development regulations, and policy that would reduce the risk posed by violent ground shaking and ground failure. Loss estimates can also be used to evaluate the cost-effectiveness of alternative approaches to strengthening potentially hazardous structures. Preparing to respond, understanding the scope and complexity of earthquake damage is essential to effective preparedness. The EIMS can forecast damage to buildings, casualties and disruption of utilities. These estimates can serve as the basis for developing emergency response plans and for organizing tests and exercises of response capability.

6. About EIMS

Beginning in the late 1950s, planners began development and use of computerized models, planning information systems and decision-support systems to improve EI management performance. They have found tools to enhance their analytical and geospatial technologies which may be different from one country to another. The industrialized nations are well adapted to this information technology. They use it in many fields. Governments apply urban information systems in all aspects of the planning process, including data collection, storage, data analysis and presentation, planning and policymaking, communication with the public, policy implementation and administration. The United States is the pioneer in this field. They began working with urban information systems in the 1970s. Canada and Australia have developed systems. And European countries like France, Germany and the Netherlands have been successful in applying these technologies. Turkey is a latecomer in this field because of financial constraints, their other priorities, a lack of technical expertise and different administrative mentalities. But today, the urban information system is a popular notion among local governments in Turkey. The first initiative of local governments to use urban information systems was in the cities Bursa and Ayden beginning in the mid-1990s. Since then three other metropolitan municipalities, Istanbul, Ankara and Izmir, studied the digitization of maps and plans and began to create inventories of their cities.

In India, findings showed that the Disaster Information Management System (DIMS) was launched by SRISTI. The SRISTI participated in relief and rehabilitation work in Kutch. However, their relief work suffered immensely due to lack of information and proper planning. When answers to important questions that were cropping up were needed – for instance, whether there is a database on the distribution of available resources and expertise with individuals, institutions and corporations – SRISTI discovered the information wasn't available. This revealed the need for a system for disaster mitigation and for documenting the experiences of individuals and organizations, which might provide a knowledge database that can assist coordination in future disasters. Thus, SRISTI initiated an effort to build a "Disaster Management Information System." Through this initiative, the development of a database-driven information system for Disaster Management Authorities (DMA) in various states, NGOs and other organizations is underway. SRISTI appealed to NGOs, relief workers, DMAs and individuals to share their experiences and volunteer their services and resources to the online database maintained on the SRISTI website. The database currently contains information from more than a thousand volunteers who have offered their services and resources in times of emergency. About 700 organizations and institutions are indexed on the site, as are other resources and web links. The DMIS is a voluntary activity run with in kind contributions of time and services by SRISTI volunteers, NGOs and, above all, civil institutions across the world. All the information shared with us is accessible to all, except in cases in which the volunteer has chosen to limit access to the relevant authorities. [17-18]

7. EIMS in Afghanistan

Our research reinforces the belief that Afghanistan possesses the potential for many natural disasters. Therefore, a DIMS, especially an EIMS, would be particularly helpful. Disaster management is a needs a wide variety of information, needs to track different locations and during different periods, and this information must have a set format in order that key staff can employ the information in decisions. A new project named "Management Information for Natural Disasters" (MIND) in Kabul and Kunduz provinces in Afghanistan has been operating since the beginning of 2012 and has been doing well for the last 8 months. Its goal was to establish and expand a crisis information management system. It is frequently updated and provides information to governments. MIND has increased Afghanistan's crisis management capacity nationally, supporting the training of disaster managers and improving city services by building governmental organizations in management information for natural disasters. Natural disaster management in these two provinces is primarily guided by estimates of damages which are used to direct rescue operations. There is currently no system to avoid or decrease disaster damages. Before and after a disaster, management is very weak in these countries and they are therefore dependent on the UN or NGOs for response. Information needed for the EIMS includes the availability and distribution of response personnel and spatial information stored in GIS to determine the areas of greatest destruction and locations of great danger. In this system, satellite data are crucial for identification of crisis locations and understanding their distribution. [17,19] To record the information that is acquired, an Information System Unit is trained to input data and information and to manage stations of the informative system. The DIMS for earthquakes has tended to not be useful in many parts of the country primarily because of the lack of timely information from disaster areas.

8. EIMS in Japan

The Japanese DIMS is called "PHOENIX" (Preement Hyogos Emergency Management Network for Disaster Information Exchange). [20] In this system, information about the amount and degree of earthquake damages and on-going developments of conditions in a disaster area are collected and processed. Information is provided by agencies, involved organizations, individuals (including those from governments, experts, volunteers and others), monitoring stations and other data sources employing several communication methods (including the Internet, radio, print, televison and satellite). Recording and collecting earthquake information is centralize by informatics centers of local society of province. Japan's Red Cross, Rescue Team, NGOs, health organizations and others [21] do the estimating, calculating, and publishing of the information that is needed, and they send them to the relevant agencies. PHOENIX crisis management is designed for access and use by individuals, local communities and the national government. All satellite, land-based and atmospheric data will be transmitted over the Internet and displayed on local pages for Hyogo people. This system has been established for the entirety of Japan. [20] The Hygo Province crisis management network is directly supervised by the prime minister and his/her ministry. According to their documents, this system has been very successful. So it is expected that after they have completed their analysis, the system will be on-line for local, national and international users. [20]

9. EIMS in Turkey

Our findings reveals that every governmental office in Turkey has begun development of electronic systems to meet their needs. Hence, e-government has become an important tool. As a result, the Turkish government has resolved to provide public services online in accordance with EU targets. As a part of this process, the prime ministry of Turkey has chosen Istanbul as a pilot-project area where many complex governmental tasks are carried out. Turkey is situated in an extremely active seismic zone. Since Istanbul has been growing rapidly without proper planning, great precautions should be taken to mitigate and prepare for future disasters. Therefore, Turkey has committed to build a natural disaster management information system immediately and it is called AFAYBIS. AFAYBIS is designed as a minor part of their e-Government system. It was based upon the information acquired in surveyes of government and private-sector data providers. The system will use geographical analysis to identify the regions with the greatest disaster potential. The project is also intended to quickly and effectively create a tool for management of response and relief during and after disasters. After an analysis of the current state of affairs was completed, the data and the data sources were identified. The system is designed as two parts: a database and a communication system. The communications component is to constantly update data before disasters and to provide continuous supply of data. Consequently this disaster information system is designed according to the standards of the Turkish e-government, which is always intended to be up-to-date. The disaster management information system that has been developed to solve this problem will result in optimum efficiency during disaster. This system contains the structure that determines its relationships to data and access to its information, disaster management communication, risk mitigation and disaster preparation, and post-disaster coordination of the prime minister, governors and other institutions. The services and duties of the institutions are also developed into the system so as to avoid modification of their existent organizational structures. [22] Earthquake management in Turkey, without exception, is a problem. It is unsystematic, unplanned, static and awareness of it is low.

10. EIMS in Iran

Disaster management systems are often designed because of the lack local management. Disasters are managed nationally in Iran and such management tends to cause disasters to spread, impacting many more people. [1] Despite the national approach, there is no official department called the "Department of Earthquake Information Management System." There is an EIMS. Information has been recorded by hand or using computers. Management of disasters has been done through the crisis office of the health ministry. All of the universities of Iran and the health minister are responsible for information management. This system is equipped to communicate information from crisis offices in the country's universities. After an earthquake, these units are prepared to produce up-to-date information (about hospitals, the Red Crescent Society, ambulances, facilities and other important resources) and report it to the crisis-control office. In universities, the crisis rooms are expected to report information as rapidly as possible. The EIMS in Iran tended to be incapable of reporting important information that was needed in advance of, during and after earthquakes. Defective, insufficient and inaccurate registration of data, declaration and publication of different and contradictory population data and a lack of reliable information disabled the development of preventative systemic planning. To make an EIMS work in Iran, we need to provide support for managers, and to do this, modified model of the EIMS should be designed. [1] The modified model includes information about: the responsible organizations, their functions, and the work-flow that were reflected in the Delphi Technique.

We offer a model that shows the relationships between organizations related to the EIMS in Iran (Figure 1). In this model, the responsibility and function of every organization is determined. These duties are classified according to registration and collection of earthquake data, the storage and processing of these data, and the analysis and distribution of information and recommendations produced by the EIMS.

11. Evaluating the effectiveness of EIMS design in each country

The highest sum of scores of the effectiveness of EIMS are found in India and the lowest in Iran (Table 2 and 3). The weaknesses of EIMS are found in that: the EI stores systematically, there are parallel and repeated activities by various organizations, and the access to the EI is not easy and nor fast, particularly in Iran's EIMS. In the range of ranks, Afghanistan's and India's systems were classified in the very good range and Iran's was in the moderate range. [17]

The use of mass media is imperative for communicating news and information to the public. Responsible journalism can also help to clear up inaccurate rumors and to influence the public's attitude toward preparing for disasters. Moreover, press coverage of old disasters may provide good data to fill the gaps in circumstances where official records do not exist. However, this study has revealed that the press has largely failed in terms of guidance toward disaster mitigation and preparedness. It seems that media are more interested in reporting disastrous news than informing the public of ways to avoid disasters. The Turkish media has been more influential in urging both the public and government officials to prepare for the earthquakes. Television appears to be a more effective tool to achieve this. [23]

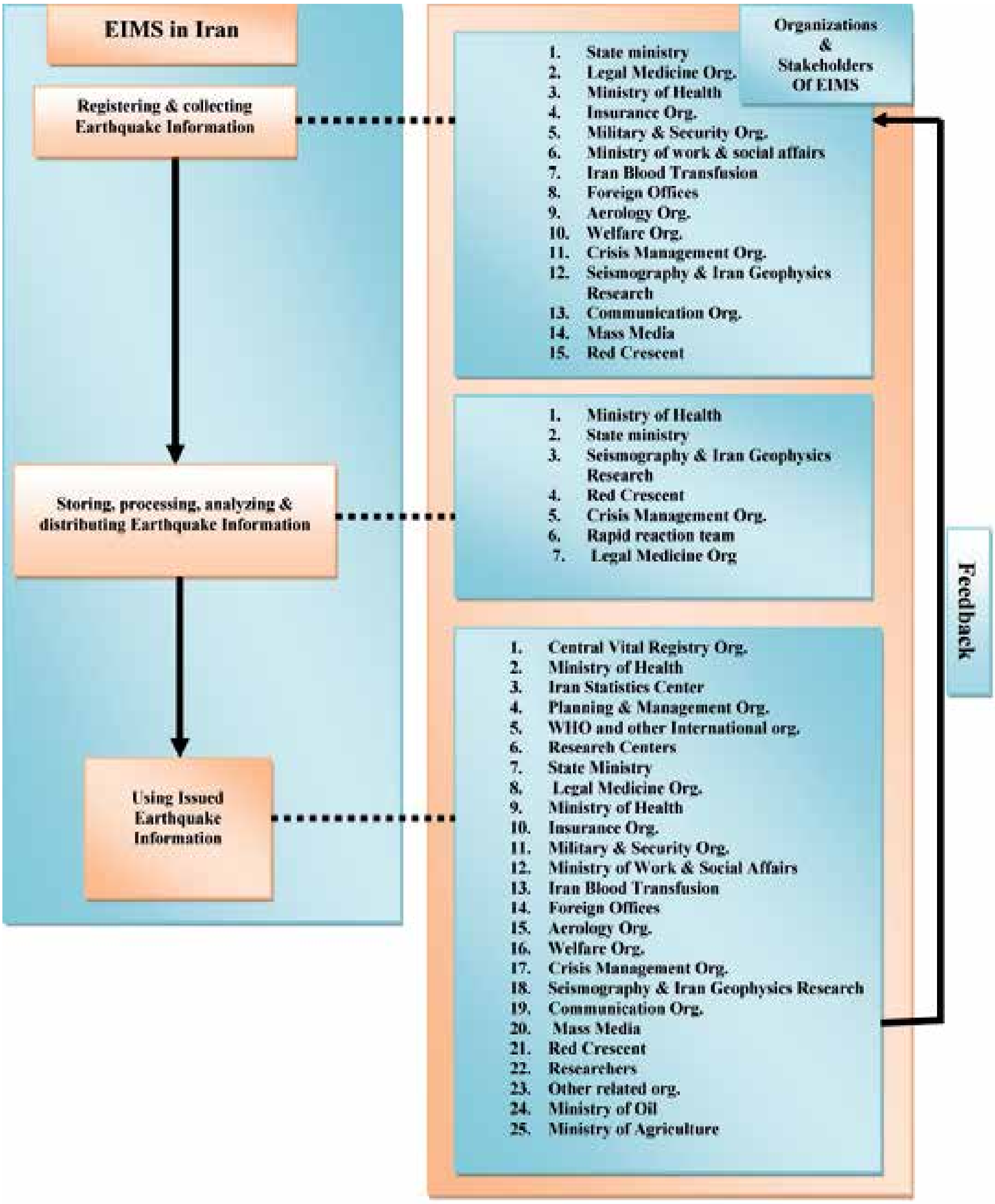

Figure 1. The proposed model of EIMS that shows process of relationships between organizations related to EIMS in Iran

The Japan Meteorological Agency (JMA) is responsible for producing EI and tsunami forecasts and they have developed an earthquake notification system in Japan. At present, JMA issues the following kinds of information successively when a large earthquake occurs:

prompt reports of the occurrence of large earthquakes and major seismic intensities caused by earthquakes within about 2 minutes after the earthquake; tsunami forecasts in around 3 minutes; expected arrival times and maximum heights of tsunami waves in around 5 minutes; and location of the hypocenter and the magnitude of the earthquake, intensity at each observation station, times of high tides and the expected tsunami arrival times within 5–7 minutes. To issue the above information, JMA has established an advanced nationwide seismic network with about 180 stations for seismic-wave observation and about 3400 stations for instrumental seismic intensity observation, in addition to the approximately 2800 seismic intensity stations maintained by local governments. [24]

12. Conclusion

The initial effort to systematically collect and analyze data in developing countries should be undertaken by national program managers. Based on our investigation of current earthquake information management in India, Afghanistan and Iran, we can stress the need for further development of EIMS because of: the critical need for the information that must be gathered; a concern about continuous improvement of the data made available; its ability to help manage emergency response and relief in natural disasters (through more rapid availability and retrieval in an EI); a need for timely reporting and feedback to managers; the need to analyze information and render reports that define strengths, weaknesses, threats and opportunities; the need for monitoring the status of healthcare services and the needs of such services; the crucial need to coordinate activities between government and non-governmental sectors through the EIMS; the need to reduce deaths and establish health priorities and planning to decrease mortality after future earthquakes; the ability to use the outcomes of crisis to determine the causes of earthquake mortalities and other problems in order to prevent future impacts; and the need to formulate strategies for disease prevention and to reduce preventable deaths in earthquake zones.

A rapid response to a damaging earthquake will reduce the loss of life, lessen the complications that stem from injuries and secondary damage, and expedite relief to victims. Reliable and up-to-date information can have an impact on the mitigation of risk and prevention of disaster. Because of the financial and human costs of disasters, the establishment of a general, scientific and practical earthquake information management network is desperately needed.

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Section 3

Crisis Management and Disaster Recovery

Chapter 7

Five Star Crisis Management — Examples of Best Practice from the Hotel Industry

Outti Niininen

Additional information is available at the end of the chapter

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1. Introduction

The *background* for this study is in the complex and fragmented business environment of today when many organisations are interdependent from each other across the globe thus making it harder for companies to insulate themselves against a crisis event [1]. Furthermore, the media of today is ready to inform us of any critical events around the world at a moment's notice [2, 3]. The 'everyone can be a journalist' culture is encouraged by popular media requesting photographs and video footage from individuals currently caught in an unexpected chain of events. Today, words like 'crisis' and 'disaster' are featured in everyday vocabulary to grab attention, thus resulting in a depreciation of the actual meaning of this term. Overall, an atmosphere hungry for crisis has been created.

At the same time, there has been a plethora of international crisis demonstrating how fragile the business environment can be. The most cited crises have been caused by nature (e.g. tsunami, hurricanes, bushfires, floods or disease) or by man (e.g. terrorism and the current Economic Tsunami). In this environment, the Hotel Managers' duty of care should also involve planning and preparing for unforeseen events; running 'what if' scenarios, designing action plans for all departments, allocating individual responsibilities; building back-up capacity and training their staff to respond in appropriate manner to security concerns. Therefore, the *aim* of this paper is to highlight good procedures already practiced by hotels participating in this study. The study *Methodology* consisted of in-depth interviews with Hotel Managers or Hotel Security Managers located in Hong Kong, London and Finland. Many of these hotels were associated with large multinational chains and the most of the interviewees had managed a variety of crises situation, often in contrasting cultural or geographical locations.

This paper is set out in the following structure: the basic crisis management concepts are outlined and applied to the tourism (and hospitality) settings. This is followed by a brief outline of the methodology utilised. The findings/discussion section is structured to reflect the key practical tips offered by the interviewees: '*Being prepared for crisis situations*'; '*Managing costs during crisis*'; '*Make full use of local advice*'; '*Maintaining good communication with guests*' and how to '*Use technology to enhance hotel security*'.

2. Crisis management

Crisis management has its roots in strategic planning incorporating contingencies for unexpected events. The challenge for organisations is to recognise the early 'warning signals' and take appropriate action. Crisis can be classified by several variables: *those resulting from internal actions of the company* vs. *trends taking place in the market place* or *changes in the immediate environment outside the organisation*. Another approach to crisis classification is: *the crisis that can be managed* vs. *crisis that manage us* [the organisation][3].

Generally speaking, crisis as an event is characterised by its unexpected nature inflicting severe impact on those involved. Moreover, a crisis typically demonstrates the characteristics of suddenness, uncertainty and time compression thus demanding immediate action from the manager – often the crisis management decision-making is also based on incomplete facts [4, 5]. How any of these challenges are managed can determine the magnitude of the impact a crisis will have on the organisation. Prompt and expertly dealings with a crisis situation and those affected by this crisis can also open new opportunities for future business success [6]. Unfortunately the crisis reported in the news today will inevitably result in some financial losses as well as human suffering. As a result some businesses will be closed or relocated. The cynics amongst us argue that the crisis simply brought forward what was inevitable and that a 'natural process of weeding out the weak' has taken place.

Regrettably crisis events are commonplace, [7] as organisations are regularly dealing with the pre-crisis; during-crisis or post-crisis issues thus highlighting the need for an early 'diagnosis and treatment' of a crisis to reduce the negative impact to the company. Moreover, a crisis can also be a chain of events that are impossible to control or plan for, thus resulting in 'death or significant injuries' to those involved, disrupt the business operations as well as damage to or destruction of company assets. In other words, a crisis situation turns 'business as normal' into impossibility [3, 6].

Tourism as an industry has many characteristics that can make a crisis more probable, magnify the impacts of a crisis and attract extreme media coverage for the event. Firstly, tourism is big business and often cited as the 'largest peacetime industry' [8] and tourism is also advocated as the industry offering sustainable (and quick yielding) development opportunities to the least developed countries. Secondly, the tourism industry is highly integrated with several other industries. In other words, the ripples of a crisis event from the hotels' supply chain can result in a flood of issues/problems for the business of providing hospitality [1]. Thirdly, the tourism industry is about the movement of people

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(i.e. all individuals with the means and motive to travel are potential tourists). Thus the variety of psychological or social responses to unexpected events from the guests of an international hotel will challenge even the 'best laid [crisis] plans' as well as the communications skills of experienced PR Managers to maintain calm [2]. Fourthly, since the consumption of a tourism product requires the customer to travel to a destination the demand for tourism products is sensitive to reports on security and health issues; and finally, many tourists are attracted to fragile locales particularly vulnerable to the forces of nature (e.g. tropical weather, proximity to sea and even seismic activity) or destination with low degree of infrastructure development (so called 'unspoilt' destinations) [5, 9-11].

Moreover, tourism participation is a discretionary activity for most international travelers, many countries (or destinations) have invested heavily on new campaigns in order to acquire the misplaced inbound tourists or to generate alternative demand from domestic travelers [12, 13]. Therefore, in tourism industry, '… it is no longer a question whether [a crisis] will arise, but when and how it will be dealt with' [7] therefore hotels' crisis plans should be more generic in nature, thus offering personnel accepted behavioural protocols without attempting to script for every eventuality. The wide variety of potential crisis in the hospitality industry also supports this argument.

3. Methodology

The findings in this paper are based on in-depth interviews conducted during October 2008. Non-probability sampling was used to select locations due to the range of past crisis events varying from financial crisis (e.g. current financial crisis worldwide and the financial crisis in Finland in the early nineties), health concerns (e.g. SARS reports linked to Hong Kong) to terrorism (e.g. the UK and London) reported in those locations. At each city, major stakeholders from educational institutions to trade associations were approached to request contact details for hotel managers willing to participate in research projects. Individual interview requests were made through e-mail and the final number of interviews conducted was 12 (three in Hong Kong; six in London and three in Helsinki).

Each respondent received the planned interview questions in advance together with background information for this study and the University research ethics procedures. Although General Managers were approached initially, in some cases the interview request was delegated to the Head of Hotel Security thus resulting in a mixture of nine Hotel Managers and three Hotel Security experts. Collectively, the respondents hold decades of crisis management experience across the world with focus on the hospitality industry as well as other segments of the security industry like Police or Fire departments. Naturally, the personal crisis experience of each person influenced the examples and policies highlighted by each individual thus making the data more rich. The 'default' identification for each respondent was to code them by location e.g. 'Hotel A, HK' or 'Hotel K, UK' etc.

4. Findings and discussion

The first observation during the data collection process was how well prepared all hotels interviewed were. Most interviewees arrived with their crisis management plans, in one incident; a major evacuation practice was due to take place later on the same day.

The probability of incidents or crisis events taking place in a hotel increases with the volume of business and the size of the establishment; 'when the company [the hotel or the chain of hotels] provides thousands of bed nights every year, something is likely to happen'. One important contributor to hospitality industry incidents or crises are the guests or visitors to the property. The Hotel Manager can select their staff members and train them to respond to events in the desired way. Unfortunately, such luxury does not always exist with the visitors and guests. This is not to say that the visitors would be deliberately causing harm but the mixture of varying cultural norms, language barriers and lack of understanding of the prevailing condition can confuse the guests, thus causing an incident or making the crisis control extremely difficult for the hotel employees [2]. However, clever use of the *extended Marketing Mix* resulting in the market *positioning*, the *rates* charged as well as the *physical evidence* of the hotel can, on one hand, discourage segments that might not respond well to the guidance by the hotel employees. On the other hand, the *physical evidence* evident in a 5* hotel can also have a surreal calming effect on visitors not used to such luxury and formality possibly resulting in the incidental visitor to 'be on their best behaviour'. Furthermore, policies like 'no Buck's nights' as well as good records of past visitors can also be used to discourage segments outside the hotel's target market.

The reported crises experienced by the respondents can be classified as internal (within their property) and external (outside their property). The internal crises varied from technical/ power failures to death of a hotel guest and the external crises varied from mass cancellation of hotel bookings due to the current financial crisis, to accidental or deliberate incidents of vehicles crashing into the hotel buildings (such deliberate damage to the hotel property and risking of human lives would be classified as terrorism) (Hotel A, HK).

All respondents referred to the Hotel Manager's responsibility for the well being and safety of staff and guests. In fact the Hotel Manager's *duty of care* was the most commonly cited expression across all interviews. Another conclusion from the data collected is that hotel security was often delegated to individuals who already had responsibility for Occupational Health and Safety (OHS). Furthermore, basic hotel security training was also cited to be part of the overall induction to new staff members (Hotel L, UK).

4.1. Being prepared for crisis situations

All respondents advocated the importance of being prepared for crisis situations and most respondents arrived to the interview with their Crisis Preparation Manuals. Furthermore, in one hotel, a crisis response practice was scheduled to take place shortly after the interview. The obvious/visual display of security measures (e.g. metal detectors at the entrance) is appropriate for specific target segments or situations only. The examples illustrated the varied degree of security measures needed for mega events like the 2012 London Olympics (all London respondents) and offering hotel services to the top politicians in the EU or other VIP guests (Hotel E, Finland). In such instances the security protocols are set externally and specialist security personnel is provided by the event organisers. A more common request for additional security takes place when a corporate client uses the hotels conference facilities for a strategically significant meeting. In these situations public access to some parts of the hotel may be restricted (Hotel D, Finland).

The day-to-day security operations included the 'secondary' security role assigned to most front line employees. This approach allows for a more discrete security operations and maintaining the appropriate quality of service. For example, the concierge limits the access to the hotel by suspicious individuals (Hotel D, Finland and Hotel L, UK) and front of house personnel diplomatically offering assistance to visitors who do not seem to belong. Such helpful attention to visitors was also experienced by me as the 'out of place interviewer'.

4.2. Managing costs during crisis

Managing costs effectively during any crisis is probably the key to being able to remain in business during and after crisis, as any reduction in hotel occupancy rates will translate into a drop in the revenues. However, this cost saving exercise should be conducted in a way that allows the hotel to bounce back quickly once the demand for their services returns. For example, short term cost cutting can result in years of Good Will from all stakeholders disappearing, thus resulting in difficulty in securing supplies and recruiting personnel after the crisis is over. A key cost area for service industries is the payroll, therefore if substantial cost cutting is required to survive the current crisis. Therefore, the Hotel Manager will need to 'look for ways of reducing costs whilst maintaining their support to the staff' (Hotel C, HK). The labour cost and capacity can be reduced by asking volunteers to take vacation during crisis (Hotel B, HK) or by changing operating procedures (Hotel C, HK). Another response to a crisis event is to stop recruiting (Hotel G, UK).

Moreover, a significant drop in demand and revenues due to a crisis will also require cutting costs in any area possible. For example, the supply costs for power and/or electricity can be managed by closing areas of the property; e.g. by closing a floor and concentrating the guests accommodation in dedicated areas will save power and allow for better utilisation of staff (Hotel B, HK). By concentrating the fewer visitors to specific areas can also help create the perception that the hotel is not badly hit by the current crisis situation, e.g. the worldwide economic crisis. And finally, a drop in demand and revenues should also prompt the Hotel Management to re-evaluate further investment plans. In conclusion, during a crisis event it is important not to waste resources (Hotel G, UK).

4.3. Make full use of local advice

The advice to 'make use of local advice' that is often also offered for free, was most frequently communicated by interviewees based in Finland and London. However, such observation could be purely incidental; e.g. in Finland only three respondents were interviewed, one of them had recent experience in providing accommodation for high ranking EU delegates (Hotel E, Finland); the London hotels were getting ready for the 2012 Olympics, and therefore, a greater collaboration between hotels and authorities is to be expected.

The type of free advice offered by local authorities (as well as other organisations) is determined by the location of the hotel. For example, the location of the hotel will determine the required building standards as well as the requirement for a formal rescue plan to be lodged with the authorities, the frequency of relevant safety inspections, and the extent to which the authorities are working with the hotels in a proactive manner (Hotel D, Finland).

Two of the London Interviewees made unprompted comments on how they 'welcomed the need for fire compliancy and regular inspections' since 'the fire certificate ensures compliance with fire safety'. Moreover, through a thorough crisis preparedness plan the hotels were also able to save in their insurance premiums (Hotel G, UK). Furthermore, 'regular fire inspections help hotels enhance/update their fire safety plans' (Hotel L, UK).

The closer links between the London Metropolitan Police and the hotels had also resulted in the Police issuing regular updates on specific criminal activities targeting hotels as well as fraudulent individuals to watch out for (Hotel L, UK). Finally, the time to develop positive relationships with authorities like the police or fire/rescue departments is during the quiet times, as good links to the authorities would be needed during crisis (e.g. Hotel L, UK; Hotel D, Finland).

4.4. Maintaining good communication with guests

In a large hotel good customer records are the basis for excellent customer relations. These records will allow the hotel to learn about their frequent guests and to keep their loyal customers (e.g. Hotel D in Finland). However, such inside knowledge should not be used to exhaust the guests with direct mail but rather preserve such communications for times when there is a need to attract business (Hotel L, UK). Furthermore, good guest history [and incident reports] also help dealing with complaints that may be received later.

Accurate record keeping should not be limited to the Customer Relations Department but be a standard across all the departments within the hotel. Moreover, all well documented procedures can also stop a minor incident from becoming a major crisis. For example, accurate temperature control in food preparation processes, maintenance work carried out, and even the details of deliveries taken, may be questioned months after the guest has departed. One Hong Kong based Hotel Manager (Hotel A) commented on guests from several months ago inquiring whether they had been served milk products sourced from China at any stage during their visit to the hotel. These guests had heard international news reports about contaminated baby milk in China and wanted to know if any food or beverages consumed in the hotel could have traces of such contaminated milk (for more on milk contamination in China please see [14]). This example highlights the need of thorough record keeping across all departments within the hotel, as these files are needed to reply to a concerned guest whether they have been exposed to any external health risks

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during their stay at the hotel (Hotel A, HK). For example, international news reports on poor air quality, polluted rivers or even faulty air-conditioning units near the hotel location could cause some negative word-of-mouth if the hotel is not able to demonstrate appropriate duty of care through well maintained records.

Hotels also provide the venue and catering for different types of events. Such functions serve specialist menus to groups up to several hundred guests. The participants of these specialist events can continue their celebrations in various independent restaurants outside the hotel and may even conclude the night with a snack from a street vendor. A guest suffering from food poisoning might blame the hotel for their symptoms even when they are not able to identify all food items consumed during their celebrations. A hotel can eliminate false accusations of poor food hygiene by preserving/freezing a small sample of food prepared for a major banquet. If required, the hotel can get the preserved food samples analysed by an independent laboratory before accepting any liability (Hotel B, HK). Finally, the prevalence of food allergies today requires detailing and standardising the ingredients for every item on the menu (Hotel D, Finland).

4.5. Use of technology to enhance hotel security

Technology can be used to enhance the overall hotel security and cameras in corridors as well as other public spaces are the norm today (Hotel D, Finland). Well positioned cameras and other visible security measures are welcomed by the guests as they increase the perception of security (Hotel I, UK). However, excessive use of cameras can give the impression of specific security problems on the premises (Hotel L, UK). Electronic key cards are also the norm today and the CCTV is viewed invaluable in securing the hotel premises (Hotel K, UK).

Recording security cameras at key positions, alarms and motion sensors indicating unauthorised access, as well as digital monitoring of access to the premises, were nominated as common tools for maintaining hotel security. The hotels in Finland were already using external security agencies to monitor their alarms as well as patrol the premises (Hotel D). Some of the London based hotels were considering such an option as well (Hotel G).

The Internet and e-mail were seen as a tool for enhancing the hotel security as well as a potential risk to the operations or the image of the hotel. The need for up-to-date firewalls to protect the hotels' computer networks was highlighted by some of the interviewees (e.g. Hotel D, Finland). Furthermore, the need to backup the data together with alternative communications channels outside the primary premises was also identified (e.g. Hotel B, HK; Hotel, UK). Moreover, licence plate readers were installed in the garage of one busy London hotel (Hotel L, UK). Finally, the collaboration between hotels and the police also involved e-mail alerts of scams targeting hotels complete with photographs of the suspects the hotels should look out for (Hotel D in Finland; Hotel K, UK).

Finally, many types of technology was utilised by all interviewees in maintaining the hotel security, and to some extent overt security measures facilitated by technology (e.g. electronic key cards, security cameras in public places) are now expected by the hotel guests. However, the underlying guideline for the use of technology in hotels was the need to 'protect the privacy of our guest' (Hotels H and L, UK),

5. Conclusions

The main contribution from this study is the accumulation of practical advice that all Hotel Managers can utilize, regarding of the size of their hotel. The practical advice offered by the participants of this study is based on accumulation of decades hotel management experience across the globe. The findings from these interviews can be grouped under the following headings: *Being prepared for crisis situations*; *Managing costs during crisis*; *Make full use of local advice*; *Maintaining good communication with guests*; and the *Use of technology to enhance hotel security*. The need to offer high levels of service, local collaboration as well as the secondary security related responsibilities of all existing staff were another overlapping theme throughout the interviews.

The findings of this study could be presented as a benchmark for good practice for crisis prevention in large international hotels. The examples cited by the interviewees covered crisis situations from small accidents to terrorism or accidental death within the premises.

The limitations of this study are, therefore, outcome of the limited resources (time and funding for data collection) and the bias towards large, international hotels. The timing of the data collection also coincided with the Economic Tsunami of 2008 where the signs for economic slowdown were already evident (reduced advance bookings, lower than usual occupancy rations as well as the cancellations of large bookings).

The conclusion of this paper should also cite two quotes reflecting the many years of crisis management experience by the Interviewees: 'every cloud has a silver lining' (Hotel K, UK) and that hotels can 'come out of crisis stronger' (Hotel I, UK)

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Chapter 8

Learning from Lisbon: Contemporary Cities in the Aftermath of Natural Disasters

Diane Brand and Hugh Nicholson

Additional information is available at the end of the chapter

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1. Introduction

Cities survive earthquakes and rebuild with improved urban strategies, architectural designs and building technologies. This chapter will present a detailed analysis of the response, recovery, planning and rebuilding processes after the Lisbon earthquake and compare them to the recent events in Christchurch, New Zealand. Archival research from libraries and museums in Portugal will inform the historical analysis, and interviews and official documents from New Zealand relief and reconstruction agencies will underpin the contemporary analysis. The study aims to identify opportunities and challenges in facilitating good urban design in the process of recovering from a natural disaster, using case studies which are separated by over 250 years, but which both attest to the centrality of urban design in the reconstruction process.

2. Lisbon 1755

This section will look at the Lisbon earthquake and its aftermath, with a view to understanding how design, leadership and governance processes contributed to the production of an 18th century, state-of-the-art urban quarter in the wake of a national tragedy. Particular attention will be paid to the coincidence of enlightened political, economic and technical skills which were judiciously applied to the re-planning of the city. By many counts the thinking was modern, and bears a worthwhile comparison to the recent seismic events in Christchurch, which will be the subject of the second part of the chapter.

3. The event

An estimated 8.4 magnitude earthquake in Lisbon on the morning of All Saints' Day in 1755 reverberated throughout the Iberian Peninsula, Madeira, the Azores, and North Africa. Tsunamis affected the Caribbean and the Atlantic coasts of Europe [1]. Of a population of 250,000, up to 20,000 people perished in the quake, tsunami and fires that followed [2]:

At this moment the earth shook, the sea rose up foaming in the harbour and dashed to pieces the ships lying at anchor. The streets and squares were filled with whirling masses of flame and cinders. The houses collapsed the roofs crashing down on shattered foundations. Thirty thousand inhabitants were crushed beneath the ruins [3]

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Aid came from Portugal's colonies and her allies and trading partners England, Germany and Holland. Strategically, local merchants donated a 4% surcharge on imports to the relief effort which gave them critical political influence in determining new land uses for the reconstruction [4].

Figure 1. Panoramas of Lisbon before the 1755 earthquake [various authors] Museu da Cidade de Lisboa

4. Recovery: A vision of economic and political reform

The man in charge of the reconstruction effort, the Minister of State (1756-1777), Sebastião José de Carvalho e Melo, was decisive and commanding in his response to the disaster, relief and the forward planning of the city and his leadership in the crisis cemented his political power over his adversaries until the death of his supporter King José I in 1777. The King would make him the Marquis of Pombal 15 years after the earthquake in recognition of his

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leadership during the crisis. In a swift and articulate response to the emergency, the city was immediately surveyed and new construction was prohibited. Looters were publicly hung and able-bodied deserters were prevented from leaving the city and pressed into relief work by the army. Monasteries and public squares were filled with the homeless, and tent cities occupied by merchants and nobles sprouted (King José I and his family occupied an extensive tent and pavilion court in the hills of Ajúda at the edge of Lisbon for some months after the earthquake). Pombal moved about the city directing the recovery operation from his mobile headquarters a carriage which he had commandeered from the royal family.

What followed in the next two years was the ruthless and all-encompassing implementation of a radical plan which would change the political landscape and dramatically improve Portugal's economic position in Europe. The Terreiro do Paço (Figure 1) or Palace Square, had evolved as an elongated, spatially contained, urban space at the edge of the Tagus River in association with the Ribeiro Palace. In the wake of the earthquake the space was reconfigured, along with the adjacent central Baixa district, as the Praça do Comércio, a formal axial square surrounded by monumental public edifices where the business of an empire could be effectively conducted.

Pombal's previous roles as political envoy to London and Vienna and Minister of Foreign Affairs and War (1750-1756), where he oversaw town planting in Brazil, had seen him develop sophisticated ideas on mercantilist economic reform and coherent town planning. In the reconstruction of Lisbon's heart he found the perfect vehicle for both. The aim was to create a modern political centre where commerce could thrive. He had, in his ministerial role, overseen the dismantling of the Portuguese inquisition, the secularisation of education, and the nationalisation of industry [5]. He therefore favoured an institutional shift away from the old nobility (whom he considered corrupt and impractical) and the Jesuits, to the city's commercial elites who had helped finance the reconstruction. A strategically timed and implemented legal re-configuration of property ownership in the Baixa, transferred land from the aristocracy and ecclesiastic authorities to emerging merchant elites, whose collective economic enterprise would eventually succeed in rebuilding Portugal's indigenous economy. The waterfront square was edged with public buildings, which encompassed business, city government, and customs and exchange, in an effort to stimulate local trade and industry, and reverse high local unemployment levels and the traditional dominance of foreign merchants.

Urban renewal in the aftermath of the earthquake was appropriate for other reasons. Portugal had entered an era of nation-building with the consolidation of her borders in in 13th and 14th centuries. By the 16th century, Lisbon's image and role as the capital of a nation and a vast empire stretching from Angola to Macau was considered important, and urban embellishment was funded by gold and diamonds from Brazil. During the reign of King João V significant new urban projects were planned in the west of the city to boost the capital's status. The Águas Livres Aquaduct in 1728 is the best example of a new project that combined the provision of infrastructure with urban-scaled monumentality. Other projects included the construction of the vast and extravagant convent -palace at Mafra, the interior embellishment of 65 medieval and baroque churches and the building of dozens of new places of worship in the neoclassical style.

More significantly, Enlightenment-thinking from Northern Europe opened up the possibility of a scientific explanation for disaster rather than a religious one, rendering reconstruction a rational rather than a superstitious exercise, while the destruction of a splendid European court generated political uncertainties and revolutionary possibilities. As part of the reconstruction exercise, Pombal surveyed the populace in search of technical and scientific data about the earthquake, and his findings pointed to new methods in construction. Liquefaction had been observed in the riverside areas, so new buildings there were constructed on timber piles driven into the soil to act as anti-seismic stabilisers. Timber buildings had survived the quake better than masonry buildings, so new buildings had internal seismic frames added to their fabric. The new streets were widened so that even if the buildings on both sides had collapsed, there would remain an evacuation passage between them [6].

Ana Araújo [7] suggests that the press of the time stimulated a pan-European debate about issues of pragmatic responsiveness to natural disasters and unity of action across national borders. It was certainly the first example of a truly international relief effort after a calamity of such magnitude. Fact and fiction merged in the minds of the populace, fuelled by exaggerated emotive accounts of the catastrophe printed in cheap popular news pamphlets [8]. These served to fuel superstitious terrors, displays of religious fanaticism and dire predictions associated with natural phenomena such as Halley's Comet which was expected to appear in 1757 or 1758. The auto da fé, (act of faith, or public burning of heretics) held in the Terreiro in June 1756 was devised as a collective atonement for the earthquake of the previous year [9].

The event also presented political opportunity for the Minister of State to distribute anti-Jesuit propaganda in the capitals of Europe via anonymously authored opinion pieces in major newspapers [10]. Pombal co-opted some of the most influential men of the day in literature and science [11] to disseminate news and views about earthquake recovery, the necessity of repressive civil protection measures adopted post-disaster, and public health and welfare interventions. In the interests of civil obedience, state terror replaced the religious fear of the past.

5. Experience and expertise

The group charged with the recovery and rebuilding of Lisbon were an elite cohort of military engineers whose routine duties involved cartography, architecture and town planning, including the design and construction of infrastructure, (roads, aqueducts, ports, defence structures and fortifications) and associated buildings. They were a geographically mobile and flexible group of men, deployed in situations ranging from the frontier towns at outer reaches of the global Portuguese empire, to its busy cosmopolitan centre of trade and commerce. Their expertise embodied a high level of practical knowledge gained from work in the field as well as state of the art scientific knowledge. Their training via an apprenticeship system at the University Coimbra, represented a productive intersection of the knowledge embodied in foreign treatises such as those of Alberti and Vitruvius, and the real world they encountered in their active service.

Their approach to the built environment appears to privilege the site-specific adaptation of useful typologies, while giving a high priority to public space and infrastructure (especially port infrastructure, given that so many of the Portuguese colonial settlements and *feitórias* (trading posts) were coastal)[12]. Their sensitivity to the scale differential between the city and the building via a unified architectural language is a notable aspect of the Lisbon plan. Many of the best military personnel were in Lisbon at the time of the earthquake, and others joined them for the special mission of rebuilding the capital. Their designs were infused with the utopianism of the Portuguese school of the rational and civic-minded town planning demonstrated in new world cities such as Goa, Rio, Macapà and Luanda [13].

In 1910, cavalry officer Christovam Sepúlveda published Manuel da Maya e os Engenheiros Militares Portuguêses no Terromoto de 1755 (Manuel da Maya and the Portuguese Military Engineers in the 1755 Earthquake) [14] which identified Maia's central role as the strategist in the planning and rebuilding exercise. Jacôme Ratton [15] identifies military architect Eugénio dos Santos as the person who formulated the principles of the reconstruction.

Sepúlveda highlights two important aspects of the organisational culture of the military engineers. The first was their adherence to hierarchy, discipline and teamwork in military operations and the second was the heavy investment they made in strategic planning. Maia's role in executing both these practices is evident in the terms of reference for the reconstruction that were which embodied in the Dissertacão and other critical supporting official documents published in the late 1750s. Manuel da Maia's 1755 Dissertacão [16] describes the strategic solution for the rebuilding of Lisbon after the 1755 disaster. In addition to emphasising leadership, Sepúlveda deemed the teamwork, training and field experience of this group of elite military engineers in the colonial realm as essential preparation for the task.

There was ample regional and local precedent for disaster recovery as earthquakes had plagued Lisbon since its founding. A seismic event on the 26th of January 1531 had struck the city with equal force, but produced a far less acute political reaction due to the relative social stability at the time [17]. The Portuguese had certainly benefited from the study of other disasters such as the 1666 fire of London and the numerous volcanic events of in Sicily, particularly those affecting the city of Catania. Maia had been involved for many years in surveying and engineering projects around Lisbon, and this formed the basis of his knowledge to reconstruct the city. Critically he had been involved in the surveying and building of the Main Fortification Line in 1716, the Águas Livres Aquaduct, between 1720 and 1730, and the Santa Isabel survey in the 1740s. This deep knowledge of the terrain subsequently allowed him to swiftly prepare the alternative plans. He authored the Dissertacão which described the methods and processes leading up to the publication of the 1756 plan (Figure 2).

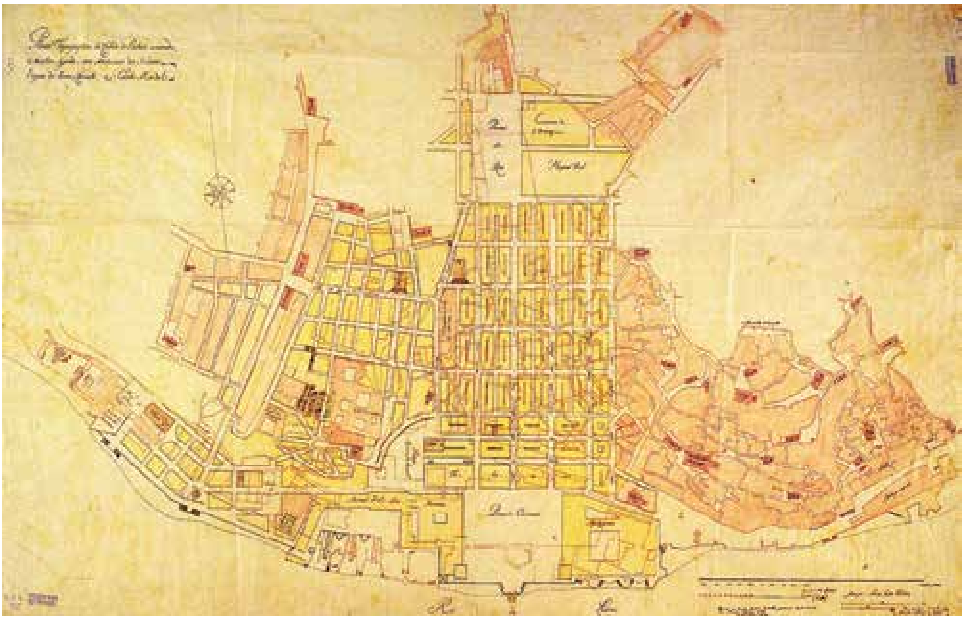

Figure 2. A Topographical Plan of the city of Lisbon [Carvalho and Mardel] 1755 Museu da Cidade de Lisboa

6. Planning: The dissertacão

The town planning principles for rebuilding Lisbon were established within 5 months of the event, in Part I of the Dissertacão, which directed that options for both rebuilding and relocating the city be considered. There was an impetus to rebuild and relocate the court in a better place (either at Bélem or São João dos Bem-Casados) which opened up the possibility for locating new public buildings in the Baixa. Layouts were subsequently developed by military architects Eugénio dos Santos and Carlos Mardel.

Part ll of the Dissertacão was comprised of a legal decree in May 1756 that governed land ownership, construction and finance for the rebuilding of the devastated centre, and a set of development rules for areas of expansion at the periphery. Part III of the Dissertacão was comprised of the alternative plans, which covered a range of rebuilding and relocation options. Maia presented six options investigating variations of street widening, ground re-levelling, adjusted building heights, all contributed to a radical new block morphology, residential-building typology (with trade and craft premises at ground level) and sense of urban scale [18]. A prefabricated, technically innovative and stylistically simplified four-

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storey building type was developed. This building ingeniously incorporated fire walls that extended above the roof line and earthquake resistant diagonally braced, timber load-bearing cages called gaiola that sat independently within the masonry perimeter walls. Building components were prefabricated on a large scale off-site, allowing speedy on-site assembly with minimal traditional craft involvement [19].

The plan ultimately chosen, incorporated the following mechanisms and characteristics which are documented by Claudio Montiero [20]:

1. A standardised building type
2. A standardised construction solution incorporating fire separations and seismic frames
3. A rational and generous public space network based on pre-existing places
4. The use of the rubble from the ruins to raise and regularise the levels of the Baixa by 1.2 metres, and reclaim new land from the Tagus
5. A disregard of property ownership boundaries (especially the location of churches) so as not to compromise the rigorous geometry of the new plan

This formed the basis for the legal provisions of the legal decree of June 1758 which finalised the plan. It had taken two years for the plan and the legal and financial exchanges to align. A year later, in June 1759, re-building finally commenced.

These critical ownership reforms relied on Pombal's public credibility and private influence at Court. The period was dogged by multiple conspiracies, including a palace coup in 1756, and an assassination attempt on the King in 1758. These behind-the-scenes machinations lengthened the plan's implementation time, but unlocked the heart of the city as a centre of trade and commerce, thereby better serving the emerging merchant class and challenging the historic power of nobility and clergy. The plan largely preserved the places and names of the historic city and retained the location, hierarchy and functions of three main squares (with the re-naming occurring later). Churches that had been free-standing were now integrated into the Baixa blocks.

The Praça do Comércio doubled the size of the former Terreiro do Paço, by reclaiming land from the river Tagus. The new square's symmetry, focusing on an equestrian statue (flanked by the animals of Portugal's far-flung continental empires), and the triumphal arch to the main street, Rua Augusta, constituted the axis of the plan as a whole. The post-earthquake square had a statue of King José I at its heart but perimeter uses were designated for functions of state, with the palace itself relocated to the city edge at Ajúda [21]. While symbolically, a royal statue still stood at the centre of Lisbon, functionally it was now a place for commercial enterprise (Figure 3). Blocks were configured in a simple proportional and compositional system that supported elegant and environmentally comfortable street sections and public-space footprints. There was a hierarchy of three main streets, each 60 palms wide, that were named for the guilds (Rua da Prata, Rua do Ouro or Silver and Gold Streets respectively), cross streets that were named for church and parish interests, and North-South streets, each of widths of 40 palms, that were also named for guilds.

Figure 3. Praça do Comércio [Rick Allender] 2007

The streets determined the building fabric. The building heights were to be no higher than the width of the streets and thus set a new standard for access to light and air in an urban building. A system of dividing dwellings by floors, with retail at ground-level and artisans' workshops at basement-level, was developed. The arrangement of three floors of identical apartments plus an attic above the ground-level floor was the origin of modern mixed-family ownership in Portugal, and the typology represented the potential for a mixing of classes in one edifice, each with its own separate entrance. Both shops and apartments were built to be rented, thus facilitating urban housing as a form of property investment.

The plan's implementation was directed by José Monteiro de Carvalho, who materialised the abstract rules for scale and the architectural features of the urban blocks at a large scale, while enforcing technical standards such as fire compartments between tenancies, new sewer locations and the cage structures. He was also attentive to the finer details of serial design elements required for cast-steel balconies, the ashlar masonry trim to building bases and openings, and consistent window and door joinery profiles (Figure 4). Up to this time he had been in charge of demolition, which earned him the nickname Bota-Abaixo or knock-it-down.

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Figure 4. century standardised building types in Chiado District [Diane Brand] 2004

This aesthetic and technical system became the basis for re-planning Lisbon as a whole, especially around the new palaces, and in areas developed at higher densities in the western part of the city. The scheme set the tone for a future direction of urbanism in Lisbon that embodied a new rational Cartesian pattern but which was firmly anchored in a traditional morphology. Over time the plan set aesthetic, technical and legal precedents but these were not fully appreciated until the modern era, when separate built environment professional disciplines such as architecture and planning emerged and their histories were fully researched.

7. Rebuilding

Claudio Monteiro [22] suggests that legislative reform enacted during the reconstruction of Lisbon was driven by the plan's necessary transformation of the structure of urban property ownership, and the careful reconciling of individual rights with the security of future investment. The reconstruction plan and the resultant legislative reform were the tools that brought about eventual political and economic reform. Pombal's aim was to consolidate the power of the King while at the same time modernising the nation's legal, economic and social structures.

The measures used to achieve these included:

1. The surveying of existing buildings at the time of the earthquake to avoid disputes during reconstruction, especially when an overhaul of the land ownership arrangements was contemplated (Wren's plan for London after the fire in 1666 had been frustrated by an inability to rationalise the nobility's ownership of the large estates in central London).

2. A prohibition on constructing or reconstructing buildings before the plan's approval:

a. Outside of Lisbon, to stop the city growing randomly and

b. Within Lisbon, to prevent the rebuilding of buildings partially destroyed by fire (less than one third of the original buildings were in a habitable condition and no alternative accommodation existed apart from tent cities and timber shacks erected in public spaces).

The plan was approved two and a half years after the earthquake, and the first lots were reconstructed three and a half years later. Nevertheless, illegal urban development had sprung up in spite of harsh enforcement of the decrees.

3. Freezing rents and freezing the price of construction materials, to combat speculation, eviction and exploitation around the shortage of construction materials and rental accommodation. This was done by restricting any new lease agreements to perpetual leases or long-term rental contracts.

4. Creating the conditions for legal, religious and political reform by freely compensating and transferring pre-existing property ownerships into newly agreed formats

5. The complete demolition of the Baixa to make way for a despotic but utopian and progressive plan [23]

8. Compensation

Land within the Baixa was immediately appropriated by the state and re-allocated, with preference given to existing land owners, leaseholders or administrators for nobles, the church or the crown. Compensation was based *only* on site area, and not the post-earthquake building condition. New lots were allocated on the condition that redevelopment would be completed within five years, effectively rendering the exercise a land re-adjustment operation rather than an exercise in eminent domain, while preventing long-term speculation of development leap-frogging.

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Undersized lots, oversized lots and lots eliminated by the creation of new public spaces or streets were paid fair land swap or cash compensation in proportion to the frontage width of the site. Cash payments were necessary since there was a greater total area for public space in the new plan and therefore an undersupply of new sites. Maia proposed a proportional reduction of all buildable areas to account for improved amenity as a result of more public space in new areas. The chief surveyor of the inspections, Alexandre José Montanha divided the Baixa into seven zones of value, thus setting up a financial mechanism by which properties were exchanged or compensation calculated with a 'premium payment' embedded for superior sites adjacent to public space.

In this way the plan created value. The overall effect was to replace certain types of landowners (nobles and secular clergy) with merchants, sparking what Subtil called 'political earthquakes' in Portuguese society [24]. The compensation system and plan stimulated investment from the business community who had financed the reconstruction (via credit or purchase). This in effect led to a significant redistribution of wealth, a consolidation of economic power among the middle class, and a new degree of upward social mobility. The move also unlocked the encumbrances and liens strictures embedded in the medieval property codes that had inhibited clean development processes within the city.

Complete execution of the plan took over 40 years. An initial displacement of Lisbon's population to the west immediately after the earthquake inhibited the uptake of property in the centre. The ancient elites also retreated, taking the court sector with them.

9. Authoritarian processes

Authoritarian processes were the key to the effective reconstruction of Lisbon. Pombal was appointed by the King to his position as Minister of State and he used this mandate to centralise political power by removing the Senate from the state decision-making processes and from the implementation of the Baixa plan, thereby breaking a longstanding tradition of local autonomy in planning and taxation matters. The institutional makeup of the reconstruction process evolved as the pragmatics of the situation dictated, with two complementary bodies emerging: The first was the Lisbon Neighbourhoods Inspectorate as the civil defence responder in 12 neighbourhoods city-wide. This agency was also instrumental in clearing debris, removing and burying bodies, executing surveys and re-allocating land. The second was the Public Works Department which was formed to implement the plan, and projects including public spaces and new buildings. The technical team, comprising of army officers in the civil administrative hierarchy, originated at the Lisbon Public Works Draughting Office (*Casa do Risco da Obras Públicas*) which later became the Public Works Department. This reduced, focused and disciplined chain-of-command, facilitated the absolute control required for such sweeping changes to the urban space configuration and the resulting shift in political and economic hegemony.

The first order of business was the creation of the public realm, with new streets, squares and gardens. Public health was foregrounded with upgraded sanitary infrastructure, water supply and transport systems given priority. The construction of essential public buildings for trade and business continuity such as the Customs Building in Praça do Comércio was also critical as they served an influential special-interest group. Reconstruction took roughly until 1807 to complete, ironically coinciding with the royal family's flight to Brazil as Napoleon's troops massed on the border during the Peninsular Wars.

10. Urban design opportunities

A pamphlet at the time of the 1755 disaster optimistically stated that 'Lisbon could not have suffered a more fortunate tragedy', indicating the potential the populace saw in the reconstruction process [25]. A major aspect of this fortune clustered around the implementation of a good example of urban design, one that was ground-breaking for its time and which still ranks as outstanding. The plan proceeded with a new gridded layout for the Baixa quarter, based on the disaster and re-planning precedents of the fires in London and Rennes, and the earthquake in Catania and planning precedents such as the 1620, 1673 and 1714 extensions to Turin [26]. Among precedents for the Baixa Plan were Wren's 1666 plan for London (new street alignments and property subdivision), new Turin (the regularised geometry of public space and city blocks) and the Place Royale, Place Vendôme and the Royal Palace at Bordeaux (the continuous articulated facades, marked entry points and arcaded bases of the buildings which framed the public space) [27]. It represented a successful example of contemporary urban disaster and urban design knowledge of in 18th century Europe.

The Terreiro do Paço was reconstructed and renamed the Praça do Comércio (Figure 5). Rubble from the earthquake was recycled (eliminating the disposal problem) and an area of land equal in size to the original square was reclaimed, extending the urban platform into the Tagus. The reconstruction of Lisbon presented an opportunity to integrate the waterfront square into the urban fabric. The new monumentally scaled square used symmetry and architecture to integrate a complex of buildings embracing the space into the urban fold, and created a powerful central axis penetrating into the city behind via Rua Augusta, thereby linking the square to the Rossio (Lisbon's other principal square) beyond. Pombal's project redressed the problems that had beset the Terreiro as an urban square. Certainly the architectural and urban legibility of the square was enhanced, the buildings were better scaled to city blocks and there was more permeability to the Baixa, with vistas along Rua da Prata, Rua Augusta and Rua do Ouro. However, the authoritarian method of delivery required the subordination of individual property rights to the public interest, with new development and construction precisely defined within the strict constraints of the plan. The effect was also to subordinate architecture to urban design, with exacting and specific controls placed on building envelopes, construction methods, uses, appearance and materials.

Figure 5. Praça do Comércio [Susana Pereira] 2011

The following section discusses urban design initiatives arising from a series of devastating earthquakes in the new world city of Christchurch, New Zealand and compares them to the 18th century event in Portugal. Two years after the earthquakes, urban design strategies to rebuild the broken city have been formulated but are not yet implemented.

11. Christchurch 2010 and 2011

Christchurch was planned in the mid-19th century as the last Wakefield settlement to be established by a private colonization enterprise called the New Zealand Company. The company was involved in the establishment of six urban centres in New Zealand: Wellington [1839] Wanganui [1840], Nelson [1841], New Plymouth [1842], Dunedin [1848] and Christchurch [1850]. The New Zealand Company brought more than 9,000 hopeful settlers to New Zealand up until 1843 [28], with each of the towns achieving numbers of between 1000 and 4000 in the first years of settlement. Christchurch was sponsored by the Church of England and aspired to recreate a stable agrarian, hierarchical society on fertile land, between the Pacific coast and the Southern Alps on terrain purchased from the local Ngai Tahu tribe. A rectangular grid was surveyed onto flat swampy land and adjusted where necessary to accommodate the Avon/Otakaro River, which meandered across the site. The diagram of the city incorporated the grid, the river, two diagonal roads registering the principal transport routes to the port of Lyttelton and the main road north, a cross-shaped central square (where a cathedral was later built), a market adjacent to the Avon River, two asymmetrical peripheral squares, and parklands providing generous and varied public and recreational space. In June 2010 the city was New Zealand's second largest, with a population of 376,700.

12. Events

In the early morning of Sunday the 4th of September 2010 a magnitude 7.1 earthquake located 40 km west of Christchurch on an east-west fault, not previously identified, struck the city. The fortuitous timing of the event explains the lack of fatalities but there was widespread damage to unreinforced masonry (URM) structures [walls and chimneys] in Christchurch and surrounding towns. Nineteenth century URM shop fronts collapsed into main thoroughfares in the CBD, and there was widespread liquefaction to eastern suburbs' residential areas close to rivers. This earthquake triggered a series of aftershocks that moved progressively closer to the city, culminating in a shallow, 5km deep, M 6.3 earthquake on February 22, 2011 (Figure 6) centred at Lyttelton. This too occurred on an unidentified fault. This second major event resulted in 181 deaths, with more than half of these occurring in the collapse of the Canterbury Television Building. This earthquake caused further significant damage and collapse to URM structures in the CBD, more liquefaction to eastern suburbs' residential areas close to rivers and rock falls and landslides to the south and southeast. The result is that between 50% and 70% of buildings in the CBD are likely to be condemned for demolition with the discovery that many structures are out of vertical axis alignment due to differential settlement and the realization that the repair of others is uneconomic.

Figure 6. A 6.3 magnitude earthquake strikes Christchurch on February 22nd 2011 [Gillian Needham]

The civil defence response was immediate, with international urban search and rescue terms arriving from nations such as Australia and Japan to relieve local emergency services. Emergency response centres were swiftly established in parks, and sports and community buildings, with temporary accommodation provision in the form of tents, caravans, and prefabricated houses deployed by the Department of Housing and Construction. The entire CBD was cordoned off and placed under police and army jurisdiction for an extended period, leaving many businesses without access to their premises. The slow and uneven process of insurance compensation has led to businesses relocating to other centres in New Zealand or locally to the western edge of the city close to the airport. The entertainment centre of the city has re-established itself in the west along Riccarton Road. With more than half of Christchurch's listed heritage buildings (250) located in the CBD, the city's patrimony has been particularly hard hit with more than 100 demolitions to date. The iconic Anglican Cathedral, the Catholic Cathedral of the Blessed Sacrament and the Canterbury Provincial buildings suffered significant damage (Figure 7).

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Figure 7. Canterbury provincial buildings post-earthquake [Diane Brand] 2011

13. Recovery

After the second earthquake it was clear that existing central and local government agencies were not equipped to facilitate recovery operations, and The Canterbury Earthquake Recovery Authority (CERA) was formed on March 29, 2011 as a special government agency for the co-ordination of the recovery and rebuilding activities in Canterbury. The Canterbury Earthquake Recovery Act [29] gave unparalleled (in New Zealand terms) authoritarian powers to the Minister of Earthquake Recovery, The Right Honourable Gerry Brownlee, although in practice the powers have been exercised only with the agreement of the cabinet (the government's executive level ministerial group). In particular the CER Act allows a recovery plan approved by the minister to override the requirements of New Zealand planning legislation frameworks embodied in the Resource Management Act, the Conservation and Reserves Acts and large parts of the Local Government Act (although not the funding provisions, and the Land Transport Act).

The government's response to the Canterbury earthquakes occurred in an environment of mistrust between national and local government, characterised by the dissolution of the regional council, Environment Canterbury, in March 2010, and the quite different leadership styles of the mayor and the minister. Part of the reason for the distrust lay in the different underlying political philosophies, with the ruling national government espousing a 'shrinking government' position together with the sales of government assets as a means of reducing the national deficit. In contrast, local government in general, and in particular the Christchurch City Council (CCC) supported maintaining the level of local government services as a minimum, with the CCC pursuing a clear position of holding onto city assets in city-owned holding companies and using these to generate income or reduce tax liabilities.

In 2011, the government introduced an amendment to the Local Government Act aimed specifically at limiting the services local governments could provide and the levels of rate increases they could introduce. The CER Act specifically excluded the minister from making changes to the funding provisions of the Local Government Act and there have been continuing discussions about the allocation of costs between national and local government ranging from the emergency response costs to repair and rebuilding costs. The national government has clearly stated on a number of occasions that it believes that the CCC should sell some of its assets to fund the recovery bill.

The CER Act established a new government agency to oversee the recovery of Canterbury and the government's investment in the rebuilding of Christchurch. The act specifies that the minister can direct the city council, but does not clearly establish the respective roles of the organisations, or create any direct organisational links or lines of management apart from general requirements to consult. The newness of the government agency CERA, coupled with the pre-existing responsibilities of the council, has led to a lack of clarity about their respective roles, with duplication happening at a number of levels between the two organisations.

The CER Act specifically required the CCC to develop a draft recovery plan for the central city in nine months for the minister's approval, including public consultation. Planning for the rest of the Christchurch metropolitan area was the responsibility of CERA. The Draft Central City Plan (CCP)[30] was completed in eight months, however the minister spent a further seven months reviewing it. When the minister received the draft he endorsed the vision contained in the first volume, with the exception of the proposed transport changes, but he set aside the proposed regulations for further investigation [31]. The 'blueprint' plan [32], subsequently approved by the minister, broadly adopted the range of major infrastructure projects proposed in the Draft CCP and retained the majority of the proposed regulations including the reduced height limits. The major changes from the Draft CCP was the removal of the regulations requiring improved environmental performance from buildings (the BASE assessment developed with the NZ Green Building Council), the removal of the financial incentives for rebuilding proposed by the council and the removal of the majority of the transport provisions pending further investigation.

The Canterbury earthquakes resulted in extensive land damage and areas of liquefaction, particularly in the eastern part of the city (Figure 8). The resulting changes in elevation included some areas in the Port Hills rising by up to 500 millimetres while areas around the estuary and Avon River subsided by more than 500 millimetres (Figure 9). In extensive areas

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the cost of land remediation, flood protection and/or the restoration of services made it uneconomic to rebuild on the terrain. The government assessed all residential land in Christchurch and the surrounding towns based on extensive geotechnical studies and eventually classified them as either 'green' (fit to rebuild) or 'red' (unfit to rebuild). Subsequently, the government has set about purchasing more than 6,000 houses in the residential red zone based on the 2009 rateable valuations. The houses are generally either clustered in low lying areas around the Avon River and Estuary or vulnerable to rock fall in the Port Hills.

Figure 8. Liquefaction in the eastern suburbs of Christchurch (2011) New Zealand Aerial Mapping Ltd for LINZ

The retreat of settlement along the Avon River and Estuary in Christchurch has provided a microcosm of the kinds of issues likely to be faced by many coastal cities worldwide, if sea level rises predicted over the next century occur [33]. The model of strategic retreat, from vulnerable areas may become relevant in many other areas. While the Christchurch model has addressed the issues of strategic retreat and attempted to manage the economic impact on residents, no attempt has been made to address the impacts at a community level. However, a map showing the areas where 'red zoners' have relocated reveals a scattered pattern determined by the prices and availability of houses, rather than any managed attempt to relocate communities.

The CER Act facilitated the immediate use of earthquake rubble for reclamation work to extend the container port at Lyttelton. This would have been difficult and protracted under the RMA. The port is one of the key economic drivers for the Canterbury economy, and the port extension reflects the changing scale and technologies of port logisitics. The CER Act has also been used to fast-track residential subdivisions, thereby short circuiting the currently protracted consent and environment court processes. The intention has been to free up residential land so that people who have been displaced by the earthquakes, and workers arriving in Christchurch to assist with the rebuild can be adequately housed. In doing so, the minister has confirmed the overall urban form proposed in the Greater Christchurch Urban Development Strategy which sets out urban limits, greenfield residential areas and housing densities, targets for intensification, urban design outcomes and key transport corridors (although these measures are currently being challenged through the courts). The need to dispose of a huge quantity of rubble in a very short timeframe, and to expedite the provision of new housing stock to replace that damaged and destroyed are common issues for cities struck by earthquakes. Both Lisbon and Christchurch used authoritarian powers to address these issues in a timely and economically beneficial manner.

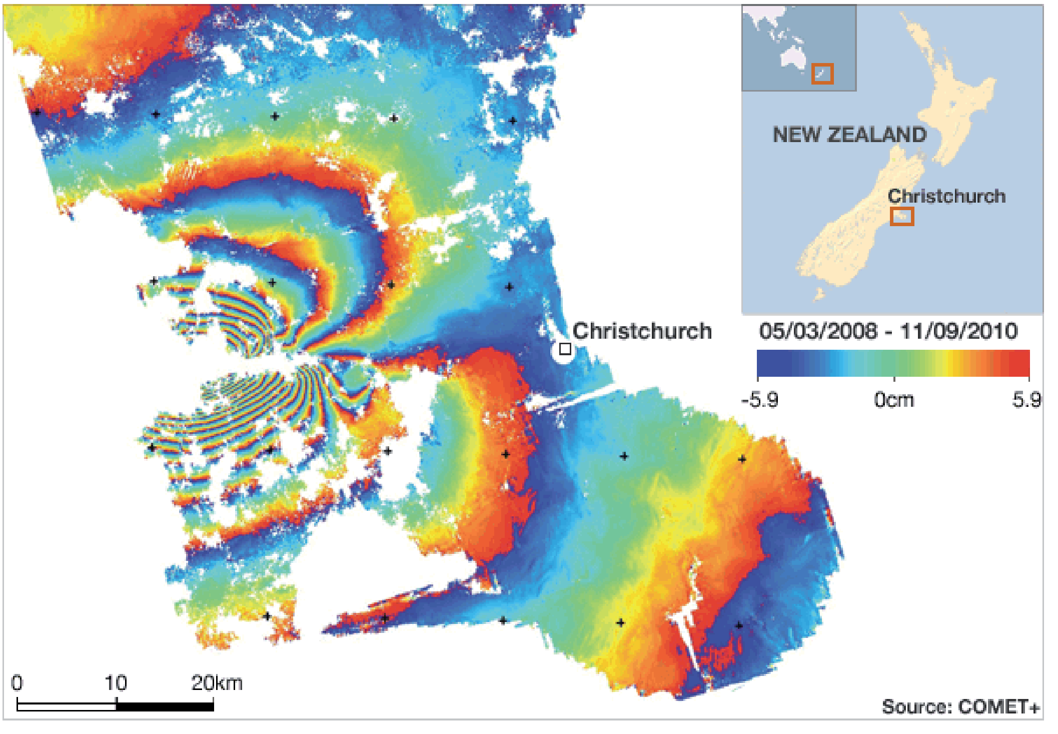

Figure 9. Lidar Map of Christchurch showing ground level changes (2010) COMET

14. Compensation

After a wave of earthquakes that plagued New Zealand between 1929 and 1942 (the worst of which was the M7.8 Hawkes Bay earthquake of 1931 which completely devastated the cities of Napier and Hastings), the Labour Government created the Earthquake and War Damage Commission. The commission eventually insured all residential properties, including the land (up to \$100,000 for buildings and \$20,000 for contents) against damage from natural disasters [34]. Commercial property must be privately insured. In early 2010, the EQC had reserves of NZD 5.6 billion backed by a government guarantee. However the total insurance estimate for the Christchurch earthquakes is up-

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wards of NZD 30 billion [35] and represents the worst natural disaster in a developed nation relative to size of economy. Private insurance fared no better, with the market dominated by only 5 principal providers, several of whom have struggled to pay out claims without government assistance. The compensation for damage is an on-going saga of bureaucratic complexity, delays and individual suffering which has been exhaustively documented by the nation's media. Policy neglect had contributed to the underinsurance of the majority of New Zealand homes, with EQC covering a quarter of the average value of a New Zealand home, and maximum premiums still at their 1973 level of NZD 67.50 per annum in spite of advice to increase these in 2008. A premium for land insurance had never been charged, but this type of damage turned out to be the most expensive. While the annual EQC premiums were raised in the immediate aftermath of the earthquakes, policy revision in the insurance sector is still under consideration. Discussions include the introduction of land insurance, better processes of alignment between land use decision making in territorial local authorities and disaster insurance agencies, and the level of future risk-sharing between EQC and private insurers [36].

15. Experience and expertise

Local government manager Warwick Isaac, who was overseeing the demolition of buildings in Christchurch, was appointed to lead the Central Christchurch Development Unit (CCDU) which is tasked with leading the rebuilding of the central city. Dubbed 'the demolition man', a Tom Scott cartoon has him lamenting "If I had known you were going to put me in charge of the rebuild Minister I wouldn't have pulled so much down." Both the council's Draft Central City Plan and the 100-day Blueprint subsequently produced by the CCDU were prepared by multidisciplinary teams led by urban designers. Although the approaches were fundamentally different, with a community-led bottom-up process for the Draft Central City Plan and a technocratic top down 'masterplan' in the Blueprint, both documents were 'design-led' in that they used design as the key method of developing the plans with built environment professionals (urban designers, landscape architects, architects) holding the key leadership roles responsible for developing plan content.

The Draft Central City Plan was developed by a multidisciplinary in-house team of council staff that included seconded team members from national and international consultancies including Gehl Architects from Copenhagen. Hugh Nicholson, the Principal Urban Designer at the Christchurch City Council, was responsible for delivering the content of the plan. The team included urban designers, architects, landscape architects, engineers, economists, planners, community advisers, communication specialists, sustainability advisers and recreation and open space planners.

The 100-day Blueprint was prepared by a consortium of design companies led by Boffa Miskell, a local company specialising in landscape architecture, urban design and landscape planning. The consortium included local architects Warren and Mahoney and Sheppard and

Rout as well as specialist convention centre and stadium designers. The team was led by landscape architects Don Miskell and Rachel De Lambert and urban designer Marc Bailey.

16. Planning

Within three months of the February earthquake, an extensive public consultation exercise was undertaken with the people of Christchurch to help shape the future plan of the devastated city. The website shareanidea.org.nz generated 58,000 hits and engaged the public in four key areas: move (transportation), market (business), space (public place and recreation) and life (mixed uses), across traditional and social media networks. This was followed by an interactive expo, 10 community workshops, 100 stakeholder meetings and a professional competition for 5 selected sites. An unprecedented level of public participation generated 106,000 ideas over six weeks and these informed the development of the Draft Central City Plan.

One of the firm assumptions underlying the Draft Central City Plan was the maintenance of the existing street and land ownership patterns. In part this recognised the strong urban form provided by the existing grid and its heritage values. In part it was in response to initial estimates that suggested 50% of the buildings in the commercial core might be demolished (subsequently this looks to be greater than 60%). This implied that there was still a substantial residual value in the remaining buildings and services which the city could not afford to lose. In terms of broad urban design objectives, both the draft CCP and the Blueprint set out to provide an enhanced network of green open spaces based around the Papa o Otakaro (Avon River Park) and Cathedral Square, to rebuild a more compact intensive low-rise commercial core, to increase the number and density of inner-city residents, and to promote mixed-use developments in areas surrounding the core. The plan also proposed more sustainable transportation systems, including a light-rail system from the university to the CBD, that would eventually connect into a regional rail network and a grid of cycle-ways. The redevelopment clustered around a set of core projects seeded by government, which were designed to attract investment and rebuilding in the CBD and these included a greening of Cathedral Square, a sports hub, a convention centre, a central library and a hospital campus.

One of the more controversial urban design proposals in the Draft CCP was a reduction in height limits to 28 metres or seven stories. Christchurch was the first major Australasian city to propose a low-rise urban form, moving away from the modernist podium and tower model of development. The reasons for this were partly the high level of community support for low-rise buildings and their desire to create a more human-scale environment with better environmental conditions, including improved sunlight access and reduced wind funnelling. Additionally, economic modelling indicated that due to the increased foundation and structural costs required to build higher than six to seven storeys, the most economically viable built-form with the highest rate of financial return was in this height range. The final reason was to address the oversupply of commercial land in the core, by rebuilding a

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more consistent intensity of development over the area of the core, avoiding the spikes of oversupply and undersupply provided by the tower model. There was a strong backlash from the business community against the proposed height limits and this was one of the provisions that the national government set aside when it reviewed the Draft CCP. However at the end of the review, they reconfirmed the height limits based primarily on the economic impact assessment and the land supply issues.

Figure 10. The CCUP Blueprint (2012) CCUP

The Draft CCP proposed using built-form restrictions to further promote a compact commercial core, with a higher intensity of development through the use of incentives and by limiting development potential outside the core. The Blueprint adopted a far more interventionist approach by establishing a 'green frame' (reinstating nineteenth century parklands) and compulsorily acquiring large areas of land surrounding the core. The long-term future of the proposed frame is not entirely clear. Some parts of it appear to be intended as permanent open spaces, some parts such as the health precinct are earmarked for campus-style commercial development, while other parts appear to form a potential land bank for release once land in the core has been fully developed.

In summary, the Draft CCP adopted a multifaceted approach to recovery that incorporated a wider range of projects and implementation tools. The vision balanced incentives and regulation to deliver major catalyst and public space projects, alongside sustainability, housing, arts and transport projects. The blueprint focuses more deliberately on national government priorities, providing a regulated vision embodied in a range of catalyst projects that involve rebuilding critical public and economic infrastructure such as the hospital and the convention centre. At the second anniversary of the first earthquake, the city has started to rebuild with 1000 building consents in the past 12 months. Processes are being put in place by CCUP to fast track significant projects through an urban design board process while the CCC Urban Design Panel is doubling in size to cater for the anticipated increasing volume of resource consent applications.

17. Conclusion

Events in Lisbon and Christchurch stand apart in chronology, severity and extent, recovery management, and design outcome, but have sufficient in common to draw some interesting and relevant conclusions to 21st century disaster-response strategies. Prime amongst these is the use of urban design as a revitalisation mechanism, as it is a natural aspiration to want to rebuild a devastated metropolis anew, correcting the mistakes of the past by implementing new and state-of-the-art practices to envision a better city.

Lisbon suffered not only a cataclysmic earthquake but also a devastating tsunami and fire. Fortunately for Christchurch the latter two stressors were absent, and 250 years of improved planning, seismic and fire engineering performance, reduced the relative death toll from building collapse while generous provision of public space allowed the population to escape to safer areas. Christchurch, in achieving this high level of technical preparedness, is much indebted to Lisbon which pioneered many contemporary post-earthquake response strategies. Two hundred and fifty years before the terms resilience or sustainability entered the built environment lexicon, their guiding principles were applied in Lisbon. Pombal's engineers made the decision to rebuild in the same location, but not before investigating six alternative sites and researching the technical failures that led to the high death toll. In so doing they were embedding in the plan the future sustainability of the city and built in resilience for future seismic events, not only for themselves but also for others who chose to follow their example.

The civil defence emergency response was, for the first time in history, an international one, with Portugal's trading partners stepping in to assist. The necessary revenue for recovery was raised via import taxes levied by local businesses. Exploitative behaviours were curtailed by punishing looters, freezing rents and the price of materials. The immediate surveying and demolition of the area reduced the territory to a uniform and indisputable condition in terms of future claims. Prior to any rebuilding, a post-disaster analysis was conducted to establish which buildings had survived and why. These investigations led to a number of technical innovations that required a new formal and technical building typology. This simple and elegant solution to rebuild the city relied on three crucial pillars: the complete demolition of the devastated Baixa, the re-drawing of property lines, and an urban design plan that integrated these technical provisions into a best-practice vision (based on solid interna-

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tional precedent) for a commercial rather than an institutional centre for Lisbon. The implementation of these strategies was only possible due to the authoritarian nature of the governance system at the time, and an emergency response which delivered this power unilaterally into the hands of the Minister of State.

A similar approach is clearly not possible or appropriate in a modern democracy, although the potential exists and was contemplated within the New Zealand legislation introduced to affect recovery plans in Christchurch. The national government has committed substantial leadership resources and legislative support to the recovery of Christchurch and the Canterbury region. Of particular note has been the strategic land use withdrawal from the residential red zone, the on-going demolition of dangerous buildings, and the proposed major infrastructure and facilities as catalyst projects. The authoritarian powers provided through the CER Act have enabled these initiatives to occur with the minimum of delay or inappropriate process, although some delays have occurred due to the lack of clarity about the respective roles of the council and CERA. The Draft CCP proposed an integrated plan for the central city, while the blueprint approved by the minister focuses on rebuilding the major infrastructure and facilities and leaves out much of the 'glue' - the smaller scale projects that hold the big moves together. The absence of urban residential typologies or social housing to accommodate earthquake victims from the list of prioritised projects, overlooks the capacity and necessity of embedding these in the plan as community or capital investment opportunities in the way they were in the Lisbon plan. The council currently intends to continue with a number of these smaller projects in tandem, so the end outcome may well be the same albeit encapsulated in two plans rather than one. The major omission of the majority of the transport provisions is the subject of a further study.

The Draft CCP and the approved blueprint have both been led by urban designers and shaped by urban design propositions, in particular a low-rise, more intensively developed city based on economic factors with high quality green and public spaces shaped for people. The extent to which they can replicate the success of the Lisbon reconstruction is at least in part subject to international economic forces and remains to be seen. Equally important is the clarity developed around future urban design controls. While these exist in the Draft CCP, the minister has side-stepped council involvement in consent processes and set up a new consent authority to oversee central-city consents, with one representative each from the council, CERA and Ngai Tahu, (with no articulated formal role for Christchurch City Urban Design Panel). This body has a mandated consent turnaround of 5 working days as compared to the usual 20- to 85-day timeframe (depending on levels of compliance).

The top-down process enacted in the Lisbon earthquake or more recently the Kyoto earthquake, and the bottom-up process followed after Hurricane Katrina, sit at either extreme of the continuum of possible response management strategies to natural disasters. A balance between these extremes is more feasible, the balance depending on the socio-cultural and economic context and the governance systems in place at the time of the crisis.

Communication Technologies have had a major impact on response capability in the intervening centuries between Lisbon and Christchurch. Tsunami early warning systems and international media networks give instant alerts of impending disasters allowing preparation or evacuation. Cell phone networks, satellite communications and GPS tracking and positioning technologies contribute to more effective search and rescue operations. Collective media and social network platforms pressure reconstruction authorities to deliver on their promises in a timely manner. The internet collapses the time required for widespread public consultation leading to more effective community buy-in into new urban proposals.

In Christchurch, the lack of alternative design proposals from official sources has been a response to the short timeframes imposed by the government. This is less concerning or necessary given the wide consultation undertaken to reach the plan outcome. Again in spite of the 250-year separation and with different professional actors, Lisbon and Christchurch had good levels of technical expertise available to generate an urban design-led reconstruction effort using current contemporary urban theory around sustainability and resilience planning in combination with deep local knowledge.

The technical planning and architectural detail is not yet present in the Christchurch plan and will be managed by planning consent processes that have not yet been well defined. Lisbon provides an excellent model for reinventing a modern local urban type (a mixed-use, low-rise, multi-tenancy, structurally sound and fire-protected building) and designing an urban block morphology that reflects a historical vernacular. This will be the fabric that weaves the plan framework and the demonstration projects into a real city.

New Zealand government agencies in charge of engineering, building and construction standards have not yet integrated the lessons from the 2010 and 2011 earthquakes into upgraded performance codes. As a nation located on a chain of islands on the Pacific 'ring of fire', uptake of resilience strategies like those in enlightenment Portugal must encompass flexible governance systems, high-level technical expertise in national, regional and urban planning sectors, and innovative architectural, communications, engineering and material technologies. This in combination with communities helping themselves is the best insurance against future calamity.

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Chapter 9

Open Space Innovation in Earthquake Affected Cities

Martin Bryant and Penny Allan

Additional information is available at the end of the chapter

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1. Introduction

'One of the best ways to understand a system is to disturb it.' [1]

1.1. Resilience

There are two types of resilience: engineering resilience, and ecological resilience. [2] Engineering resilience is drawn from environmental sciences where the resistance to disturbance and rate of return to an optimal equilibrium is paramount. It is predicated on understanding the componentry of a system, the universal applicability of resilience principles, and its 'efficiency, constancy and predictability' [3] – all attributes at the core of engineers' briefs for fail-safe design.

Ecological resilience (ex ecological sciences) is about the interrelatedness of a system's components and forces; how a system can undergo change and still retain function and structure; how it can self-organize; and how it can increase the capacity for learning and adaptation. [4] Evolution exemplifies ecological resilience: it is a force (within a system) that uses random mutations of components (of a system) to lasting advantage. But it is hard to predict how it will work. The characteristics of ecological resilience are immeasurable, different at different scales, dependent on persistence, change and unpredictability, balanced by multiple equilibria, and accepting of experimentation, knowing that it is safe to fail. These characteristics may not always be apparent, but will probably surface when there is a disturbance, when there is a need to adapt. [5] Nature tells us, paradoxically, that it is perhaps a mistake to try too hard to avoid shocks; that stability lets risk accumulate without providing capability or capacity to deal with disaster; and that volatility actually keeps things manageable [6].

In the wake of apocalyptic disturbances, such as hurricanes, floods and earthquakes, the concept of resilience has penetrated recent urbanism theory. But which type of resilience?

Engineering resilience, one would think, should have a stranglehold on urban design. The environment of the city – the makeup of the entire field of the city including its landscape, its infrastructure and its buildings – is the componentry of the urban system that needs to 'bounce back' quickly and efficiently to facilitate recovery after a disturbance. It is the focus of engineers, planners and city makers as they piece together recovery.

Yet a city's contextual interrelationships are often the result of its non-linear processes [7]. The nested but discontinuous scales of the building plot, the street block, the neighbourhood and the region [8] demonstrate that a city's morphology is structured like an ecological system. Furthermore, systems-based urbanist theories share ecological sciences' resilience concepts of diversity, modularity, variability and innovation. [9] Hence, we can examine a city's recovery after disturbance in terms of its ecological resilience, in which the agents of adaptation would be urban designers, institutions / government and, more often, community driven by a changing social, cultural, political, economic and environmental contexts.

After a disturbance in nature, competitive forces are at large, creating tensions between the pre-existing trying to re-establish; the aspirants who want to do better; and competition who invite innovation and change, often through experimentation. Does the same happen in a city? How do the agents of adaptation in a city – the government, the urban designers, the community – know how, where and at what scale they can innovate? What is innovation in urban design?

1.2. Innovation

Innovation, whose etymology comes from the Latin word meaning to change, is bilateral. It entails something 'new', and it entails systematic implementation. The 'new' may be new needs, but it may also be 'old' needs that are met in 'new' ways. It can entail 'new' products, 'new' processes, 'new' values, or 'new' technologies. It differs from invention which refers more specifically to ideation: innovation is a change to a system.

The relationship between innovation and disturbance is at the core of commerce and economics literature. Joseph Schumpeter described the distinguishing trait of innovation as 'creative destruction', [10] in which the 'new' wipes out the 'established', calling it radical innovation. Henderson and Clark subsequently recognised slower moving, 'incremental' innovations where systems' architecture may be enhanced rather than destroyed [11]. Tushman et al highlighted the important role of the consumer in innovation: a change to a market is a change to the system, even if it is not accompanied by a new technology [12]. Verganti points out that this process, which culminates in society accepting new 'meanings' of old technologies, is not necessarily led by consumer feedback, but is more often 'design- driven'. [13] Research and development, often by and through design, is thus fundamental to innovation.

Innovation is also one of the hallmarks of a resilient ecological system. 'A resilient system would subsidise experimentation – trying things in different ways – and offer help to those who are willing to change. Enabling innovation is an important way of creating space… Resilience thinking is about embracing change and disturbance rather than denying or constraining it'…When rigid connections and behaviours are broken 'opportunities open up and new resources are made available for growth….the warning bell to a resilient thinker is increasing preoccupation with process… a resilient approach would advocate initiating a disturbance or freeing things up to recapture the dynamics of a growth phase.' [14]

So what does urban design innovation look like? Sola de Morales suggests that the Carrer de Ferran, an urban intervention undertaken in the mid 19th century that widened and straightened a cross street in medieval Barcelona, was 'unquestionably the most innovative urban intervention in the old town…. It was innovative not just in form, but also in its ideological and political underpinnings … [where] the new forms were the driving force of a new era, cultured, egalitarian and progressive, in contrast to the old feudal and aristocratic stratification.' [15] Not as radical as Haussmann's contemporary transformation of Paris, the one kilometre long Carrer de Ferran project (see figure 1) resulted in a modest nine metre street width, and took 40 years to implement. But it established a significance to the role of the city's cross axes which informed later moves such as Gran Via, Carrer Ample and Cerda's Eixample. Carrer de Ferran's innovation was that it set a new agenda for the city's form because the cross streets catalysed exponential growth. But perhaps more importantly Carrer de Ferran suggests that innovation in urban design is not just stylistic or typological, and does not have to be large scale or transformative, but is significant when it rethinks the political, social and civic context with broad catalysing implications. In urban design this is usually a slow process. 'It is very difficult to identify clearly the turning points in the history of the city.' [16]

Urban design has, of course, always heralded the importance of context, milieu and networks. So does the psychology of creative thinking and the management of knowledge creation. In psychology divergent thinking, the foundation of creativity and innovation, is thought to emanate when designers and artists draw together previously unconnected threads in their context to create the 'new'. [17] Management theory also recognises how new knowledge emerges from tacit or intuitive knowledge via externalisation and socialisation. [18] In urban design, more so than in other spatial design disciplines, social, political, historical and environmental contexts provide the basis for design solutions. But the parallels often stop there usually because urban design practice, unlike urban design theory, uses context objectively (like an engineering science) rather than symbiotically (like an ecology). [19] The problem is compounded by conservative governments and property owners who usually resist broad-scale changes to a city: the reality of institutional democracy and Benthian utilitarianism tends to nullify risk and untie the link between creativity and its application in the public domain. Ann Forsyth [20] suggests the opportunity for urban design innovation may be best achieved through academic research because it is ideally placed to take time to explore data and technique, experiment, and ground ideas to remove risk. The large scale effect of Jane Jacobs' thesis on urban systems, [21] and the research into low impact urban ecology provide evidence of the innovative outcomes of research. But it does not have to be the exclusive domain of academics. If recovery could occur at a pace that will allow everyday research and experimentation to occur, a disturbance may be the ideal opportunity to investigate the potential for innovation, when the system is exposed, when new players are involved in adaptation, when cultural shifts occur in the relationships between people, governments and place, and a new kind of thinking alters the way contexts are interpreted.

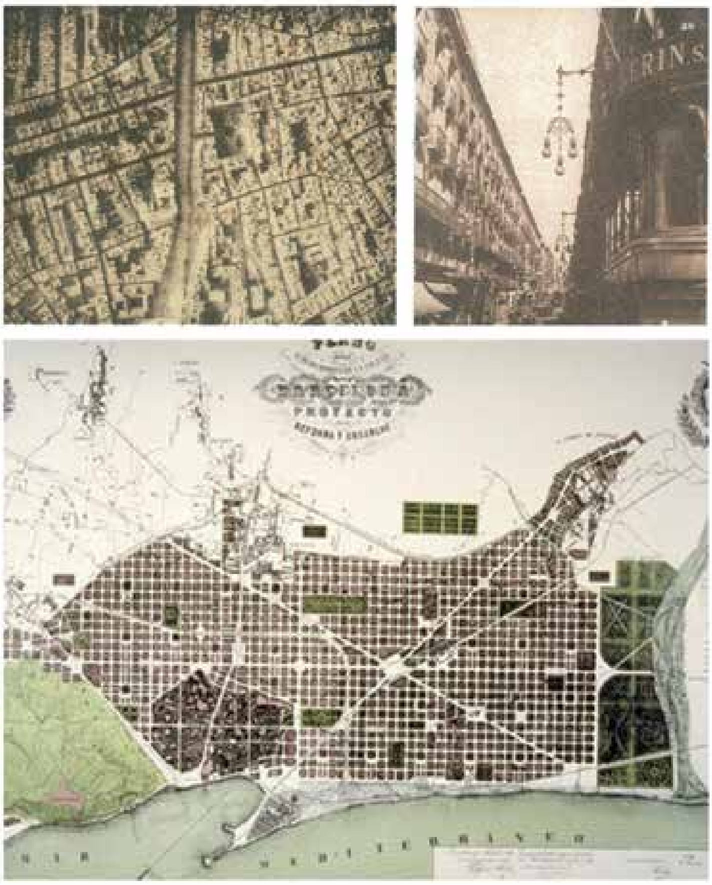

Figure 1. Carrer de Ferran, clockwise from top left: the new street cuts horizontally through the old city; street view; and the street forms the plumb line for the Cerda plan of Barcelona. (source: Sola de Morales, M. Ten Lessons on Barcelona. COAC: Barcelona; 2007.)

1.3. Innovation after disturbance

In the past, post-disaster adaptation has had divergent consequences. It has led to abandonment (Antigua in Guatemala, 1773) and irrevocable structural change (Lisbon, 1755) [22]. But broadscale change is usually the exception. Having experienced numerous tremors in the nineteenth century and becoming adept at recovery, San Francisco rebuilt the city without changing its street pattern after the major 1906 earthquake. After the Great Kanto Earthquake of 1923, despite authorities' unusually ambitious plans [23], the Japanese citizens wanted stability and relief and strongly opposed major changes to the urban structure. The desire to quickly rebuild their lives promoted rapid rebuilding of the city according to traditional protocols [24]. A similar scenario has arisen after the Christchurch earthquakes in 2010 and 2011, where the seemingly 'safe' option of building back what was there before is an accepted objective in recovery management. The community reiterates, just get 'back to normal'. There are Freudian parallels: loss leads to grieving which ends when the mourner accepts a substitute for what was lost. [25] The collective memory of the citizenry errs towards a replacement for the known, rather than experimenting for the new.

But building back does not necessarily tap into the latencies in a system that an earthquake exposes. The Government's focus in Christchurch on like-for-like replacement of engineered structures (roads etc.) with some improvements – also known as 'betterment' – is a risk averse strategy, built from the remit of engineering resilience. [26] In an interesting development, Christchurch's Port Hills' communities want to rethink the irretrievably lost recreational amenity – not just the infrastructure of transport and utility services, but also the infrastructure of landscape - which was what attracted people there in the first place (see figure 2). The loss of natural and cultural assets has elevated the government-community conflict over what the map of infrastructural recovery includes and looks like. The government wants to just rebuild the roads and utility services; the community wants something that was not there before: a new pathway along the coast that might cement the new-found social capital, might foster the diversity of lost recreation facilities, and might provide an 'essential' redundancy - an access route for when the only main road is blocked by landfall. It is an innovation with the potential to create a new typology of pathways across the city, with far reaching impact on health, culture and environment. But it is the inherent uncertainty of qualitative outcome, its experimental nature that deters Government. Therein lies the paradox of ecological resilience: it needs to be capable of failure to succeed.

Can we be sure that change is productive? As an experiment, is it not subject to failure? In a more radical case Tangshan in China, after its 1985 earthquake, reformatted their urban structure in accordance with the then-current (but now-outdated) recovery planning mantra that spreads the components of settlement far enough apart to minimise the impact of a disaster. Institutionally it seems sound, but it left no options for the diversity that urbanism theorists [27] champion. Not surprisingly, problems have arisen because the change was too one-dimensional and predictable. It's hard for Tangshan to reverse this: 'the wide streets, low rise buildings and lack of an identifiable centre of a post-earthquake reconstruction have left it somewhat lacking in what some have called "urbane refinements" [28]. Such an approach to dispersed-ness is not really palatable in modern urban theory as humanity faces environmental issues of potential resource depletion, increased catastrophes [29] and inexorable population growth [30]. Can we experiment without creating Tangshan's irreversible problems?

1.4. Clues

Scale may provide a clue. Innovation is obviously less risky when experiments occur on the small scale as opposed to the neighbourhood scale or the regional scale. But we are concerned here with urban design, and as scale gets broader government traditionally has an increasingly influential role as the agent of adaptation unless, of course, there is competition from community. If, at the broadest scale, risk-averse economics dominate, if community is sidelined, if the blanket approach of 'building back' or 'building back better' is politically adequate, and if fast-tracked formulaic change and mono-functional planning are preferred, the systems of

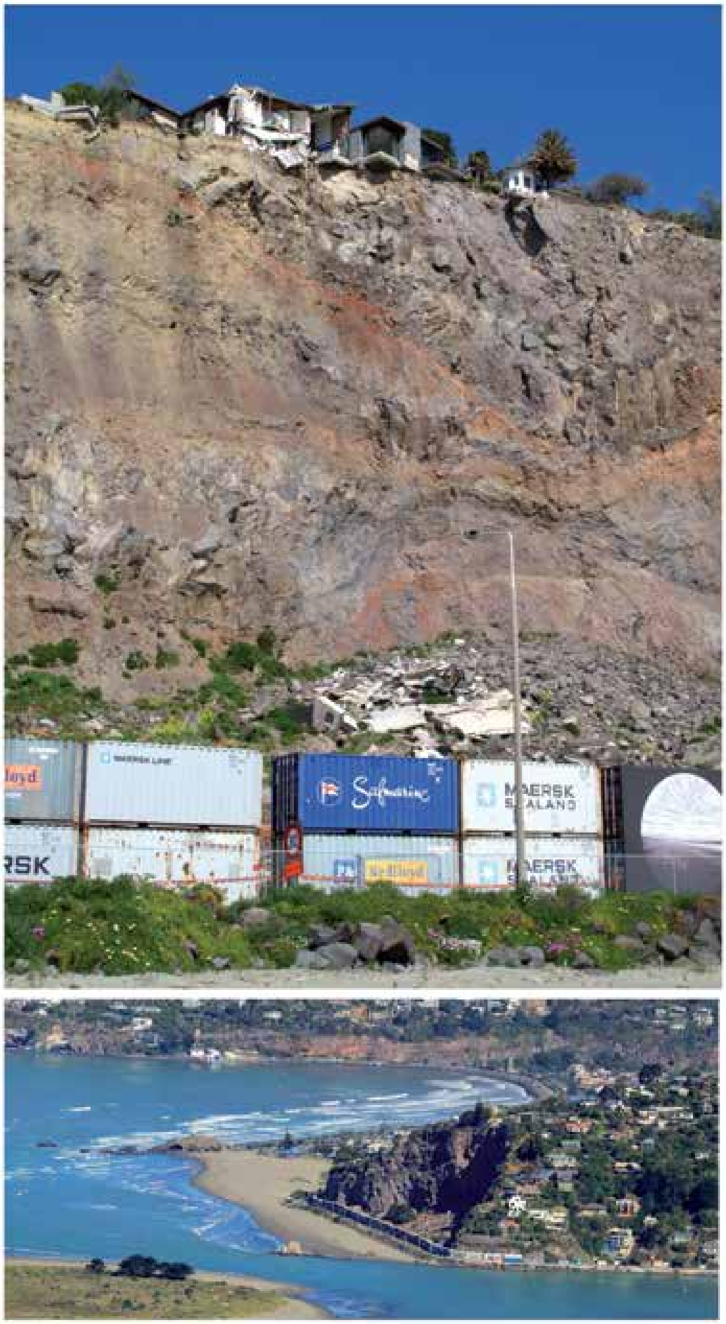

Figure 2. The collapse of Christchurch's Port Hills in the 2010/11, where fallen cliff faces have not only led to loss of property, but have also threatened access and recreation opportunities. There is now tension between community and government on the rebuilding of the road, pathways and other open space facilities (sources top: N. Jones; below: BeckerFraser Photos).

research and experimentation that are embedded in ecological resilience are unable to gain traction. To achieve ecological resilience at larger scales and buy time for design research, perhaps there needs to be a greater involvement by community in public space design, because the community has more time to explore options and understand their implications and meaning, more time to understand what is 'possible in a system'. [31] Not surprisingly ecological resilience theories place emphasis on society: the concepts of social capital and overlapping governance are important threads in social and urban theories of resilience [32].

Context provides another clue, especially the cultural context. Cultural context is invariably woven into the physical context of the city and its landscape. Cognitive forces such as the memory of an earthquake provide a re-reading of physical context and how it might change to satisfy the need for safety. The sweeping destruction may seldom effect structural innovation, but it will shift cultural perceptions of what is important and valued, which could affect the redesign of the spatial language of the urban fabric. So, if communities have a say in public space design, the ensuing change in cultural context will influence adaptation of urban fabric, initiating innovation in the meaning of public space and its role in the recovery process. Public space potentially could mean something 'new' after an earthquake.

This chapter discusses how innovation might, at appropriate points, be a catalyst for recovery, what influences it and what it contributes to the resilience of an urban system. By looking at case studies we are able to match community adaptation with urban morphological change and establish a basis for evaluation of a fine grained resilience. To do this we have looked at the newly constructed open spaces of Kobe after its 1995 earthquake, after it has 'recovered' (normally considered to be a 10 year period). [33] We highlight five urban parks that show how innovation operates at the urban and community scale as a key part of recovery. We review the way people adapt their land holdings, their attitudes to community and their activities in a city after a major disturbance.

2. Kobe's earthquake

2.1. Kobe's urban morphology pre 1995

In 1868, when the Meiji restoration opened Japan to international trade, Kobe was one of the key ports that facilitated Japan's transformation from commercialisation to industrialization [34].The geomorphological transect of Rokko Mountains, lowlands and deepwater harbour all within close proximity had served a string of rice farming, fishing and merchant communities administered by the centralised nationalistic state of Japan's hierarchical shogunate. By the 1920s two of the most powerful steel fabricators in the world had appropriated most of the port for its plant. Institutional planning for urbanisation focused on industrial and transport infrastructure. But urban governance of built form and urban parks was poor. [35] As the non-rural population grew with factory employment, the rice paddy was adapted as the template of urban residential structure: the paddy fields were reclaimed for low-rise housing, often sold to multiple owners, with plots set out in a dense, finely-grained matrix accessed by a squared network of alleys; the raised edges of the paddy field formed a gridded city road network in

100 metre squares; in plan, the squares (cho) rotate with the topography to form terraces, once part of the paddy field system's hydrology, now the definition of neighbourhoods (see figure 3). Open space was located on the periphery or in conjunction with temples, and as such there was a lack of spatial diversity in the size of parks. There was no doubt a strong reverence for nature in the large urban parks, but many of the smaller urban parks 'increasingly in the hands of municipal bureaucrats, became hard-surfaced and functionalist, with cookie-cutter layouts and standardized equipment, and remained so for much of the twentieth century.' [36] They were rarely part of the housing pattern. Streets provided the main setting for community life and activity.

During WWII American bombs laid waste much of the city, but Japan modernised in a programmatically functional way: building highways and transport and industrial infrastructure. Private land units were unaffected, except when the land readjustment instruments juggled free holdings to make way for wider arterial roads or transport routes [37]. Modernisation was not deferential to the value of open space within the city: city planners focused on efficiencies of transport while few controls were exercised over private development. As a result, Kobe faced the 3rd millennium as a dense and vibrant city rich in street culture with a strong sense of identity afforded by its neighbourhood densities. Unlike the disappearing cities of Fordist modernism [38], Kobe's wartime disasters had primed the city for diversification when its industrial plant became uncompetitive in a bullish Asian economy. The earthquake of 1995 was a further catalyst for change.

2.2. Kobe post 1995

The earthquake caused significant damage to the infrastructure of transport, the port areas, and to the traditional housing areas. The government's response was typical engineering resilience - infrastructure was replaced as quickly as possible, upgraded with improvements to meet modern standards [39]. 'The object of recovery is to aid victims to get back to normal life…measures are conducted as swiftly and smoothly as possible' [40]. In some places Modernist practices such as streets widening, high rise buildings, and local parks of one hectare were introduced – a universal approach to urban planning without input from local culture. It appears that the government pursued recovery as a means of renewing fabric, without addressing change in community culture. Shin Nagata was a model. The streets and built form were all transformed to create a safe and accessible urban setting, where density was relocated vertically. But the change was not really innovation: more a reversion to globally established standards.

Modernisation did not coalesce altogether with Japanese culture. A grass roots planning movement called Machizukuri (community-building) emerged out of citizen participation and community organisation in the 1980s and a reaction to globalised modernism [41]. After Kobe's earthquake, community action galvanized because of the slow and somewhat inhumane response of the national government to the earthquake victims [42]. Machizukuri and government contested the urban landscape. Land readjustment, park design and street layouts all became areas of tension, where the community sought to address the lessons of the earthquake and experiment in the way they might shape their public spaces. Although some commentators

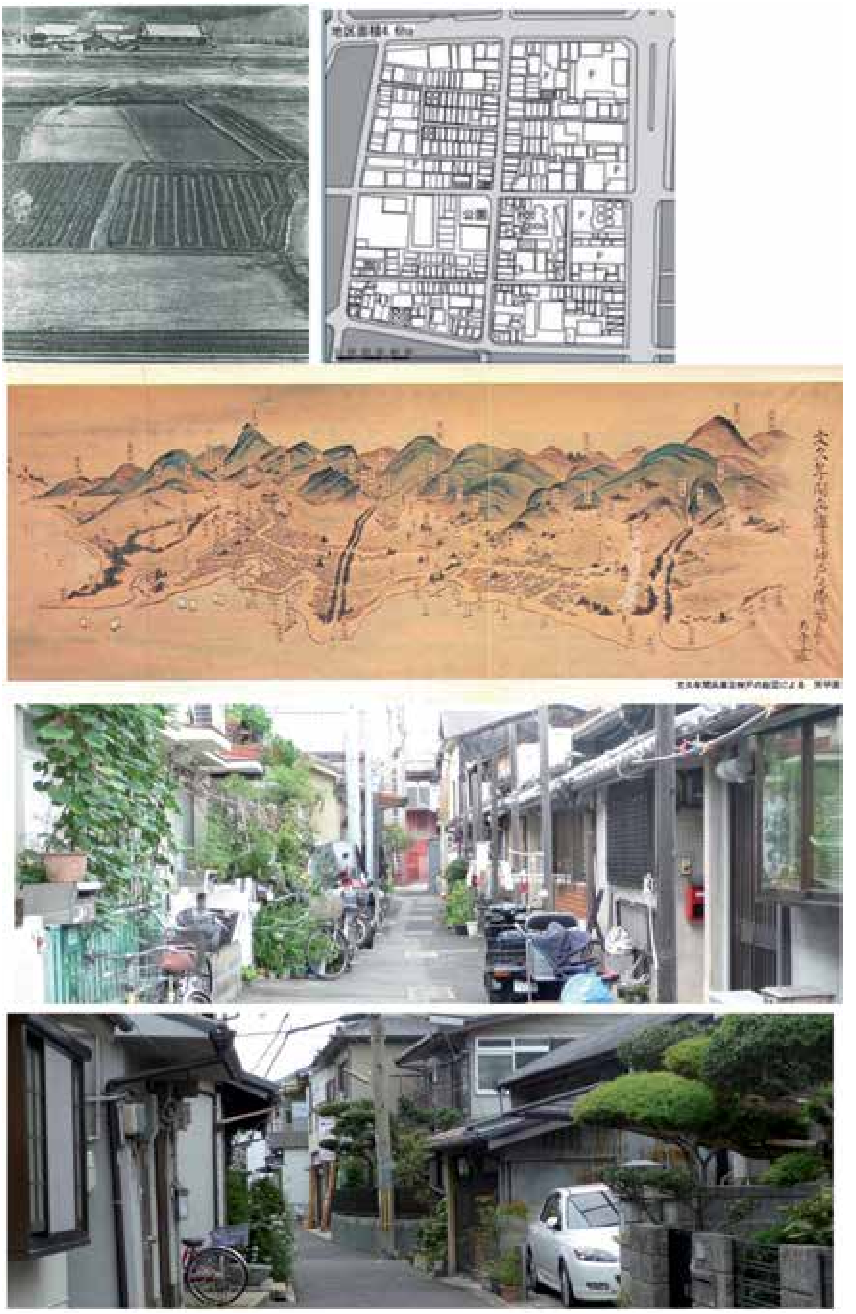

Figure 3. From top left: Rice paddies formed the basis of Kobe's street and block grid (Source: Ishihama et al. Nikon No Bi Vol 14 Kansai. Kokusai Joho Sha. (1968)); typical cho layout and street grid (Source: Miyasada Akira , cited in Yasui, E. Community vulnerability and Capacity in Post-Disaster Recovery: the cases of Mano and Mikura Neighbourhoods in the wake of the 1995 Kobe Earthquake. Unpublished PhD thesis. UBC. (2007)); aerial view of Kobe in 1861 (Source: Kobayashi, I. Kobe: 100 years of urban history. Unpublished paper. 2003.); typical street scenes in traditional housing (M. Bryant).

have dismissed Machizukuri as being characterised by 'long-drawn-out procedures' that 'generally operate only at very closely limited spatial reference levels' [43], some of the outcomes that have emanated in the aftermath show an innovation in the way open space has been researched and re-imagined by community will.

3. Five parks

There are five parks that seem to demonstrate various aspects of innovation in post- earthquake Kobe. All of the parks were slow to emerge, being built as part of the 'development restoration period', the final phase of recovery identified by Haas [44] and which Mileti [45] identified as a social process as well as a physical process. Each shows an approach to innovation that demonstrates an ecological resilience, where experimentation in form was driven not by institutional compliance, but by the changing community values that sought to integrate the disparate but important threads of Modernisation, social heritage, grass-roots politics and the memory of the disaster. The latter influence is pervasive: the earthquake became part of the consciousness of the community, a trigger for formal change. Not surprisingly, four out of five are bottom-up community-designed parks. The other is a government design commission which tests the social norms embodied in the formal idea of an urban park.

3.1. Rokko Kaze No Sate Koen

Traditional typologies of urban open spaces are either a place of respite, or a place of civic activity. The former are often dressed like an Arcadian idyll, the latter a fusion of simplicity and activity. Suburban parks often sit somewhere between these two, mixing both, without inventing the new. But can there be another typology?

Rokko Kaze No Sate Koen (see figure 4) is the ultimate community park, built in Rokko Michi, a dense urban area. The park was established after land readjustment established a one hectare space and government agreed to community involvement in the design. The land readjustment took six months; but the design of the park took seven years, mainly because there was so much interaction, discussion and research amongst the political atmosphere of an empowered community. The idea for the park embodied respite. Trees, vegetation and open space were paramount. The park also incorporated places for civic activity. A community centre was prominently positioned to frame an edge of the park; a baseball pitch was defined; and an outdoor gathering space and activity areas addressed needs of children and adults.

But what is interesting and innovative was that each of these somewhat traditional ideas was interpreted in a way that could only have come out of the experience of living through an earthquake. Play areas were dominated by water bodies, that had pumps and wells that anticipate the next disaster. Seats were designed to be adapted for cooking pits, or toilets. Tree species were selected for edible fruit. The park's form provided for recreation and civic activity: the design was a deliberate gesture that embodied intensity of activity throughout and a diversity of spaces in an otherwise everyday setting. But it also addressed the social need for the community to be self-sufficient for the next disturbance.

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Is it a short lived over reaction to a crisis? Maybe, but, because it also tells the story of what these people experienced, why this place is significant, and how it serves as a physical memorial of the crisis that passed, it embodies the grieving process of the community. The park's innovation is not in the stylistic physical detail, but in how it has intensified the recreational and social programmes of a community in a small park. It is another way of thinking what a suburban park's role might be in Japan. The park needs to embody memories as well as Arcadian and civic interventions to make a place resilient. In doing so it liberates the neighbourhood of institutional overtones and allows adaptation to take place.

Figure 4. Rokko Kaze No Sate Koen: clockwise from top right: Aerial image of Rokko michi before the earthquake (Source: Geospatial Information Authority of Japan), showing location of future park; photo of plan of park; children playing beside water pump; children playing beside seat which has potential to act as toilet; vegetable gardens and community centre. (Photos by P. Allan)

3.2. Matsumoto

Suburban parks want to be all things to all people: to do this they need to be a size that can reflect the needs of its catchment of population and fulfil recreational / civic roles. What if they don't? What if they are just there to provide open space, and what if they are just there as a symbol of the neighbourhood and its legibility. The pocket parks in Matsumoto (see figure 5) assume this role, and they do it not by concentrating the essence of the neighbourhood in one place, but by creating 10 more or less identical parks in 10 more or less identical chome, in a necklace that threads its way across the neighbourhood.

Figure 5. Photo of maps of Matsumoto showing parks before and after in each of the chomes; image of one of the pocket parks (Photos by P.Allan).

Formally there is not much that distinguishes these parks. They each form an off-centre centerpiece to a modest chome – the 100m square Japanese street block. Each is within 50 metres of all the houses in its chome, and no more than 100metres from each other. Each park is tiny: 20m x 20m, and each has a gravel area, a few playground equipment pieces, a water pump and a clock. Placing each in the heart of the neighbourhood is relatively orthodox piece of urban planning, but they don't have the diversity to accommodate the broad range of needs of the community. Instead they just repeat themselves. Inefficient? Redundant? Yes, but these are some of the hallmarks of a resilient system.

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The urban experiment is their size and proximity to each other. Institutional land readjustment urged this neighbourhood to adopt a large 1 hectare park, but the community pursued an idea that each chome wanted spatial structure to match the scale of their chome. So ten parks were created. The simple modularity of the system shows the importance of the neighbourhood of chome as an urban unit fundamental to Kobe's settlement. There are, of course, antecedents to this idea, not the least of which is embodied in Spanish colonization and their laws of the Indies, which some commentators say emanate from earthquakes and the need for accessible open space. [46] The integration of this idea in a modernist planning framework is extraordinary, because efficiencies are sacrificed to achieve a greater sense of legibility and ownership. The size of community is an important aspect often disregarded in urban planning which is preoccupied with a critical mass that creates efficiencies. Matsumoto represents another innovate approach to open space because it experiments with the size of parks rather than their formal or programmatic content.

And the clocks serve as a reminder of the bonds of the small community in times of disaster.

3.3. Minato No Mori

Can a downtown urban park be a community park? If there is no one living around a park, how does it become part of the everyday lives of people who know each other? How does it come part of their identity, their collective memory? And if it is surrounded by multistory intersecting motorways, doesn't it look like urban planning gone wrong? More often the prescription for the siting of urban parks entails natural beauty, lots of residents nearby, and a civic ambience.

Minato No Mori is an urban park that breaks the rules. It is a large urban parkland space, divorced from the harbour, badly connected to the city's business district and framed by motorways. Yet it is here, on disused railyards, that community driven by a newly found momentum of social capital (not government driven by mitigation of impact) resolved to create an oasis in the city's transport infrastructure, and in so doing challenged the monofunctional infrastructural systems that dominate urban planning.

The three hectare park (see figure 6) has a reasonably traditional structure: a large flexible centre dominated by a grass space, and an intense edge either programmed for community gardens and play, or planted with forest. In one area is a traditional physical memorial to the earthquake. In another are the defacto memorials: the community spaces that provide lifelines to the next event: a place for gathering and camping, an elevated area for viewing problems, water tanks and place for food security. It is framed not by well-proportioned buildings, as urban formula would suggest, but by spaghetti of an overhead road system.

The approach exemplifies diversity and its role in resilience in a number of ways. Firstly it shows that parkland can diversify monofunctional pieces of infrastructure, so as to say space under freeways is not wasted. It also shows the unorthodoxy that freeways are not necessarily alien scaled objects in an urban landscape, but rather a piece of topography that can be addressed and integrated. And finally it shows at the detailed scale the importance of diversity

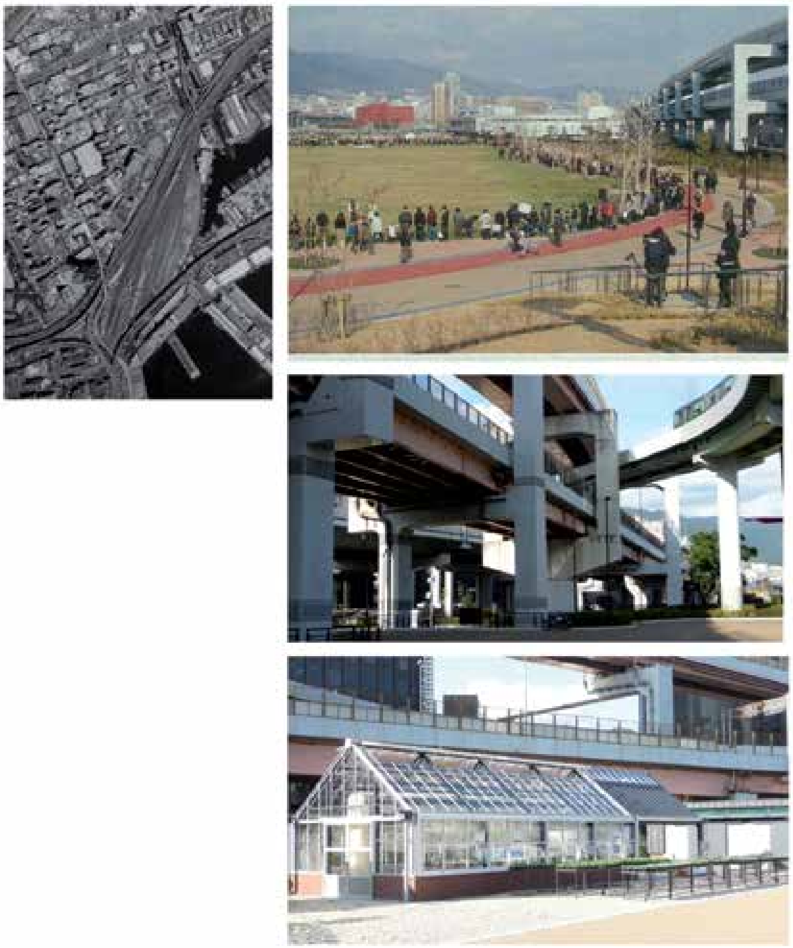

Figure 6. Minato No Mori framed by motorways, built on former railway land by the community. Aerial photo: Geospatial Information Authority of Japan. Top photo: Amakawa Yoshimi, Bottom photos: M.Bryant.

in park planning: spatial diversity in elements that drive different programs and also temporal diversity that recognises that the park can fulfil functions at different times.

But the need for diversity is not just what this place is about. It also shows a willingness to experiment in the city grid, to free up rigid ideas of monofunctional connections and allow for growth in new ways. In this way the park is more than a formal expression of diversity in urban design it is also an expansion of the potential for community to colonise the infrastructure of the city.

3.4. Komagabayashi cho 1 chome

Some places weather the impacts of earthquakes and continue to operate as before. But sometimes the impact of a disturbance warrants investigation to reveal the latencies that have

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Figure 7. Aerial photo of cho pre earthquake; pavement signage and photo of pocket park established after earthquake destruction left vacant space. Aerial photo: Geospatial Information Authority of Japan. Photos P. Allan

not been exposed before. Some of the traditional residential areas of Shin-nagata were left intact by the earthquake, and after some repair to building stock the area more or less continued to operate as it had. No need to intervene? Perhaps not. But one of the legacies that the earthquake left was an understanding of why open space was important. It was something to be treasured. But there was no room for park in a traditional neighbourhood with multiple ownerships. The only open space in many of these traditional places was disused plots not much bigger than 400metres square, which generally felt 'unhealthy… unattractive… unsafe… insecure... inactive'. [47] The community in cho 1 chome rehabilitated their alleyways with signs for safety and developed a pocket park in one of the disused lots to amplify the qualities of living in a traditional neighbourhood place, and feeling safe (see figure 7).

The park was rehabilitated as simple community space, prepared for the next disaster. It had a water pump, a seat, some flat space and tree planting for shelter and shade. Compared to previous examples this is less overwhelming as a piece of innovation. But the minimal nature of the transformation is the park's point of difference. The community- based designers left the traditional Japanese settlement pattern relatively untouched. The subtle interventions created beauty and the potential for recovery: a place that integrated community meeting areas and a pathway system that gave directions within a community to find safety. It shows that resilience is not so much embodied in changing form, but in changing community attitudes.

This project questions the hierarchical thinking of traditional post-earthquake recovery. It suggests that, even if an earthquake causes little physical destruction, and even if communities have limited resources, there may still be a significant psychological impact that encourages communities to change the physical fabric of their neighbourhoods in innovative ways and retain the unique alleyways and densities of their traditional settlement patterns.

3.5. Waterfront park

The final case study is not a community project. It is an institutional project, designed by one of Japan's great architects, Tadao Ando. The park shows qualities that are unusual for a waterfront: its formal expression is a series of garden-scaled rooms mostly screening the harbour view; its spatial language controls and frames the vast scenery rather than confronting it; and its programme is contemplation, achieved at a human scale, not at the scale of industrial waterfronts. The outcome is a sense of safety. In so doing Ando reinterprets Japanese culture in a globalized modern context.

Waterfront parks have been following a formula for the last 50 years when heavy industry has been forced out, containerization shipping has made ports more efficient and cities have sought to diversify. Kobe was undergoing this transformation prior to the earthquake, and the Waterfront Park was intended to be part of the gentrification of industrial space by drawing on the industrial or archaeological heritage. But an earthquake has a way of wiping out the heritage: needing to start anew, the tableau rasa. So how can a park cling to its context when the context has been erased?

Tadao Ando's Waterfront Park at HAT (see figure 8) is exemplar of rethinking spaces in parks using the historical context of Japans garden culture [48]. It subdivides space for community ownership rather than as a grand gesture where one can see all. It does this formally by creating a series of park spaces – empty gardens separated by walls. The interconnected walls create a maze of connections, but also allow spaces for people to contemplate – not dissimilar to traditional Japanese gardens which embody Taoism. It abandons the idea that a park needs to be open with surveillance. The spaces in the park provide areas where people can gather but be apart. The tension between the need for gathering and privacy is summarized perfectly. In many ways this park is a memorial to that attitude and to the spirit of Kobe. In this way the park is an innovation not only in form but in reinventing the Japanese psyche in a modern setting.

4. Discussion

There are some important considerations from this collection of projects.

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Figure 8. Ando's contemplative Waterfront Park, with 'community rooms'. Photos: P. Allan; aerial view from Jodidio, P. Ando: Complete Works. Hong Kong: Taschen. 2007

Firstly, a caveat: it may be too early and too subjective to say whether the experiments were an innovative-defining success that could add knowledge to the generic ideas of open space design. The projects are each intertwined with a specific community, a specific place and a specific spatial morphology, and so the innovations will take time before they germinate elsewhere, if at all.

Secondly there is clearly an innovation in process of park procurement that has occurred as a result of the earthquake. This process stemmed from the competitive and catalytic tension between the agents of adaptation; between the institutional planning agencies and the small scale designers of the Machizukuri. The competition was not just over control of the outcome, but over the process. While both government and community had a role in rebuilding urban fabric, the design of each park was hard fought by the community, and the outcome appears to be highly treasured. Furthermore, each park then took a long time to come to fruition, because they each took time to be researched, debated and explored at the micro scale of the community after the earthquake. Each of these projects became (perhaps unintentionally) experiments in the social processes of form making, where the social processes were more important and more innovative than the formal outcomes. This long and risky and unpredictable procurement process, precipitated by competition, was itself an innovation, a new way of producing public space.

Thirdly, and leading on from the above, the innovative processes led by the communities has generated an innovation in cultural contexts through spatial change. Importantly, the formal solutions are not necessarily novel: each seemed to take the typical model of the modern park – a non-Japanese urban model of the small park, the neighbourhood park and the urban park. What is interesting is that each park explored cognitive transformations in the idea of public space and what it offered as a place of safety, and as a place of memory. They each had a new social and political meaning. The most material form of these transformations, which have become apparent in the spatial language, is in the divergent ideas of intensity, repetition, diversity and redundancy. It appears that these principles are important qualities in urban design because they demonstrate a re-reading of the physical context and a shift in culture and thereby demonstrate capacity for ecological resilience.

5. Conclusion

This study lays down an important challenge for urban designers and government agencies working in recovery after disasters. Undoubtedly there will always be a need to patiently work in the interest of citizens in building back what existed prior to any disaster, to replace what was lost and to provide a stronger urban fabric, one with better engineering resilience. But pre-empting or excluding community involvement in the recovery process can actually make communities more vulnerable [49]. And avoiding risk at all costs will not strengthen communities against all possible disasters. Although ecological resilience attributes, like innovation, are unlikely to dominate recovery of urban fabric, they need to be addressed in some way, just as much as engineering resilience does.

Designers therefore need to play a strategic role, negotiating between community and government, while also leading research and experimentation. In this process designers can help find the best way to achieve outcomes for the community with design interventions that are tactical and yet responsive, and assist government with cost effectiveness and timeliness. Part of this approach will entail an understanding of a community's cultural context and how that may be influenced by spatial design. Spatial design by itself may have little meaning. But small scale experiments in public space can be developed in some sort of partnership with active communities to develop an acute understanding of how spatial design can positively affect cultural context and cognitive memory.

The ecological resilience approach is a good model for public space design because, even though it may entail a lot of design research, it suggests that interventions can be targeted and relatively minimal, generated from the 'bottom-up', with whatever is at hand. This kind of design is about adjusting, encouraging innovation and redundancies, making 'space', exploring new ways and relationships between community and place.

The Kobe examples provide a basis to build up a body of knowledge on how the process of adaptation after disturbances may galvanise innovation and reinforce ecological resilience.

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The success of the outcomes may not be clear for some time: they may not be stylistically creative, and perhaps need even more research, but they may, instead of entrenching the status quo of the 'efficient', provide a basis for a new way of thinking about space that addresses the persistence of communities.

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Chapter 10

The Implications of Post Disaster Recovery for Affordable Housing

Jacqueline McIntosh

Additional information is available at the end of the chapter

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1. Introduction

Disasters, both natural and man-made and involving the massive destruction of habitats, have been with us since the beginning of time. While responses have varied by countries, depending on their population, wealth and culture; and while the magnitude of disaster has also varied, as does the capacity for a country to respond, each country strives to restore its infrastructure to at least its original state, if not better.

At the same time, affordable housing is also a persistent and world-wide imperative. Common strategies to respond to this need include subsidy, reducing quality, simplification and self-help (Katz et al, 2003; Johnson, 2006; Thorns, 2006; FAS 2008a; Gurran et al, 2008). Subsidy, involving agency payment for part or all of the costs of housing (and seeking to recovery) has been challenged by issues relating to internal objectives and external teaming initiatives (Bratt, 2002, FEMA 2008a). Quality has been compromised by issues relating to longevity, generosity, politics and lack of agreement about the minimum acceptable level of service to be provided (Anderson et al, 2003; FEMA 2008b, Lindberg et al, 2010). Simplification refers to the stripping of any superfluous details such as decoration, outdoor spaces and methods of construction and delivery. Self-help refers to the potential for self-building and in some cases self-financing (Harris, 1999; Bredenoord and van Lindert, 2010; HUD, 2007, Leishman, 2012). These policies have been implemented to differing degrees of success, but affordability crisis persists (RAND, 2008b).

The prospect of more frequent and more extreme exceptional weather events, engendered by climate change, further exacerbates the housing affordability crisis. Nowhere is the intersection of these two issues—post disaster recovery and affordable housing—more intense than in the recovery programmes following a disaster such as an extreme weather event. In the face of growing public awareness and concern for global warming and the potential for climate change, the challenges of post-disaster recovery and affordable housing have been intensified with a resurgence of interest in sustainability and green building (Hamin, 2008; Levine et al, 2007; Hayles, 2010). The new imperative for sustainable construction demands that *any* new housing be able to weather and mitigate damage from future extreme weather events. No longer is it sufficient to simply temporarily house victims of a disaster. Post-disaster recovery goals demand that this be accomplished using community processes and that new structures are better and stronger, will mitigate damage from future events and will be culturally appropriate (Berke et al, 1993; Comerio, 1998; Kennedy et al, 2008). All this must be achieved within the constraint of affordability.

This chapter explores the problem of providing affordable and sustainable housing in the context of a post-disaster recovery both in the short term and in the longer term. It focuses specifically on the sustainable construction strategies adopted by various US government agencies in the aftermath of Hurricane Katrina. It begins with a description of the response to the hurricane and the unexpected new housing issues that it created. The chapter then explores the sometimes conflicting mandates of federal and state housing providers as well as the providers of affordable housing within the context of a 'sustainability aware' design community. Finally, it identifies some of the broader implications that can be drawn from this case study.

2. Hurricane Katrina and the housing market

Hurricane Katrina devastated the US Gulf Coast in August 2005, inflicting major damage on housing, commercial property and infrastructure (Elliott and Pais, 2006; Nigg et al, 2006; Popkin, et al, 2006; FAS, 2008b). While the US has had longstanding experience coping with hurricanes, Hurricane Katrina was the first to impact the central urban area of a major city. Prior to Katrina, the housing stock in the New Orleans region consisted of a mix of single-family dwellings, multi-dwelling units and mobile homes (Nigg et al, 2006). The majority of these were owner-occupied. Most rental housing was privately owned (as opposed to state-owned) and consisted of both single-family homes and multi-unit dwellings purposely built for rental.

During the hurricane, as could be expected, poorly constructed housing sustained greater damage then did housing of better construction (Elliott and Pais, 2006). It was common to find that lower-income families inhabited the more poorly constructed housing (Peacock et al, 2007). Rental housing was generally more poorly constructed than owner-occupied housing. Despite the widespread extent of the damages to housing stock throughout the region, there were significant differences in the extent and intensity of damage among submarkets (Johnson, 2006). The most severely affected subset was the multifamily rental submarket—almost 80 percent of such units were damaged, and one-third of all multifamily rental units suffered severe or moderate damage. About one-half of the single-family residences (owned and rented) suffered damage, and almost 20 percent of all single-family units were severely or moderately damaged (RAND, 2008a).

Following the hurricane, there was a significant increase in demand for affordable rental housing. While the US had typically relied on market forces to supply the bulk of its rental housing requirements, in this instance, the market did not respond as expected (Popkin, et al, 2006). Instead of rushing to rebuild rental housing, many private investors delayed or indefinitely deferred the decision to rebuild. This is evident in the rates of recovery by housing type (Katz, 2008). The rate of recovery moved more rapidly for single-family dwellings than for multifamily units and it was higher for moderately damaged buildings than for severely damaged units. It was also especially true for most severely damaged properties of uninsured and underinsured homeowners and landlords (for example those with multi-unit rental properties). Landlords with severely damaged buildings faced with "overheated" construction costs and financing shortfalls had the ability to "take their investment money elsewhere," delaying rebuilding until the market cooled off. This was deemed to have been particularly true for the 'mom and pop' landlords who depend heavily on the cash flow from rents (Gulf Renewal, 2007 McCarthy, K and Hanson M, 2008).

In addition to those homeowners seeking to restore their housing, some homeowners were not happy with the directions that their former neighbourhoods were taking in the rebuilding process, so they took the cash from their insurance to rebuild elsewhere, often out of state (Johnson, 2006). As a result, the number of private landlords dropped significantly following the hurricane, the proportion of renters relative to owners increased, the demand for affordable housing increased (also inflated by the influx of low-paid construction workers—many of whom were migrants) and the 'market' showed signs of not recovering fast enough to meet demand, putting added pressure on the state to provide affordable housing—fast (Gulf Renewal 2007, Quarantelli, E. 1995).

2.1. Federal emergency management response to Hurricane Katrina

Shortly after Hurricane Katrina struck, the Federal Emergency Management Agency (FEMA, 2008b) provided temporary emergency housing, drawing from their existing inventory of temporary trailers and the purchase of 102,000 additional travel trailers. The FEMA trailers were a mix of new and used small trailers (18.5 m^2), larger travel trailers (37 m^2), and even larger mobile homes (see Figure 1).

Figure 1. FEMA travel trailer types

Designed for mobility and rapid deployment, the trailers were provided on wheels for ease of movement into trailer parks or onto individual lots. To meet the massive demand, the new trailers were manufactured using the least expensive and most readily available materials and methods, then constructed in haste with little time spent drying out in the factory. This was to backfire later when trailers were found to not only be unsustainable due to their relative expense and short life expectancy, but that they were unhealthy for the occupants (Popkin, et al, 2006).

In addition to the trailers, FEMA had also ordered 25,000 Building America Structural Insulated Panel (BASIP) homes (see Figures 2 and 3). The program for the house design was developed in the 1970s and, like the travel trailers they were designed for temporary shelter, for periods that do not exceed 18 months (Thomas-Rees, 2006). These houses differ from travel trailers both in terms of size and construction. Seeking a more sustainable housing option, the proposed BASIP house design uses prefabricated insulated panels for walls and the roof, resulting in greater energy efficiency and improved durability. Each unit has 3 bedrooms and 2 bathrooms and have been designed for expansion through the joining of a second unit to create a 'double wide.' Other proposed features included special shutters to provide future hurricane protection and solar shading, a retractable awning for solar shading and an additional square area.

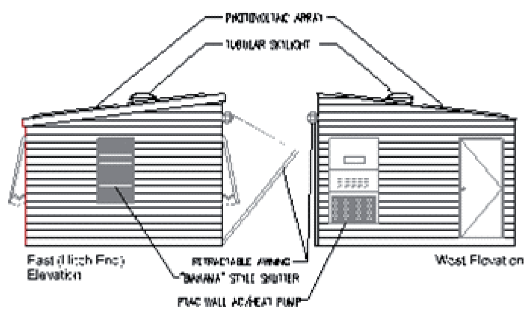

Figure 2. BASIP Homes

Some of the other sustainable features include the potential for integration of photovoltaics to meet power needs in situations where utilities have not been restored or during times when service is interrupted (Thomas-Rees, 2006). In terms of external appearance however, BASIP's homes look very much like a larger version of the FEMA trailer only with a pitched roof.

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Overall, the FEMA travel trailers were widely criticized for providing less than desirable temporary housing (Majority Staff Report, 2008). The Internet is filled with personal accounts of unhappy occupants, reports of unhealthy living conditions and overall dissatisfaction. Although the travel trailers were never intended to be used long term (i.e. their use was limited to 18 months), the extended use of travel trailers following disasters of this nature was common in the southern US, with people continuing to live in them for many years. As of mid-August 2007—two years after the hurricane, 60,000 people were still living in 'temporary' shelter FEMA trailers in Louisiana and Mississippi (Blueprint for Gulf Renewal)

2.2. State response to loss of housing

While the federal government focussed its efforts on the provision of emergency shelter, the state governments response tended to look further into the future in search of a more holistic and sustainable housing approach that took in the entire urban community (Hassett and Handley, 2006). It became readily apparent to Governor of Mississippi, Hayley Barbour, and his advisors that the so-called temporary shelters had, by necessity, become more permanent fixtures. With their interest in affordable housing models, state officials wanted to go beyond the Band-Aid solutions previously employed for disaster recovery and introduce a more sustainable solution (Peacock et al, 2007). This prompted the governor to employ New Urbanist planner Andres Duany to explore other possibilities. Duany has argued that that shelter is not enough, that a sustainable model had to be fast, flexible and able to transition from temporary shelter to temporary housing and on to permanent housing (Evans-Cowley, 2009). Only through this capacity to transition would costs stay reasonable. Moreover, Peacock et al

Figure 3. BASIPS park in LaPlace, St John Parish, LA.

(2007) point out that the capacity of an individual family household to recover is inextricably tied to housing recovery.

Figure 4. The original Katrina Cottage

The houses envisaged by Duany and his partner and wife, Elizabeth Plater-Zyberk, were developed as temporary shelter which could be located in new green-field sites, or at the rear of existing properties, as in-fill properties on vacant pockets of land or could even provide additional dwelling spaces for guests or aging relatives. Initial affordability was achieved largely through their small size. Challenging a group of architects to find an alternative to the FEMA trailer, Duany found what he was looking for in a cottage designed by architect Marianne Cusato (see Figure 4). Her house became known as the 'Katrina cottage', named after the hurricane that prompted it's inception. Seeking an intermediate size somewhere between the 18.5 m^2 and 27.8 m^2 FEMA trailers, the first cottage was designed at 27.8 m^2. The cottages were kitset, using prefabricated panels specially designed for hurricane conditions and able to withstand high wind-load conditions and excessive moisture without incurring damage or destruction. In sum, to meet with new objectives, the cottages had to be sustainable, to be able to mitigate damage from future storms, to be appropriate to regional conditions, culture and climate and deliverable by all major delivery methods. This vision extended beyond simple cottage design to an all encompassing community design, avoiding the less than desirable temporary community plans formerly employed (Talen, 2008; Evans-Cowley, 2009).

Other designers continued to build on Duany and Plater-Zyberk's ideas, expanding the original Katrina cottage idea to 20 different cottage models, including the Kernel House, which was designed to grow from an initial 46.4 m^2 module to a 120.7 m^2 home with added wings (See Figure 5).

Figure 5. Kernel cottages designed for expansion

These projects attempted to create sustainable post-disaster recovery housing, but one of the more sustainable and interesting is the Green Mobile Project (see Figure 6), which 'represents a blend of key emergency housing needs with energy efficient and affordable housing that can serve as a temporary or permanent dwelling--emphasizing innovative site design features, green building technologies, durability, expandability with an open interior design that can be adapted to varied family needs. The units, therefore, result in 'reduced energy consumption and affordable living' (United States Government Accountability Office Washington, DC 2007, FEMA website).

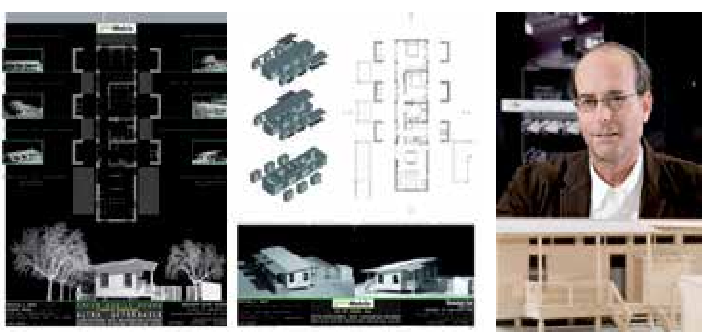

Figure 6. MSU architecture professor Michael Berk shows a model of GreenMobile.

2.3. Post-disaster recovery housing becomes affordable (and desirable)

Meanwhile the prototype Katrina cottage had caught the imagination of designers throughout the southern US, eliciting a host of Katrina copies with varying degrees of sustainable construction. Currently there are dozens of listings on the Internet for Katrina cottages that available for rent (Lane, 2008, Benfield, 2010). They are being used for long-term housing and for uses including vacation homes, granny cottages and home offices (Benfield 2010, Stark, 2006). The trailers arrived on site ready to inhabit, flexible for use in a variety of situations and as temporary dwellings, they did not require building consent. The following quotes from the Internet illustrate the range of uses and locations that the cottages have been deployed, well beyond their intended post-disaster recovery housing based in the New Orleans region.

“The Katrina cottage - with living quarters about the size of a McMansion bathroom - is now appealing to people well beyond the flood plain. Californians want to build one in their backyards to use for rental income to help with the mortgage payment. Modestly paid kayakers in Colorado see it as a way to finally afford a house. Elsewhere, people envision building one so a parent can live nearby.” (M Cusato, Katrina cottage designer)

"We have lot sizes that are too small for a... single-family, detached household, so the idea is to bring in these extremely attractive dwellings to provide affordable housing," (City councillor, Connecticut)

‘Meanwhile, in the iconic new urbanist resort town of Seaside, Florida, Katrina Cottages are being employed for a small educational facility’ (Kaid Benfield)

"A developer in Virginia wants to do some as affordable houses. People see it and realize it's a dignified way to live." (M Cusato)

Driven by the desires of the public, the US had found a desirable housing model suited not only to post-disaster recovery, but to the wider development of sustainable, community-oriented, affordable housing.

3. Conclusions and discussion

The Hurricane Katrina experience has graphically shown the critical importance of planning and designing post-disaster recovery housing well before the disaster strikes. This advanced planning and design needs to be conducted at both the level of the individual dwelling as well as the community in which that dwelling will be located. It is also critical that these advanced designs be tested particularly when trialling new technologies and processes (Miller, 2006). It is also vital that leadership for these design initiatives be initiated by both the federal and the state government (Bathurst, et al 2011). Once these are initiated, it is imperative that communities and local businesses become fully engaged in the evolutionary design processes *prior* to the disaster (Popkin, 2006; Cowley-Evans, 2009; Talen, 2008).

In planning and designing post disaster recovery housing, it is important to work backwards, from a sustainable housing model that is suited to the needs of the current rental market, but adaptable for disaster situations. It is also critical to develop the manufacturing technologies and delivery processes that can be ramped up in large numbers and in short time frames. These are best resolved well before any emergency arises. This is the only way to get beyond the constraints imposed by supply and demand economics.

The experience of the post-disaster recovery period in the US following Hurricane Katrina suggests that it is possible to build sustainably and affordably, but it is difficult (Johnson, 2007). The following lessons regarding sustainability and affordability can be gleaned from the events that took place in the aftermath of Hurricane Katrina:

1. There is no such thing as 'temporary' with respect to housing, post-disaster recovery or otherwise. Sustainable housing is more than a discrete 'product'. It must also be considered as a cultural artefact that has particular meaning for the community within which it is located.

2. Significant cost and waste results from non-cooperation between agencies. Conflicting organisational objectives must be aligned in order to achieve long-term sustainable solutions.

3. Even in the most liberal capitalist society, the government should endeavour to lead the way by providing well-researched advanced design solutions. The government needs to play an important role modelling function in facilitating a desirable outcome that will allow the market to follow.

The convergence of post-disaster recovery and sustainable housing research practices has fortuitously created important new directions and opportunities. While the solutions that were created in response to Hurricane Katrina might be vastly different from those appropriate for Third World countries or other cultural settings, the process for 'getting to sustainable, affordable housing' is more universal in its application. *Any* new housing must, within the confines of what is affordable, be able to weather and mitigate damage from future extreme weather events, be culturally appropriate, and strengthen community structures. This leaves us with only one major remaining challenge: Who is deserving of sustainable affordable housing? One intriguing possibility has been put forward by a Californian architect from one of the oldest architectural firms based in that state:

'One of the problems that I see with it, and I probably shouldn't say this, is that it looks nice. I think the government has a very hard time giving things away to people or underwriting things that go beyond some sort of bureaucratically understood minimal gesture'.

The political reality that this architect alludes to is that a significant proportion of the wealthier sectors of society are resistant and vocal about granting the very poor considerably better housing stock to that prior to what they had (or perceived to be had) prior to the disaster. In a post-disaster recovery situation this political and socio-cultural hurdle is mitigated by a combination of public sympathy to widespread loss and the benchmark of the pre-existing housing. Overall, replacement housing should be of equal or only marginally better 'value' than that which existed before. In the cases of the extreme poor, the homeless, or those without property, establishing these benchmarks seem to pose an insurmountable problem.

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