Chapter 1

Introduction

Almost daily we hear that another massive disaster has impacted human life and property somewhere on the planet. Severe earthquakes, cyclones, and floods cause widespread devastation and generate sensational images for months or even years after their occurrence. Understandably these types of hazards captivate the attention of policy makers and the general public, many of whom are directly impacted by such events.

One category of natural hazard, flash floods, rarely garners that level of attention. Yet according to the World Meteorological Organization (WMO), flash floods are the most lethal form of natural hazard (based upon the ratio of fatalities to people affected), and cause millions of dollars in property damage every year.[1] This is because flash floods, which are flood events of short duration with a relatively high peak discharge, tend to occur frequently but at a very small scale. Flash floods often impact poorer populations in remote locations. Individually they rarely capture news headlines, but cumulatively they can severely undermine a region's development.

Flash floods can be dangerous and destructive in almost any part of the world. In Italy in June 1996, more than 40 cm (15.7 inches) of rain fell in less than six hours, pouring as much as 8.8 cm (3.5 inches) in 30 minutes, a near-record rate for Italy. The village of Cardoso in the Versilia Valley was severely damaged by the resulting flash flood. Thirteen people died.

Definitions of "Flash Flood"

1. **World Meteorological Organization:** *a flood of short duration with a relatively high peak discharge.*
2. **American Meteorological Society:** *a "…flood that rises and falls quite rapidly with little or no advance warning, usually as the result of intense rainfall over a relatively small area."*
3. **U.S. National Weather Service:** *a rapid and extreme flow of high water into a normally dry area, or a rapid water level rise in a stream or creek above a predetermined flood level, beginning within six hours of the causative event (e.g., intense rainfall, dam failure, ice jam). However, the actual time threshold may vary in different parts of the country. Ongoing flooding can intensify to flash flooding in cases where intense rainfall results in a rapid surge of rising flood waters.*

More recently, flash floods swept through the town of Aguas Calientas, Peru, in late January 2010, trapping 4,000 tourists on their way to or from the ruins of Machu Picchu. They were stranded in the tiny town for two or more days before helicopters could carry them out. The swollen Urubamba (Valcanota) River (Fig. 1.1) washed away bridges and destroyed many

[1] World Meteorological Organization, *Global approach to address flash floods*, in MeteoWorld (June 2007), www.hrc-lab.org/publicbenefit/downloads/wmo-flashflood.pdf

Figure 1.1 Flash flooding of the Urubamba River, Peru, January, 2010.

sections of the railroad that takes tourists there. One rain gauge 100 km upstream recorded 23.6 cm in 13 hours prior to the floods. Authorities estimated the floods destroyed 2,000 homes.

In September 2009, heavy overnight rains in the vicinity of the İkitelli district of Istanbul, Turkey, produced 2 meter (6-7 foot) flash floods that washed through a commercial district of the city in the early morning as people were going to work, killing 13 truckers asleep in their cabs and 7 women just exiting their van on their way to work in a textile factory. Many others were forced to climb atop roofs and cars to escape the flood and had to be rescued by helicopter or rope. The flood heavily damaged homes, businesses, and farms. Meteorologists said the rainfall was the worst in 80 years, and Turkey's prime minister called it "the disaster of the century."

In the United States, flash floods can be deadly, even with state-of-the-art forecasting equipment. In 2003, 150-200 mm (6-8 inches) of rain fell in three hours in a 5 km^2 (two-square mile) catch basin feeding tiny Jacob Creek, in the Midwestern state of Kansas. A few hours later, a 2 meter (6-7 ft) wall of water unexpectedly swept across the Kansas Turnpike, a major interstate highway, when the Jersey barriers holding the water back gave way. Twelve 4,500 kilogram (10,000 pound) concrete barriers floated away "like feathers," in the words of one witness, and seven cars on the bridge followed. Six people died, including a mother and her four children and a man who had gotten out of his car to help others. Although the U.S. National

Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) had issued a Flash Flood Watch for the area that day, there had been no warning.

Flash floods are typically caused by torrential rainfall, but can also occur from a dam break, a levee break, or even ice jams in rivers during the winter and spring months. Urban flash flooding is a serious and increasingly common problem as cities grow and sprawl. Impervious surfaces like concrete or compacted bare soils, along with alterations to the natural drainages, create instant high energy runoff from heavy rainfall that can inundate roads and buildings very quickly.

Despite the significance of these flash flood events, few countries have implemented flash flood warning systems. This is due in part to the technical complexity of predicting flash flood events with enough confidence (accuracy) and lead time (advance warning) to take precautionary action. Some countries have established Flash Flood Early Warning Systems (EWS) and have not sustained them. Recent computer modeling, precipitation sensing, and communications technology advancements are making flash flood EWS increasingly affordable, effective, and sustainable. But it must also be noted that at the present time even with the most robust of forecasting schemes employing dense rain gauge networks, radar coverage, satellite algorithms, high resolution computer models of atmospheric processes and distributed hydrologic models, it is beyond the state of the science to accurately forecast with effective lead time where flash flooding will occur from convective storms in some situations. Flash flood events are still missed by even these most sophisticated warning systems due to science's inability to pinpoint the location and timing of small-scale heavy rain. But now, flash-flood prone countries with vulnerable populations do have a range of options for creating local or regional early warning systems or even participating in global early warning systems capable of providing some protection from flash floods. These options include:

1) Heavy rain event detection via rainfall/streamflow gauge networks, radar networks, satellite sensors, or some combination of the three.

2) Manual or computerized short-fused nowcasts of imminent flash floods from diagnosed heavy rain events.

3) Atmospheric fine-scale models, possibly coupled with distributed hydrology models, to forecast the risk of flash flooding in a basin or basins a short time in the future.

It should not be overlooked that flash floods are both complex hydrometeorological and sociological phenomena. That is to say it is not sufficient to develop a robust detection and/or forecasting methodology. Attention must also be paid to the human tendencies to ignore or minimize the personal impact of warnings. Sharif [2] found that Texas ranks number one among U.S. states in total deaths from flooding (840) for the 50 year period 1959-2008. Of those deaths, 77 percent died in vehicles while attempting to cross flooded roads and bridges, often driving around barricades meant to save their lives.

[2] Hatim Sharif, Univ. Texas San Antonio Dept. Civil and Environmental Engineering presentation at Flood Coalition Meeting Dec. 2009.

Purpose of the Guide

This Guide is intended to provide a reference for the implementation of flash flood early warning systems within the framework of Multi-Hazard Early Warning Systems (MHEWS) based upon proven and effective methods already in use in flash-flood prone areas around the world. It is intended to serve as a reference to both governmental (especially meteorological forecast centers[3]) and non-governmental decision makers who may be uncertain of the process and components that constitute a robust, coordinated flash flood guidance and early warning system. This Guide will use the popular term "end-to-end system" as short-hand for such a system even though it does not adequately describe the non-linearity created by crucial feedback links.

This Guide will also be of interest to:

- International, regional, subnational, and community policy makers
- National and local authorities responsible for emergency services and preparedness
- Communities at risk from flash floods
- Non-Governmental Organizations (NGOs)
- International development specialists
- Donors
- Emergency management specialists
- Hydrologists
- Meteorologists
- Journalists
- Research scholars, teachers and students
- Private citizens

What Is an Early Warning System (EWS)?

Building a Global Warning Capability

In January 2005, the United Nations convened the Second World Conference on Disaster Reduction in Kobe, Hyogo, Japan. During this conference, an agreement called the "Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters"[i] (HFA) was negotiated and adopted by 168 countries. The paradigm for disaster risk management was broadened from simply post-disaster response to a more comprehensive

[3] In the 52th Session of the Executive Council (paragraph 11.2.32) WMO defines NHS as National Hydrologic Service, NMS as National Meteorological or Hydrometeorological Service, and NMHS as National Meteorological and Hydrological Service.

approach that also includes prevention and preparedness measures. HFA also stresses the need for, "identifying, assessing and monitoring disaster risks and enhancing early warning systems."

Following this agreement, efforts are underway to incorporate early warning systems as an integral component of any nation's disaster risk management strategy, enabling governments and communities to take appropriate measures toward building community resilience to natural disasters.

EWS are increasingly recognized at the highest political level as a critical tool for the saving of lives and livelihoods, and there are increasingly more investments by national and local governments, international development agencies, and bilateral donors to support such systems. A major conclusion of the Global Early Warning Survey Report,[ii] launched at the Third International Early Warning Conference (EWC – III), in Bonn, Germany (March 2006), was that many challenges must still be met to ensure that EWS are implemented as an integral part of multi-hazard disaster risk reduction strategies. These challenges include legislation, finances, organization, technical difficulties, operations, training, and capacity building. Results of a country-level survey conducted by WMO in 2006-07,[iii] indicated that over 70% of countries require development and strengthening of core capacities such as hydrometeorological observing networks, 24/7 forecasting systems, and communication systems to ensure that EWS are effectively implemented. Also, results of an EWS assessment report compiled and drafted by WMO in collaboration with 18 other United Nations (UN) agencies to support the 2009 Global Assessment Report on Disaster Reduction[iv] reveals that many countries, especially those at highest risk, remain challenged in building and sustaining their EWS.

In 2006, during EWC-III, a Checklist for Developing Early Warning Systems was provided[v] as a tool for governments developing or evaluating EWS. WMO is working systematically to assist countries in developing their EWS with a multi-hazard approach. The First International Expert's Symposium on Multi-Hazard EWS,[vi] hosted by WMO in May 2006, identified criteria for "good practices." At the Second WMO International Expert's Symposium on Multi-Hazard EWS in 2009,[vii] experts from around the world discussed several national good practices using the four operational components of effective early warning systems. The components of an effective EWS, as illustrated in Figure 1.2 include:

1) Detecting and forecasting hazards and developing hazard warning messages
2) Assessing potential risks and integrating risk information into warning messages
3) Disseminating timely, reliable, and understandable warning messages to authorities and at-risk public
4) Community-based emergency planning, preparedness and training focused on eliciting an effective response to warnings to reduce potential impact on lives and livelihoods

A multi-hazard approach helps a country leverage various capacities and resources and address sustainability and interoperability issues across and within the four components of the system. Coordination between national agencies and communities is an essential ingredient needed for warnings to lead to protective actions and mitigation of losses.

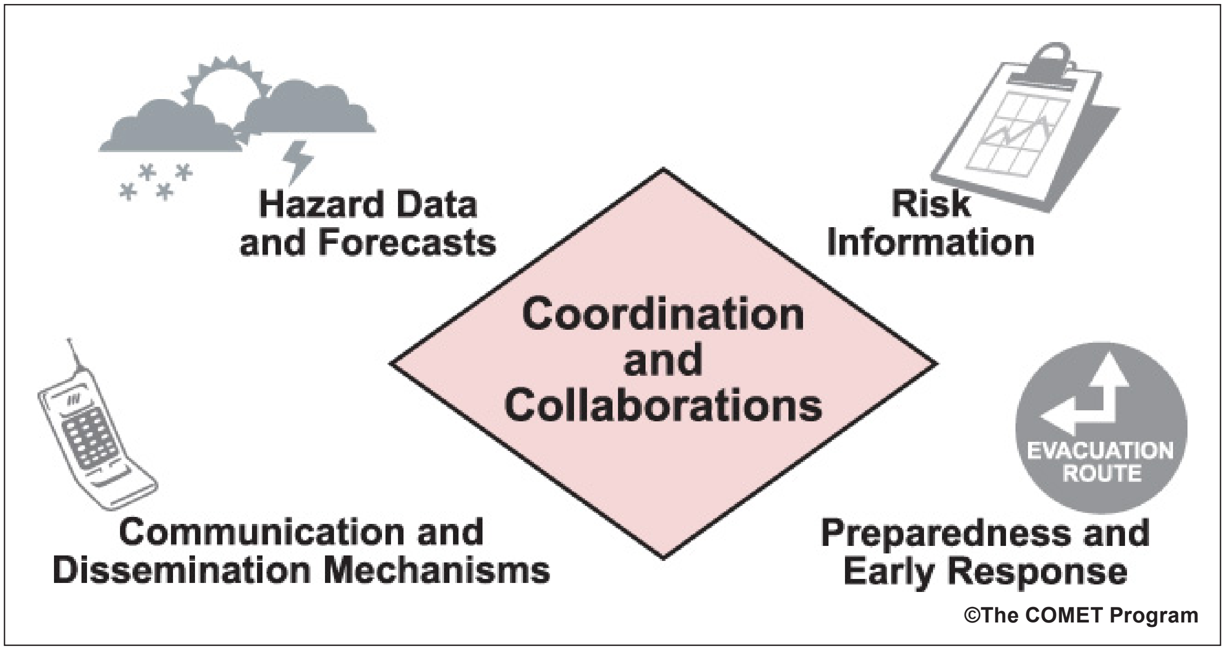

Figure 1.2 Simplified version of an original figure produced by WMO on components of an effective Early Warning System.[viii]

In 2010, WMO will define "good practices" in early warning systems (EWS), and prepare a document titled *"Institutional Partnerships and Coordination in Multi-Hazard Early Warning Systems."* [ix] The WMO Guidelines are being developed in cooperation with other UN and international partners as well as its Members. The guidelines will describe a systematic process for documenting good practices in EWS and provide a recipe for developing countries to utilize in establishing a strong MHEWS.

This Guide follows the good practices recommendations being developed by WMO and focuses on establishing an End-to-End Flash Flood Early Warning and Response System as practiced in the U.S. Any EWS will have its own unique requirements and operating conditions, and no single system will work for everyone. But all effective systems share certain common features. This Guide describes those common features and provides examples of various systems in operation in the United States and around the world today.

Development and sustainability of a Flash Flood EWS requires political commitment and dedicated investments. This document assumes that an organization building a flash flood warning capability has a mandate by law to warn citizens of impending flash floods.

The primary objective of an Early Warning System (EWS) is to empower individuals and communities threatened by hazards to act in time and in an appropriate manner to reduce the possibility of personal injury, loss of life, damage to property and the environment, and loss of livelihoods. Governmental agencies (particularly NMHSs, national and local disaster management agencies), non-governmental organizations, corporations, academic institutions, international partners, and local communities each play an essential part in the successful design and implementation of most natural hazard early warning systems.

Figure 1.3 suggests that a Flash Flood Early Warning System (EWS) does not have to stand alone but can be a "system within a MHEWS." The Flash Flood EWS is composed of both hazard-specific and shared subsystems that, when integrated with other natural hazard early warning systems like those for hurricanes, severe weather, tsunamis, etc., have the ability to function as a single, effective MHEWS. That is to say not all subsystems are unique to a specific hazard. For a flash flood EWS, the *risk information* and the *hazard data and forecasts* subsystems are quite specific to hydrometeorology, however the *communication and dissemination* and the *preparedness and response* subsystems have components that may be equally effective for other types of hazards.

The Costs and Benefits of Investing in Natural Hazard Management

The United Nations International Strategy for Disaster Reduction (ISDR) and the World Bank recommend the use of economic analysis to investigate the feasibility of implementing natural hazard management systems. Not only is "cost-benefit analysis" crucial to understanding the financial implications of procuring, operating, and maintaining such systems, it is also important to understanding how hazard management systems might impact human life, the environment, and long-term social interests. Cost-benefit analysis provides a powerful tool to

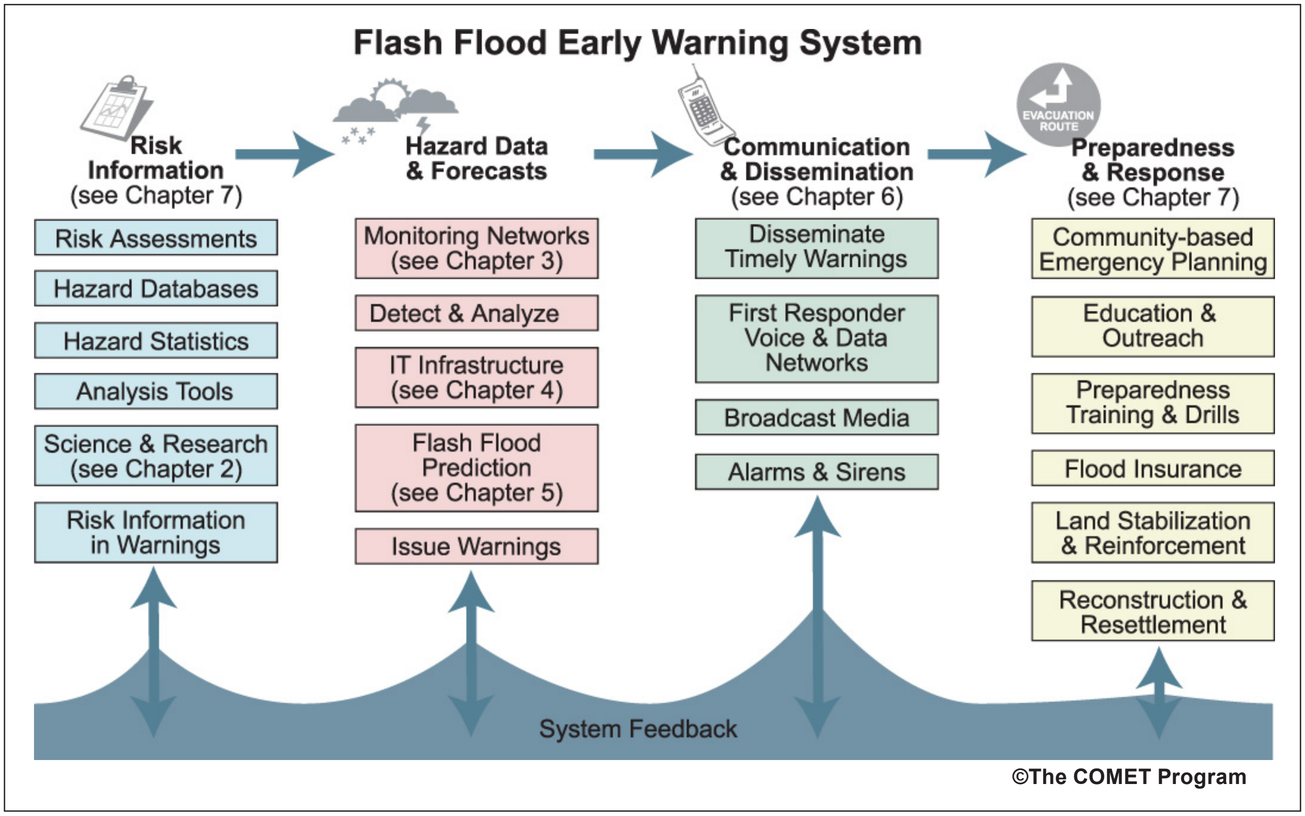

Figure 1.3 Components of a flash flood EWS.

balance infrastructure investments against longer-term aspirations, such as socio-economic security and development.

More information about how to perform a cost-benefit analysis for hazard management is available from several leading institutions, including:

1) The National Oceanic and Atmospheric Administration and the National Center for Atmospheric Research in the United States. "Primer on Economics for National Meteorological and Hydrological Services" (Lazo et al, September 2007)

2) The ProVention Consortium. "Cost-benefit Analysis" under the menu "Resources" on the ProVention Consortium website: **http://www.proventionconsortium.org/**

Organization of the Guide

This Guide provides an overview of the operational and organizational requirements for a flash flood forecasting subsystem within the framework of a multi-hazard early warning system. Because it is written primarily from the perspective of a NMHS, there are certain aspects of *risk information* and *preparedness* (as depicted in Fig. 1.3) that are beyond the scope of the Guide. Chapter 2 is a brief overview of the hydrology of flash floods, followed by five chapters that describe the various elements (subsystems) of some of the successful systems in operation around the world today. Each of these chapters begins with a general description of a subsystem element and its role within an end-to-end system so that the reader immediately understands its relative purpose. The remaining sections of each chapter provide additional levels of detail about the subsystem elements. The eighth chapter provides examples of successful end-to-end systems, and the final chapter is a roadmap for developing a concept of operations (ConOps) for EWS. The ConOps provides a high-level description of the resources, methods, and procedures often employed to operate the EWS.

Critical information and examples are highlighted in **tip boxes** throughout this document. In addition, a list of acronyms, a glossary of terms, and a variety of helpful references are provided in the appendices at the end of the Guide.

The structure of the guide is as follows:

Chapter 1 – Introduction

This chapter describes the purpose of flash flood early warning systems and provides a general definition of what constitutes a EWS. It also introduces the importance of understanding the full costs and benefits of implementing such systems so that appropriate investments can be made in capacity building, technology development, social infrastructure and sustainability.

Chapter 2 – Flash Flood Science

This chapter contains an overview of the science of flash flood hydrometeorology. After defining the term "flash flood," it surveys their causes and the process by which their prediction can be integrated into hydrological forecasting programs.

Chapter 3 – Hydrometeorological Monitoring Networks

Flash flood forecasting is data-intensive and highly dependent upon the timely processing of a variety of information before and during flash flood events. Some types of data are available in real time through the internet and satellite downlinks. Most types of data, however, are collected using local sensors and communicated using regional wired and wireless infrastructure. Multiple-sensor networks are critical to the success of an end-to-end system, and Chapter 3 reviews key considerations for planning that aspect of a flash flood EWS.

Chapter 4 – Technology Infrastructure

The previous chapters make clear that forecasting flash floods can be technology-intensive. This chapter summarizes the infrastructural requirements for implementing and operating a flash flood early warning system. Since information technology is constantly changing, no attempt is made to discuss specific technologies; instead, this section describes basic system capabilities essential to predict flash floods.

Chapter 5 – Flash Flood Forecasting Subsystems

This chapter focuses on describing technical details of several distinct methodologies used for flash flood detection and prediction. The first methodology, often referred to as a Local Flood Warning System (LFWS), is composed of manual and/or automatic hydrometeorological gauges plus some method for collecting and processing their readings at a central location. The second methodology utilizes Flash Flood Guidance (FFG). Employed by several countries around the world, this process compares observed precipitation to flash flood guidance (FFG) values. This FFG represents rainfall-to-runoff relationship that describes the rainfall needed to produce a flash flood, given antecedent moisture conditions and other factors such as local terrain, land use, soil conditions, and vegetation characteristics. The chapter also discusses the emerging Global FFG system (GFFGS) and briefly discusses emerging hydrologic distributed forecast models.

Chapter 6 – Warning Dissemination and Notification

An effective and well-understood protocol for issuing warnings is an essential yet often-overlooked element of EWS. Chapter 6 describes a recommended approach to the preparation and dissemination of warnings and the associated strategies for maximizing the impact of those bulletins. Examples of bulletins are provided in Appendix E.

Chapter 7 – Community-Based Disaster Management

Local communities play an essential role in flash flood disaster preparation and response. This chapter describes community-based management methodologies that promote local capacity that is both sustainable and effective before and after flash flood events. Building partnerships, targeting communications and training, and creating local ownership are just some of the strategies that promote successful flash flood EWS.

Chapter 8 – Examples of End-to-End Flash Flood Early Warning Systems (EWS)

This chapter illustrates how flash flood forecasting subsystems fit into overall end-to-end early warning systems by providing detailed descriptions of several full end-to-end flash flood forecasting systems that are currently operational or under development in North America, Latin America, Europe and Asia. The examples in this chapter are more detailed than the short descriptions of flash flood forecast subsystems discussed briefly in Chapter 5.

Chapter 9 - Development of a Concept of Operations

The final chapter of this Guide describes the development of a concept of operations ("ConOps") for a flash flood EWS–that is, the strategies, tactics, policies, and constraints that describe how impacts of flash flood events will be reduced by the EWS. The ConOps provides a high-level description of the resources, methods and procedures that will be employed to operate the EWS.

Appendices - Additional References

Appendix A: Acronyms
Appendix B: Glossary
Appendix C: ALERT and IFLOWS System Descriptions
Appendix D: Flash Flood Potential Index (FFPI) Description
Appendix E: Examples of Flash Flood Products

Endnotes

i http://www.unisdr.org/eng/about_isdr/isdr-publications/07-hyogo-framework-for-action-english/hyogo-framework-for-action-english.pdf

ii In 2005, following the tragic Indian Ocean tsunami, UN Secretary General, Kofi Annan requested a global early warning survey. This survey was coordinated by ISDR Secretariat with the support of a multi-agency task team, co-chaired by WMO and OCHA. The survey can be accessed at: http://www.reliefweb.int/rw/lib.nsf/db900sid/AMMF-6VKH6Z/$file/UNISDR-Sep2006.pdf?openelement.

iii Of the 187 WMO Members, 139 participated in the survey. The survey has been synthesised in the "Assessment Report of National Meteorological and Hydrological Services in Support of Disaster Risk Reduction": http://www.wmo.int/pages/prog/drr/natRegCap_en.html.

iv Global Assessment Report on Disaster Reduction: http://www.preventionweb.net/english/hyogo/gar/

v The Checklist can be accessed at Third International Conference on Early Warning (EWC III) website: http://www.ewc3.org/.

vi This symposium brought together nearly 100 experts from networks of 20 international, regional and national agencies. MHEWS-I identified (i) Bangladesh Cyclone Preparedness Programme, (ii) Tropical Cyclone Early Warning System of Cuba, (iii) French Vigilance System, (iv) Shanghai Multi-Hazard Early Warning and Emergency Preparedness Programme v) Multi-Hazard Early Warning Systems in the USA: Institutional Coordination and Cooperation of the U.S. National Weather Service vi) The Warning Management of the Deutscher Wetterdienst and, vii) Multi-Hazard Early Warning System in Japan. as examples of "good practices". The Meeting noted that this is not a comprehensive list as there are such practices that could be identified and added to this list. Further details about the outcomes of MHEWS-I are available from http://www.wmo.int/pages/prog/drr/events/ews_symposium_2006. The Co-sponsors included WMO, IFRC, OCHA, UNDP, UNESCO, the World Bank and the ISDR Secretariat.

vii Second Experts' symposium on Multi-Hazard Early Warning Systems (Toulouse, 2009), www.wmo.int/pages/prog/drr/events/MHEWS-II/index_en.html

viii http://www.ewc2.org/

ix the guidelines have been prepared based on documentation of seven good practices in Early Warning Systems and will be published in the forthcoming book "Institutional partnerships in Multi-Hazard Early Warning Systems, Golnaraghi M. (Ed)