Comprehensive Risk Assessment for Natural Hazards

World Meteorological Organization

WMO/TD No. 955
1999

Cover photo: Drought Monitoring Centre, Nairobi

WMO/TD No. 955

NOTE

The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of any of the participating agencies concerning the legal status of any country, territory, city or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries.

CONTENTS

AUTHORS AND EDITORS

AUTHORS:

Chapter 1

Charles S. Melching	United States of America
Paul J. Pilon	Canada

Chapter 2

Yadowsun Boodhoo	Mauritius

Chapter 3

Renée Michaud (Mrs)	United States of America
Paul J. Pilon	Canada

Chapter 4

Laurent Stiltjes	France
Jean-Jacques Wagner	Switzerland

Chapter 5

Dieter Mayer-Rosa	Switzerland

Chapter 6

Olivier Lateltin	Switzerland
Christoph Bonnard	Switzerland

Chapter 7

Charles S. Melching	United States of America

Chapter 8

Charles S. Melching	United States of America

EDITORS:

Charles S. Melching	United States of America
Paul J. Pilon	Canada

FOREWORD

The International Decade for Natural Disaster Reduction (IDNDR), launched as a global event on 1 January 1990, is now approaching its end. Although the decade has had many objectives, one of the most important has been to work toward a shift of focus from post-disaster relief and rehabilitation to improved pre-disaster preparedness. The World Meteorological Organization (WMO), as the United Nations specialized agency dedicated to the mitigation of disasters of meteorological and hydrological origin, has been involved in the planning and implementation of the Decade One of the special projects undertaken by WMO as a contribution to the Decade has been the compilation and publication of the report entitled *Comprehensive Risk Assessment for Natural Hazards.*

The IDNDR called for a comprehensive approach in dealing with natural hazards. This approach would thus need to include all aspects relating to hazards, including risk assessment, land use planning, design codes, forecasting and warning systems, disaster preparedness, and rescue and relief activities In addition to that, it should also be comprehensive in the sense of integrating efforts to reduce disasters resulting from tropical cyclones, storm surges, river flooding, earthquakes and volcanic activity. Using this comprehensive interpretation, the Eleventh Congress of WMO and the Scientific and Technical Committee for the IDNDR both endorsed the project to produce this important publication. In the WMO Plan of Action for the IDNDR, the objective was defined as "to promote a comprehensive approach to risk assessment and thus enhance the effectiveness of efforts to reduce the loss of life and damage caused by flooding, by violent storms and by earthquakes".

A special feature of this report has been the involvement of four different scientific disciplines in its production. Such interdisciplinary cooperation is rare, and it has indeed been a challenging and fruitful experience to arrange for co-operation between experts from the disciplines involved. Nothing would have been produced, however, if it were not for the hard and dedicated work of the individual experts concerned I would in particular like to extend my sincere gratitude to the editors and the authors of the various chapters of the report.

Much of the work on the report was funded from WMO's own resources. However, it would not have been possible to complete it without the willingness of the various authors to give freely of their time and expertise and the generous support provided by Germany, Switzerland and the United States of America.

The primary aim of this report is not to propose the development of new methodologies and technologies. The emphasis is rather on identifying and presenting the various existing technologies used to assess the risks for natural disasters of different origins and to encourage their application, as appropriate, to particular circumstances around the world. A very important aspect of this report is the promotion of comprehensive or joint assessment of risk from a variety of possible natural activities that could occur in a region. At the same time, it does identify gaps where there is a need for enhanced research and development. By presenting the technologies within one volume, it is possible to compare them, for the specialists from one discipline to learn from the practices of the other disciplines, and for the specialists to explore possibilities for joint or combined assessments in some regions.

It is, therefore, my sincere hope that the publication will offer practical and user friendly proposals as to how assessments may be conducted and provide the benefits of conducting comprehensive risk assessments on a local, national, regional and even global scale. I also hope that the methodologies presented will encourage multidisciplinary activities at the national level, as this report demonstrates the necessity of and encourage co-operative measures in order to address and mitigate the effects of natural hazards.

(G.O.P. Obasi)
Secretary-General

Chapter 1
INTRODUCTION

1.1 PROJECT HISTORY

In December 1987, the United Nations General Assembly adopted Resolution 42/169 which proclaimed the 1990s as the International Decade for Natural Disaster Reduction (IDNDR). During the Decade a concerted international effort has been made to reduce the loss of life, destruction of property, and social and economic disruption caused throughout the world by the violent forces of nature. Heading the list of goals of the IDNDR, as given in the United Nations resolution, is the improvement of the capacity of countries to mitigate the effects of natural disasters such as those caused by earthquakes, tropical cyclones, floods, landslides and storm surges.

As stated by the Secretary-General in the Foreword to this report, the World Meteorological Organization (WMO) has a long history of assisting the countries of the world to combat the threat of disasters of meteorological and hydrological origin. It was therefore seen as very appropriate for WMO to take a leading role in joining with other international organizations in support of the aims of the IDNDR. The forty-fourth session of the United Nations General Assembly in December 1989 adopted Resolution 44/236. This resolution provided the objective of the IDNDR which was to "reduce through concerted international action, especially in developing countries, the loss of life, property damage, and social and economic disruption caused by natural disasters, such as earthquakes, windstorms, tsunamis, floods, landslides, volcanic eruptions, wildfires, grasshopper and locust infestations, drought and desertification and other calamities of natural origin." One of the fine goals of the decade as adopted at this session was "to develop measures for the assessment, prediction, prevention and mitigation of natural disasters through programmes of technical assistance and technology transfer, demonstration projects, and education and training, tailored to specific disasters and locations, and to evaluate the effectiveness of those programmes" (United Nations General Assembly, 1989).

The IDNDR, therefore, calls for a comprehensive approach to disaster reduction; comprehensive in that plans should cover all aspects including risk assessment, land-use planning, design codes, forecasting and warning, disaster-preparedness, and rescue and relief activities, but comprehensive also in the sense of integrating efforts to reduce disasters resulting from tropical cyclones, storm surges, river flooding, earthquakes, volcanic activity and the like. It was with this in mind that WMO proposed the development of a project on comprehensive risk assessment as a WMO contribution to the Decade. The project has as its objective: "to promote a comprehensive approach to risk assessment and thus enhance the effectiveness of efforts to reduce the loss of life and damage caused by flooding, by violent storms, by earthquakes, and by volcanic eruptions."

This project was endorsed by the Scientific and Technical Committee (STC) for the IDNDR when it met for its first session in Bonn in March 1991 and was included in the STC's list of international demonstration projects. This project was subsequently endorsed by the WMO Executive Council and then by the Eleventh WMO Congress in May 1991. It appears as a major component of the Organization's Plan of Action for the IDNDR that was adopted by the WMO Congress

In March 1992, WMO convened a meeting of experts and representatives of international organizations to develop plans for the implementation of the project. At that time the objective of the project was to promote the concept of a truly comprehensive approach to the assessment of risks from natural disasters. In its widest sense such an approach should include all types of natural disaster However, it was decided to focus on the most destructive and most widespread natural hazards, namely those of meteorological, hydrological, seismic, and/or volcanic origin. Hence the project involves the four disciplines concerned. Two of these disciplines are housed within WMO itself, namely hydrology and meteorology. Expertise on the other disciplines was provided through contacts with UNESCO and with the international non-governmental organizations International Association of Seismology and Physics of the Earth's Interior (IASPEI) and International Association of Volcanology and Chemistry of the Earth's Interior (IACEI).

One special feature of the project was the involvement of four scientific disciplines. This provided a rare opportunity to assess the similarities and the differences between the approaches these disciplines take and the technology they use, leading to a possible cross-fertilization of ideas and an exchange of technology. Such an assessment is fundamental when developing a combined or comprehensive risk assessment of various natural hazards. This feature allows the probabilistic consideration of combined hazards, such as flooding in association with volcanic eruptions or earthquakes and high winds.

It was also felt that an increased understanding of the risk assessment methodologies of each discipline is required, prior to combining the potential effects of the natural hazards. As work progressed on this project, it was evident that although the concept of a comprehensive assessment was not entirely novel, there were relatively few, if any, truly comprehensive assessments of all risks from the various potentially damaging natural phenomena for a given location. Chapter 6 presents an example leading to composite hazard maps including floods, landslides, and snow avalanches The preparation of composite hazard maps is viewed as a first step towards comprehensive assessment and management of risks resulting from natural hazards Thus, the overall goal of describing methods of comprehensive assessment of risks from natural hazards could not be fully achieved in this report. The authors and WMO feel this report provides a good starting point for pilot projects and the further development of methods for comprehensive assessment of risks from natural hazards.

1.2 FRAMEWORK FOR RISK ASSESSMENT

1.2.1 Definition of terms

Before proceeding further, it is important to present the definitions of risk, hazard and vulnerability as they are used throughout this report. These words, although commonly used in the English language, have very specific meanings within this report. Their definitions are provided by the United Nations Department of Humanitarian Affairs (UNDHA, 1992), now the United Nations Office for Coordination of Humanitarian Affairs (UN/OCHA), and are:

Disaster:
A serious disruption of the functioning of a society, causing widespread human, material or environmental losses which exceed the ability of affected society to cope using only its own resources. Disasters are often classified according to their speed of onset (sudden or slow), or according to their cause (natural or man-made).

Hazard:
A threatening event, or the probability of occurrence of a potentially damaging phenomenon within a given time period and area.

Risk:
Expected losses (of lives, persons injured, property damaged and economic activity disrupted) due to a particular hazard for a given area and reference period. Based on mathematical calculations, risk is the product of hazard and vulnerability.

Vulnerability:
Degree of loss (from 0 to 100 per cent) resulting from a potentially damaging phenomenon.

Although not specifically defined within UNDHA (1992), a natural hazard would be considered a hazard that is produced by nature or natural processes, which would exclude hazards stemming or resulting from human activities. Similarly, a natural disaster would be a disaster produced by nature or natural causes.

Human actions, such as agricultural, urban and industrial development, can have an impact on a number of natural hazards, the most evident being the influence on the magnitude and frequency of flooding. The project pays close attention to various aspects of natural hazards, but does not limit itself to purely natural phenomena. Examples of this include potential impacts of climate change on meteorological and hydrological hazards and excessive mining practices and reservoirs on seismic hazards.

1.2.2 Philosophy of risk assessment

One of the most important factors to be considered in making assessments of hazards and risks is the purpose for which the assessment is being made, including the potential users of the assessment. Hazard assessment is important for designing mitigation schemes, but the evaluation of risk provides a sound basis for planning and for allocation of financial and other resources. Thus, the purpose or value of risk assessment is that the economic computations and the assessment of the potential loss of life increase the awareness of decision makers to the importance of efforts to mitigate risks from natural disasters relative to competing interests for public funds, such as education, health care, infrastructure, etc. Risks resulting from natural hazards can be directly compared to other societal risks. Decisions based on a comparative risk assessment could result in more effective allocation of resources for public health and safety. For example, Schwing (1991) compared the cost effectiveness of 53 US Government programmes where money spent saves lives. He found that the programmes abating safety-related deaths are, on average, several thousand times more efficient than those abating disease- (health-) related deaths. In essence, detailed risk analysis illustrates to societies that "the zero risk level does not exist". It also helps societies realize that their limited resources should be directed to projects or activities that within given budgets should minimize their overall risks including those that result from natural hazards.

The framework for risk assessment and risk management is illustrated in Figure 1.1, which shows that the evaluation of the potential occurrence of a hazard and the assessment of potential damages or vulnerability should proceed as parallel activities. The hazard is a function of the natural, physical conditions of the area that result in varying potential for earthquakes, floods, tropical storms, volcanic activity, etc., whereas vulnerability is a function of the type of structure or land use under consideration, irrespective of the location of the structure or land use. For example, as noted by Gilard (1996) the same village has the same vulnerability to flooding whether it is located in the flood plain or at the top of a hill. For these same two circumstances, the relative potential for flooding would be exceedingly different. An important aspect of Figure 1.1 is that the vulnerability assessment is not the second step in risk assessment, but rather is done at the same time as the hazard assessment.

Hazard assessment is done on the basis of the natural, physical conditions of the region of interest. As shown in Chapters 2 through 5, many methods have been developed in the geophysical sciences for hazard assessment and the development of hazard maps that indicate the magnitude and probability of the potentially damaging natural phenomenon. Furthermore, methods also have been developed to prepare combined hazard maps that indicate the potential occurrence of more than one potentially damaging natural phenomenon at a given location in commensurate and consistent terms. Consistency in the application of technologies is required so that results may be combined and are comparable. Such a case is illustrated in Chapter 6 for floods, landslides and snow avalanches in Switzerland.

The inventory of the natural system comprises basic data needed for the assessment of the hazard. One of the main problems faced in practice is a lack of data, particularly in developing countries. Even when data exist, a major expenditure in time and effort is likely to be required for collecting, checking and compiling the necessary basic information into a suitable database. Geographic Information Systems (GISs)

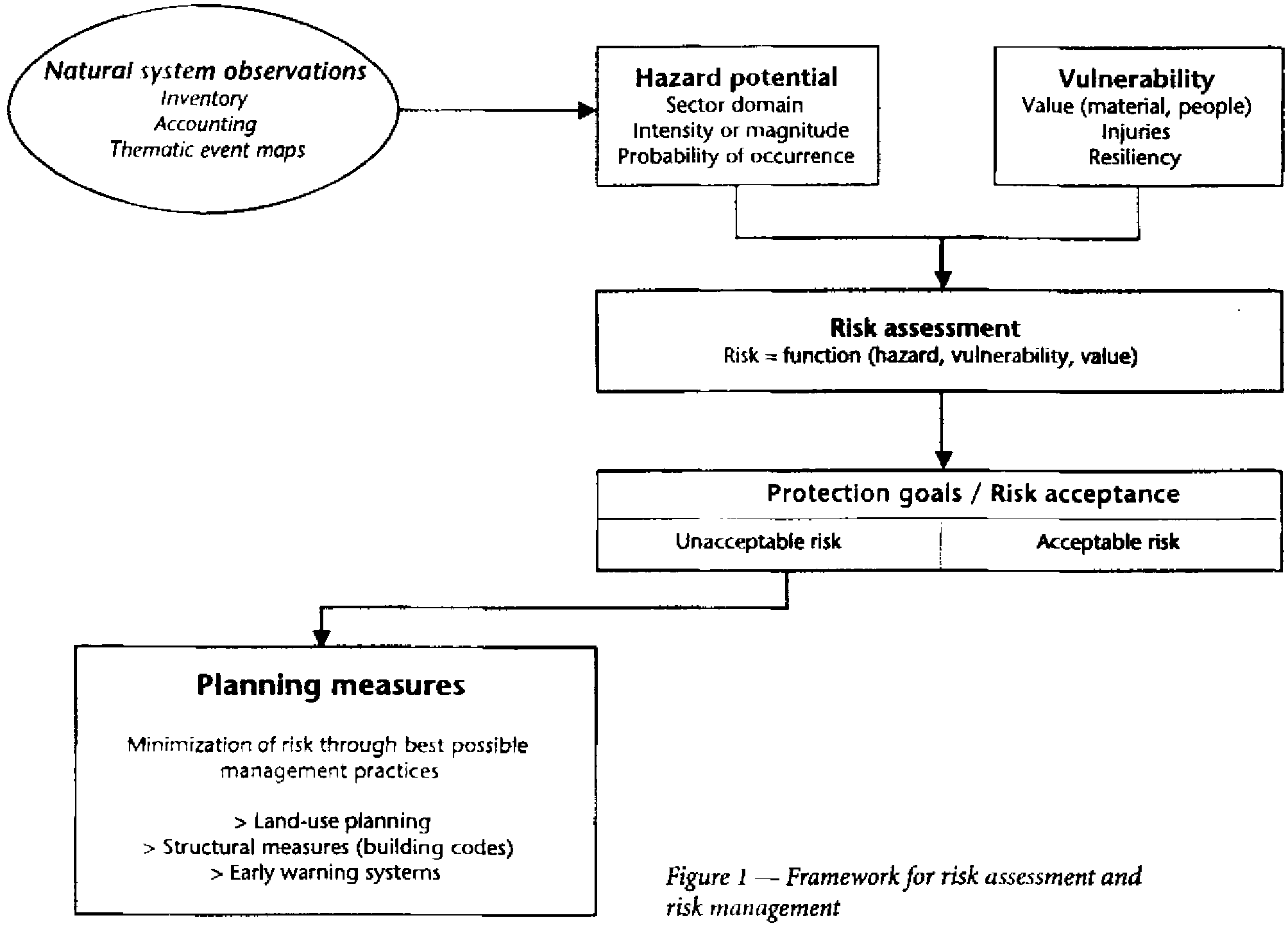

Figure 1 — Framework for risk assessment and risk management

offer tremendous capabilities in providing geo-referenced information for presentation of risk assessment materials held in the compiled database. They should be considered fundamental tools in comprehensive assessment and form an integral part of practical work.

Figure 1.1 shows that the assessments of hazard potential and vulnerability precede the assessment of risk. Risk assessment infers the combined evaluation of the expected losses of lives, persons injured, damage to property and disruption of economic activity. This aspects calls for expertise not only in the geophysical sciences and engineering, but also in the social sciences and economics. Unfortunately, the methods for use in vulnerability and damage assessment leading to the risk assessment are less well developed than the methods for hazard assessment. An overview of methods for assessment of the economic aspects of vulnerability is presented in Chapter 7. There, it can be seen that whereas methods are available to estimate the economic aspects of vulnerability, these methods require social and economic data and information that are not readily available, particularly in developing countries. If these difficulties are not overcome, they may limit the extent to which risk assessment can be undertaken with confidence.

In part, the reason that methods to evaluate vulnerability to and damages from potentially damaging natural phenomena are less well developed than the methods for hazard assessment is that for many years an implicit vulnerability analysis was done. That is, a societally acceptable hazard level was selected without consideration of the vulnerability of the property or persons to the potentially damaging natural phenomenon. However, in recent years a number of methods have been proposed and applied wherein complete risk analyses were done and risk-mitigation strategies were enacted on the basis of actual consideration of societal risk acceptance/protection goals as per Figure 1.1. Several examples of these risk assessments are presented in Chapter 8.

The focus of this report includes up to risk assessment in Figure 1.1. Methods for hazard assessment on the basis of detailed observations of the natural system are presented in Chapters 2 to 6, methods for evaluating the damage potential are discussed in Chapter 7, and examples of risk assessment are given in Chapter 8. Some aspects of planning measures for risk management are discussed in Chapters 2 through 6 with respect to the particular natural phenomena included in these chapters. Chapter 8 also describes some aspects of social acceptance of risk. The psychology of societal risk acceptance is very complex and depends on the communication of the risk to the public and decision makers and, in turn, their perception and understanding of "risk". The concept of risk aversion is discussed in section 1.2.3 because of its importance to risk-management decisions.

Finally, forecasting and warning systems are among the most useful planning measures applied in risk mitigation and are included in Figure 1.1. Hazard and risk maps can be used in estimating in real-time the likely impact of a major forecasted event, such as a flood or tropical storm. The link goes even further, however, and there is a sense in which a hazard assessment is a long-term forecast presented in probabilistic terms, and a short-term forecast is a hazard assessment corresponding to the immediate and limited future. Therefore, while forecasting and warning systems were not actually envisaged as part of this project, the natural link between these systems is illustrated throughout the report. This linkage and their combined usage are fundamental in comprehensive risk mitigation and should always be borne in mind.

1.2.3 Risk aversion

The social and economic consequences of a potentially damaging natural phenomenon having a certain magnitude are estimated based on the methods described in Chapter 7. In other words, the vulnerability is established for a specific event for a certain location. The hazard potential is, in essence, the probability of the magnitude of the potentially damaging phenomenon to occur. This is determined based on the methods described in Chapters 2 through 5. In the risk assessment, the risk is computed as an expected value by the integration of the consequences for an event of a certain magnitude and the probability of its occurrence. This computation yields the value of the expected losses, which by definition is the risk.

Many decision makers do not feel that high cost/low probability events and low cost/high probability events are commensurate (Thompson *et al.*, 1997). Thompson *et al.* (1997) note that engineers generally have been reluctant to base decisions solely upon expected damages and expected loss of life because the expectations can lump events with high occurrence probabilities resulting in modest damage and little loss of life with natural disasters that have low occurrence probabilities and result in extraordinary damages and the loss of many lives. Furthermore, Bondi (1985) has pointed out that for large projects, such as the storm-surge barrier on the Thames River, the concept of risk expressed as the product of a very small probability and extremely large consequences, such as a mathematical risk based on a probability of failure on the order of approximately 10-5 or 10-7 has no meaning, because it can never be verified and defies intuition. There also is the possibility that the probability associated with "catastrophic" events may be dramatically underestimated resulting in a potentially substantial underestimation of the expected damages.

The issues discussed in the previous paragraph relate mainly to the concept that the computed expected damages fail to account for the risk-averse nature of society and decision makers. Risk aversion may be considered as follows. Society may be willing to pay a premium — an amount greater than expected damages — to avoid the risk. Thus, expected damages are an underestimate of what society is willing to pay to avoid an adverse outcome (excessive damage from a natural disaster) by the amount of the risk premium. This premium could be quite large for what would be considered a catastrophic event.

Determining the premium society may be willing to pay to avoid excessive damages from a natural disaster is difficult. Thus, various methods have been proposed in the literature to consider the trade-off between high-cost/low probability events and low-cost/high probability events so that decision makers can select alternatives in light of the societal level of risk aversion. Thompson *et al.* (1997) suggest using risk profiles to show the relation between exceedance probability and damages for various events and to compare among various management alternatives. More complex procedures have as well been presented in the literature (Karlsson and Haimes, 1989), but are not yet commonly used.

1.3 THE FUTURE

Each discipline has its traditions and standard practices in hazard assessment and they can differ quite widely. For the non-technical user, or one from a quite different discipline, these differences are confusing. Even more fundamental are the rather dramatically different definitions and connotations that can exist within the various natural sciences for the same word. Those concerned with planning in the broad sense or with relief and rescue operations are unlikely to be aware of or even interested in the fine distinctions that the specialists might draw. To these people, areas are disaster prone to varying degrees and relief teams have to know where and how to save lives and property whatever the cause of the disaster. Therefore, the most important aspect of the "comprehensive" nature of the present project is the call for attempts to be made to combine in a logical and clear manner the hazard assessments for a variety of types of disaster using consistent measures within a single region so as to present comprehensive assessments. It is hoped this report will help in achieving this goal.

As previously discussed and illustrated in the following chapters, the standard risk-assessment approach wherein the expected value of risk is computed includes many uncertainties, inaccuracies and approximations, and may not provide complete information for decision-making. However, the entire process of risk assessment for potential natural disasters is extremely important despite the flaws in the approach. The assessment of risk necessitates an evaluation and mapping of the various natural hazards, which includes an estimate of their probability of occurrence, and also an evaluation of the vulnerability of the population to these hazards. The information derived in these steps aids in planning and preparedness for natural disasters. Furthermore, the overall purpose of risk assessment is to consider the potential consequences of natural disasters in the proper perspective relative to other competing public expenditures. The societal benefit of each of these also is difficult to estimate. Thus, in policy decisions, the focus should not be on the exact value of the benefit, but rather on the general guidance it provides for decision-making. As noted by Viscusi (1993), with respect to the estimation of the value of life, "value of life debates seldom focus on whether the appropriate value of life should be [US] $3 million or $4 million. .the estimates do provide guidance as to whether risk reduction efforts that cost $50 000 per life saved or $50 million per life saved are warranted."

In order for the results of the risk assessment to be properly applied in public decision-making and risk management, local people must be included in the assessment of hazards, vulnerability and risk. The involvement of local people in the assessments should include: seeking information and advice from them; training those with the technical background to undertake the assessments themselves; and advising those in positions of authority on the interpretation and use of the results It is of limited value for experts to undertake all the work and provide the local community with the finished product. Experience shows that local communities are far less likely to believe and use assessments provided by others and the development of local expertise encourages further assessments to be made without the need for external support.

As discussed briefly in this section, it is evident that comprehensive risk assessment would benefit from further refinement of approaches and methodologies. Research and development in various areas are encouraged, particularly in the assessment of vulnerability, risk assessment and the compatibility of approaches for assessing the probability of occurrence of specific hazards. It is felt that that society would benefit from the application of the various assessment techniques documented herein that constitute a comprehensive assessment. It is hoped that such applications could be made in a number of countries. These applications would involve, among a number of items:

- agreeing on standard terminology, notation and symbols, both in texts and on maps;
- establishing detailed databases of natural systems and of primary land uses;
- presenting descriptive information in an agreed format;
- using compatible map scales, preferably identical base maps;
- establishing the local level of acceptable risk;
- establishing comparable probabilities of occurrence for various types of hazards; and
- establishing mitigation measures.

As mentioned, the techniques and approaches should be applied, possibly first in pilot projects in one or more developing countries. Stress should be placed on a coordinated multidisciplinary approach, to assess the risk of combined hazards. The advancement of mitigation efforts at the local level will result through, in part, the application of technologies, such as those documented herein.

1.4 REFERENCES

Bondi, H., 1985: Risk in Perspective, in *Risk: Man Made Hazards to Man*, Cooper, M.G., editor, London, Oxford Science Publications.

Gilard, O., 1996: *Risk Cartography for Objective Negotiations*, Third IHP/IAHS George Kovacs Colloquium, UNESCO, Paris, France, 19-21 September 1996.

Karlsson, P-O. and Y.Y. Haimes, 1989: Risk assessment of extreme events: application, *Journal of Water Resources Planning and Management*, ASCE, 115(3), pp 299-320.

Schwing, R.C., 1991: Conflicts in health and safety matters: between a rock and a hard place, in *Risk-Based Decision Making in Water Resources* V, Haimes, Y.Y., Moser, D.A. and Stakhiv, E.Z., editors, New York, American Society of Civil Engineers, pp. 135-147.

Thompson, K.D., J.R. Stedinger and D.C. Heath, 1997: Evaluation and presentation of dam failure and flood risks, *Journal of Water Resources Planning and Management*, American Society of Civil Engineers, 123 (4), pp. 216-227.

United Nations Department of Humanitarian Affairs (UNDHA), 1992: *Glossary: Internationally Agreed Glossary of Basic Terms Related to Disaster Management*, Geneva, Switzerland, 93 pp.

United Nations General Assembly, 1989: *International Decade for Natural Disaster Reduction (IDNDR), Resolution 44/236*, Adopted at the forty-fourth session, 22 December.

Viscusi, W.K., 1993: The value of risks to life and health, *Journal of Economic Literature*, 31, pp. 1912-1946.