

# Landslide Hazard and Risk

## Editors

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# Contents

<i>List of Contributors</i>	<i>page</i> viii
<i>Preface</i>	xii
<b>1 Landslide Hazard and Risk: Issues, Concepts and Approach</b> <i>Michael J. Crozier and Thomas Glade</i>	<b>1</b>
<b>PART 1 CONCEPTUAL MODELS IN APPROACHING LANDSLIDE RISK</b>	<b>41</b>
<b>2 The Nature of Landslide Hazard Impact</b> <i>Thomas Glade and Michael J. Crozier</i>	<b>43</b>
<b>3 A Review of Scale Dependency in Landslide Hazard and Risk Analysis</b> <i>Thomas Glade and Michael J. Crozier</i>	<b>75</b>
<b>4 Systematic Procedures of Landslide Hazard Mapping for Risk Assessment Using Spatial Prediction Models</b> <i>Chang-Jo F. Chung and Andrea G. Fabbri</i>	<b>139</b>
<b>5 Vulnerability to Landslides</b> <i>David Alexander</i>	<b>175</b>
<b>PART 2 EVALUATION OF RISK</b>	<b>199</b>
<b>6 Landslide Risk Perception, Knowledge and Associated Risk Management: Case Studies and General Lessons from Glacier National Park, Montana, USA</b> <i>David R. Butler and Lisa M. DeChano</i>	<b>201</b>
<b>7 Cultural Consideration in Landslide Risk Perception</b> <i>Garth Harmsworth and Bill Raynor</i>	<b>219</b>
<b>8 Reply of Insurance Industry to Landslide Risk</b> <i>Hans-Leo Paus</i>	<b>251</b>

9	<b>The Role of Administrative Bodies in Landslide Risk Assessment</b> <i>Kurt Hollenstein</i>	285
10	<b>Addressing Landslide Hazards: Towards a Knowledge Management Perspective</b> <i>Susan Michaels</i>	311
<b>PART 3 MANAGEMENT OF LANDSLIDE RISK</b>		<b>329</b>
11	<b>Management Frameworks for Landslide Hazard and Risk: Issues and Options</b> <i>Michael J. Crozier</i>	331
12	<b>Reducing Landslide Hazards and Risk in the United States: The Role of the US Geological Survey</b> <i>Gerald F. Wieczorek, Paula L. Gori and Lynn M. Highland</i>	351
13	<b>Basic Data and Decision Support for Landslide Management: A Conceptual Framework</b> <i>Walter Pflügner</i>	377
14	<b>Instability Management from Policy to Practice</b> <i>Robin McInnes</i>	401
15	<b>Geomorphological Mapping to Assess Landslide Risk: Concepts, Methods and Applications in the Umbria Region of Central Italy</b> <i>Paola Reichenbach, Mirco Galli, Mauro Cardinali, Fausto Guzzetti and Francesca Ardizzone</i>	429
16	<b>Remote Sensing of Landslides</b> <i>Vern Singhroy</i>	469
17	<b>The Rise and Fall of a Debris-flow Warning System for the San Francisco Bay Region, California</b> <i>Raymond C. Wilson</i>	493
18	<b>Reforestation Schemes to Manage Regional Landslide Risk</b> <i>Chris Phillips and Michael Marden</i>	517
19	<b>Geotechnical Structures for Landslide Risk Reduction</b> <i>Edward Nicholas Bromhead</i>	549
<b>PART 4 'END-TO-END SOLUTIONS' FOR LANDSLIDE RISK ASSESSMENT</b>		<b>595</b>
20	<b>Towards the Development of a Landslide Risk Assessment for Rural Roads in Nepal</b> <i>David N. Petley, Gareth J. Hearn and Andrew Hart</i>	597

<b>21</b>	<b>Quantitative Landslide Risk Assessment of Cairns, Australia</b>	<b>621</b>
	<i>Marion Michael-Leiba, Fred Baynes, Greg Scott and Ken Granger</i>	
<b>22</b>	<b>The Story of Quantified Risk and its Place in Slope Safety Policy in Hong Kong</b>	<b>643</b>
	<i>Andrew W. Malone</i>	
<b>23</b>	<b>Rockfall Risk Management in High-density Urban Areas. The Andorran Experience</b>	<b>675</b>
	<i>Ramon Copons, Joan Manuel Vilaplana, Jordi Corominas, Joan Altimir and Jordi Amigó</i>	
<b>24</b>	<b>Landslide Risk Assessment in Italy</b>	<b>699</b>
	<i>Marino Sorriso-Valvo</i>	
<b>25</b>	<b>An Initial Approach to Identifying Slope Stability Controls in Southern Java and to Providing Community-based Landslide Warning Information</b>	<b>733</b>
	<i>D. Karnawati, I. Ibriam, M.G. Anderson, E.A. Holcombe, G.T. Mummery, J.-P. Renaud and Y. Wang</i>	
<b>PART 5</b>	<b>SYNOPSIS</b>	<b>765</b>
<b>26</b>	<b>Landslide Hazard and Risk – Concluding Comment and Perspectives</b>	<b>767</b>
	<i>Thomas Glade and Michael J. Crozier</i>	
	<i>Glossary</i>	<b>775</b>
	<i>Thematic Index</i>	<b>795</b>
	<i>Locations/regions</i>	<b>801</b>

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# Preface

Investigation of landslide hazard and risk has been a major research focus for the international community over the last decade. During this period, efforts were directed towards two scales of investigation: site-specific analysis and regional assessment. Site-specific analysis may involve a wide spectrum of slope instability and all types of landslide activity covering areas ranging from just a few square metres to whole mountainsides. The objectives for this scale of investigation generally include a range of activities, involving: mapping the geometry and extent of the failure, mapping the environmental setting, determining the degree of activity by either surface measurements or subsurface observations, collecting soil or rock samples, analysing geophysical and geotechnical properties, assessing slope hydrology and porewater pressures, constructing geomorphic and geotechnical models of the site, and performing slope stability calculations. In particular, the last activity allows definition of site sensitivity to various changes in stability factors, enabling the modelling of future behaviour, either with or without protection measures. These investigations are commonly prompted by the existence of a specific or anticipated problem, for example real or expected failure of a road segment, movement of valley slopes along dammed lakes, cracks in buildings, displacements of lifelines such as railways, roads, sewerage systems, transmission lines and so on. Site-specific investigations are based on methods and concepts developed within engineering disciplines such as geotechnics and soil mechanics, but they are also informed by natural sciences, including engineering geology, geomorphology, geography and geophysics.

In contrast, regional assessments cover areas ranging from a few hectares to thousands of square kilometres. These assessments rarely involve the direct assessment of stress conditions; they are rather based on heuristic models, identification of parameters of indirect but theoretical significance to stability, or on statistical treatment of empirical data. A regional study may constitute the initial scoping stage of a wider landslide hazard assessment programme and may be the precursor to more detailed and expensive site investigation. Commonly, the main aim is to characterize both spatial and temporal conditions that have determined the occurrence of past events and to use these characteristics to locate future landslides in time and space. These assessments are generally carried out by natural scientists from fields such as engineering geology, geomorphology, soil science, forestry and geography.

Both scales of investigation are addressed in numerous monographs, edited books, publications and reports. Some of the best-known books covering these approaches include: Turner and Schuster (1996), Dikau *et al.* (1996), Crozier (1989), Selby (1993), Veder and Hilbert (1981), Berry and Reid (1987), Craig (1992), Terzaghi and Peck (1948), Wu (1976), Záruba and Mencl (1969), Brunsdon and Prior (1984), and Anderson

and Richards (1987). In addition to a wide range of scientific journals, the proceedings of international conferences on debris flows (e.g. Chen, 1997; Wieczorek and Naeser, 2000), landslides (e.g. Bonnard, 1988; Bell, 1992; Senneset, 1996; Anderson and Brooks, 1996; Bromhead *et al.*, 2000; Rybár *et al.*, 2002) and on general aspects of natural hazards and risks (e.g. INTERPRAEVENT, 2000, 2002) provide a wide coverage of recent developments.

Over the last decade, the focus of landslide research has moved beyond process investigations and stability assessment towards consequence analysis. Thus the integrated assessment of both hazard and risk is becoming accepted and expected practice in risk reduction management. Varnes (1984) was one of the early advocates of this approach to landslide research and engineering practice. The requirements for integrated hazard and risk studies are beginning to be systematized in such standard references as Turner and Schuster (1996) and Cruden and Fell (1997).

Despite the valuable research on landslide hazard and risk from an engineering and natural science perspective, there is also a need to address other important issues associated with the threat from landslides. Many of these have yet to be researched and fully understood. Some are addressed by the following questions:

- Besides immediate impacts, what is the full suite and duration of indirect and delayed effects associated with landslide hazard?
- What is the distribution of costs associated with the landslide hazard and how are they met; costs of mitigation, costs assumed by regional government, insurance, individuals, and so on?
- How do societies react to a given event in different social and cultural settings?
- What are the perceptions of landslide risk held by the different actors involved; how can they be measured and managed?
- How can levels of intolerable, tolerable and acceptable risk be measured; are they culturally specific?
- What are the most appropriate coping strategies for local authorities, communities, families and individuals?
- What levels of aesthetic, emotional and psychological impact are experienced as a result of landslide events?
- Where do responsibilities lie for: reducing risk, provision of risk information, education, communication, mitigation, remediation and rehabilitation? To what extent should risk be internalized or externalized by affected parties?

While the physical problems associated with risk assessment need continual science and engineering attention, some of the foregoing questions represent important areas of future research. Disciplines addressing these issues include social and economic science, psychology, civil and public law, planning and politics, to name only a few. Surprisingly, very few publications are available that attempt to bridge this gap between physical investigations and the social implications of hazard and risk. In this book we try to meet that challenge. In our view this can only be achieved by bringing together authors who approach the same ultimate goal of risk reduction but from widely different discipline perspectives. Rather than interpreting, paraphrasing and inevitably diluting these different perspectives, we have placed them largely unmodified in juxtaposition in broadly related sections of the book. We have striven to represent not only different disciplines but

also different professional roles: university researchers, engineers, government scientists, private consultants and insurance industry officers.

This book is divided into five major parts dealing with (1) conceptual models in approaching landslide risk, (2) evaluation of landslide risk, (3) management of landslide risk, (4) end-to-end solutions of landslide risk, and finally (5) a synopsis. In the first chapter, Crozier and Glade position landslide hazard and risk within the broader generic concepts of risk, health and safety. The need for integrated multidisciplinary and holistic approaches is stressed. They identify and explain the concepts, issues, language and stakeholders in the study of landslide hazard and risk. Attention is given to the requirements, attributes, drawbacks and different levels of sophistication of the various approaches to hazard assessment, risk analysis, risk assessment and risk management.

Part 1 presents contributions largely at a conceptual level on the fundamental aspects and approaches to landslide hazard and risk. Initially, the impacts of landslide events are characterized. The means to assess the hazard are explored, along with ways of representing the spatial aspects of risk. And finally vulnerability, one of the most critical factors in explaining spatial difference of risk, is explored.

In particular, Chapter 2 on the nature of the hazard and impact, by Glade and Crozier, outlines the range of landslide hazards and the typical situations where impact occurs. It discusses the impact characteristics of different types of slope movement, from those that produce ongoing chronic problems to catastrophic failure that may bring about disaster. Standard terminology is introduced to discuss the range of hazardous situations, from debris flows in settled alpine regions, reservoir/dam shoreline failures, through a range of landslide types in urban and rural settings that are life-threatening or have the potential to degrade resources and environmental quality. The social and physical reasons for increased risk in these situations are outlined.

Chapter 3 covers the assessment of landslide hazard at various scales. Glade and Crozier discuss the range of methodologies employed to assess landslide hazard. It is acknowledged that the calculation of landslide and slope stability is relatively well established for various temporal and spatial scales. Different approaches are reviewed, from statistical to physically-based models that couple not only geotechnical and hydrological components but also significant surface elements such as vegetation. The prediction of the damaging characteristics of movement is important but less well established. This chapter also defines the different elements at risk and introduces various approaches to estimating the potential damage. Each threatened element is differently exposed to the risk. The exposure of a given risk element might change in time and/or in space. Different approaches in determining the vulnerability of risk elements are reviewed. For more than a decade, different landslide risk assessments have been undertaken, ranging from site-specific to regional scales. Different examples demonstrate the potential use of these approaches in context of their physiographic, economic and social controls.

In the following chapter, Chung and Fabbri present systematic procedures for landslide hazard mapping of risk assessments using spatial prediction models. They state that there is almost an infinite number of ways to construct prediction maps, from simple heuristic opinion-based procedures with little data, to sophisticated mathematical models supported by complex databases and using advanced software and hardware technologies. Existing quantitative techniques are reviewed and some of their common deficiencies are identified. This contribution provides guidance for avoiding the following deficiencies:

(1) simplification of input data; (2) poor handling of mixed categorical/continuous data; (3) lack of awareness of the assumptions implicit in prediction models; (4) lack of validations of prediction results; and (5) the need to use conditional probabilities of future landslides to perform risk assessment via vulnerability analysis. Most important, the authors state that, as in any prediction, the different methods of prediction do not have any scientific significance without accompanying measures of the validity of the prediction results.

Alexander devotes the fifth chapter to vulnerability to landslides and reviews the concept of vulnerability and its role in determining landslide risk. Landslide hazard processes are discussed in terms of their impact on human settlement, activities and land use. Four major sources of vulnerability to landslides are identified: expanding tropical cities, peri-urban slums, inhabited mountain areas, and densely settled steep volcanic terrains. Methods for assessing vulnerability to landslides are reviewed, including financial and category-based approaches.

Within Part 2, the focus is on the evaluation of risk. Social science research, for example sociology and psychology, explores the perception of risk held by different affected groups. Research issues include first of all the identification of the actors, defined as all parties involved (private land owners, consultants, governmental agencies, research institutions, insurance, etc.). The determination of the perception of risk within each group, but also between these groups, is of major concern. Of specific interest in this respect is the role of communication, because knowledge about the respective hazards influences the risk evaluation strongly. Personal risk evaluation is also highly dependent on the distance to the respective natural hazard as well as on the period since its last occurrence. This section addresses the sociological and psychological issues as well as highlighting the risk perception of the different actors involved in landslide management.

In Chapter 6, Butler and DeChano analyse landslide risk perception, knowledge and associated risk management, and relate the theoretical background to activities in Glacier National Park, Montana, USA. These issues are examined among visitors and employees through questionnaires. Results show that the employees have accurate perceptions of debris flow and landslide risk zones in the Park but visitors, on the other hand, are completely unaware of the likelihood of mass movements in the Park, and have poor perceptions of actual landslide risk zones.

The cultural factor in landslide risk perception is examined by Harmsworth and Raynor, using case studies from New Zealand and Micronesia in Chapter 7. Cultural groups are often attached to natural environments in ways not usually reflected or addressed by risk assessment. To understand the importance of culture within landslide risk perception, factors need to be identified that constitute cultural characteristics and differences. These factors include traditional beliefs, values, religion, social structure, historical occupation, historical and modern experiences, land tenure, learning and environmental perspectives. The landslide risk perception of cultural groups is also based on interaction with and dependence on the natural environment for economic and social benefit. Landslide risk perception is investigated for two examples: from an indigenous Maori perspective in Aotearoa–New Zealand, and from an indigenous and community perspective in Pohnpei, Micronesia.

The insurance industry plays a significant role in landslide management. Paus examines, in Chapter 8, the response of insurance companies to landslide risk in detail. Natural

disasters put an increasing burden on the global economy. Although the share of mass movements is still a rather small component of the total cost, it is increasing at a disproportionate rate. Globally acting insurance companies are starting to feel the consequences of such trends and are trying to adapt their business strategies. In particular, the primary insurance sector urgently needs techniques to identify small-scale local risks. One method is presented which is based on the use of numerical earthquake simulations and on digital elevation models to identify zones of elevated landslide hazard. This method is applied to study sites in Taiwan and Switzerland and shows how the insurance sector itself gathers more detailed information on hazard and risks posed by landslides.

In Chapter 9, Hollenstein highlights the potential role of administrative bodies in the assessment of landslide risk. Administrative bodies can perform assessments themselves, define procedural guidelines, provide subsidies, require such assessments as a precondition for subsidizing their activities, approve assessments as a part of land use planning, or provide data for assessment purposes. The degree to which the administrative body is engaged in landslide risk assessments depends on the legal basis, the acceptance of the risk concept, the resource availability, the type of involvement and the organizational setting. Three case studies: the Vaiont Reservoir disaster of 1963 in Italy; a slow-moving landslide; and numerous fast-moving landslides (the latter two cases from Switzerland) are examined with respect to the role of administrative bodies during the events.

Part 3 is devoted to the management of landslide hazard and risk. Hazard and risk management involves having effective systems and procedures in place for identifying, calculating and evaluating the risks, assessing and implementing risk reduction options, and balancing the different components of associated cost in an acceptable way. The options for reducing risk, the individual and political will, and the resources vary greatly throughout the world. This part of the book describes systems and protocols for effective planning, information management, and risk reduction procedures. Procedures for arriving at appropriate solutions and putting policy into practice are discussed. Separate contributions examine detailed systems for handling spatial data and various specific risk reduction options, including reforestation, geotechnical structures and warning systems.

Michaels's contribution deals with the application of knowledge management to landslide risk in Chapter 10. Knowledge management means managing how knowledge is created, acquired, represented, disseminated and applied. Utilizing knowledge management to address landslide hazards is in its infancy. Selected explanations are provided as to why scientific knowledge of landslide hazards is not more of a consideration in decision making. However, current successes in dissemination are illustrated by examples in California. Michaels concludes that in order to move beyond the current successes in disseminating landslide hazard information, employing specific knowledge management concepts and practices is essential.

Crozier analyses issues and options of management frameworks in Chapter 11. Factors driving the awareness of risk and the desire to react are discussed and a rationale for apportioning the costs of risk management is presented. The difficult question of assessing who is responsible for creating risk (and perhaps who should pay) is discussed. Procedures and frameworks for planning and management are reviewed and examples of effective risk management legislation are offered, together with an evaluation of the fundamental human resources that are needed to make them work.

Wieczorek *et al.* describe the role of the US Geological Survey (USGS) in reducing landslide hazards and risk in the United States in Chapter 12. Since 1879 the USGS has

served as the primary governmental agency in the United States, with the responsibility for conducting scientific studies of geologic hazards, in particular, of assessing landslide hazards and risks. The specifically designed USGS Landslide Hazards Program (LHP) has adopted the primary role of directing examination of post-landslide events and of developing improved methods for assessing the future hazard and risk of landslides on local, regional and national scales. With these improved methodologies, the LHP has developed methods of evaluating landslide susceptibility and probability, and of issuing landslide warnings. Information on landslide hazards is conveyed to the public in a variety of ways through the National Landslide Information Centre, which maintains a website with access to published documents and descriptions of recent landslide events. Underlying arguments, decisions and protocols for effectively addressing these issues and options are presented.

A conceptual framework for basic data and decision support for landslide management is given by Pflügner in Chapter 13. This contribution focuses on decision support, and presents a conceptual framework in terms of damage potential determination and socio-economic values for establishing an appropriate decision support system (DSS). Pflügner demands a DSS specifically designed for landslide issues, which must enhance a 'normal' GIS to provide more sophisticated integrative and dialogue-based systems.

McInnes gives an example of instability management that shows how to move from policy to practice in Chapter 14. Many parts of the world suffer from an inheritance of unplanned communities and developments built in unsustainable locations on, for example, eroding cliff tops and unstable slopes. Many problems can be reduced if there is a long-term programme of active landslide management in place. Local communities need to come to terms with the situation and learn to 'live with landslides'. In addition to an improved understanding of instability issues, dissemination avenues must be used to communicate the understanding derived from research to policy makers, key agencies and to local agencies. McInnes highlights these issues for the Ventnor community, Isle of Wight, UK.

Concepts, methods and applications of geomorphological mapping to assess landslide risk are presented by Reichenbach *et al.* in Chapter 15. The methods they use for evaluating landslide hazards and risks at the site scale involve geomorphological approaches and are based on the recognition of existing and past events, on the scrutiny of the local geological and morphological setting, and on the study of site-specific and historical information of past landslide occurrences. For each study area, a multitemporal landslide inventory map is prepared through the interpretation of various sets of stereoscopic aerial photographs. In addition, information from field mapping and the critical review of site-specific investigations enhance the approach. Distribution of vulnerable elements is ascertained and, by combining both information sources, specific landslide risk is estimated.

How earth observation systems can be used for landslide management is explained by Singhroy in Chapter 16. Over the last decade, earth observation systems have become increasingly important for landslide management. Recent studies have shown that more use can be made of current high-resolution stereo Synthetic Aperture Radar (SAR) and optical images to produce better standardized landslide inventory maps, which will assist hazard planning. In particular, Interferometric SAR (InSAR) methods could be viewed as most promising, and give spatial distribution of slope and motion maps. When conditions are suitable, InSAR is a useful tool for detecting and monitoring mass movements.

Early warning systems are becoming increasingly important in landslide management. Wilson from the USGS describes in Chapter 17 the rise and fall of a regional debris-flow warning system. Real-time warning systems can play a significant role in debris-flow hazard mitigation by alerting the public when rainfall conditions reach critical levels for hazardous debris-flow activity. Wilson describes a system that was operated for nearly a decade in the San Francisco Bay region. Unfortunately, organizational changes and decreases in funding and staffing forced the termination of the debris-flow warning system in 1995. Despite its political failings, the warning system produced several technical accomplishments, and valuable operational experience that might be useful for the development of similar systems elsewhere.

In contrast to alert systems, reforestation schemes are an alternative option for managing regional landslide risk, described by Phillips and Marden in Chapter 18. Besides engineering structures and planning tools for reducing landslide risk, 'semi-natural' protection schemes have been developed. These reforestation schemes are known to enhance slope stability and reduce the incidence of landslides. On-site and off-site benefits, but also disadvantages, are reviewed. However, the success of the reforestation scheme is hard to gauge, largely because erosion control benefits of this type are long-term in nature and there is a significant lag between tree planting and the accrual of off-site benefits, in particular. These issues are reviewed with the example of the East Coast Forestry Scheme in New Zealand and demonstrate the potential application options.

How geotechnical structures can reduce landslide risk is explored by Bromhead in Chapter 19. He highlights various possibilities of structural design for different landslide types, considering also the accrued changes in landslide risk. Within this chapter, the cost-benefit issue of such structures is discussed. Various examples give potential applications of proposed geotechnical structures.

Part 4 addresses the end-to-end solutions for landslide risk assessment. By demonstrating an integrative approach to risk reduction, various examples of integrated (end-to-end) landslide risk assessments are given by each contribution. An end-to-end methodology is formulated from specific (case-study) origins that illustrate the range of integrated approaches required in different settings.

In Chapter 20, Petley *et al.* present developments towards a landslide risk assessment for rural roads in Nepal. In the Himalayas, the occurrence of landslides has become increasingly acute. This is partly a result of increased vulnerability of people, partly due to the impact of land use change, and partly due to the initiation of infrastructure development, notably roads, which are both vulnerable to the effects of landslides and play a role in their initiation. Numerous landslide hazard and risk assessments schemes have been developed for the Himalayas. However, the use of these schemes in low-cost road projects has been essentially prevented because of their complexity and the need for high levels of technical knowledge. Therefore, Petley *et al.* suggest a simple susceptibility analysis that uses only geology and slope angle as input. Using an example from the Baglung district in West Nepal, the effectiveness of this approach is shown.

Leiba *et al.* carried out a quantitative landslide risk assessment for Cairns, Australia to provide information to the Cairns City Council on landslide hazard, vulnerability and risk, for planning and emergency management purposes. This project is fully discussed in Chapter 21, along with methods of quantitative risk analysis and their place in policy. Input requirements in terms of field measurements and digital data as well as the analytical

capacities are described in detail. Due to the scale of the approach, however, detailed analyses have to be carried out to evaluate the specific risk for a given property. This chapter highlights the advances and limitations of regional landslide risk assessments.

The history of risk quantification and its place in slope safety policy in Hong Kong is reviewed in Chapter 22 by Malone. He traces the emergence in the 1960s of the idea of putting numbers to landslide risk and examines chronologically the application of the process of risk management in Hong Kong. Malone shows that risk concepts help to answer difficult questions faced by hazard-prone communities: Complete safety being unattainable, how safe is safe enough and what is an appropriate level of effort and expenditure on slope safety? How should the effectiveness of effort and expenditure on slope safety be measured?

Copons *et al.* examine rockfall risk management in high-density urban areas with an example from Andorra in Chapter 23. The rockfall risk management has been developed from three work plans: the “Rockfall Master Plan”, the “Risk Mitigation Plan” and the “Surveillance Plan”. The first task to be completed was the Master Plan, which included zoning of land in accordance with hazard and guidelines for urban development. Following the Master Plan, the Mitigation Plan and the Surveillance Plan have been developed simultaneously. The Mitigation Plan makes provision for the design and installation of permanent passive defences. The Surveillance Plan seeks to document the rockfalls with the aim of verifying the results obtained in the Master and Mitigation plans, and to carry out trail predictions of large rockfalls. The stepped policy of rockfall risk management seeks to protect buildings in areas of high hazard, control urban growth and to raise public awareness to rockfall problems.

A review of landslide risk assessments in Italy is given by Sorriso-Valvo in Chapter 24. Nationwide research projects on landslides were initiated in the late 1970s and still operate within the framework of an agreement between the National Civil Protection Agency and the National Research Council (CNR). Established in 1998, a specifically designed law for landslides requires deadlines for the mapping of landslides and the assessment of the related hazard and risk throughout the country. By 2002, nearly all Basin Authorities had fulfilled this requirement. However, Sorriso-Valvo concludes that while Italy has a unique, standardized ranking system of landslide hazard, assessment procedures differ significantly and, therefore, the five hazard and risk classes are not comparable from one region to the other.

Rain-induced landslides represent a major hazard in some of the poorest regions of the world. Thus community-based slope management and warning systems are being developed, the results of which can be readily communicated to those communities lacking easy access to education and social welfare. The first part of Chapter 25 by Karnawati *et al.* briefly assesses Indonesian landslide conditions. A numerical hydrology–slope stability model, parameterized by the slope conditions reviewed, is then developed and applied to typical slope conditions. From these numerical experiments a series of thresholds for rainfall and porewater conditions is identified which are formulated and presented in a sufficiently simplified manner appropriate to local community needs.

Within Part 5, an overall conclusion is drawn. Glade and Crozier integrate the diverse strands that have been presented thus far for landslide hazard and risk assessments. Suggestions are developed for appropriate models for integration which provide specifications and contexts for the next generation of process models. Such models should incorporate

economic, social, legal and related components as part of their framework. The questions of the pivotal role of management and risk reduction are addressed, together with how such approaches can be implemented through different types of relevant organizations, consultant engineers, planners, landowners, emergency services and so on.

This book offers concepts and methods for landslide hazard and risk research and management that extend beyond well-established engineering and natural sciences approaches. These concepts and methods will have value for research institutions, governmental agencies, consultancies and private individuals. The variety of issues and concepts covered by this book arises from different discipline perspectives and from authors with a wide range of professional experience within universities, research institutions, governmental agencies and private consultancies.

The editors have designed this book to provide valuable insights, guidance and advice to research scientists, engineers, policy makers, planners, managers and all those who share the common interest of effective landslide risk reduction. We hope the multidisciplinary approach extends their vision, adds to their understanding and facilitates their work.

The book is rich with material that will support the teaching of the subject in educational institutions, seminars and short courses.

We wish to express our gratitude to all those authors who have made this volume possible, and to the staff of Wiley for all their support.

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Malcolm Anderson  
Michael Crozier

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# 1

## **Landslide Hazard and Risk: Issues, Concepts and Approach**

*Michael J. Crozier and Thomas Glade*

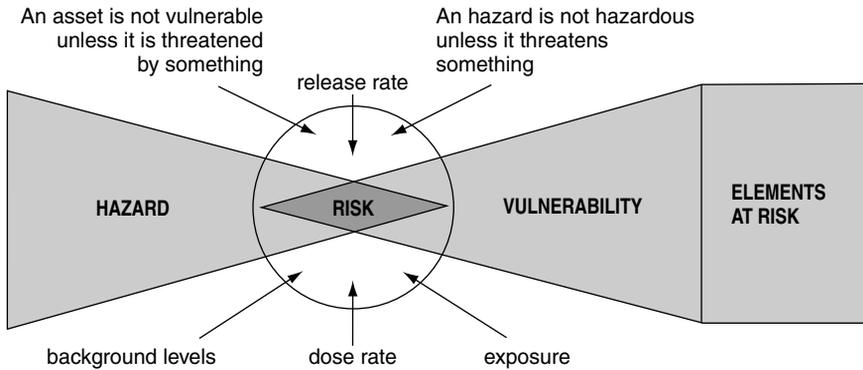
### **1.1 Underpinning Issues**

In the broad non-technical sense ‘hazards’ are defined as those processes and situations, actions or non-actions that have the potential to bring about damage, loss or other adverse effects to those attributes valued by mankind. The concept is thus applicable to all walks of life. In industry a hazard might be a power failure or a computer malfunction, in business it might be a breach of security or a poor investment decision, and in the environment it might be a spill of toxic substances or even a damaging landslide. Although the potential for something adverse to occur is appreciated, there is uncertainty as to when the hazard will realize its potential, and thus the threat is generally expressed as a likelihood or probability of occurrence of a given event magnitude in a specified period of time. Technically, we refer to this adverse condition as ‘the hazard’. Thus, in common usage, the term ‘hazard’ has two different meanings: first, the physical process or activity that is potentially damaging; and second, the threatening state or condition, indicated by likelihood of occurrence. Generally the meanings are obvious from the context within which they are used.

The consequences of hazard occurrence can be great or small, as well as direct or indirect; the latter linked to the primary impact by a chain of dependent reactions that may be manifest at some distance in time and space from the initial occurrence. Clearly the consequences depend on the context in which they occur, the particular elements and attributes affected, and their value and level of importance.

In simple generic terms, the important concept of ‘risk’ can thus be seen as having two components: the likelihood of something adverse happening and the consequences if it

## 2 Landslide Hazard and Risk



**Figure 1.1** Conceptual relationship between hazard, elements at risk, vulnerability and risk (Alexander, 2002)

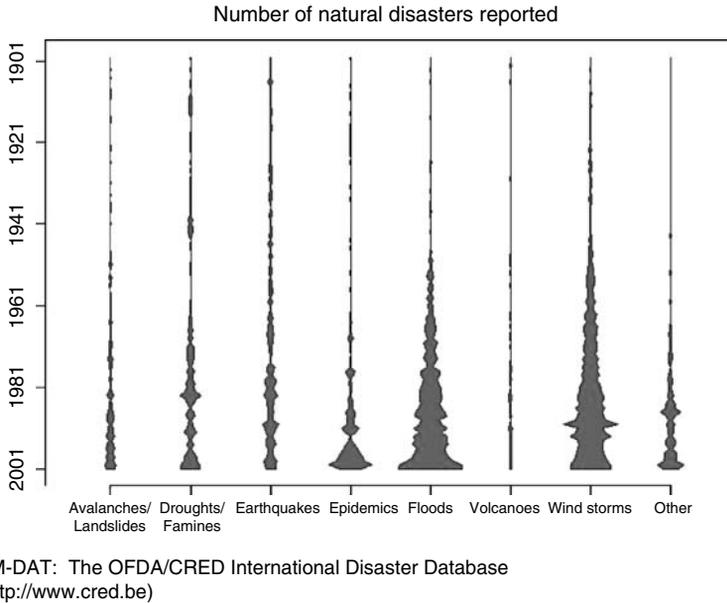
does. The level of risk, then, is the combination of the likelihood of something adverse occurring and the consequences if it does. The level of risk thus results from the intersection of hazard with the value of the elements at risk by way of their vulnerability (Figure 1.1).

Traditionally hazard and risk studies have been developed separately for industrial, financial, human, environmental and natural systems. For example, industrial systems may focus on operational malfunctions and consequent economic losses; financial systems on investment risks; human systems on crime, health or conflict; and environmental systems on pollution and resource quality. Within natural systems, where landslides are recognized as one of the 'natural hazards', the focus is on potentially dangerous events and situations arising from the behaviour of the atmosphere, biosphere, lithosphere and hydrosphere. The fact that natural forces are responsible for generating the threatening conditions distinguishes natural hazards from those of other systems, although there are many situations where the distinction between systems is not clear-cut.

The generic concepts pertaining to hazard and risk outlined above are equally applicable to landslides although they may be expressed in more process-specific terms. For landslides, the 'adverse something' might be a large rockslide and its 'likelihood' expressed as the probability of its occurrence. Similarly, the consequences will depend on what is affected by the landslide, the degree of damage it causes and the costs incurred.

In global terms, landslides generate a small but important component of the spectrum of hazard and increasing risk that faces mankind (Figure 1.2) (Alcántara-Ayala, 2002). If there were a choice, people would inhabit and rely for their well-being on the safe places of the earth – away from the threat of landslide. But even then that would presume there was sufficient knowledge of hazard and risk to allow an informed decision. However, mankind has been placed progressively at the mercy of nature through population pressure, increasing demands for resources, urbanization and environmental change. It is the intersection of humanity with landslide activity that has recast a natural land-forming process into a potential hazard (Figure 1.3a). Furthermore, economic globalization has enhanced reliance on communication and utility corridors. Fuel lines, water and sewage reticulation, telecommunication, energy and transport corridors, collectively referred to as 'lifelines' in hazard studies, are highly vulnerable to landslide disruption (Figure 1.3b).

Landslides present a threat to life and livelihood throughout the world, ranging from minor disruption to social and economic catastrophe. Spatial and temporal trends in



**Figure 1.2** Comparison of the number of natural disasters from different natural hazards reported within the International Disaster Database maintained by OFDA/CRED (refer to <http://www.cred.be> for most recent numbers)

the level of this threat (Figure 1.4) have driven the current international and national concerns about the issue of hazard and risk reduction. However, these trends are difficult to determine accurately because of the variable quality and consistency of record keeping. These problems arise from a range of factors, including: variability and improvements in observational techniques; changes in population density; the mix of different agencies involved and the variability of recording protocols; as well as heightened economic and social awareness. One source for economic data of damage caused by natural hazards is the statistics regularly published by the re-insurance company Munich-RE (Münchener Rückversicherung, 2000). Although one has to be cautious with interpretations based on these figures, a trend is visible of increased economic costs for the insurance companies resulting from natural events. As well as economic loss, landslides have also caused numerous humanitarian disasters throughout history. A selection of major landslide disasters of more than 1000 deaths is given in Table 1.1.

Two hundred years or so of science and practice related to slope stability problems have transformed the landslide from an ‘act of God’ into a comprehensible geophysical process. Society demands that such knowledge carries a responsibility, a ‘duty of care’ and, in some instances, an obligation to act. The formalization and apportioning of this responsibility is in its infancy in many parts of the world. Nevertheless, whether driven by legal, moral or economic concerns, there is a continuing need to seek out and refine tools for risk reduction, be they scientific, engineering, legislative, economic or educational.

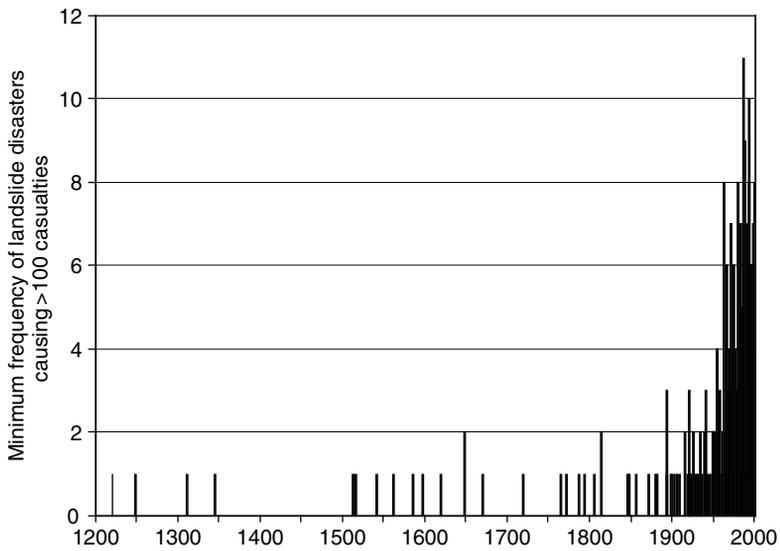
In the simplest terms, landslide hazard can be depicted as the physical potential of the process to produce damage because of its particular impact characteristics and the magnitude and frequency with which it occurs (or is encountered). Landslide risk, on the



**Figure 1.3a** *Examples of a society exposed to natural processes from Bildudalur, Iceland. A petrol station on a bridge that crosses a drainage line susceptible to snow avalanches, debris flows and slush flows (photo by T. Glade)*



**Figure 1.3b** A pole of the main power supply, a freshwater tank, and a school in the background close to the same drainage line (photo by T. Glade)



**Figure 1.4** Minimum frequency of recorded landslide disasters for the world, causing more than 100 deaths (Glade and Dikau, 2001). Refer to Table 1.1 for a selection of data

**Table 1.1** Selection of major natural disasters due to landslides causing more than 1000 deaths. All data are based on respective sources. Type of process named where identifiable from the source (based on Glade and Dikau, 2001)

Event	Trigger	Date	Location, region, country	Consequences	Source
Bergsturz	n.i.	1219	Plaine d'Oisans, Isère, France	>1000 casualties	Flageollet (1989)
Bergsturz	n.i.	24.11.1248	Mont Granier, Savoie, France	1500 to 5000 casualties	Flageollet (1989)
Landslide	n.i.	1310	Zhigui, Hubei, China	3466 casualties	Tianchi (1989)
Landslide	n.i.	1561	Xitan, Zhigui, Hubei, China	>1000 casualties	Tianchi (1989)
Bergstürze	Earthquake	24.11.1604	Arica, Chile	>1000 casualties	Nussbaumer (1998)
Bergsturz	n.i.	25.08.1618	Plurs, Bergell, Switzerland	>2000 casualties	Nussbaumer (1998)
Landslide	Earthquake	19.06.1718	Gansu Provonz, China	40 000 families buried	Tianchi (1989)
Lahar	Volcanic erup.	12.08.1772	Vulkan Papandayan, Java	2000–3000 casualties	Nussbaumer (1998)
Landslide	Earthquake	10.10.1786	Kangding-Louding, Sechuan, China	100 000 casualties	Tianchi (1989)
Lahar	Volcanic erup.	10.02.1792	Vulkan Unzendake, Japan	10 000 casualties	Nussbaumer (1998)
Lahar	Volcanic erup.	19.02.1845	Vulkan Nevada del Ruiz, Colombia	1000 casualties	Nussbaumer (1998)
Landslide	n.i.	09.1857	Montem./Basilic., Italy	5000 casualties	Nussbaumer (1998)
Lahar	Volcanic erup.	1919	Java, Indonesia	5110 casualties, 104 villages dest.	Brand (1989)
Landslide	Earthquake	16.12.1920	Kansu, China	>200 000 casualties	Bell (1999); Nussbaumer (1998)
Landslide	Earthquake	1920	Haiyuan, China	100 000 casualties	Tianchi (1989)
Landslide	Earthquake	25.08.1933	Sichuan, Diexi, China	6800 casualties	Tianchi (1989)
Debris flow	n.i.	14.12.1941	Huaraz, Peru	4000–6000 casualties, 1/4 of Huaraz dest.	Erickson et al. (1989); Nussbaumer (1998)