Mass-Movement Hazards and Risks

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Glossary

Elements at risk These include people, their well-being, buildings, infrastructure, economic activity, and all other things valued by the community.

Hazard (physical) A hazard is a potentially damaging process or condition, for example, an earthquake above a certain intensity or a landslide of sufficient size, depth, or displacement to cause damage or disruption or, as an example of a condition, the presence of weak foundation material.

Hazard (temporal condition) The probability of a potentially damaging event (a landslide) occurring in a unit of time. This probability varies with the magnitude of the event (generally small landslides occur more frequently than large landslides). Consequently, hazard is often expressed as the probability of occurrence of a given magnitude of event. Defined in this way, hazard represents a state or condition and is assessed and applied to a particular place, for example, site, unit area of land surface, region, or object, such as lifelines, hydrodams, etc.

Risk Expected consequences emanating from a hazard, expressed as the probability and severity of loss to the elements at risk for a unit area, object, or activity, over a specified period of time. Risk is a function of the magnitude and frequency of hazard, the elements exposed to the hazard and their vulnerability.

Susceptibility The propensity of a designated area to experience a particular physical hazard, based on the presence of indicative conditions, stability analysis, or precedence established from historical records or other proxy evidence. Susceptibility assessments do not provide a measure of hazard (temporal condition). However, susceptibility of an area is commonly ranked (or zoned) from high to low based on the strength of indicative parameters.

Vulnerability The degree of damage expected from given magnitude of hazard, usually expressed as a ratio of the existing value. For example, a structure that receives damage amounting to 50% of its value would record a vulnerability of 0.5, whereas complete destruction would be recorded as 1.0.
Abstract

Mountains and steeplands offer conditions conducive to high magnitude and frequent mass-movement hazards, most dramatically in the form of landslides. These conditions in many instances are being exacerbated by global environmental change emanating from both physical and human systems. The concepts of susceptibility, hazard, vulnerability, and risk from landslides are examined in the light of these changes. In addition, the specific information requirements and approaches for assessing hazard and risk are explored. In particular, emphasis is placed on understanding the different characteristics of landslide processes, including intensity, magnitude and frequency, and location. Assessment methodologies and decisions based on their outcomes need to acknowledge the rapid evolution of hazard and risk in response to unprecedented rates of environmental change.

7.26.1 Introduction

Mountains have played an important part in understanding the geomorphology of the Earth and have a long-held fascination for geomorphologists. They are the most obvious source of the principal fluxes of sediment and water that travel over the Earth's surface as rivers, intermittently depositing and re-entraining until they reach the ultimate sink of the ocean. The great debates on the evolutionary relationship between land form and process along this pathway, stimulated by luminaries such as Gilbert (1877), Davis (1899), Penck (1933), and Hack (1960), have been seminal for geomorphology. However, today much steepland research is focused on understanding process rather than interpreting form (Clague, 2009; Korup et al., 2010) – a shift in emphasis that has been stimulated by concern over the increasing impact of natural hazards associated with human activity (Cendrero et al., 2006; Remondo et al., 2005; Marston, 2008) and the far-reaching consequences of global warming for mountain regions (Haeberli et al., 1997; Huggel, 2009; Crozier, 2010). Mountains and steeplands are not only important and emphatic morphological terrains of grand scale but also the domain where gravity can dramatically demonstrate its power over earth materials, with sometimes catastrophic results (Evans and DeGraff, 2002). The intersection of human activity with these high-energy geomorphic systems, together with the accelerating pace of social and environmental change, enhances hazard and risk, and exacts an increasing toll on mankind (Slaymaker, 2010).

7.26.2 The Physical Context

7.26.2.1 The Energy of Processes

The potential energy of geomorphic systems can be represented by the mass of slope-forming material or water together with its elevation in the landscape. When material and water (solid or liquid) are released to move downslope, that potential energy is converted into kinetic energy, which is capable of carrying out geomorphic work and impacting human systems. The kinetic energy of a moving body is equal to half of the product of mass times velocity squared – the power on the velocity term indicating its preeminence in determining the energy of a geomorphic process. For any given material in motion down a mountain slope, velocity, in turn, is a function of the slope gradient and resistance mobilized by slope conditions such as surface roughness and vegetation cover. With such factors controlling the energy of geomorphic processes, it is not surprising that mountain lands provide examples of some of the highest energy and most destructive geomorphic processes observed on the Earth.

7.26.2.2 Mass Movement

In the context of high-energy, active geomorphic processes in mountain lands, a range of different processes and influencing factors operate at different scales (Glade and Crozier, 2005; Slaymaker, 2010). However, here the focus is on mass-movement hazards and risk and as such requires some specific definitions in order to constrain the boundaries of the discussion. Mass movement is defined as the outward or downward movement of slope-forming material under the influence of gravity. Whereas this definition precludes water as a hydraulic transportational agent, water is commonly a critical agent in reducing strength and allowing ambient gravity conditions to promote movement. As a geomorphic process, mass movement (involving blocks or aggregates undergoing shearing and brittle or plastic strain) represents one end of a spectrum of transportational processes that, with increasing water content, grade initially into slurry flow (e.g., debris flow). As water content further increases, debris becomes transported as hyperconcentrated flow and ultimately hydraulic flow which operate as turbulent Newtonian fluids. Some mass-movement processes, such as soil creep, are almost imperceptibly slow and diffuse, while others are discrete, fast moving, and with clearly identifiable boundaries, commonly in the form of shear surfaces. It is these discrete processes, referred to as landslides, that represent the most hazardous of all mass-movement processes (Crozier, 1999a). Comprehensive accounts of mass-movement hazards in mountain lands have been provided by Eisbacher and Clague (1984), Korup and Clague (2009), and Alcántara-Ayala and Goudie (2010).

7.26.2.3 Mass Movement in Mountains

Most forms of mass movement, particularly landslides, are episodic in occurrence and their onset is commonly (but not always) associated with a climatic (Glade et al., 2000; Guzzetti et al., 2008) or seismic trigger (Keefer, 1984; Keefer and Wilson, 1989; Hancox et al., 1997). Mountains generate their own climates, in places displaying extreme rainfall, dramatic altitudinal and aspect gradients in temperature, humidity, precipitation, and associated vegetation and soil conditions, which in turn affect the type and magnitude and frequency
of geomorphic processes (Starkel and Sarkar, 2002). Although some mountain ranges and steeplands exhibit low levels of seismicity, most of the world's dominant mountain ranges are associated with compressional plate boundaries and are subject to earthquakes, active faulting, folding, and crushing – all of which are conducive to the development of a range of mass-movement processes from widespread frequent downslope movements to rarer high-magnitude catastrophic failure (Evans and DeGraff, 2002).

Mountain lands, therefore, are subject to processes that both lower stability by reducing rock strength and provide triggering mechanisms for failure, producing a set of potent conditions highly conducive to the onset of rapid mass movement. To give one example, the Alpine ranges of New Zealand that show complex response to plate convergence at rates of up to 50 mm yr\(^{-1}\) exhibit strain by buckling, faulting, rock shattering, mylonitization, and orogenic uplift. The rates of uplift occurring on the Australian Plate in the North Island are about 4 mm yr\(^{-1}\), whereas, in the South Island, uplift of the Pacific Plate is in excess of 10 mm yr\(^{-1}\) (Cooper and Norris, 2008). Although plate convergence and uplift are ongoing, these mountains are considered to have reached an equilibrium altitude where uplift is matched by denudation (King, 2008). To achieve that equilibrium mass movement, processes need to be exceedingly efficient. Orographically enhanced rainfall in the Southern Alps of New Zealand in places reaches 15 m yr\(^{-1}\) and together with frequent earthquakes in excess of M\(_7\) along range bounding and inter-mountain faults (Figure 1), sufficient triggers exist to induce catastrophic mass movement (Korup et al., 2004).

A notable example from the Southern Alps is the Green Lake Landslide – one of the largest terrestrial landslides ever recorded. The landslide has a volume of \(\sim 27\) billion cubic meters, covers an area of \(\sim 45\) km\(^2\), dropped 700 m vertically, and moved 2.5 km laterally. A debris dam 800 m in height retained a lake 11 km in length. The landslide is thought to have been triggered by an earthquake about 12–13 k years BP; however, de-buttressing of slopes by glacier wasting may have also been a factor (Hancox and Perrin, 2009).

**Figure 1** Multiple rock and debris slides triggered by an M\(_{\text{w}}\) 7.2 earthquake, 22 August 2003 Fiordland, New Zealand. Photo by M.J. Crozier.

### 7.26.3 The Human Context

Although landslides represent a natural geomorphic process that in the absence of people or property is of little concern, it is the juxtaposition of landslides, human use, and habitation that exacts a cost. The potential loss from processes in such situations defines both the hazard and the risk. Of all the areas subject to mass-movement hazards, mountain lands are clearly the most hazardous. In some areas of the world, for example, New Zealand, apart from a few tourist centers, the mountains are virtually uninhabited and consequently risk is low. By contrast, in the mountainous country of Tajikistan with about 6 million inhabitants, rockfalls and rockslides have accounted for over 100,000 deaths during the twentieth century (Slaymaker, 2010). From a hazard and risk perspective, Slaymaker (2010) classified mountains into four categories reflecting demography and land use: polar mountains (population density of \(< 0.1 \text{ km}^{-2}\)), for example, Svalbard; low-population-density temperate mountains (population density of 0.1–25 km\(^{-2}\)), for example, Southern Alps of New Zealand; high-population-density temperate mountains (population density of 25–75 km\(^{-2}\)), for example, Europe and Japan; and tropical mountains (population density of 50–100 km\(^{-2}\)), for example, Indonesia.

### 7.26.4 Social and Physical Environmental Change

There is little doubt that increasing impact of hazards is driven by accelerating population growth, associated increased demand for land resources, urbanization, and the capability of modern technology to drastically change land form and processes (Figure 2). Wright (2004) has noted that, since the year 1900, the world has experienced a four-fold increase in population and a 40-fold increase in economic activity. Rapidly accelerating urbanization and globalization mean that transportation routes and other lifelines for transmission of water, sewage, telecommunications, electricity, gas, and oil are being expanded, commonly through terrain subject to mass-movement hazards. In many parts of the world, population pressures or poverty has seen habitation expand into areas otherwise considered unsuitable for occupation (Figure 3). Increased exposure to hazards can also be voluntary, as indicated by the surge of new housing in coastal locations, where benefits of proximity to the sea and views have been the attraction. Cendrero et al. (2006) argued that many exploitative activities resulting from increased population and wealth not only increase exposure of the population to hazard but also, by alteration of the landscape through such activities as deforestation and mining (Figure 4), exacerbate the onset of hazards.

Numerous international databases indicate the increasing loss from natural hazards and the disproportionate impacts in less-developed countries. It is clear that improvement in risk-reduction procedures and technology, although successful in reducing loss in advanced economies, has not been able to stem the rising global impact. Although much of this can be attributed to increasing population and its consequences, the physical environment also appears to be undergoing radical change. If climate changes to the extent
predicted by intergovernment agencies, then many areas of the world can expect intensification of the thermal regime and changes in precipitation, with some areas receiving significant increases in both total rainfall and intensity. Crozier (2010) has outlined how such changes may influence the geotechnical and geomorphic controls of mass movement.

Currently, the possible impacts of global climatic change are being pursued in a number of approaches: general circulation models (GCMs), downscaling of GCMs to assess local climate, modeling slope stability using downscaled GCM scenarios (Dehn et al., 2000), paleoenvironmental interpretation (Borgatti and Soldati, 2010), and observations (Haeberli et al., 1993; Haeberli et al., 1997). Although GCMs appear to be producing verifiable results, downscaled data still lack sufficient resolution to predict changes in mass-movement activity with any certainty. Nevertheless, observational results are becoming increasingly indicative of climate change, whereas paleoenvironmental evidence, using a wide range of proxy data, suggests a strong correlation between climatic conditions and phases of mass-movement activity throughout the Quaternary.

Figure 2  Social and physical factors contributing to increased landslide risk and loss.

Figure 3  High-density residential tower blocks in proximity to steep landslide prone terrain, Lantau Island, Hong Kong. Photo by M.J. Crozier.

Figure 4  Rock avalanche deposits in the Ok Tedi River valley, triggered by mining activity, August 1989. The landslide totaled 170 million tonnes and traveled 3.5 km downstream. Photo by M.J. Crozier.
7.26.5 Concepts: Hazard, Risk, and Susceptibility

Mankind resides within and ultimately gains its livelihood from the natural environment – a relationship that has never been without risk. The concept of natural hazard recognizes that some aspects of that natural environment can be dangerous.

The concepts discussed below, although generic and applicable to all hazardous situations and processes, are discussed with reference largely to landslides, the most dangerous form of mass movement.

7.26.5.1 Hazard

In natural hazard literature, two accepted meanings of the term hazard occur. The first refers to an actual physical entity (process or situation) that has the potential to cause damage (e.g., a large rockslide or a long-runout debris flow). This is the common nontechnical understanding of hazard. However, this meaning of the term hazard is also used in some legal and statutory documents, with statements such as notification to local authorities: “to record the date and location of hazards, including landslide, debris flow, surface flooding, subsidence, etc.” The second meaning of the term hazard is more technical and refers not to a process but rather to a threatening condition resulting from the activity (magnitude-frequency) of that process, expressed as the probability of occurrence of a damaging landslide (Crozier and Glade, 2005). Probabilities are sometimes expressed as recurrence intervals in years but for risk-assessment purposes they are generally given in the form of annual probabilities. For example, for a landslide of given magnitude with a recurrence interval of 20 years, the reciprocal (1/20) represents the annual probability, that is, 0.05, expressed as a 5% chance of occurring in any year.

7.26.5.2 Risk

The consequences related to 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, 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 happens. Risk thus results from the intersection of hazard with the value of the elements at risk by way of their vulnerability (Crozier and Glade, 2005).

Varnes (1984) was one of the first to apply the generic formulation of risk to the phenomenon landslides as

\[ \text{Hazard} \times \text{Elements at risk} \times \text{Vulnerability} = \text{Risk} \]  

This fundamental hazard risk formulation can be further modified for risk assessment in specific situations. For example, the risk of people being killed in a particular building in a subdivision at the base of an unstable slope would need to take into account a number of additional factors. These might include not just the probability of a landslide occurring, but also the probability that it could run out into the subdivision, the probability that it is large enough to impact the building of concern (spatial probability), the number of people occupying the building, constrained by a temporal probability, usually reflecting the difference between daytime and nighttime occupancy, and a vulnerability factor reflecting the structural integrity of the building and commonly the location of the occupant within the building.

7.26.5.3 Susceptibility

Susceptibility is the ability or the propensity of an area to produce landslides. With reference to triggering factors, susceptibility is sometimes construed as terrain sensitivity or physical vulnerability. It can be determined by a range of techniques, including geomorphic mapping, stability analysis, or even expert opinion. Depending on the spatial resolution of susceptibility assessment, the terrain may be ranked into areas of greater or lesser susceptibility. Although susceptibility can be determined independently for different types of landslides, it indicates very little about the magnitude and frequency, that is, temporal probability of occurrence. Nevertheless, susceptibility assessments commonly represent an important first step in hazard and risk assessment.

7.26.5.4 Vulnerability

The concept of vulnerability is widely debated, especially among social scientists. Essentially, it is the degree of damage that can be expected from a given magnitude of landslide. Where definitions diverge, it depends largely on the element at risk of concern. In the case of a building or fixed asset, vulnerability depends on the structural integrity of the feature, for example, mud brick houses are much more vulnerable than those constructed with reinforced concrete. In this sense, vulnerability is often referred to as the damage ratio. However, if the element of risk is more complex, for example, an individual or a community, then it is the integrity of social structures as influenced by factors such as social networks, demographics, awareness, and preparedness that may determine the level of vulnerability.

A related but different concept applied to individual and communities is resilience. Whereas vulnerability refers to how easily wounded an element may be, resilience refers to its ability to bounce back or recover. Although many of the factors affecting community vulnerability also influence resilience, others specifically aid resilience such as robust transport networks, access to finance, or medical facilities. Given these influencing factors, it is not surprising that hazards have a disproportionately high impact in less-developed countries. (Hufschmidt and Glade, 2010).

7.26.6 Assessing Hazard and Risk

In simple terms, in order to make rational decisions with respect to living or carrying out activities in a hazardous area it is essential to know ‘what’ might happen (nature of the hazard

land involved, in most cases, preclude the implementation of expensive mitigating measures. Conversely, in the case of site-specific hazards, several mitigation options are presented, including, avoidance, warning systems, and engineering works (Bromhead, 2005).

7.26.6.1.3 Landslide type
The type of landslide also provides some indication of how potentially damaging the landslide might be. Landslides have been classified by many systems but the types represented in the scheme developed by Cruden and Varnes (1996) are the most widely accepted. Their scheme recognizes the mechanisms of, fall, topple, translational slide, rotational slide, flow, lateral spread, and complex movements. These mechanisms are differentiated principally by the nature of the material involved in the initial failure: earth, debris, and rock. Landslide types are also broadly correlated with the velocity of movement; falls, topples, and rock avalanches (Korup et al., 2004) exhibit the highest velocities, whereas other mechanisms can display a wide range of velocities. This scheme also recognizes that there can be different degrees of disruption of the displaced mass. Given the parameters used in this classification, identification of landslide types can give an approximate indication of the destructive qualities or intensity of landslides.

From the few records that are available (Alexander, 2005), it appears that debris flows and mudflows account for the most number of fatalities from landslides over short periods of time, whereas over longer time frames individual large rockslides and rock avalanches can exact huge death tolls.

7.26.6.1.4 Intensity of landslides
Whereas hazard is generally defined as the frequency of a given magnitude of event, this construction assumes that magnitude, generally represented by the volume of the landslide, reflects the destructive qualities of the event. Although this may be realistic, for example, for earthquake magnitude or wind speed, it is not so clear in the case of mass-movement hazards. In reality, the destructive qualities (or intensity) of a landslide relate to a range of characteristics. These include...
principally volume and velocity but importantly qualities such as degree of disruption, extent of dislocation, depth of movement, and run-out length. Regrettably, many of these key intensity characteristics are not recorded in landslide inventories – consequently establishing return periods for intensity is not always possible.

7.26.6.2 Where Landslides Occur: Susceptible Terrain

There are sufficient geomorphic indicators to suggest that with respect to mass-movement hazards certain hot spots can be identified in the landscape. The most obvious ones include alpine couloirs and avalanche chutes, debris flow fans, fault scarps, coastal cliffs, slopes recently exposed by glacial wasting, and erosional reaches of rivers, especially outside bends of rivers encroaching on steep topography. In terms of development, these sites should be treated with extreme caution. These locations, together with the morphologic, sedimentologic, or dendrogeomorphic evidence of previous landslides, can be included in geomorphic maps to provide an indication of landslide susceptibility. The advent of light detection and ranging (LiDAR) technology with its ability to see through the vegetation cover greatly enhances this approach. With sufficient dating resolution, these techniques can also provide information of magnitude and frequency and hence hazard. Thus, comprehensive geomorphic maps represent the first order of landslide susceptibility mapping.

Alternative approaches to mapping susceptibility may involve geotechnical slope stability analysis, where areal units, from pixels to natural slope elements, can be analyzed in terms of their factors of safety (Crozier and Glade, 2005) pertaining to a range of climatic and hydrological conditions. This approach requires data on slope geometry, slope material, strength and stress, and hydrological or seismic conditions likely to reduce the factors of safety. Such methods are amenable to distributed slope modeling within the geographical information system (GIS) environment (van Westen, 2010) – the units once assessed then need to be aggregated and classified to indicate varying degrees of susceptibility to mass movement.

A more traditional approach to assessing susceptibility is based on slope stability theory, and involves mapping all those factors considered conducive to promoting mass movement, such as rock type, rock structure, slope morphology, vegetation type, and hydrological conditions. In many cases, experience allows certain factors to be weighted more heavily than others. This approach has also been facilitated by the development of GISs whereby various parameter or thematic maps (layers) can be superimposed (intersected) to define clusters of parameter combinations that can then be ranked in terms of influence on susceptibility.

Landslide inventories provide an extremely important empirical basis for susceptibility mapping and with sufficient spatial reference can be used as indicators of susceptibility in their own right. Maps of landslide distribution derived from such inventories have also been combined with theoretical parameter maps in order to discriminate those parameters that are exclusively or predominantly associated with the presence of landslides from those associated with stable terrain. Discriminant analysis, logistic regression, hierarchical factor analysis, and other statistical techniques are commonly used to test the strength of relations before consequent susceptibility models are developed.

Landslide inventories as well as continued monitoring are of particular value in validating susceptibility mapping. State-of-the-art methodology on susceptibility mapping and zonation has been documented by Fell et al. (2008).

Essentially, however, susceptibility mapping only ranks the terrain in terms of where certain landslides are able to occur. Although this is an important first step, land and resource managers need to know more than that – they need to have these maps converted into indications of hazard and risk.

7.26.6.3 Frequency of Occurrence

To convert susceptibility maps into hazard maps, estimations of magnitude and frequency of the expected events are required (Crozier, 1996; Crozier, 1999b). This represents one of the most intractable problems in hazard and risk assessment, especially with respect to reactivation of movement. Essentially, an extensive database is needed on the magnitude and frequency of landslides in the area of concern, including reactivations. Although some jurisdictions have databases or historical written records that can assist, this is not the case in most areas and relict landslide forms and deposits need to be assessed and dated to establish a suitable record. In many cases, this requires resort to proxy records from landslide deposits, for example, in lake sediments or from other records of landslide impact on vegetation. However, as with any historical data, application to future predictions needs to take into account the changes that have occurred, or are likely to occur in the environmental conditions conducive to landsliding. This consideration is particularly important today in the face of unprecedented rates of global environmental change.

An alternative approach to determining frequency requires the identification of the magnitude of the triggering agent required to initiate landslides and then the application of this threshold to the long-term record of the triggering agent in order to determine the frequency of threshold exceedance. This method has been used extensively for rainfall-triggered landslides (Glade et al., 2000) as well as for earthquake-triggered landslides (Wilson and Keefer, 1985; Hancox et al., 1997).

Much of the above discussion is predicated on there being a presence of landslides or evidence of former landslides in the area under concern, and that hazard, as defined here, can only be assessed with resort to magnitude and frequency derived from landslide evidence. However, the concept of first-time failure is an important consideration, particularly where there are critical elements of risk exposed. The development of reservoirs is a case in point. Even though there may be no evidence of former landslides in the vicinity, changes in the slope hydrological regime associated with dam construction should address the possibility that landslides may be initiated. In this case, susceptibility is generally established through geotechnical stability analysis, and probabilities are thereby assigned on the basis of factors of safety, and the natural variability in parameters used in the stability assessment.
7.26.6.4 Risk

In a comprehensive study of world landslide hazards carried out between 1993 and 2002, Alexander (2005) recorded over 40,000 deaths from landslides alone, and of these the majority of deaths was caused by debris flows and mudflows resulting from largely intense and prolonged rainfall. His data set recorded a much lower death toll from slumps, debris avalanches, and rock falls, and only few were attributed to triggering by earthquakes and volcanic activity.

However, longer records indicate that massive death tolls can arise from a range of different sources. For example, the earthquake-triggered Huascaran rock and ice avalanche in Peru of 31 May 1970 killed 2000 people in the village of Ranranhirca and 19,000 in the town of Yungay (Browning, 1973). Similarly, an earthquake in 1920 in Kansu, China, caused landslides in loess that resulted in 10,000 deaths. In another instance, intense rainfall produced debris flows and floods on 16 December 1999 in Venezuela, resulting in a death toll of 30,000. More recently, the Szechwan earthquake of 12 May 2008 produced hundreds of landslides, many creating temporary dams, and resulted in 75,000 deaths. These events are essentially the realization of risk (Figure 6).

Ultimately, risk is determined, as outlined earlier, through determining the probability of loss based on the value of elements at risk, their vulnerability, and exposure to hazard. Although mass-movement hazards may be one aspect generating risk to an individual or community, they are often accompanied simultaneously by other hazards such as earthquake shaking or flooding. Risk assessments need to factor in the probability of multiple hazard occurrences so that emergency management and risk-reduction planning can respond accordingly. The nature of that response, however, is dependent not only on how those risks are evaluated but also on the ability and resources available to the community.

7.26.7 Conclusion

Hazard and risk are not static. Their assessments in any region are subject to becoming redundant with time. Consider the causative factors of landslides. These include pre-conditions, preparatory factors, and triggering factors. Pre-conditions such as stratigraphic disposition, slope gradient, and slope material are generally considered constant. Nevertheless, slope conditions and material are constantly being modified by urban development, mining, and quarrying. Preparatory factors relate to changes that lower the stability of the slope, such as deforestation or groundwater changes alongside reservoirs. These are increasingly being changed by accelerating demand for resources. Triggering factors that initiate movement on unstable slopes are primarily the result of rainfall, earthquakes, and slope under-cutting. Global environmental changes are likely to enhance both rainfall intensity and slope modification. The bottom line is that historical assessments of hazard are subject to dramatic changes in the future. The capability to predict, cope with, and mitigate such changes requires the geomorphologist to realize and anticipate the rates and impact of climate and social change.

References


Figure 6 The Abbotsford landslide that destroyed 69 houses, 8 August 1979, Dunedin, New Zealand. Photo by W. Brockie.


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Biographical Sketch

Michael Crozier is Professor Emeritus at Victoria University of Wellington where he held a personal chair in geomorphology from 1998 to 2009 in the School of Geography, Environment and Earth Sciences. He is president of the International Association of Geomorphologists and immediate past president of the New Zealand Geographical Society. He has received a number of Academic awards including a Fulbright Scholarship to USA, a Leverhulme fellowship to University of Bristol, and a distinguished visiting professorship at the University of Durham. Professor Crozier has been a member of the New Zealand Conservation Authority with responsibility for National Parks. He is a geomorphologist with research interests in landslides, natural hazards, and human impact on natural systems.