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Geomorphological Mapping to Assess Landslide Risk: Concepts, Methods and Applications in the Umbria Region of Central Italy

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15.1 Introduction

Following a catastrophic landslide disaster in the Campania region on 5 May 1997, when tens of people were killed by debris flows, on August 1998 the Italian government passed new legislation on landslide and flood risk assessment and mitigation (*Gazzetta Ufficiale della Repubblica Italiana*, 1998). The new legislation requires that the regional governments and the National River Basin Authorities identify and map areas where landslide risk is most severe, and take action to reduce societal risk and economic damage. The government of the Umbria region and the Tiber River Authority commissioned the Italian National Research Council (CNR), Institute for Geo-Hydrological Protection (IRPI) in Perugia to assess landslide hazard and risk in Umbria. To respond to this request, we devised a geomorphological methodology to evaluate landslide hazards and risk at site-specific scale.

In this chapter we briefly review landslide risk assessment methods, illustrate the geomorphological methodology we have devised to determine landslide hazards and risk in Umbria, and demonstrate applications of the method in three study areas representative of the main geological and physiographical provinces in the region. We conclude by discussing advantages and limitations of the proposed approach.

Landslide Hazard and Risk Edited by Thomas Glade, Malcolm Anderson and Michael J. Crozier
 ISBN: 0-471-48663-9

15.2 Concepts and Terminology

Many different triggers cause landslides, including intense or prolonged rainfall, earthquakes and rapid snowmelt. On earth the area of landslides spans nine orders of magnitude and the volume of mass movements spans 15 orders of magnitude; landslide velocity extends over 14 orders of magnitude, from millimetres per year to hundreds of kilometres per hour. Mass movements can occur singularly or in groups of up to several thousands. Multiple landslides occur almost simultaneously when slopes are shaken by an earthquake, or over a period of hours or days when failures are triggered by rainfall or by snowmelt. Landslides can involve flowing, sliding, toppling or falling movements, and many landslides exhibit a combination of these types of movements (Varnes, 1978). The extraordinary breadth of the spectrum of landslide phenomena makes it difficult to define a single methodology to ascertain landslide hazards and to evaluate the associated risk.

Assessing landslide hazards and risk is a complex and uncertain operation that requires the combination of different techniques and methodologies, and the interplay of various types of expertise, not all of which pertain to the realm of the earth sciences. A review of the vast literature on landslide hazard assessment (see Varnes and IAEG Commission on Landslides and other Mass-Movements, 1984; Hutchinson, 1995; Soeters and van Westen, 1996; Guzzetti *et al.*, 1999b; and references therein), and of the literature on landslide risk evaluation (Einstein, 1988; Fell, 2000; Cruden and Fell, 1997; and references therein) is beyond the scope of this chapter. In this section we briefly review the concepts and terminology related to landslide hazard and risk assessment.

Landslide hazard refers to the natural conditions of an area potentially subject to slope movements. In a well-known report, Varnes and the IAEG Commission on Landslides and other Mass-Movements (1984) (henceforth Varnes – IAEG) proposed that the definition adopted by UNDRO for all natural hazards be applied to landslide hazard. Landslide hazard is therefore 'the probability of occurrence within a specified period of time and within a given area of a potentially damaging phenomenon'. Guzzetti *et al.* (1999b) amended this definition to include the magnitude of the event, that is, the area, volume, velocity or momentum of the expected landslide. The amended definition incorporates the concepts of location, time and magnitude. Location refers to the ability to forecast where a landslide will occur; magnitude refers to the prediction of the size and velocity of the landslide; and frequency refers to the ability of forecasting the temporal recurrence of the landslide event (Guzzetti *et al.*, 1999b). Quantitative (probabilistic or deterministic) and qualitative approaches to ascertain landslide hazards are possible. Reviews of quantitative approaches are given by Soeters and van Westen (1996) and Guzzetti *et al.* (1999b). In this work we utilize a qualitative approach.

Landslide risk evaluation aims to determine the 'expected degree of loss due to a landslide (*specific risk*) and the expected number of lives lost, people injured, damage to property and disruption of economic activity (*total risk*)' (Varnes and the IAEG Commission on Landslides and other Mass-Movements, 1984). Quantitative (probabilistic) and qualitative (heuristic) approaches are possible (Einstein, 1988, 1997; Michael-Leiba *et al.*, 1999; Fell, 1994, 2000; Fell and Hartford, 1997).

Quantitative risk assessment aims to establish the probability of occurrence of a catastrophic event, for example, the probability of loss of life, or the probability of a landslide causing a given number of casualties or fatalities. The method requires a catalogue of landslides and their consequences. A few such lists have been prepared for landslides with human consequences, that is, deaths, missing people and injuries (Evans, 1997; Guzzetti, 2000; Kong, 2002; Guzzetti *et al.*, 2003). To compile accurate and complete lists of landslides that have caused other types of damage is more difficult, due to the lack of relevant information. When this information is available, levels of individual and societal risk can be determined. Individual risk is the risk posed by a hazard to any identified individual, and is expressed using mortality rates, which are given by the number of deaths per 100 000 of any given population over a predefined period. Societal (collective) risk is the risk imposed by a hazard (i.e. a landslide) on society, and is established by investigating the relationship between the frequency of the damaging events and their intensity, as measured by the number of fatalities. Acceptable risk levels are determined by comparison with other natural, technological, social and medical hazards for which acceptable risk levels have already been established (Fell and Hartford, 1997; Salvati *et al.*, 2003). The completeness and time span of the landslide catalogue greatly affect the reliability of such quantitative risk assessments.

When attempting to evaluate landslide risk for a site or region where slope movements are likely to take various forms or pose various types of threat, the quantitative approach often becomes impracticable. As an example, the quantitative assessment of the risk posed by mass movements to structures and the infrastructure is defined as the 'product' of landslide hazard and the vulnerability of the structure or infrastructure (Varnes – IAEG, 1984). The latter ranges from 0 to 1, 0 meaning no damage and 1 representing complete destruction. The definition of landslide risk requires that both hazard and vulnerability be defined as independent probabilities (of occurrence, for hazard; and of damage, for vulnerability). In practice, it is rarely possible to define hazard and vulnerability as probabilities, limiting the rigorous application of the definition of landslide risk.

Considering that it may not be easy to ascertain the magnitude, frequency and forms of evolution of landslides in an area, that detailed information on the vulnerability of the elements at risk is often lacking, and that accurate and reasonably complete catalogues of historical events with consequences may not be readily available, in some areas a qualitative approached can be pursued so as to establish qualitative levels of landslide risk. This can be accomplished by investigating the impact of mass movements in a given area, and by designing landslide scenarios.

The impact that slope failures have had, or may have, in a given area can be established in two ways. First, where a historical catalogue of landslides and their consequences is available, the sites repeatedly affected by catastrophic events can be determined and the vulnerability of the elements at risk ascertained (Budetta, 2002; Kong, 2002). Alternatively, where a detailed landslide inventory map and a map of structures (houses, buildings, etc.) and infrastructure (roads, railways, lifelines, etc.) at risk are available in GIS form, simple geographical operations allow one to determine where landslides may interfere with the elements at risk. For the Umbria region, Guzzetti *et al.* (2003) intersected in a GIS a detailed geomorphological landslide inventory map showing more than 45 000 landslides with maps of the built-up areas and of the transportation network. The operation revealed 6119 sites where known landslides intersect (i.e. may interfere) with built-up areas, and 4115 sites where landslides intersect roads or railways. At these localities damage due to landslides can be expected, particularly during major landslide-triggering events (e.g. prolonged rainfall, snowmelt events, etc.).

The design of a landslide scenario is a complex, largely empirical procedure that involves: (i) identification of the types of slope processes present in the study area (ii) accurate mapping of the existing landslides; and (iii) assessment of the possible (or probable) evolution of the slope movements. The last can be ascertained qualitatively by experts, or determined quantitatively using mathematical or physically based models which simulate the expected evolution of a landslide. Multiple landslide scenarios can be prepared, one scenario for each landslide or landslide type present in the study area. By combining multiple landslide scenarios with information on the location and the type of structures and infrastructure and their vulnerability, one can determine qualitative levels of landslide risk. We accomplished this in 79 villages in Umbria, where we have adopted a qualitative, heuristic approach to ascertain landslide risk based on the definition of multiple landslide scenarios.

15.3 Settings and Previous Landslide Studies

The Umbria region covers 8456 km^2 in central Italy (Figure 15.1), with elevation ranging from 50 to 2436 m a.s.l. The landscape in the region is hilly or mountainous, with open valleys and large intra-mountain basins, drained by the Tiber River, which flows to the Tyrrhenian Sea. Rainfall occurs mainly from October to December and from March to May, with cumulative annual values ranging between 500 and 2100 mm. Snowfall occurs every year in the mountains and about every five years at lower elevations.

Due to the lithological, morphological and climatic setting, landslides are abundant in Umbria (Servizio Geologico d'Italia, 1980; Guzzetti *et al.*, 1996). Mass movement occurs almost every year in the region in response to prolonged or intense rainfall, rapid snowmelt and earthquake shaking. Landslides in Umbria can be very destructive and have caused damage at many sites. In the twentieth century a total of 29 people died or were missing and 31 people were injured by slope movements in Umbria in a total of 13 harmful events (Salvati *et al.*, 2003).

Research on slope movements is abundant in Umbria. Landslide inventory maps were compiled by Guzzetti and Cardinali (1989), Antonini *et al.* (1993) and Cardinali *et al.* (2001). Such studies revealed that landslides cover about 8% of the territory. Locally, landslide density is much higher, exceeding 20%. Geomorphological relationships between landslide types and pattern, and the morphological, lithological and structural settings were investigated among others by Guzzetti and Cardinali (1992), Barchi *et al.* (1993) and Cardinali *et al.* (1994), and were summarized by Guzzetti *et al.* (1996). Site-specific, geotechnical investigations on single landslides or landslide sites were conducted at several localities, mostly in urbanized areas (Crescenti, 1973; Tonnetti, 1978; Diamanti and Soccodato, 1981; Calabresi and Scarpelli, 1984; Lembo-Fazio *et al.*, 1984; Canuti *et al.*, 1986; Cecere and Lembo-Fazio, 1986; Righi *et al.*, 1986; Tommasi *et al.*, 1986; Ribacchi *et al.*, 1988; Capocecere *et al.*, 1993; Felicioni *et al.*, 1994). Landslide hazard assessments have been completed in test areas and for different landslide types by Carrara *et al.* (1991, 1995) and Guzzetti *et al.* (1999b, 2004). A regional landslide hazard map for the upper Tiber River basin, most of which lies in Umbria, was completed by Cardinali *et al.* (2002a). Historical information on the frequency and recurrence of failures in Umbria was compiled by a nation-wide project that archived data on landslides and

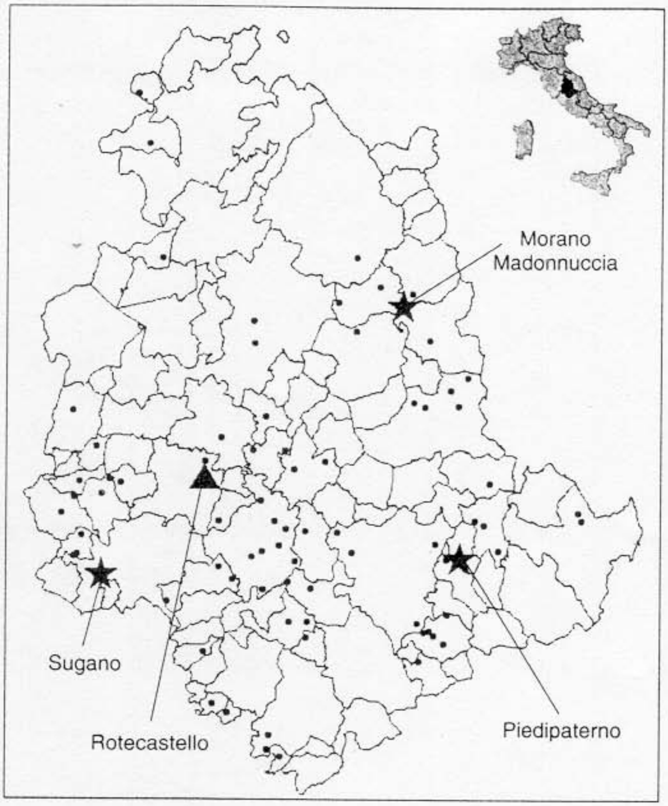

Figure 15.1 Umbria region with municipality boundaries. Black dots show the location of 79 sites where landslide risk was ascertained. Stars show the location of the three study areas described in the text. Triangle shows the location of the village of Rotecastello where landslide risk was first determined by Cardinali et al. *(2002b)*

floods for the period 1918–2000 (Guzzetti *et al.*, 1994). This information was recently summarized by Guzzetti *et al.* (2003). A reconnaissance estimate of the impact of landslides on the population, the transportation network, and the built-up areas in Umbria was attempted by Guzzetti *et al.* (2003). Despite these efforts, definition of landslide risk at site scale remains an open problem.

15.4 Methodology

We devised a methodology to assess landslide hazard and risk at site scale using a geomorphological approach based on the interpretation of multiple sets of aerial photographs, combined with the analysis of site-specific and historical information (Antonini *et al.*, 2002a; Cardinali *et al.*, 2002b). We start with the definition of the study area and the careful scrutiny of the 'state of nature', that is, of all the existing and past landslides that can be identified in the study area. Based on the observed changes in the distribution and pattern of landslides, we infer the possible short-term evolution of the slopes, the probable type of failures, and their expected frequency of occurrence. We use this information to estimate the landslide hazard, and to evaluate the landslide risk. The methodology involves the following seven steps:

(a) definition of the extent of the study area,
(b) compilation of a multitemporal landslide inventory map, including landslide classification,
(c) definition of landslide hazard zones,
(d) assessment of landslide hazard,
(e) identification and mapping of the elements at risk, and assessment of their vulnerability to different landslide types,
(f) evaluation of specific landslide risk, and
(g) evaluation of total landslide risk.

15.4.1 Definition of Study Area

Preliminary to any landslide hazard or risk assessment is the definition of the area to be investigated. This apparently trivial problem is essential to the analysis and the application of the results. In our study, we define a 'site' as an area bounded by drainage and dividing lines around the place selected for the landslide risk assessment. A site is an ensemble of one or more adjacent 'elementary slopes' or watersheds (Carrara *et al.*, 1991). To outline the site we select major dividing and drainage lines, wherever possible. Where this is not feasible, we select minor dividing or drainage lines. Mapping of elementary slopes or watersheds is accomplished at 1:10 000 scale, using large-scale topographic base maps, locally aided by the analysis of large- and medium-scale aerial photographs. At each site, the number and the extent of the elementary slopes depend on the local geological and morphological setting, and on the type, number and extent of landslides.

15.4.2 Multitemporal Landslide Map

In Umbria region landslides show a remarkable spatial recurrence (Cardinali *et al.*, 2000; Guzzetti *et al.*, 2003). Mass movements tend to repeat where they have occurred in the past, within or in the vicinity of other landslides, or in the same slope or watershed. Guzzetti *et al.* (2003) pointed out that in Umbria region detailed knowledge of the location of past failures is the key to forecast future landslide occurrence. This is not unique to Umbria or central Italy. Nilsen and Turner (1975) determined that most landslides that caused damage to man-made structures in the urbanized parts of Contra Costa County, California, from 1950 to 1971, occurred on pre-existing ancient landslide deposits.

Within a study area we ascertain the spatial distribution of landslides through the interpretation of multiple sets of stereoscopic aerial photographs and detailed field surveys. In Umbria, for a period of about 60 years (from 1941 to 2001) seven sets of aerial photographs taken in different years are available. The oldest photographs were taken in 1941, and the newest in 1997. Nominal scale of aerial photographs ranges from 1:13 000 to 1:73 000. Only three sets of photographs cover the entire territory, whereas the other flights are limited to specific areas. Field surveys used to test the methodology were carried out mostly in the years 2000 and 2001 (Cardinali *et al.*, 2002b).

To compile the multitemporal landslide inventory map, we began by identifying landslides on the 1954–55 aerial photographs. We selected this set because it is the oldest flight covering the entire region, because the aerial images were taken in a period when intense cultivation of the land by machine had not started, and the forms of old and recent landslides were clearly visible on the photographs (Guzzetti and Cardinali, 1989). We then analysed the other sets of aerial photographs, separately and in conjunction with the 1954–55 photographs and with the other flights. In this way we prepared separate landslide inventory maps, one for each set of aerial photographs and for the field surveys.

Landslide information collected through the interpretation of aerial photographs or mapped in the field is transferred to large-scale topographic base maps (at 1:10 000 scale). The different landslide maps are then overlaid and merged to obtain a single, multitemporal landslide inventory map. The process is not straightforward and requires adjustments to eliminate positional and drafting errors. The multitemporal landslide inventory map is then digitized and stored in a GIS database.

In the separate inventory maps and in multitemporal inventory maps, landslides are classified according to the type of movement, and the estimated age, activity, depth and velocity. A degree of certainty in the recognition of the landslide is also attributed. Landslide type is defined according to Varnes (1978) and the WP/WLI (1990, 1993, 1995). Landslide age, activity, depth and velocity are decided based on the type of movement, the morphological characteristics and appearance of the landslide on the aerial photographs and in the field, the local lithological and structural settings, the date of the aerial photographs, and the results of site-specific investigations carried out to solve local instability problems (Cardinali *et al.*, 2002b). Landslide relative age is defined as recent, old or very old, despite some ambiguity in the definition of the age of a mass movement based on its appearance. Landslides are classified as active where they appear fresh on the aerial photographs, or where movement is known from monitoring systems. Mass movements are classified as deep-seated or shallow, depending on the type of movement and the landslide volume. The latter is based on the type of failure, and the morphology and geometry of the detachment area and the deposition zone. Landslide velocity is considered as a proxy of landslide type, and classified accordingly. Rotational or translative slides, slide earthflows, flows and complex or compound slides are classified as slow-moving failures. Debris flows are classified as rapid movements. Rockfalls and topples are classified as fast-moving landslides (WP/WLI, 1995).

The adopted classification scheme, and in particular the evaluation of landslide age, activity, velocity and depth, includes uncertainty and suffers from simplifications. The classification requires geomorphological inference, but fits the available information on landslide types and process in Umbria (Felicioni *et al.*, 1994; Guzzetti *et al.*, 1996, 2003).

15.4.3 Landslide Frequency

Information on landslide frequency is essential to assess landslide hazard. The frequency of landslides can be obtained through the analysis of historical records of landslide occurrence (Guzzetti *et al.*, 1999b). In general, a complete record of past landslides from which to derive the frequency of occurrence of landslide events is difficult to obtain for a single landslide or a slope (Ibsen and Brunsden, 1996; Glade, 1998; Guzzetti *et al.*, 1999b). In this work we ascertain landslide frequency based on the analysis of the multitemporal inventory map. We define four classes of landslide frequency, based on the number of events recognized in the 47-year observation period from 1954 to 2001

Table 15.1 *Frequency of landslide events*

Landslide frequency			Events in the observation period
Category	Index	Ratio	
Low	1	1/47 (0.02)	1
Medium	2	2/47 (0.04)	2
High	3	3/47 (0.06)	3
Very high	4	>3/47 (>0.06)	>3

(Table 15.1). We ascertain the frequency of landslides, F_L, during the observation period based on: (a) the number of events inferred from the analysis of the aerial photographs; (b) the landslide events observed in the field; and (c) the information on landslide events obtained from technical reports, historical accounts and chronicles. We do not make a distinction between events inferred through the interpretation of aerial photographs and events identified in the field or described in technical or historical reports.

15.4.4 Landslide Intensity

Definition of landslide hazard requires information on landslide intensity (or magnitude; Guzzetti *et al.*, 1999b). In contrast to earthquakes, volcanic eruptions or hurricanes, no unique measure of landslide intensity is available (Hungr, 1997). Since our goal is to estimate landslide risk, we assume landslide intensity (I_L) as a measure of the destructiveness of the landslide (Hungr, 1997), and we define it as a function of the landslide volume (v_L) and of the landslide expected velocity (s_L), that is, $I_L = f(v_L, s_L)$. Table 15.2 shows how we assign the intensity to each landslide based on the estimated volume and the expected velocity. We estimate landslide volume based on the landslide type defined in the inventory map. For slow-moving landslides volume depends on the estimated depth of movements; for rapid-moving debris flows on the size of the contributing catchment and on the estimated volume of debris in the source areas and along the channels; for fast-moving rockfalls on the maximum size of a single block, obtained from field observations, or from the estimated volume of rockslide deposits. The expected

Table 15.2 *Landslide intensity, in four classes, based on the estimated landslide volume and the expected landslide velocity*

Estimated volume (m^3)	Expected landslide velocity		
	Fast-moving rockfall	Rapid-moving debris flow	Slow-moving slide
<0.001	Slight (1)		
0.001–0.5	Medium (2)		
0.5–500	High (3)	Slight (1)	
500–10 000	High (3)	Medium (2)	Slight (1)
10 000–500 000	Very high (4)	High (3)	Medium (2)
>500 000		Very high (4)	High(3)
≫500 000			Very high (4)

landslide velocity depends on the type of failure, its volume and the estimated depth of movement. For any given landslide volume, rockfalls have the highest landslide intensity, debris flows exhibit intermediate intensity, and slow-moving landslides have the lowest intensity.

15.4.5 Landslide Hazard Zones

We evaluate landslide hazard in the areas of evolution of existing (i.e. mapped) landslides (Cardinali *et al.*, 2002b). For this purpose we define a 'landslide hazard zone' (LHZ) as the area of possible (or probable) short-term evolution of an existing landslide, or a group of landslides, of similar characteristics (i.e. type, volume, depth, velocity), identified from the aerial photographs or observed in the field. In an LHZ an existing landslide can grow upslope, develop downslope, or expand laterally. An LHZ is therefore a form of landslide scenario designed using geomorphological inference.

To map an LHZ we use again the multitemporal landslide inventory map. Within each elementary slope, we map the area of possible evolution of each landslide, or group of landslides, based on the observed location, distribution and pattern of landslides, their style of movement and activity, and the local lithological and morphological setting. To design an LHZ we consider the observed partial or total reactivation of the existing landslides, the lateral, head (retrogressive) or toe (progressive) expansion of the existing landslides, and the possible occurrence of new landslides of similar type and intensity.

We identify separate landslide scenarios for the different type of failures observed in the elementary slope, for example fast-moving rockfalls and topples, rapid-moving debris flows, and slow-moving slump earthflows, block slides or compound failures. LHZ includes the crown area and the deposit of the existing landslides, and the area of possible direct or indirect influence of the landslide. LHZs were identified based on the local topographic, morphological and geological settings, and the type and extent of landslides. For slow-moving failures (e.g. slide, slump earthflow, block slides and compound failure) LHZ is limited to the surroundings of the existing landslide, or group of landslides. This limitation is justified in Umbria where the evolution of these landslides is predictable in space (Cardinali *et al.*, 2000). For relict (i.e. very old) landslides the LHZ overlaps in places with the entire elementary slope. For debris flows the LHZ includes the source areas, the river channels and the depositional areas on alluvial or debris fans. For rockfalls, topples and minor rockslides LHZ includes the rock cliffs from where landslides detach, and the talus, debris cones, or debris slopes along which rockfalls travel, and the places where they are deposited.

15.4.6 Landslide Hazard Assessment

Landslide hazard depends on the frequency of landslide movements (F_L) and on the landslide intensity (I_L), $H_L = f(F_L, I_L)$. We obtain an estimate of landslide hazard by combining the value of landslide frequency, ascertained based on the number of landslide events of the same type observed within each LHZ (Table 15.1), and landslide intensity, in four classes, based on the estimated landslide volume and the expected landslide velocity (Table 15.2).

Levels of landslide hazard are shown using a two-digit, positional index (Table 15.3, Cardinali *et al.*, 2002b). The right digit shows the landslide intensity (I_L) and the left

Table 15.3 Landslide hazard classes based on estimated landslide frequency, F_L (Table 15.1) and landslide intensity, I_L (Table 15.2)

Estimated landslide frequency	Landslide intensity			
	Slight (1)	Medium (2)	High (3)	Very high (4)
Low (1)	1 1	1 2	1 3	1 4
Medium (2)	2 1	2 2	2 3	2 4
High (3)	3 1	3 2	3 3	3 4
Very high (4)	4 1	4 2	4 3	4 4

digit shows the estimated landslide frequency (F_L). The index expresses landslide hazard, keeping distinct the two components of the hazard. This facilitates landslide hazard zoning, allowing us to understand if hazard is due to a high frequency of landslides (i.e. high recurrence), to a large intensity (i.e. large volume and high velocity), or to both. It is worth noticing that values of the landslide hazard index in Table 15.3 do not provide an absolute rank of hazard levels. Although extreme values are easily defined, intermediate conditions of landslide hazard are more difficult to rank. A landslide that exhibits a low frequency and a slight intensity ($H_L = 1\ 1$) will certainly have a hazard much lower than a landslide exhibiting very high frequency and intensity ($H_L = 4\ 4$). Deciding if the hazard of a landslide with a very high frequency and a slight intensity ($H_L = 4\ 1$) is higher (or lower) than that of a landslide with a low frequency and a very high intensity ($H_L = 1\ 4$) is not straightforward, and may be a matter of local judgement.

15.4.7 Vulnerability of Elements at Risk

To ascertain risk, one needs to know the type and location of the vulnerable elements. We prepare a map of the elements at risk, including built-up areas, structures and the infrastructure, at 1:10 000 scale by analysing large-scale topographic base maps, and recent aerial photographs. Care is taken in locating precisely the elements at risk within or in the vicinity of the landslides and the LHZ. The map is then digitized, registered to the multitemporal landslide map, and stored in a GIS database.

To classify the elements at risk we adopt a legend with 11 classes (Table 15.4), of which six refer to built-up areas and structures (houses, buildings, industries and farms, sports centres, and cemeteries), four to the transportation network (roads and railways), and one to mining activities (quarries). For the risk to the population, we assume that houses, buildings and roads in the study area are a proxy for population density, and we consider the population to be vulnerable because of the presence of structures and infrastructure. As an example, in a densely populated zone vulnerability of the population is considered higher than for sparse, farming structures. Along a secondary road vulnerability of the population is lower than along a high-transit road.

Evaluating the vulnerability of the elements at risk to different landslide types is a difficult and uncertain operation. To estimate vulnerability we adopt a simple approach, based on the inferred relationship between the intensity and type of the expected landslide, and the likely damage the landslide can cause. Table 15.5 illustrates the expected damage to buildings and roads, and to the population, if affected by landslides of different type

Table 15.4 *Types of elements at risk (for structures and infrastructure)*

Code	Elements at risk
HD	Built-up areas with a high population density
LD	Built-up areas with a low population density and scattered houses
IN	Industries
FA	Livestock farms
SP	Sports facilities
Q	Quarries
MR	Main roads, motorways, highways
SR	Secondary roads
FR	Farm and minor roads
RW	Railway lines
C	Cemeteries

Table 15.5 *Vulnerability, the expected damage to elements at risk (i.e. buildings, structures and infrastructure) and population*

Landslide intensity	*Elements at Risk*											
	Structures and infrastructure											Population
	Buildings						Roads				Others	
	HD	LD	IN	FA	SP	C	MR	SR	FR	RW	Q	
Slight												
Rockfall	A	A	A	A	A	A	A	A	A	A	A	N
Debris flow	A	A	A	A	A	A	A	F	F	A	A	N
Slide	A	A	A	A	A	A	A	F	S	A	A	N
Medium												
Rockfall	F	F	F	F	F	F	F	F	F	F	F	D, I, H
Debris flow	F	F	F	F	F	F	F	F	F	F	F	D, I, H
Slide	F	F	F	F	F	F	F	S	S	F	F	I
High												
Rockfall	S	S	S	S	S	S	S	S	S	S	S	D, I, H
Debris flow	S	S	S	S	S	S	S	S	S	S	S	D, I, H
Slide	S	S	S	S	S	S	S	S	S	S	S	I, H
Very high												
Rock fall	S	S	S	S	S	S	S	S	S	S	S	D, I, H
Debris flow	S	S	S	S	S	S	S	S	S	S	S	D, I, H
Slide	S	S	S	S	S	S	S	S	S	S	S	I, H

Note:
For elements at risk: A-aesthetic (or minor) damage; F-functional (or medium) damage; S-structural (or total) damage. For population: N-no damage; D-direct damage (fatalities); I-indirect damage; H-homeless people. For classes of elements at risk see Table 15.4. For landslide intensity see Table 15.2.

and intensity. The table is based on the information of the damage caused by slope failures in Umbria (Felicioni *et al.*, 1994; Alexander, 2000; Cardinali *et al.*, 2000; Antonini *et al.*, 2002b), our field experience and judgement, and on the review of the scant literature (Alexander, 1989; Michael-Leiba *et al.*, 1999; Fell, 2000). A crude estimate (i.e. few, many and very many) of the number of people potentially subject to landslide risk is considered, based on the extent and type of the built-up areas.

Damage to structures and infrastructure is classified as:

- Aesthetic (or minor) damage, where the functionality of buildings and roads is not compromised, and the damage can be repaired, rapidly and at low cost.
- Functional (moderate or medium) damage, where the functionality of structures or infrastructure is compromised, and the damage takes time and large resources to be fixed.
- Structural (severe or total) damage, where buildings or transportation routes are severely or completely damaged, and require extensive work to be fixed, and demolition and reconstruction may be required.

Damage to the population is classified as:

- Direct damage, where casualties (deaths, missing persons and injured people) are expected.
- Indirect damage, where only socio-economic damage is expected.
- Temporary or permanent loss of private houses (i.e. evacuees and homeless people).

In Umbria, direct damage to the population is foreseen for fast-moving landslides, or for high-intensity, slow-moving slides. Indirect damage to the population is expected where landslides can cause functional or structural damage to infrastructure, with negative socio-economic effects on public interests. Homeless are expected where functional or structural damage to buildings is foreseen.

15.4.8 Specific Landslide Risk

Landslide risk is the result of the complex interaction between the 'state of nature' (i.e. landslide hazard, H_L) and the expected vulnerability to the elements at risk (V_L), or $R_S = f(H_L, V_L)$. We use this general relationship to ascertain the specific landslide risk, R_S, that is, the risk at which a set of elements (e.g. building, roads, etc.) is subject when a landslide occurs (Einstein, 1988). We define the specific landslide risk separately for each class of elements at risk and for each landslide type present in each LHZ. If more than a single type of elements at risk is present in an LHZ, a different value of specific risk is computed for each class.

To determine specific landslide risk we use Table 15.6, which correlates the expected damage to the landslide hazard, loosely ranked from low (1 1) to high (4 4) values. Construction of Table 15.6 required extensive discussion, and it is largely based on the analysis of damage caused by two recent regional landslide events in Umbria: a rapid snowmelt that triggered thousands of failures in January 1997 (Cardinali *et al.*, 2000), and the Umbria–Marche earthquake sequence of September–October 1997 that caused mostly rockfalls (Antonini *et al.*, 2002b; Guzzetti *et al.*, 2003). Information on past landslide damage in Umbria region was also considered (Felicioni *et al.*, 1994; Alexander, 2000).

Table 15.6 *Levels of specific landslide risk, based on landslide hazard (Table 15.3) and vulnerability (Table 15.5)*

Landslide hazard	Vulnerability (expected damage)		
	Aesthetic (minor) damage	Functional (major) damage	Structural (total) damage
Low 1 1	A 1 1	F 1 1	S 1 1
1 2	A 1 2	F 1 2	S 1 2
1 3	A 1 3	F 1 3	S 1 3
2 1	A 2 1	F 2 1	S 2 1
1 4	A 1 4	F 1 4	S 1 4
2 2	A 2 2	F 2 2	S 2 2
2 3	A 2 3	F 2 3	S 2 3
3 1	A 3 1	F 3 1	S 3 1
3 2	A 3 2	F 3 2	S 3 2
2 4	A 2 4	F 2 4	S 2 4
3 3	A 3 3	F 3 3	S 3 3
4 1	A 4 1	F 4 1	S 4 1
4 2	A 4 2	F 4 2	S 4 2
3 4	A 3 4	F 3 4	S 3 4
4 3	A 4 3	F 4 3	S 4 3
High 4 4	A 4 4	F 4 4	S 4 4

Note:
Only damage to elements at risk (structures and infrastructure) is considered. Landslide hazard is loosely ranked from low (1 1) to high (4 4) values.

To show the level of specific risk we add to the left of the two-digit landslide hazard index a third digit describing the expected damage (i.e. aesthetic, functional or structural, see Table 15.5). Thus, the specific risk index shows, from right to left, the landslide intensity, the landslide frequency, and the expected damage caused by the specific type of landslide. As for the hazard index, the landslide specific risk index (R_S) does not provide an absolute ranking of risk levels. The extreme conditions are easily ranked: a house having an $R_S = \text{A 1 1}$ (i.e. aesthetic damage due to a low-frequency and slight-intensity landslide) poses a lower risk than a dwelling with $R_S = \text{S 4 4}$ (i.e. expected structural damage caused by a very high-frequency and very high-intensity landslide). Deciding for the intermediate conditions may not be straightforward. A decision should be made on a case-by-case basis, considering the type of elements at risk, their vulnerability, the possible defensive measures, and the economic and social implications of landslide risk.

15.4.9 Total Landslide Risk

Where an absolute ranking of landslide risk is required, total risk has to be determined (Varnes – IAEG, 1984; Einstein, 1988). Total landslide risk is the ensemble of all the specific landslide risk levels. Different strategies can be used to lump the detailed information given by the specific landslide risk index into a limited number of classes of total landslide risk. In this chapter we use a system that attributes to each LHZ a value of total landslide risk, in five classes, based on the type and severity of the largest specific landslide risk attributed in the LHZ (Table 15.7). This is different from what was

Table 15.7 Relationships between classes of total landslide risk, type of landslides, and expected damage to structures, infrastructure and the population in Umbria

Total risk	Type of landslides	Damage to structures and infrastructure	Damage to the population
Very high	Rapid and fast-moving landslides	Structural and functional damage	Casualties and homeless people expected, indirect damage expected
High	Slow-moving landslides	Structural and functional damage	Casualties not expected. Homeless people and indirect damage expected
Medium	Slow-moving landslides, fast and rapid-moving landslides of slight intensity	Aesthetic damage	Homeless people and indirect damage expected
Low	Relict, large, slow-moving landslides of very low frequency	Structural and functional damage	Homeless people and indirect damage expected
Very low	Landslides are present	Nil (elements at risk are not present)	Nil (population is not present)

proposed by Cardinali *et al.* (2002b), which attributed a value of total landslide risk to the entire study area, based on the largest specific landslide risk attributed in the study area.

Very high total landslide risk is assigned where rapid and fast-moving landslides can cause direct damage to the population. These are the areas where debris flows and rockfalls can result in casualties or homeless people. High total landslide risk is assigned to the areas where slow-moving landslides can cause structural and functional damage to structures and infrastructure. In these areas casualties are not expected. Moderate total landslide risk is attributed where aesthetic damage to vulnerable elements is expected, as a consequence of slow-moving slope failures and fast or rapid-moving landslides of slight intensity. Large or very large, relict deep-seated landslides can cause structural and functional damage to structures and infrastructure, homeless people and indirect damage to the population. However, such areas are assigned low total landslide risk, because they are not expected to move entirely under the present climatic and seismic conditions. Lastly, a very low value of total landslide risk is assigned where landslides were identified and landslide hazard was ascertained, but elements at risk or the population are not present in the LHZ.

15.5 Examples of Landslide Risk Assessment

We utilized the described methodology to ascertain landslide risk in 79 towns in Umbria region (Antonini *et al.*, 2002a). Cardinali *et al.* (2002b) previously illustrated the application of the geomorphologically based methodology to the village of Rotecastello, in central Umbria. In the following, we describe specific and total landslide risk assessments for three sites: Morano Madonnuccia, in northeastern Umbria, Sugano, in southwestern Umbria, and Piedipaterno, in southeastern Umbria (Figure 15.1). The three sites were selected to illustrate the application of the risk assessment methodology in different physiographical and geological environments, and for different types of slope failures. At Morano Madonnuccia, landslide risk is due to slow-moving slides, slide earthflows and flows, of slight to medium intensity that involve marl and shale, and their associated soils. At Sugano, fast-moving rockfalls and rockslides coexist with slow-moving, shallow and deep-seated slides and slide earthflows, involving volcanic rocks and marine clay. At Piedipaterno, landslide risk is due chiefly to fast-moving rockfalls, and rapid-moving debris flows, involving limestone, talus and debris deposits.

15.5.1 Morano Madonnuccia

The landscape in central Umbria is hilly, with elevation ranging from 300 to about 1200 metres. Drainage density and pattern are controlled by lithology and the structural setting. Valleys are asymmetrical and controlled by the attitude of bedding planes. Slopes are long and rectilinear along dip-slopes, and short and steep where bedding planes dip into the slope. In the area, there are outcrops of flysch deposits, heterogeneous sequences of well-stratified, graded deposits composed of soft and weak layers of marl, sandy shale and clay, orderly interbedded with coarse and fine sandstone, graywackes and calcarenites, in various percentages.

Due to the lithological and structural setting, landslides of various types are abundant in the area. Large, deep-seated slides, block-slides, and complex or compound mass movements predominate where bedding is nearly parallel to the slope, or less steep than the slope. Along reverse slopes, rotational slides, rockslides, and slide earthflows are most abundant. On the surface of large landslides, on the soils mantling the bedrocks, and on the locally thick colluvial deposits, shallow landslides predominate. The latter comprise soil slips, minor slumps, mudflows and minor earthflows. Badlands and areas of intense surface erosion are locally present, chiefly where clay and marl predominate and bedding is sub-horizontal (Guzzetti *et al.*, 1996).

Morano Madonnuccia is a small village in Gualdo Tadino Municipality constituted by sparse houses built along road SS 444, connecting Assisi to Gualdo Tadino (Figure 15.2). The village is located on a SW–NE trending divide, at an elevation of about 650 metres. In the area there are outcrops of thinly bedded marl pertaining to the Schlier Formation [Fm.], Burdigalian in age, and well-bedded marl, sandstone and calcarenite pertaining to the Marnoso Arenacea Fm., lower to upper Miocene in age. Locally, a chaotic mixture of clay and exotic rocks (i.e. an olistostrome) is embedded within the Marnoso Arenacea Fm.

In the Morano Madonnuccia study area we identify three 'elementary slopes', for a total area of about $2\,km^2$ (Figure 15.3). For the study area, we compiled a multitemporal landslide inventory map by analysing three sets of aerial photographs, and through field surveys (Figure 15.3). Aerial photographs were flown in May 1956 at 1:33 000 nominal scale, in June 1977 at 1:13 000 nominal scale, and in October 1997 at 1:13 000 nominal scale. Field surveys were carried out in March 1997, shortly after a major landslide-triggering event (Cardinali *et al.*, 2000), and in February 2001.

Superficial and deep-seated landslides were identified in the three sets of aerial photographs, and were classified based on relative age, inferred from the date of the aerial photographs, and on the prevalent landslide type (Figure 15.3). A total of 70 landslides

Figure 15.2 Panoramic view of the Morano Madonnuccia study area. Photograph taken from south

was mapped, for a total landslide area of 1.10 km^2. The territory affected by slope movements extends for 0.58 km^2, equivalent to 26.7% of the study area. In the study area, landslides originate from the upper part of the slopes, and where topography is concave. In the latter areas, soils and weathered deposits are thick, allowing for shallow failures to develop. Small, shallow failures take place also on pre-existing landslide deposits. Flows and slide earthflows predominate in the areas where chaotic rocks crop out. In these areas, transitional and rotational slides are present. Relict landslides are uncommon in the area. Historical information and reports on landslide events indicate that slope movements in the area are triggered chiefly by prolonged rainfall and by rapid snowmelt, which are relatively frequent in this part of Umbria.

In the Morano Madonnuccia study area we identify 22 LHZs (grey areas in Figures 15.3 and 15.4), of which 16 are for slow-moving, shallow landslides of slight intensity (2–5, 7–10, 12–13, 15–18, 20–21 on Figure 15.3C), six for slow-moving, deep-seated, rotational slides of medium (1, 6, 11, 13, 14, 19) and high (14) intensity (Figure 15.3B), and one for very old (relict), deep-seated rotational landslides of medium intensity (22 in Figure 15.3A). We obtain landslide frequency for each LHZ through the interpretation of the available sets of aerial photographs, and from field surveys in 1997 and 2001 (Table 15.8). In the 46-year observation period, landslide frequency ranges from low (one event) to very high (more than three events). The highest frequency was observed in three LHZs where shallow soil slips and earthflows occurred repeatedly (8, 13 and 15 in Figure 15.3C). Several landslides were mapped as active at the date of the photographs or the field surveys. Active landslides are shown by stars in Figure 15.3.

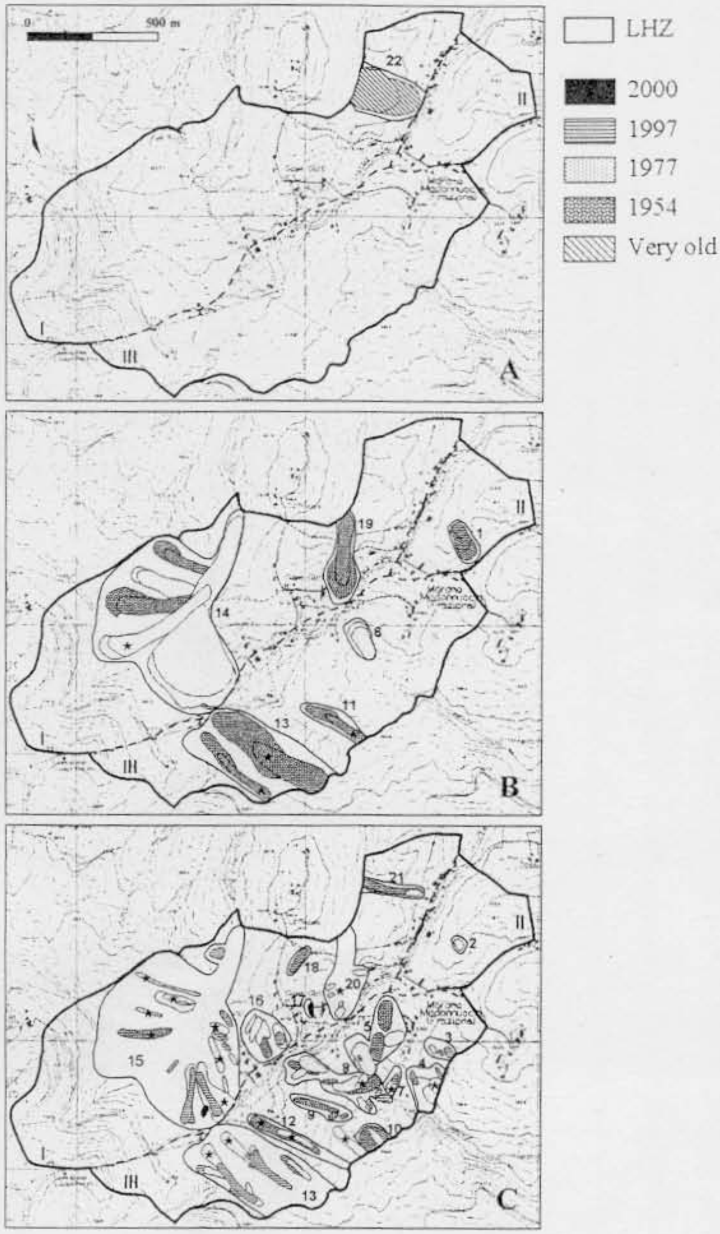

Figure 15.3 Morano Madonnuccia. Multitemporal landslide inventory map. Landslides classified by prevalent type of movement: A, relict, deep-seated slide; B, deep-seated slides and earthflows; C, shallow slides and flows. Patterns indicate relative landslide age, inferred from the date of the aerial photographs and from field surveys. Stars indicate active landslides. Grey areas with Arabic numbers are LHZs (see Table 15.8). Roman numbers indicate elementary slopes

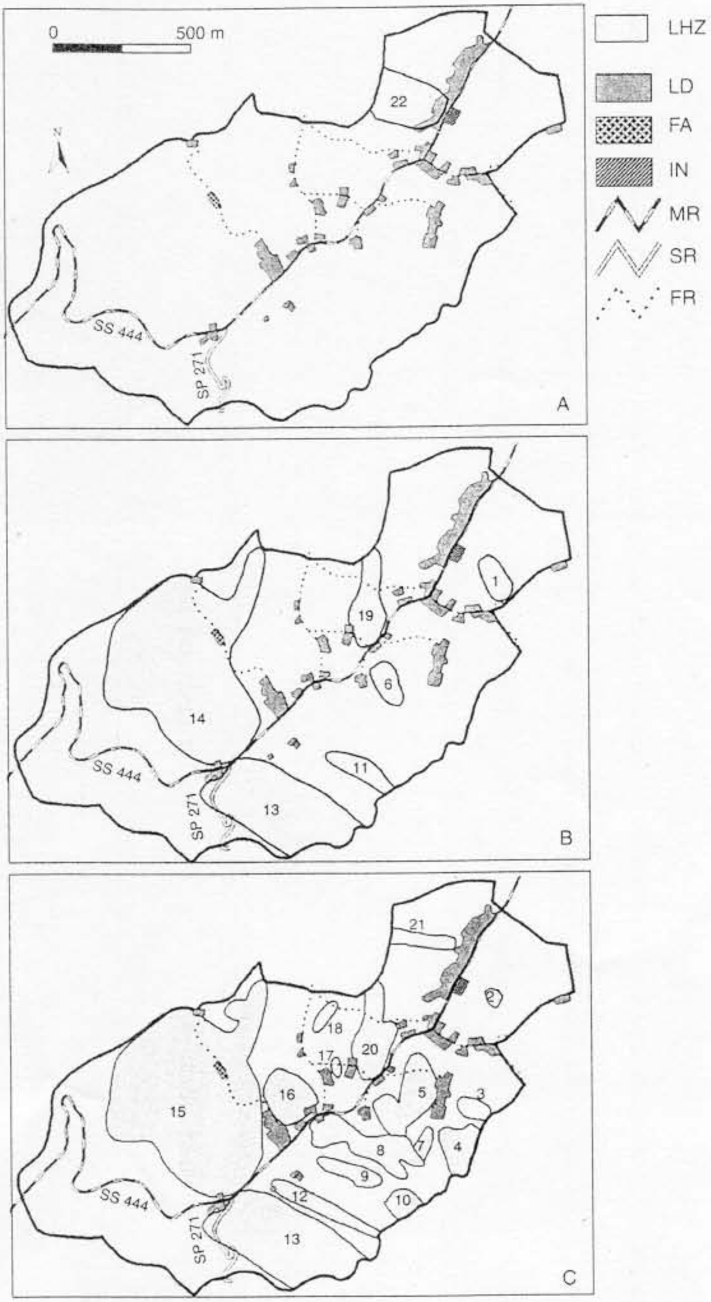

Figure 15.4 *Morano Madonnuccia. Specific landslide risk assessment (see Table 15.8). A, B and C show prevalent landslide types, as in Figure 15.3. Grey areas with Arabic numbers are LHZs. Patterns indicate types of elements at risk (see Table 15.4). Topography shown in Figure 15.3 is not shown here for clarity*

Table 15.8 *Morano Madonnuccia study area: classification of specific, R_S, and total, R_T, landslide risk*

LHZ #	Landslide type	F_L	I_L	H_L	E	V	P	R_S	R_T
1	Deep-seated slide	1	2	1 2	N	–	–	–	Very low
2	Shallow slide	1	1	1 1	N	–	–	–	Very low
3	Shallow slide	2	1	2 1	N	–	–	–	Very low
4	Shallow slide	3	1	3 1	N	–	–	–	Very low
5	Shallow slide	3	1	3 1	LD	A	N	A 3 1	Medium
					FR	S	N	S 3 1	
6	Deep-seated slide	1	2	1 2	N	–	–	–	Very low
7	Shallow slide	2	1	2 1	N	–	–	–	Very low
8	Shallow slide	4	1	4 1	LD	A	N	A 4 1	Medium
9	Shallow slide	1	1	1 1	N	–	–	–	Very low
10	Shallow slide	2	1	2 1	N	–	–	–	Very low
11	Deep-seated slide	1	2	1 2	N	–	–	–	Very low
12	Shallow slide	2	1	2 1	LD	A	N	A 2 1	Medium
13	Deep-seated slide	1	2	1 2	LD	F	H	F 1 2	High
					MR	F	I	F 1 2	
					SR	S	N	S 1 2	
	Shallow slide	4	1	4 1	LD	A	N	A 4 1	Medium
					MR	A	N	A 4 1	
					SR	F	N	F 4 1	
14	Deep-seated slide	3	2	3 2	LD	F	H	F 3 2	High
					FA	F	I	F 3 2	
					MR	F	I	F 3 2	
					FR	S	N	S 3 2	
		3	3	3 3	LD	S	H	S 3 3	
					FA	S	I	S 3 3	
					MR	S	I	S 3 3	
					FR	S	N	S 3 3	
15	Shallow slide	4	1	4 1	LD	A	N	A 4 1	Medium
					FA	A	N	A 4 1	
					MR	A	N	A 4 1	
					FR	S	N	S 4 1	

Table 15.8 (Continued)

LHZ #	Landslide type	F_L	I_L	H_L	E	V	P	R_S	R_T
16	Shallow slide	3	1	3 1	LD FR	A S	N N	A 3 1 S 3 1	Medium
17	Shallow slide	1	1	1 1	FR	S	N	S 1 1	Medium
18	Shallow slide	1	1	1 1	FR	S	N	S 1 1	Medium
19	Deep-seated slide	1	2	1 2	LD FR	F S	H N	F 1 2 S 1 2	High
20	Shallow slide	2	1	2 1	LD FR	A S	N N	A 2 1 S 2 1	Medium
21	Shallow slide	2	1	2 1	N	–	–	–	Very low
22	Very old, deep-seated slide	1	2	1 2	LD	F	H	F 1 2	Low

Note:
LHZ = landslide hazard zone; F_L = landslide frequency (Table 15.1); I_L = landslide intensity (Table 15.2); H_L = landslide hazard (Table 15.3); E = type of element at risk (Table 15.4); V = vulnerability of elements at risk (Table 15.5); P = vulnerability of population (Table 15.5).

We obtained information on the location and type of the vulnerable elements in the study area from large-scale topographic base maps at 1:10 000 scale, prepared in 1993 from aerial photographs taken in 1997, and from aerial photographs flown in October 1997. By combining this information with the landslide hazard assessment, we ascertained specific landslide risk for each vulnerable element or group of vulnerable elements. For vulnerable elements that are subject to hazards posed by different landslide types, we attributed separate levels of specific landslide risk. Table 15.8 lists the results of the risk assessment.

Our analysis indicates that deep-seated slides of medium to high intensity and high frequency (14 in Figure 15.4B) pose the highest threat to the vulnerable elements in the study area (Table 15.8). In LHZ 14 structural and functional damages to built-up areas (LD, FA) and to the transportation network (MR, FR) are expected. Indirect damages to the population and homeless people are possible, chiefly as a consequence of the expected damage to the transportation network on mobility. Significant levels of specific landslide risk are also expected where shallow landslides with high (5, 16 in Figure 15.4C) or very high (8, 13, 15 in Figure 15.4C) frequency of occurrence are present. In these LHZs, damage ranges from structural to aesthetic, and affects mostly low-density built-up areas (LD) and roads of various categories (MR, SR, FR). Based on the available information, in the Morano Madonnuccia study area shallow landslides are not expected to threaten the population. The only very old (relict), deep-seated slide identified in the area (22 in Figure 15.4A) exhibits very low frequency and medium intensity, and is expected to produce functional damage to low-density build-up areas (LD).

It is worth noticing that in the Morano Madonnuccia study area, for 10 LHZs (i.e. 1–4, 6–7, 9–11, 21 in Figure 15.3) levels of landslide hazard were ascertained, but vulnerable elements are not present (Figure 15.4). Hence landslide risk does not presently exist in these LHZs (N in Table 15.8). If houses, roads, or other elements at risk are constructed in the LHZs, landslide risk will materialize. It will then be straightforward to determine levels of specific landslide risk, based on the type of vulnerable elements, and of values of landslide hazard.

Table 15.8 also illustrates levels of total landslide risk for the 22 LHZs identified in the Morano Madonnuccia study area. Total landslide risk is estimated to be high for low-density built-up areas (LD) and for livestock farms (FA), where deep-seated landslides are present (13–14, 19 in Figure 15.4). This is chiefly because indirect damages to the population and homeless people are expected. Where low-density settlements (LD) and roads (MR, SR, FR) are affected by shallow slides of high and very high frequency, total landslide risk is medium (5, 8, 12–13, 15, 15–18, 20 in Figure 15.4). We attribute very low levels of total landslide risk to LHZs where landslide hazard was determined but that are currently free of vulnerable elements (1–4, 6–7, 9–11, 21 in Figure 15.4). In these LHZs the estimate of total landslide risk will change significantly if building, roads, and other structures are constructed.

15.5.2 Sugano

The landscape in southwestern Umbria has the tabular morphology of a mesa rimmed by an articulated escarpment formed by resistant pyroclastic rocks. Towns and villages are built on buttes and isolated mesa remnants, and at the edge of the escarpment that bounds the volcanic plateau. In the area, there are outcrops of lava flows, ignimbrites and pyroclastic deposits pertaining to the Mt Vulsini volcanic complex, Quaternary in age. The volcanic rocks overlie marine sediments, chiefly clay and subordinately sand and gravel, upper to middle Pliocene in age. The contact between the volcanic cap and the underlying marine deposits is low angle, and almost everywhere covered by thick talus deposit.

In the area, mass movements affect the edge of the volcanic cap and extend laterally for several kilometres, to form a continuous belt of landslide deposits (Guzzetti *et al.*, 1996). Landslides occur within the volcanic complex, in the jointed pyroclastic cap, and in the underlying marine clay. The relative position of stiff and deformable rocks accounts for the widespread landsliding. Failure of the volcanic cap has two main causes: the increase of tensile stresses in the volcanic rock due to the different deformability of the pyroclastic sediments in contrast to the more plastic marine sediments; and the reduction of the resisting stresses at the base of the cliff, due to landsliding in the clay (Lembo-Fazio *et al.*, 1984).

Sugano, a small town in Orvieto Municipality, extends along the edge of a tabular promontory bounded by a sub-vertical escarpment, 50–100 meters in height, where volcanic rocks crop out (Figure 15.5). The study area is bounded by a single 'elementary slope', which extends for about 1 km^2 (Figure 15.6). For the study area, we made a multitemporal landslide inventory map by studying three sets of aerial photographs, and by studying field surveys. Aerial photographs were taken in September 1954 at 1:33 000 nominal scale, in June 1977 at 1:13 000 nominal scale, and in March 1994 at 1:36 000 nominal scale. Field reconnaissance of the area was completed in May 2000.

The multitemporal inventory map shows 39 landslides, for a total landslide area of 0.41 km^2. The territory affected by slope movements extends for 0.29 km^2 (including 0.035 km^2 of rockfall source areas), 35.2% of the study area. Different types of mass

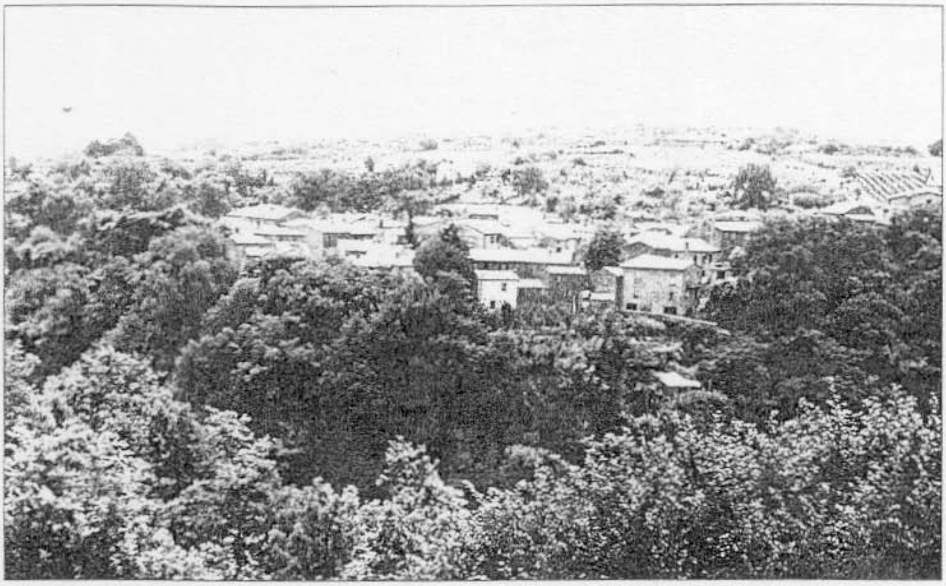

Figure 15.5 Panoramic view of the Sugano study area. Photograph taken from southeast

movements coexist in the area. Marine clays underlying the volcanic rocks are affected by large, very old (relict), deep-seated block slides (Figure 15.6A), by deep-seated slides and slide earthflows (Figure 15.6B), and by shallow rotational and translational slides, and slide earthflows (Figure 15.6C). Rockfalls, topples and rockslides (Figure 15.6D) erode the volcanic cliff, and endanger the houses located at the edge of the escarpment, some of which had to be abandoned.

Rockfall, topple and minor rockslide deposits and talus deposits form a continuous belt of coarse landslide debris at the toe of the volcanic escarpment and in the crown area of the relict, deep-seated block slides. At the base of the volcanic escarpment, deposits of disrupted rockslides, of high to very high intensity (Table 15.2), were identified under the thick forest cover. Shallow and deep-seated landslides are abundant at the toe of the relict block slides, where the Leone Creek undercuts the toe of the landslides. Shallow landslides locally affect the softened soils on the pre-existing landslide deposits.

In the Sugano study area we identify eight LHZs (grey areas in Figures 15.6 and 15.7), of which two are for very old (relict), deep-seated block slides of high intensity (7, 8 in Figure 15.6A), two for slow-moving, deep-seated, rotational slides of medium intensity (4, 5 in Figure 15.6B), three for slow-moving shallow landslides of slight intensity (2, 3, 6 in Figure 15.6C), and one for fast-moving rockfalls, topples and rockslides, of low to very high intensity (1 in Figure 15.6D).

For the eight LHZs, we obtain landslide frequency through the interpretation of the three sets of aerial photographs and the field surveys. In the 47-year observation period, landslide frequency ranges from low (one event) to high (three events). Frequency of rockfalls is assigned high, based on historical information and field observations carried out along the volcanic escarpment and on the talus slope. In the most recent set of aerial

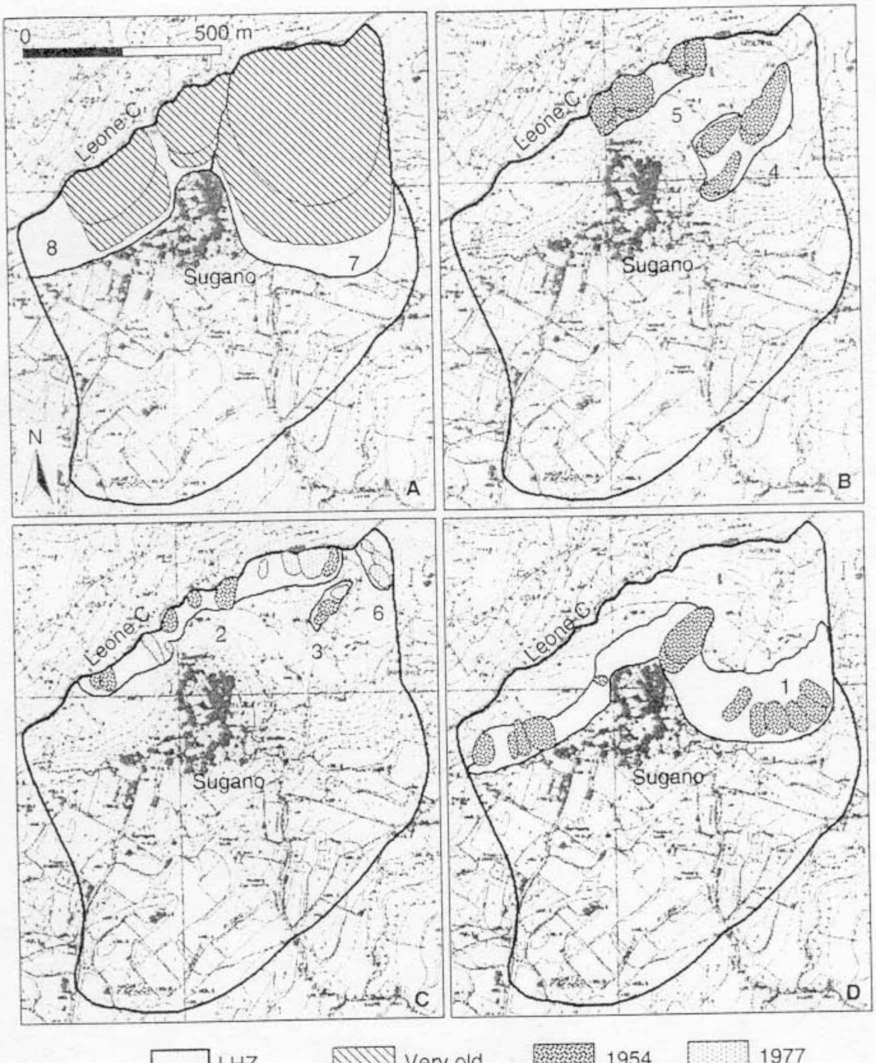

Figure 15.6 *Sugano. Multitemporal landslide inventory map. Landslides classified by prevalent type of movement: A, relict, deep-seated block slides; B, deep-seated slides and earthflows; C, shallow slides and flows; D, fast-moving rockfalls, topples and rockslides. Patterns indicate relative landslide age, inferred from the date of the aerial photographs and from field surveys. Grey areas with Arabic numbers are LHZs (see Table 15.9)*

photographs (March 1994) no new landslides were identified. Small, mostly shallow slope movements have almost certainly occurred in the period 1977–94, but they may have been rapidly hidden by intense mechanical ploughing. In addition, rockfalls and topples occurring from the volcanic escarpment may not have been visible on the aerial photographs, or their deposits may have been concealed by the forest cover (Figure 15.5).

Figure 15.7 *Sugano. Specific landslide risk assessment (see Table 15.9). A, B, C and D show prevalent landslide type, as in Figure 15.6. Grey areas with Arabic numbers are LHZs. Patterns indicate types of elements at risk (see Table 15.4). Topography shown in Figure 15.6 is not shown here for clarity*

We obtained information on the location and type of the vulnerable elements in the study area from the available large-scale topographic maps at 1:10 000 scale, prepared in 1993 from aerial photographs taken in 1987, and from aerial photographs flown in March 1994. By studying together the landslide hazard and the spatial distribution of the vulnerable elements (Figure 15.8), we ascertained specific landslide risk, R_S, for each vulnerable element in the Sugano study area. For vulnerable elements that are subject to hazards posed by different landslide types, we attributed separate levels of specific landslide risk. Table 15.9 summarizes the result of the risk assessment.

Fast-moving landslides pose the highest landslide treat in the Sugano study area. Where rockfalls, topples, and rockslides affect the edge of the volcanic cap, structural damage is expected, including total destruction of buildings (HD and LD) and roads (FR) (1 in Figure 15.7D). In this area, fatalities and homeless people are expected if fast-moving landsides should occur. Deep-seated slides and slide earthflows of medium intensity may produce functional damage to low-density settlements (LD) and structural damage to farm and other minor roads (FR) (4, 5 in Figure 15.7B). Shallow mass movements of slight intensity and high frequency are expected to cause aesthetic damage to low-density built-up areas (LD) and structural damage to minor roads (FR). Relict block slides, of high and very high intensity (7–8, Figure 15.7, Table 15.9), are expected to cause structural damage to high-density (HD) and low-density (LD) built-up areas, and to secondary and farm roads (SR, FR). In these areas, indirect damage to the population and

Table 15.9 *Sugano study area, classification of specific, R_S, and total, R_T, landslide risk*

LHZ #	Landslide type	F_L	I_L	H_L	E	V	P	R_S	R_T
1	Rock falls	3	3	3 3	HD LD FR	S S S	D, H D, H D	S 3 3 S 3 3 S 3 3	Very high
		1	4	1 4	HD LD FR	S S S	D, H D, H D	S 1 4 S 1 4 S 1 4	Very high
2	Shallow slide	3	1	3 1	LD	A	N	A 3 1	Medium
3	Shallow slide	2	1	2 1	FR	S	N	S 2 1	Medium
4	Deep-seated slide	1	2	12	LD FR	F S	H N	F 1 2 S 1 2	High
5	Deep-seated slide	1	2	1 2	LD	F	H	F 1 2	High
6	Shallow slide	1	1	1 1	FR	S	I, H	S 1 1	Medium
7	Very old, deep-seated slide	1	4	1 4	HD LD SR FR	S S S S	I, H I, H I N	S 1 4 S 1 4 S 1 4 S 1 4	Low
8	Very old, deep-seated slide	1	3	1 3	HD LD FR	S S S	I, H I, H N	S 1 3 S 1 3 S 1 3	Low

Note:
LHZ = landslide hazard zone; F_L = landslide frequency (Table 15.1); I_L = landslide intensity (Table 15.2); H_L = landslide hazard (Table 15.3); E = type of element at risk (Table 15.4); V = vulnerability of elements at risk (Table 15.5); P = vulnerability of population (Table 15.5).

homeless people is expected, mostly as a consequence of the damage to the transportation network.

Table 15.9 illustrates total landslide risk, R_T, in the Sugano study area. Total landslide risk is estimated to be particularly severe where fast-moving landslides, including rockfalls, topples and rockslides, are expected. In these areas casualties and structural damage to high-density settlements (HD) and minor and farm roads (FR) are possible (1 in Figure 15.7 and Table 15.8). A high level of total landslide risk exists where low-density settlements (LD) are affected by deep-seated slides of medium intensity, which can cause functional damage (5 in Figure 15.7 and Table 15.8). Where low-density settlements (LD) and farm and other minor roads (FR) are affected by shallow landslides, total landslide risk is medium (2–3, 6 in Figure 15.7). Where very old (relict), deep-seated slides have been identified (7–8 in Figure 15.7), total landslide risk is ascertained as low, despite the fact that structural damage to structures and infrastructure, and indirect damage to the population is possible. This is done because reactivation of the entire, very old (relict) landslides is not considered likely under the present climatic and seismic conditions.

15.5.3 Piedipaterno

Massive and layered limestone, marl and clay crop out in southeastern Umbria. These rocks pertain to the Umbria–Marche stratigraphic sequence, Lias to Eocene in age. Recent travertine sediments, talus deposits, debris cones and alluvial sediments are locally present. The structural setting of the area is determined by the superposition of two tectonic phases. A compressive phase, of late Miocene to early Pliocene age, was followed by an extensional tectonic phase of Pliocene to recent age. The compressive deformation

Figure 15.8 Panoramic view of the Piedipaterno study area. Photograph taken from southeast

produced large, east-verging folds associated with thrusts and transcurrent faults. The extensional tectonic phase produced normal faults with large vertical displacements. Morphology of the area is controlled by the lithological and structural settings. Major divides coincide with the trend of the largest anticlines, and valleys parallel to the major tectonic elements were formed along synclines, grabens or semi-grabens (Guzzetti *et al.*, 1996).

Regional landslide inventory maps for the Umbria region (Antonini *et al.*, 2002a) reveal that where layered limestone and marl crop out landslides affect about 7.43% of the area. Landslides are both deep-seated, complex or compound mass movements, and shallow failures, chiefly fast-moving rockslides, topples, rockfalls and channelled debris flows. Slow-moving failures are transitional or rotational slides and slide flows, and are most abundant where marly limestone crops out. Rockfalls, topples and rockslides are abundant where cliffs in hard rocks are present. Fast-moving landslides are triggered by different causes, including rainfall and freeze–thaw cycles, but they are most abundant during earthquakes (Antonini *et al.*, 2002b). Debris flows originate where loose debris is abundant, and in particular along the shear zone of regional faults, from talus and scree slopes, or from landslide deposits (Guzzetti *et al.*, 1996; Guzzetti and Cardinali, 1991, 1992).

Piedipaterno is a village in Vallo di Nera Municipality, at the confluence of the Lagarelle Torrent with the Nera River (Figure 15.8). The Lagarelle Torrent drains a small and steep catchment that extends for 2.4 km^2 on the eastern slope of Mount Galenne. Elevation in the area ranges from 320 m, at the confluence with the Nera River, to 1217 at the top of Mount Galenne. Slopes are very steep, locally sub-vertical to the north and northwest of the village, and along the Nera River Valley, where rock cliffs and pinnacles are present. In the area, layered limestone and marl crops out that is Cretaceous to upper Eocene in age, pertaining to the middle to upper section of the Umbria–Marche stratigraphic sequence. In the middle and upper part of the Lagarelle catchment, bedding dips into the slope (i.e. towards the west) with an angle of about 30°. In the lower part of the catchment tectonic folds are present.

In the Piedipaterno area we identify two 'elementary slopes', for a total area of about 2 km^2 (Figure 15.9). The first elementary slope comprises the catchment of the Lagarelle Torrent (I in Figure 15.9). The second elementary slope is constituted by steep rock slopes along the Nera River Valley (II in Figure 15.9).

For the study area, we obtained a multitemporal landslide inventory map by studying three sets of aerial photographs, and by looking at field surveys. Aerial photographs were taken in August 1954 at 1:33 000 nominal scale, in June 1977 at 1:13 000 nominal scale, and in October 1997 at 1:13 000 nominal scale. Field reconnaissance of the area was completed in October 1997, following the September–October earthquake sequence (Antonini *et al.*, 2002b) and in June 2000.

A total of 17 landslides was mapped in the area, for a total landslide area of 0.87 km^2. Landslides cover 0.61 km^2 (including six debris-flow areas and three rockfall source areas), 23.1% of the study area. Figure 15.9 illustrates the various types of landslides identified in the study area. Landslides are classified based on the prevalent type of movement and estimated age, inferred from the date of the aerial photographs. Inspection of Figure 15.9 reveals that the lower part of the Lagarelle catchment hosts a large, deep-seated and complex slide (Figure 15.9A). Based on the morphological appearance, we classify the very old landslide as relict. The slope movement affects the limestone and marl bedrock and the thick talus deposit. Numerous deep-seated (Figure 15.9B) and shallow (Figure 15.9C), rotational and translational landslides are present inside or at the edge of the relict landslide. Some of the slope failures are partial reactivations of the relict-landslide, whereas others are new landslides that have affected the softened cover of the very old landslide deposit. A small rotational slide identified in the 1977 aerial photographs (Figure 15.9C) produced functional damage to Provincial Road 465. Fast-moving rockfalls (Figure 15.9D) occur from the rock cliffs above the northern side of the village and along the Nera River Valley. These fast-moving landslides threaten

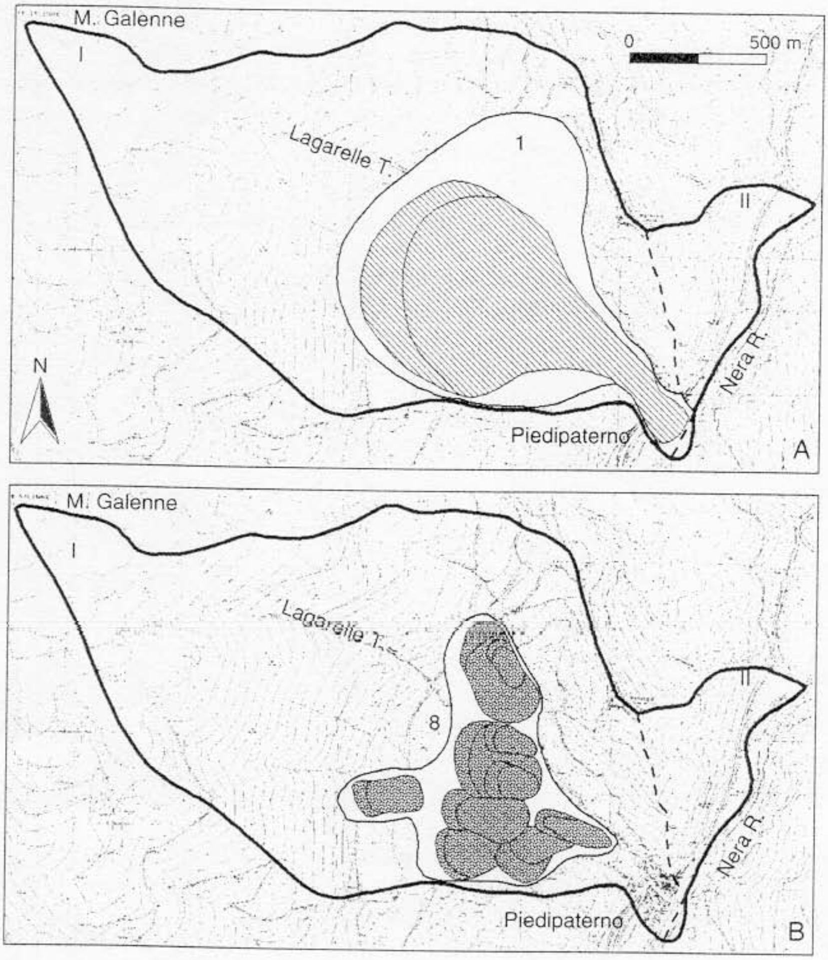

Figure 15.9 Piedipaterno. Multitemporal landslide inventory map. Landslides classified by prevalent type of movement: A, deep-seated slide; B, deep-seated slides and earthflows; C, shallow slides and flows; D, fast-moving rockfalls; E, rapid-moving debris flows. Patterns indicate relative landslide age, inferred from the date of the aerial photographs and from field surveys. Grey areas with Arabic numbers are LHZs (see Table 15.10). Roman numerals indicate elementary slopes

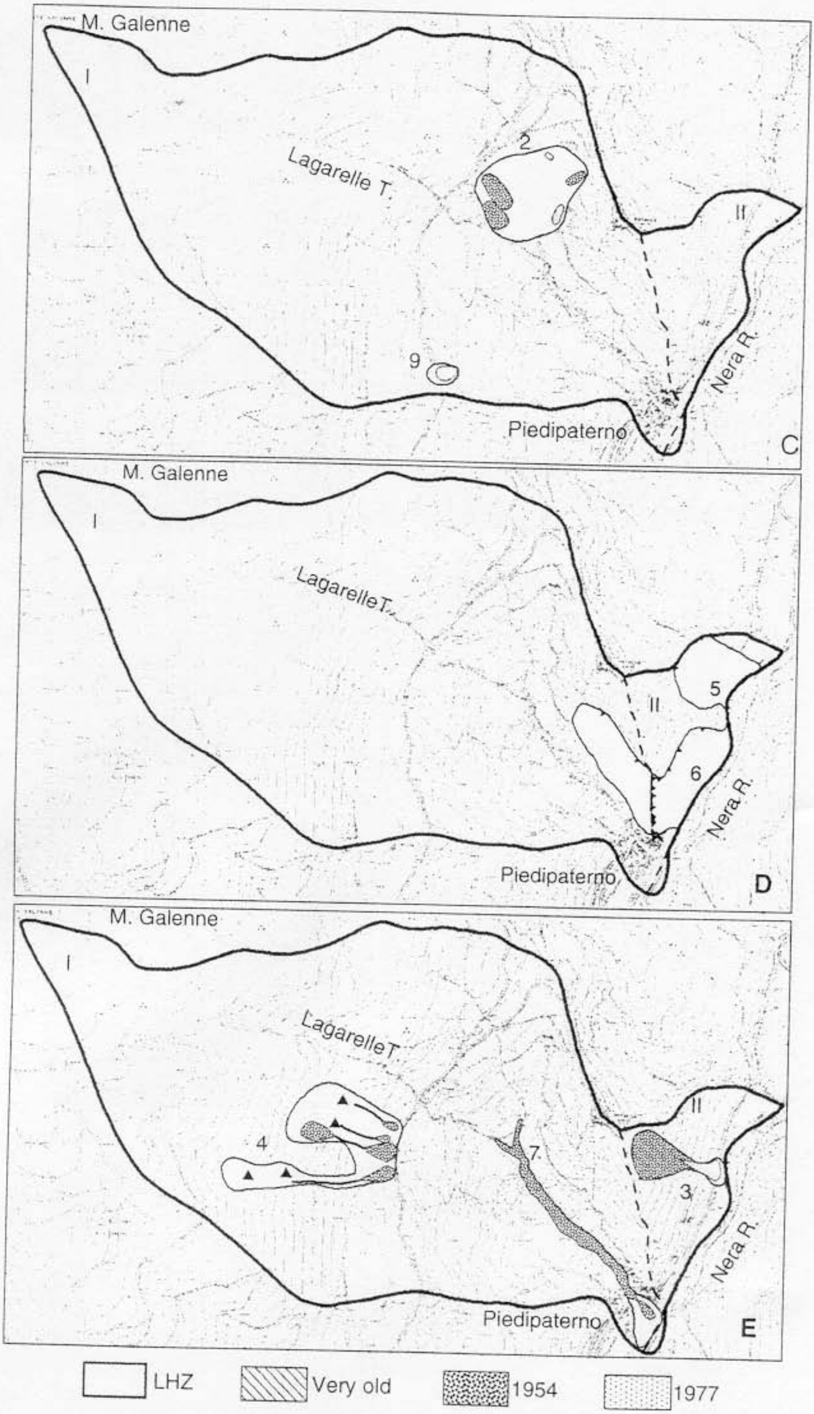

Figure 15.9 (Continued)

the northern part of the village and a 900 m long section of State Road 209. In April 1992, boulders detached from the rock cliff above the oldest part of the village, severely damaging at least a house. Following this event, elastic nets were installed to protect the houses from rockfalls. The September–October 1997 earthquake sequence apparently did not trigger significant rockfalls in the Piedipatero area (Antonini *et al.*, 2002b). Morphological evidence for debris flows was observed along the lower part of the Lagarelle Torrent on the 1954 aerial photographs. In 1965, a flash flood with associated debris flow occurred along the Lagarelle Torrent, inundating the village and producing extensive damage. Following the event, check dams were built upstream of the village to prevent further damage. Minor debris-flow sources and channels were mapped on the 1954 aerial photographs on the steep slopes of Mount Galenne, and along the Nera River Valley (Figure 15.9E).

In the Piedipaterno study area we recognize nine LHZs (grey areas in Figures 15.9 and 15.10), of which one is for a relict, deep-seated landslide (1 in Figure 15.9A), one for deep-seated, rotational slides of medium intensity (8 in Figure 15.9B), two for slow-moving shallow landslides of slight intensity (2, 9 in Figure 15.9C), two for fast-moving rockfalls (5, 6 in Figure 15.9D), and three for rapid-moving debris flows (3, 4, 7 in Figure 15.9E). For each LHZ we obtain landslide frequency through the interpretation of the available aerial photographs, the historical information, and the field surveys. In the 47-year observation period, landslide frequency ranges from low (one event) to high (three events). For rockfalls and debris flows, landslide frequency is assigned as high, based on the available historical information and on field observations. We obtained information on the location and type of the vulnerable elements in the study area from large-scale topographic maps at 1:10 000 scale, prepared in 1992 from aerial photographs taken in 1986, and from aerial photographs flown in October 1997 (Figure 15.10). By combining this information with the landslide hazard assessment, we estimated levels of specific landslide risk for each vulnerable element or group of vulnerable elements. Where vulnerable elements are subject to hazards posed by different landslide types, we attribute separate levels of specific landslide risk. Table 15.10 summarizes the result of the risk assessment.

In the Piedipaterno study area, fast-moving rockfalls and, subordinately, rapid-moving debris flows pose the highest threat. Field evidence, information on past landslide events, and the location of the vulnerable elements with respect to the rockfall source, travel and deposition areas, together contribute to very high levels of specific landslide risk to vulnerable elements and the population (Figure 15.10E). In the areas where rockfalls have occurred in the past, total or partial destruction of buildings (HD) and functional damage of roads (MR) is expected in the future. Our assessment does not consider the mitigating effect of the existing rockfall defensive structures (i.e. retaining nets and elastic fences) because the existing structures may not be adequate in stopping all rockfalls (Guzzetti *et al.*, 2004). Where rockfalls are expected, fatalities and homeless people are possible.

The section of the Piedipaterno village nearest to the Lagarelle Torrent is subject to flash floods and debris flows (7 in Figure 15.10D). In this area, debris flows can produce functional damage to buildings (HD) and roads (MR), and can cause direct and indirect damage to the population, including homeless people. Historical information indicates that this occurred in 1965. Since then the situation has worsened. Check dams upstream of the village are filled by debris and vegetation, and the Lagarelle Torrent was channelled and covered where it goes through the village (Figure 15.11), reducing significantly its water and sediment discharge capability. In addition, debris flows can cause functional damage to State Road 209 (3 in Figure 15.10D) and to Provincial Road 465 (4 in Figure 15.10D). In both areas, direct and indirect damage to people is possible.

Where deep-seated slides of medium intensity (8 in Figure 15.10) and shallow landslides of slight intensity (9 in Figure 15.10) were identified, structural damage to secondary roads (SR) is expected. The relict, deep-seated landslide (1 in Figure 15.10) can cause severe structural damage to both high-density (HD) and low-density (LD) built-up

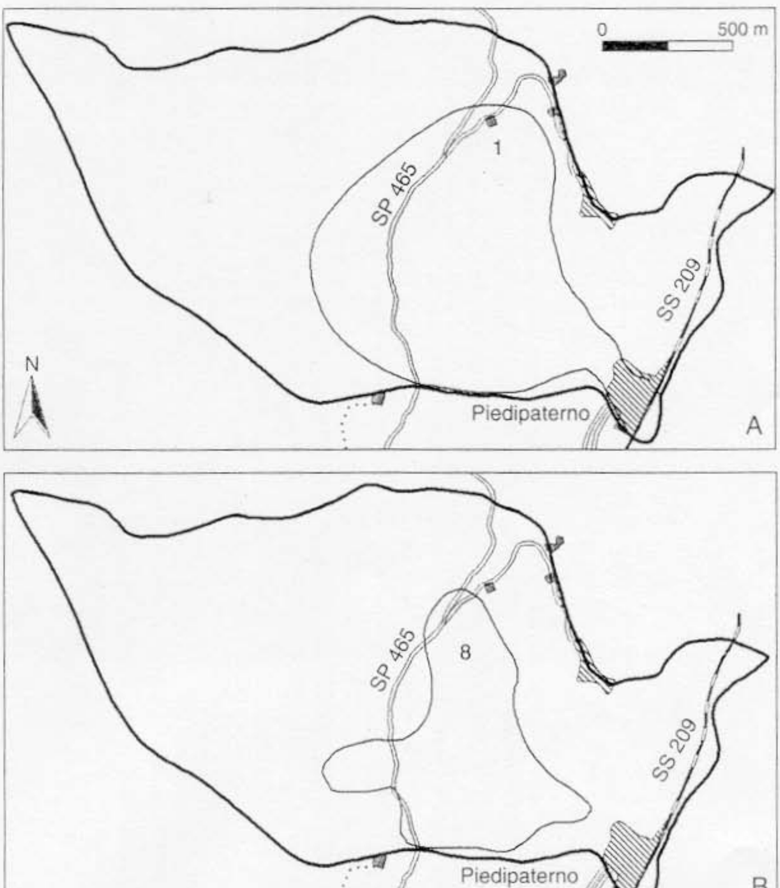

Figure 15.10 *Piedipaterno. Specific landslide risk (see Table 15.9). A, B, C, D and E show prevalent landslide type, as in Figure 15.9. Grey areas with Arabic numbers are LHZs (see Table 15.10) Patterns indicate types of element at risk (see Table 15.4). Topography shown in Figure 15.9 is not shown here for clarity*

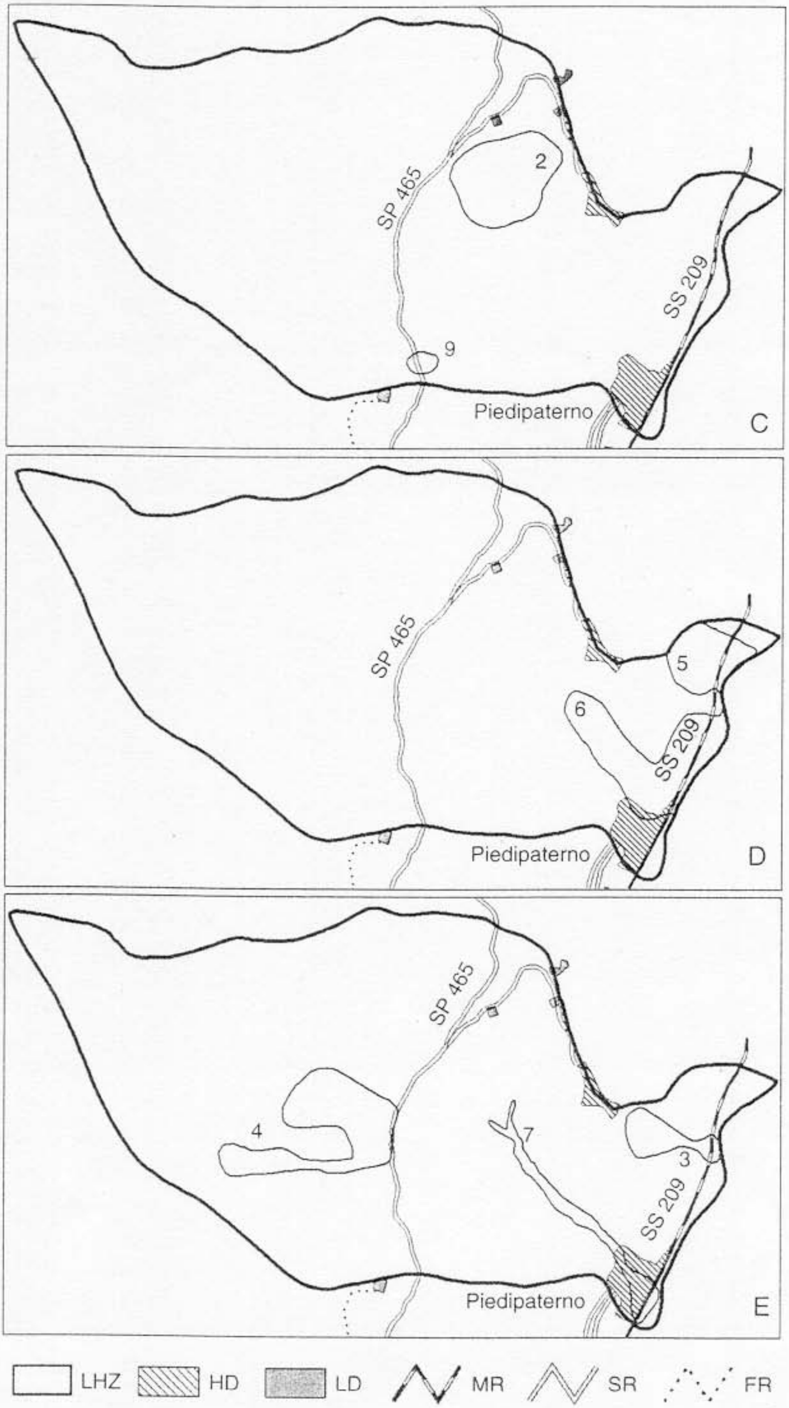

Figure 15.10 (Continued)

Table 15.10 *Piedipaterno study area, Classification of specific, R_S, and total, R_T, landslide risk*

LHZ #	Landslide type	F_L	I_L	H_L	E	V	P	R_S	R_T
1	Very old, deep-seated slide	1	4	1 4	HD LD MR SR	S S S S	H H I N	S 1 4 S 1 4 S 1 4 S 1 4	Low
2	Shallow slide	2	1	2 1	–	–	–	–	Very low
3	Debris flow	2	2	2 2	MR	F	D, I	F 2 2	Very high
4	Debris flow	2	2	2 2	SR	F	D	F 2 2	Very high
5	Rock falls	3	2	3 2	MR	F	D, I	F 3 2	Very high
6	Rock falls	3	2	3 2	HD MR	F F	D, I, H D, I	F 3 2 F 3 2	Very high
7	Debris flow	2	2	2 2	HD MR	F F	D, I, H D, I	F 2 2 F 2 2	Very high
		1	3	1 3	HD MR	F F	D, I, H D, I	F 1 3 F 1 3	Very high
8	Deep-seated slide	1	2	1 2	SR	S	N	S 1 2	Medium
9	Shallow slide	1	1	1 1	SR	F	N	F 1 1	Medium

Note:
LHZ = landslide hazard zone; F_L = landslide frequency (Table 15.1); I_L = landslide intensity (Table 15.2); H_L = landslide hazard (Table 15.3); E = type of element at risk (Table 15.4); V = vulnerability of element at risk (Table 15.5); P = vulnerability of population (Table 15.5).

areas, and to the transportation network (MR, SR). This is mostly because of the large volume of the landslide (i.e. intensity). If the landslide should move, indirect damage to the population and homeless people is possible.

Table 15.10 illustrates total landslide risk for the Piedipaterno study area. Total landslide risk is estimated to be very high where fast-moving rockfalls are expected, and in the areas that can be affected by rapid-moving debris flows. Where rockfalls and debris flows are expected, casualties and structural damage to high-density settlements and major roads are possible (3, 5–7 in Figure 15.10). The very high level of total landslide risk is assigned mostly because casualties are expected. In the case of rockfalls, the observed frequency of events results in a very high total landslide risk. Medium levels of total landslide risk arise in the areas where deep-seated and shallow slope failures can cause structural damage to the transportation network (8, 9 in Figure 15.10). Where the relict, deep-seated slide was identified (1 in Figure 15.10), total landslide risk is ascertained as low, despite possible damage to structures and infrastructure, and indirect damage to the population. As in the case of Morano Madonnuccia, this is done because reactivation of the relict landslide in considered unlikely under the present climatic and seismic conditions. For one LHZ (2 in Figure 15.10), total landslide risk is assessed as very low, despite landslide hazard being not negligible ($H_L = 21$). This is because elements at risk are not present in this LHZ.

Figure 15.11 The Lagarelle Torrent canalized and partly covered where it crosses the Piedipaterno Village. The canalized cross section is too small to contain flash floods and debris flows

15.6 Discussion

The proposed method complies with the existing and widely accepted definitions of landslide hazard (Varnes – IAEG, 1984; Guzzetti *et al.*, 1999a, 1999b) and of landslide risk (Varnes – IAEG, 1984; Einstein, 1988; Cruden and Fell, 1997; Guzzetti, 2002). The method is empirical and subject to various levels of uncertainty, but has proved to be reliable and cost-effective, allowing for detailed and comparable assessments of landslide hazard and specific and total landslide risk levels in urban and rural areas in Umbria. The method allows the comparison of landslide hazard and risk in distinct and distant areas, and where different landslide types are present.

The method was successfully applied in 210 landslide hazard zones located around or in the vicinity of 79 towns and villages in Umbria (Antonini *et al.*, 2002a; Cardinali *et al.*, 2002b). In these areas landslide hazard was determined, vulnerable elements were identified, and specific and total risk levels were evaluated. The time and human resources required for completing the risk assessment procedure at each site varied, depending on the extent of the study area, the number, type and scale of the aerial photographs, the available thematic and historical information, the extent and type of landslides present in the study area, and the local geological and morphological setting. On average, completion of the risk assessment procedure at each site required five days for a team of three to four geomorphologists, including bibliographical investigation, interpretation of the aerial photographs, field surveys, storage of landslide and thematic information in the GIS database, and the production of the final hazard, vulnerability and risk maps.

The method requires extensive geomorphological judgement. For this reason it should only be used by skilled geomorphologists. If the extent, type, distribution and pattern of past and present landslides are not correctly and fully identified, errors can occur and thus affect the estimate of landslide hazards and risk. With this in mind, the definition of the temporal frequency of landslides from the analysis of the multitemporal inventory map is particularly important. The map covers a period of about 47 years (from 1954 to 2001), which is long enough to evaluate the short-term behaviour of slopes in the areas investigated. Should information on landslide frequency be available only for a shorter period of time (e.g. 10–15 years or less), the reliability of the hazard forecast will be reduced. If a landslide event fails to be recognized, the frequency of occurrence is underestimated, and hazard and risk estimates are negatively affected. It should be noted that the method estimates the expected landslide frequency based on what has happened (and was observed) in the recent past. If low-frequency, high-magnitude events did not occur or were not recognized in an LHZ, the hazard assessment in the area may be biased, and the actual landslide risk is underestimated. This is a limitation of the method.

The method allows for detailed and articulated hazard and risk assessments. Landslide hazard is determined separately for all the different landslide types that may be present in the study area. Specific landslide risk is determined independently for each type of vulnerable element in the study area. Thus vulnerable elements may be subject to multiple levels of specific landslide risk, and landslide hazard may be ascertained where vulnerable elements are not present. The proposed method assesses landslide hazard in the areas of probable evolution of the existing landslides (i.e. in a landslide hazard zone). The method says nothing about the hazard outside an LHZ, even within the same elementary slope. In these areas minor landslides, mostly superficial failures, can occur with a low frequency. For a regional, spatially distributed landslide hazard and risk assessment, other methods should be used (see for example Soeters and van Westen, 1996; Guzzetti *et al.*, 1999b; and references therein), possibly in combination with the method proposed here.

Uncertainty varies with the different steps of the method. The production of the separate landslide inventory maps and of the multitemporal landslide map is less uncertain than the identification of the landslide hazard zones, or the possible spatial evolution of the existing landslides, which is obtained mostly through geomorphological inference. Landslides mapped through the interpretation of aerial photographs were carefully checked in the field, whereas the identification and mapping of LHZs was based on the observation of other landslides and on the inferred geomorphological behaviour of slopes. Evaluations of landslide frequency, which determine landslide hazards, are conditioned by the availability of aerial photographs and historical information, and by our ability to recognize past and present landslide events. Estimates of landslide volume and velocity, which are essential for the evaluation of landslide intensity, also exhibit uncertainty.

Uncertainty also arises because a difference exists between geomorphological and historical information on landslides in Umbria. Geomorphological information obtained through field mapping and the analysis of aerial photographs provides the basis for determining the prevalent landslide types and location, but provides poor constrain on the date (or the age) of the slope failures. Historical and archived information provide precisely the date (or even the time) of occurrence of some of the landslide events, and the type and extent of damage caused by mass movements, but provide little information on the type of failures and the precise location and extent of the landslides. As pointed out by Guzzetti *et al.* (2003), combining of geomorphological and historical information on mass movements is not straightforward, and may be a matter of local interpretation and local judgement.

The proposed method relies on a set of correlation tables which are used to define landslide frequency (Table 15.1) and intensity (Table 15.2), to ascertain landslide hazard (Table 15.3), to evaluate the expected damage to the vulnerable elements (Table 15.5), and to attribute levels of specific landslide risk (Tables 15.6). The tables used in this work are based on empirical observations and on our own experience, but are also the result of a heuristic approach. Whenever possible we tried each of several possibilities and evaluated the difference after each attempt. We believe that the tables fit the present understanding of landslide processes and match landslide damage in Umbria satisfactorily. However, the tables are not definitive, and should not be used unconditionally in all settings. If applied to other sites, or in other study areas, they should be carefully checked with the local information on landslide types and damage. If one, or more, of the tables is changed significantly, the hazard and risk assessment will vary, and may not be comparable with the one we have prepared. This is particularly important for Tables 15.5 and 15.6.

Landslide hazard and risk are expressed using a multiple-digit, 'positional' index that shows, in a compact and convenient format, all the variables used to ascertain landslide hazard and risk (i.e. intensity, frequency and vulnerability). The index allows for the ranking of risk conditions at the end of the risk assessment process, when all the necessary information is available, and not *a priori*, based on predefined (often ill-formalized) categories. We consider this a major advantage of the method, giving risk managers and decision makers great flexibility in deciding which area exhibits the highest risk, and providing geologists and engineers with a clue about why any given vulnerable element is at risk. In addition, the use of a simple index to express levels of specific landslide risk makes it possible to adopt different schemes to determine levels of total landslide risk, depending on the priorities or the specific interests of the investigators or the end-users.

When determining landslide risk, in places we decided not to consider the mitigating effects of the existing defensive measures. Structural measures may be at least partially ineffective in mitigating landslide risk. This is often the case for rockfall-retaining nets or elastic fences that can be jumped by high-flying boulders or that can be destroyed by large blocks (Guzzetti *et al.*, 2004). Check dams and channels built to prevent or to mitigate debris flows may be filled by debris and vegetation, due to lack of maintenance. The effects of structural measures on deep-seated landslides (e.g. retaining walls, piles, earthworks, drainage systems, etc.) are difficult to evaluate without accurate, long-term monitoring.

Lastly, the proposed method is not simple or straightforward. Dependable and consistent prediction requires multiple sets of aerial photographs and a team of experienced geomorphologists to interpret them. This cannot be considered a limitation: landslide hazard and risk assessments are difficult tasks, and require proper expertise and skills.

15.7 Conclusion

We have presented a geomorphological method to ascertain landslide hazard and to evaluate the associated risk, at site scale, and we have shown three applications of the method in Umbria. The method is based on careful recognition of present and past landslides, scrutiny of the local geological and morphological settings, and analysis of site-specific and historical information on past landslide events. Most of the information used to ascertain landslide hazard is obtained from the analysis of a multitemporal landslide inventory map that portrays information on the distribution, type and pattern of landslides and on their changes in time. The multitemporal map is obtained by merging landslide inventory maps prepared through the analysis of stereoscopic aerial photographs of different ages, and by use of field surveys.

The method was applied extensively in the Umbria region of central Italy, and allowed determining and comparing specific landslide risk in 210 landslide hazard zones around or in the vicinity of 79 towns and villages in Umbria. Results of the hazard and risk assessment procedure were recently incorporated in the river basin geo-hydrological hazard reduction plan, prepared by the Tiber River Basin Authority. Results were also distributed by the Umbria regional government to municipalities in Umbria. At present it is not possible to judge quantitatively how good the proposed method is, and how reliable our hazards and risk assessments are. Municipalities in Umbria are checking the landslide hazard and risk assessments, and they are comparing them to prior information and to existing planning schemes and building codes. We look forward to knowing what problems they will discover, and to investigating how they will use the new information on landslide hazards and risk. While we wait for the results of this independent analysis, we have started applying the methodology to an area extending to about $70\,km^2$ in central Umbria, that comprises several tens of elementary slopes, hundreds of landslide hazard zones, and thousands of shallow and deep-seated landslides. We hope to bridge the existing gap between hazards and risk assessments at the site scale, as presented in this study, and regional assessments of the impact of mass movements on the population, the built-up areas and the infrastructure in Umbria (Guzzetti *et al.*, 2003).

Acknowledgements

Research for this chapter was supported by CNR GNDCI and CNR IRPI funds, and by a specific grant of the Regione dell'Umbria and of the Tiber River Basin Authority. We are grateful to Earl E. Brabb for reviewing the manuscript. The paper is CNR GNDCI publication number 2806.

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