The majority of the landslides are distributed around the water divide between the Garfagnana and Versilia basins, within the 400 mm isohyet, and are classifiable as soil slip - debris flows (Figure 5). In the triggering zone, they start as small first-time slides affecting only a few decimetres of superficial loose soil debris, mainly in zero-order basins or hollows (Caredio *et al.*, 1998). They rapidly evolve into open-slope debris flows and, in most cases, reach the hydrographic network, changing into channelized debris flows or hyper-concentrated flows, increasing considerably in volume during their run-out. The rainstorm migrated progressively towards the northeast, with a maximum intensity of 173mm/h in Versilia, between 05.45 and 06.45 hrs and of 152mm/h in Garfagnana, between 12.00 and 13.00 hrs. Nearly all the soil slips seem to have been triggered by the second rainfall peak that took place after 13.00 hrs.

Due to its localized, violent character the meteorological event was virtually unpredictable, at least with the climatic models used for weather forecasting in the Mediterranean basin. The Regional Agrometeorological Service weather report for the 19 June forecast only occasional rainfall of weak intensity. On the other hand, events with these characteristics are determined by the particular microclimate of this region, with its high relief close to the open sea causing the rapid uplift of masses of moist air of Atlantic origin.

Statistical analysis of the maximum rainfall heights of different duration clearly shows the exceptional nature of the meteorological event (Castelli *et al.*, 1997). For the Fornovolasco rain gauge, where a time series of rainfall intensities over a 50-year period is available, in 1952 the maximum rainfall intensity in 12 hours was 262 mm. On 19 June 1996, 416 mm of rain fell in the same period !

In Figure 6, the curves of maximum intensity in function of the duration, for three rain gauges in the region, are compared with the threshold curves for the triggering of soil slips, proposed by different authors in different parts of the world (Caine, 1980; Moser and Hohensinn, 1983; Cancelli and Nova, 1985; Wieczorek and Sarmiento, 1988; Jibson, 1989). The exceptional character of the event is confirmed by the fact that it lies well above all the thresholds proposed in literature, even for those proposed for other climatological environments such as inter-tropical regions. For this reason it is quite difficult to determine the critical rainfall duration that set off these movements.

For all the reasons exposed above, the Versilia case represents a typical example of an event for which a temporal hazard prediction is extremely difficult. Despite this fact, the effects of the phenomenon could have been less destructive if, at the very least, a spatial prediction of zones susceptible to debris mobilization had been carried out. A spatial and typological prediction would have yielded the basic tool for programming measures of risk mitigation such as, for example, forest maintenance, creek dredging, building protective structures or limitation of land use.

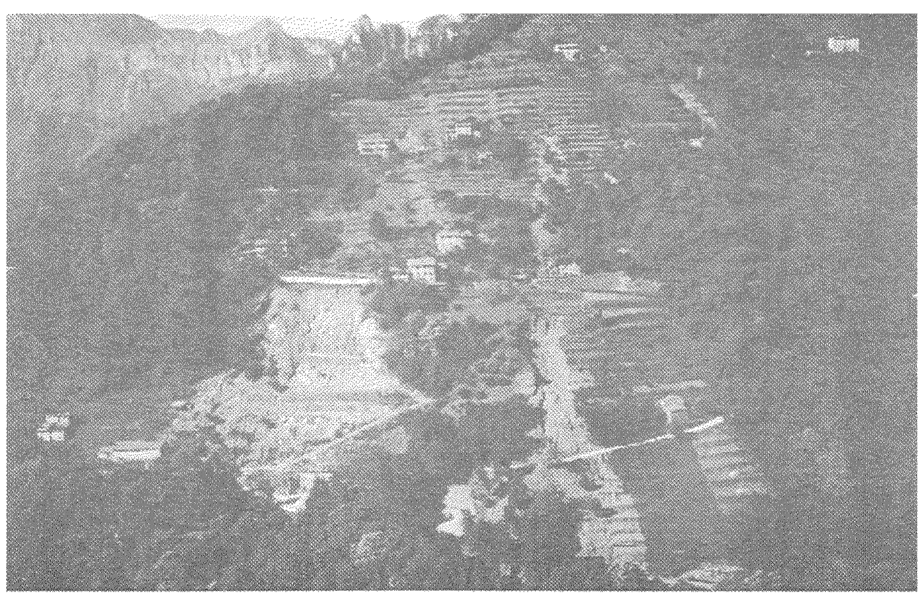

Figure 5. Soil slips – debris flows triggered by rainfall.

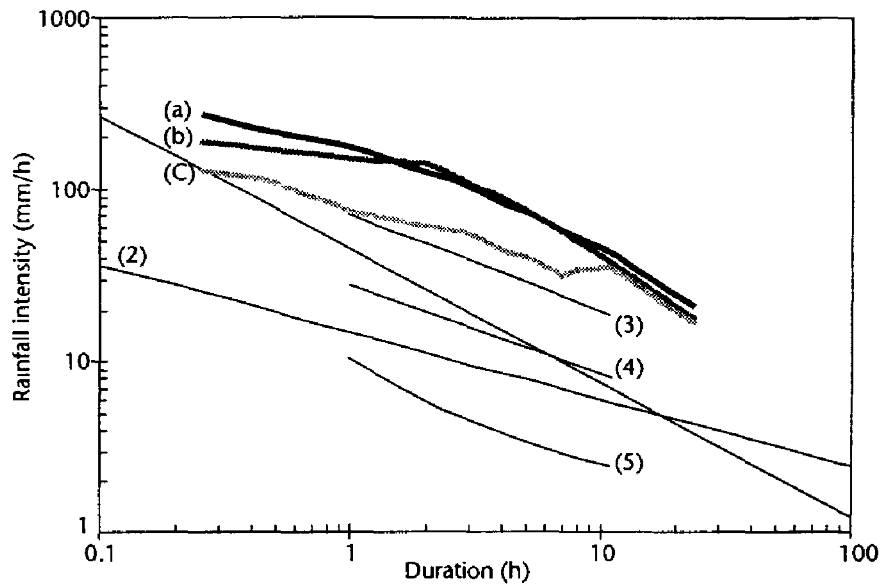

Figure 6. Comparison of the curves of maximum intensity in function of the duration for three rain gauges in the region and the thresholds of soil slip triggering proposed by different authors. (A) Pomezzana, (B) Retignano, (C) Fornovolasco. (1) Alps (Cancelli and Nova, 1985)*; (2) Worldwide* (Caine, 1980)*; (3) Puerto Rico* (Jibson, 1989)*; (4) Worldwide* (Jibson, 1989)*; (5) California* (Wieczoreck and Sarmineto, 1988)

3. PREVENTION

The prevention of landslide risk is based on the interpretation of the information collected in the prediction phase and on the establishment of a framework of measures aimed at risk mitigation. The implementation of these measures is usually the task of decision and policy makers of national or local administrations. However, the role of the scientific and technical community is of crucial importance in determining scales of priority and for the development of mitigation strategies. In areas exposed to unacceptable risk levels two general strategies are possible (Figure 7):

(a) "allowable risk" threshold increase using information means such as mass media, danger or warning signs, promotion of insurance policies.

(b) risk reduction: obtained through measures for the prevention of landslide consequences which can be further sub-divided into the following two procedures:

(b1) hazard reduction: the probability of occurrence of landslides in a given zone can be reduced with "structural measures" in two ways:

- (i) reduction of slope instability causes, such as land drainage, geo-hydrological and woodland management, reforestation, erosion control, rationalization of land use and farming practices;
- (ii) direct action on slope instability effects aimed at preventing the re-activation or the expansion of pre-existing landslides: this can be achieved with

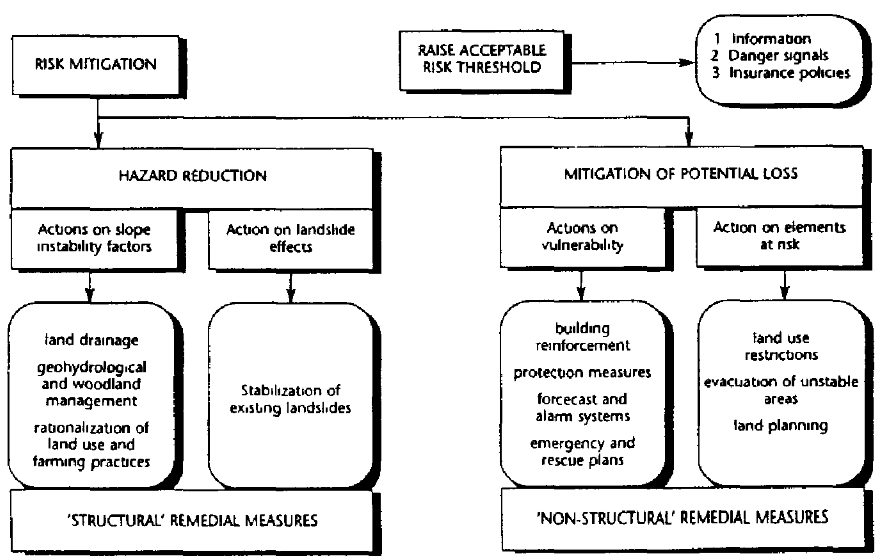

Figure 7. Formal framework for landslide risk prevention.

stabilization works, such as slope profile modification, local drainage, restraining and retaining structures, chemical or thermic treatment, grouting (Hutchinson, 1977).

(b2) mitigation of potential loss: this can be obtained with "non-structural measures" by land planners and policy makers in the following two ways:

(i) working on the vulnerability with measures aimed at lowering the probability of suffering a loss without reducing the probability of occurrence of the landslide, such as building reinforcement, protection measures (i.e. diversion and catchment structures), forecast and alarm systems, emergency and civil protection plans;

(ii) with measures for reducing the exposure of the elements at risk, such as land use restrictions, evacuation of unstable areas, land and urban planning.

The quantitative evaluation of landslide risk in the prediction phase, in terms of expected value of loss per year, permits the rational selection, on the basis of a cost-benefit analysis, of the appropriate prevention strategies. A benefit in terms of risk reduction, expressed as the decrease of the expected loss caused by landslides, can be associated to the cost of each mitigation measure.

3.1 THE SAN MINIATO LANDSLIDES IN FLORENCE: HOW SUCCESSFUL PREVENTION CAN BE COMBINED WITH A TOWN-PLANNING TRANSFORMATION

The southern extremity of the historic center of Florence, on the hydrographic left side of the Arno river, is bordered by a series of hills, known as "Colli Fiorentini", which provide suggestive panorama of the city with its artworks and monuments. The San Miniato hill (known also as Monte alle Croci or Mons Florentinus) represents the most famous of these gentle topographic features for its landscape significance and for the monuments of inestimable cultural, historic and artistic value (Figure 8). Its northern flank is cut by the "Viale dei Colli", a wide hillside boulevard which borders the southern margin of Florence, constructed between 1865 and 1876. The hilltop hosts the complex of the Romanic Basilica of San Miniato al Monte (11th c.) (Figure 9) with the annexed Palazzo dei Vescovi (14th c.), which are surrounded by the monumental cemetery of the Porte Sante (1854) and by the fortification system designed by Michelangelo Buonarroti. The fortress is connected to the "Viale dei Colli" with a monumental staircase (1865-1876) and the church of San Salvatore al Monte (1499-1504) with the contiguous San Francesco Monastery (1499-1504) are also nearby. Situated in the central portion of the slope is the famous panoramic square known as Piazzale Michelangelo (1865-1876), linked downslope to the city with the Rampe, a complex system of artificial terraces, waterfalls and masonry walls, hosting the roadway.

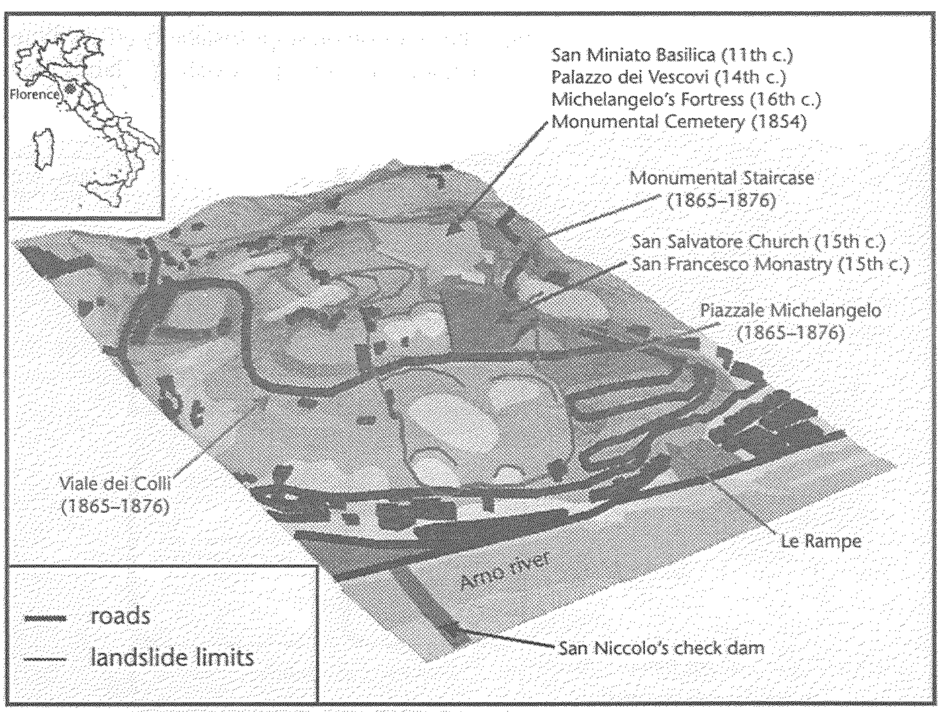

Figure 8. Isometric view of the San Miniato hill showing the main monuments and the boundaries of the dormant landslides (Computer graphics by Earth Sciences Department of the University of Siena, Italy).

Figure 9. The San Miniato Basilica (11th c.) at the top of the monumental staircase (1865-1876).

Unfortunately, the hill has always been affected by slope instability phenomena, with periodical re-activations documented in several historic documents. Most of the monuments and art works on the hill are affected by fissures which, in various circumstances during the centuries after their construction, required restoration. The first documented studies on the stability of the hill were carried out by Leonardo da Vinci in the 15th century and afterwards by various commissions appointed for the restoration works. The studies carried out in the past pointed out the presence of a generalized translational sliding of the entire hill, down the slope facing the Arno river, linked to the adversely oriented strata. Detailed geomorphological investigations showed the presence of distinct slides scattered over all the slopes of the hill (Figure 8) (Bertocci *et al.*, 1995). Their recognition and delimitation is made extremely difficult by the urbanization of the entire hill over many centuries which has led to the almost complete obliteration of the evidence of past movements. The main landslide bodies which have been detected are:

(a) the large earth slide on the northern slope which laps the Piazzale Michelangelo and the church of San Salvatore and extends over a green zone used today as a camping site;
(b) the earth slide on the western slope which affects the Monumental Staircase of San Miniato;
(c) the coalescent slides on the eastern slope which affect some private villas and some public facilities such as the Florence Orthopedic Hospital;
(d) the earth slide on the southern slope, the crown of which reaches the base of the Michelangelo bastions.

Various documents testify to the periodic re-activations of the different landslides: the main events date back to 1499, 1551, 1562, 1652, 1695, 1709 and 1853.

Between 1865 and 1876, dates which coincided with the designation of Florence as temporary Capital of the Italian Kingdom, the hill was involved in a radical town-planning transformation directed by the Architect Giuseppe Poggi. On the San Miniato hill, Poggi designed and constructed the scenic Viale dei Colli with its panoramic open squares, of which the Piazzale Michelangelo is the most famous. Among the reasons cited by Poggi to support his extremely expensive plan, was the necessity of a global geo-hydrological and hydraulic re-arrangement of the entire slope, in order to prevent the future occurrence of instability phenomena. The implementation of the project lead to a general modification of the slope profile, with excavations and fillings involving impressive earth movements, the building of drainage systems and canals which supplied water for the waterfalls and fountains, and the construction of a series of earth retaining structures along the boulevard and on the Rampe terraces (Figure 10). The most unstable zones, including the area used today as a campsite, were left green and used as public gardens.

The entire complex of works has an undoubted artistic and architectural value and represents one of the key elements of the landscape of the Florentine hills. Apart from these aesthetic aspects, it is clear that the entire works were supported by a full appreciation of the local, critical stability conditions and by the necessity of putting into effect preventive measures to protect the cultural heritage from the risk of landslides. For this reason Poggi's opera still today represents an excellent and prestigious example of appropriate land management and sustainable urban development that, unfortunately, has not always been followed in the successive periods.

3.2 THE 1988 SARNO EVENT: A DISASTER CAUSED BY THE LACK OF PREVENTIVE MEASURES

On 5 May 1998, in the Sarno area in southern Italy, 30 km east of Naples, approximately 150 shallow landslides (soil slips — debris flows) were triggered by an intense rainstorm. The mobilized material was conveyed into the hydrographic network, giving rise to large channelized debris flows that hit the urban areas of Sarno, Quindici, Siano and Bracigliano (Figure 11) This catastrophic event produced 161 casualties and heavy, widespread loss of property, services, infrastructures and economic activities. Available rainfall records show a total rainfall of 100 mm in 24 hours (4–5 May), with a peak intensity of 11 mm/h Although