landslides already mapped in the GIS have been classified according to their state of activity (WP/WLI, 1993*a*) and ranked in different classes of relative hazard. The next step was the zonation of slopes in which there was no evidence of past movements. These areas are susceptible to occasional first-time slides and also to re-activations of pre-existing dormant landslides that may have escaped systematic inventory, due to obliteration by geomorphic or anthropogenic activity. In these non-affected areas, the hazard ranking has been based on the areal frequency of landslides over homogeneous lithological units, following a criterion already successfully tested in other parts of the world (Radbruch-Hall *et al.*, 1976, 1982; Brabb, 1972; De Graff, 1978).

The available data on the state of nature permitted only a spatial and typological hazard prediction (Figure 2), with the assessment of the degree of relative hazard amongst different sectors of the territory. Data on landslide types and mechanisms also allowed a ranking in classes of relative magnitude, which can be used for an analysis of the vulnerability of the elements at risk and of the potential worth of loss. To also formulate a temporal hazard prediction, ongoing research is concentrated on correlating rainfall time series and historic records of landslide events. A first attempt, the results of which are shown in Figure 3, is the combination of a hydrological soil balance model with an empirical recharge model (Casagli *et al.*, 1999). The resulting hydrogeological function is empirically correlated with the recorded landslides. The results obtained are encouraging despite the well-known difficulties in modelling groundwater response to rainfall in low permeability terrain with deep-seated landslides.

A risk prediction is obtained by overlaying hazard maps and the elements at risk stored in the GIS. The results of this process provide a measure of the landslide impact on the region: 150 municipalities are affected by landslides, with 235 urban areas threatened by problems of instability. Where transportation facilities are concerned, the analysis shows that landslides threaten 11 882 km of railway tracks, 14 668 km of highways, 1 031 950 km of National and Provincial roads

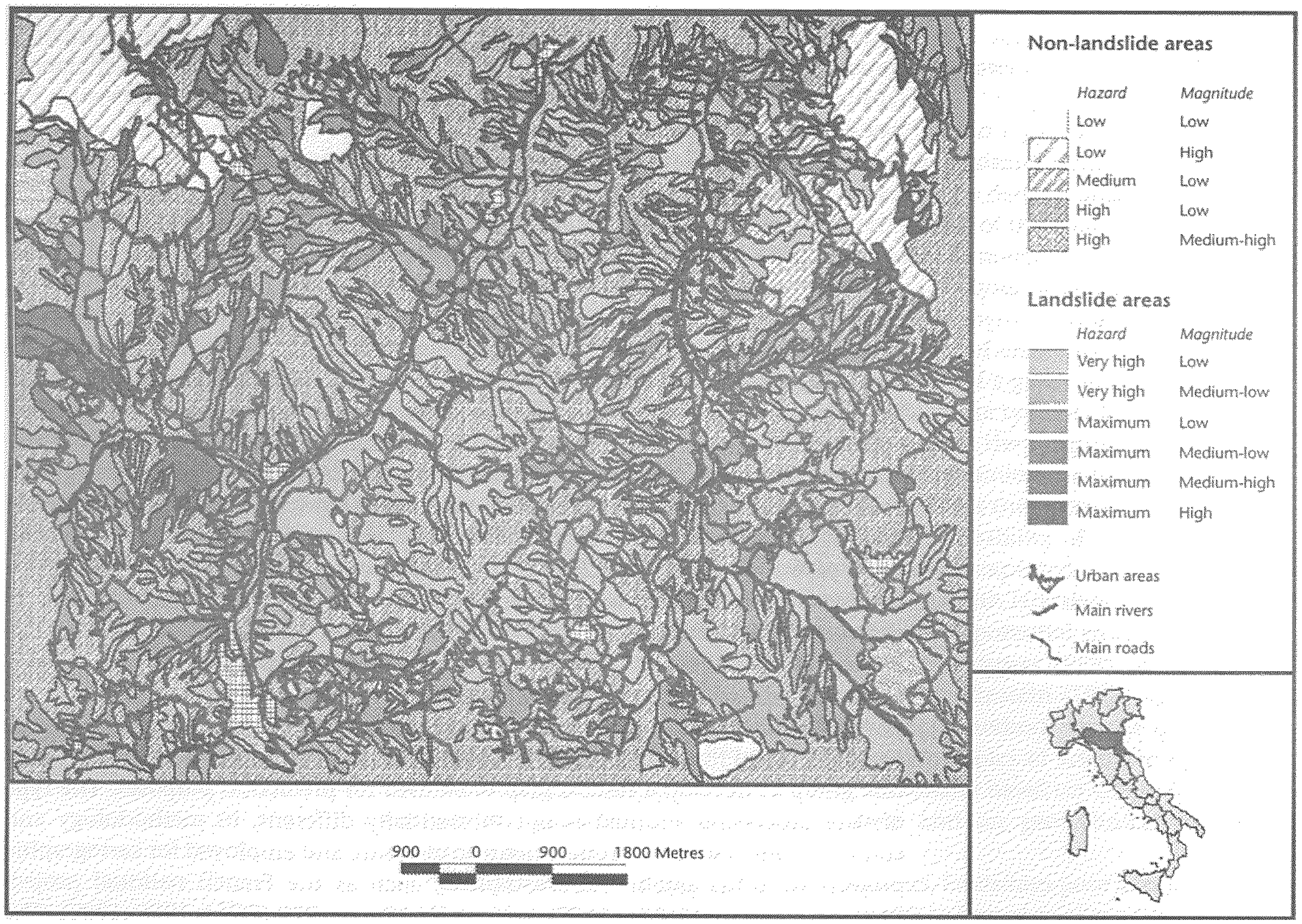

Figure 2. Example of landslide hazard and magnitude zonation from the Emilia-Romagna GIS.

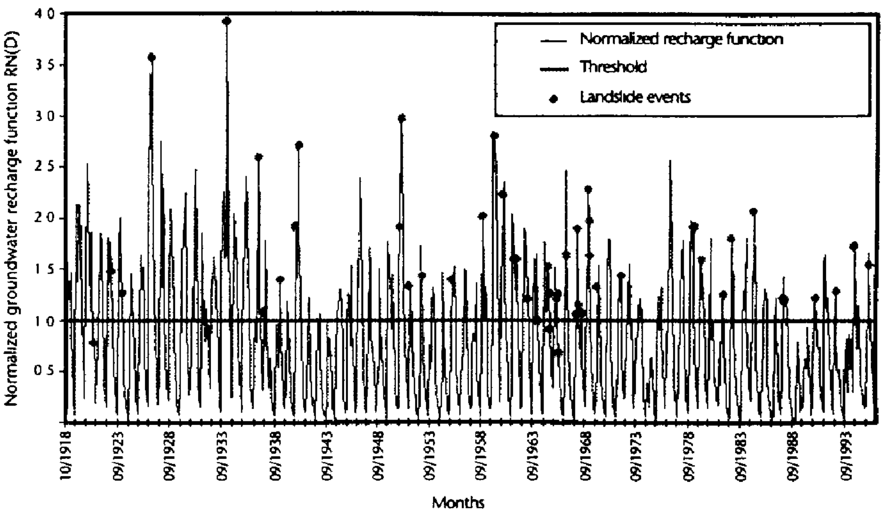

Figure 3. Preliminary results of the rainfall threshold model applied to the Reno river watershed. The groundwater function is compared with landslide reactivations in the period 1918 – 1998.

and 2 234 402 km of municipal roads (Garberi *et al.*, 1999). The Emilia-Romagna GIS on landslide hazard represents one of the most advanced tools available today for predictions over large areas. It is currently employed in planning urban development and risk mitigation measures.

The 1996 Versilia Debris-flows: an Exceptional Unpredictable Event

A meteorological event of exceptional violence and intensity took place on 19 June 1996 in the Apuane mountains, a well-known site for the extraction of high-quality marble at the northern margin of the Apennine chain. The rainstorm triggered more than 450 slope movements, causing the destruction of mountain villages, flash-floods that provoked damage along the two main rivers both in the western Versilia basin and in the eastern Garfagnana one and leaving 13 victims. A schematic reconstruction of the isohyets of the event is shown in Figure 4 together with the distribution of the slope movements. The extreme spatial concentration of the event and the high rainfall intensity are remarkable. The whole event lasted 13 hours yielding a maximum rainfall of 478 mm in Versilia and over 420 mm in Garfagnana. This underlines the exceptional nature of the event as the whole Apuane range receives a yearly mean rainfall of 1 430 mm.

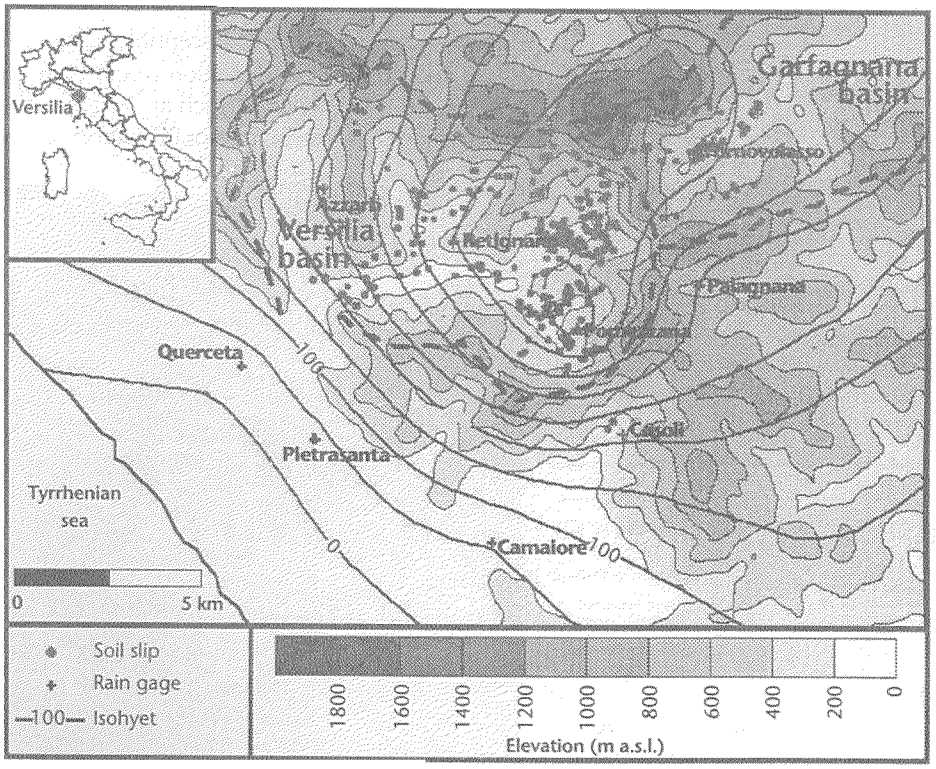

Figure 4. Isohyets of the event (relative to a duration of 13 hours) and distribution of soil slips in Versilia and Garfagnana.