

Figure 10 Original drawing of Poggi showing the Rampe plan.

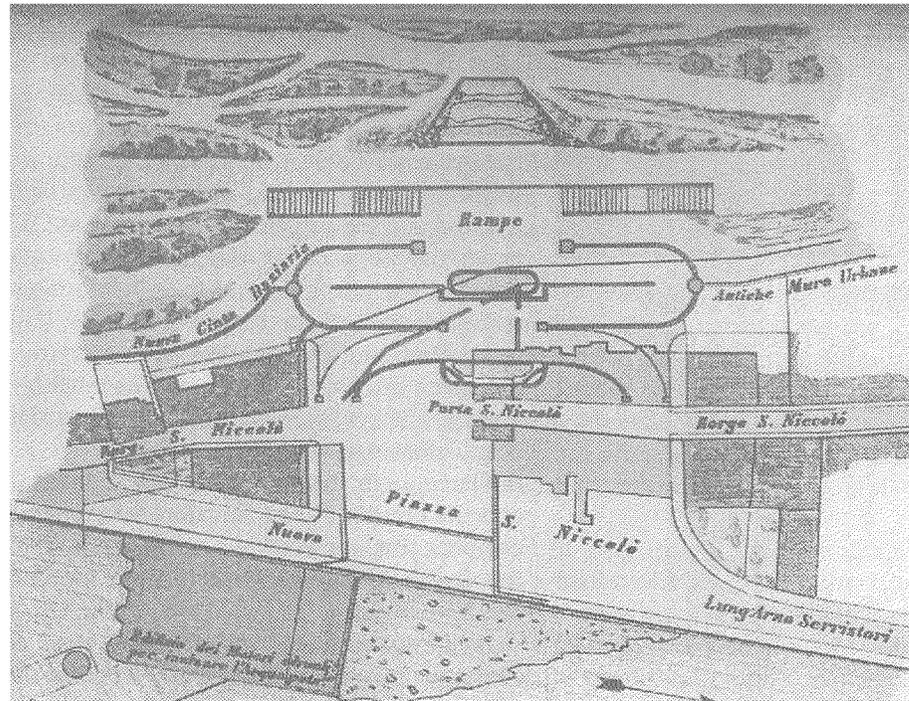


Figure 11. Debris flows reaching the suburbs of Sarno (photo courtesy of G. Falorni)



Figure 12. The channels known as Regi Lagni built in the 19th c., left in a state of abandonment (photo courtesy of P. Aleotti).

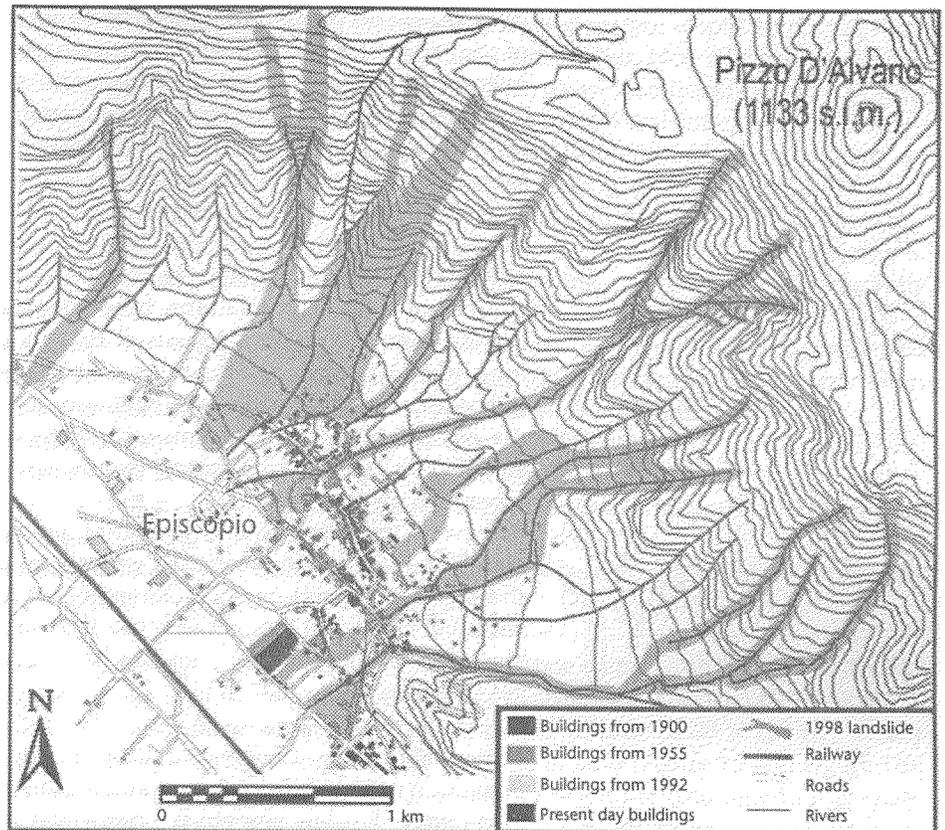
this rainfall was not exceptional. it must be noted that 175 mm of rain fell in the month of April, 147 mm of which fell in the last week preceding the triggering rainfall. Moreover, the Ponte Camerelle rain gauge is located in the lowland near the sea and its records are not representative of the precipitation on the inland slopes.

The soil slips affected a thin cover of loose or weakly cemented pyroclastic deposits (falls) from Somma-Vesuvius eruptions that overlie a karstified Mesozoic limestone bedrock. The geomorphological evolution of the slopes is determined by the mobilization of pyroclastic materials and the expansion of debris fans in the pedemont zone. The development of deeply incised gullies, first in the calcareous rock and successively in the pyroclastic deposits, has a major influence on the run-out of these phenomena. The evolution of the degree of risk in the pedemont zone is thus strictly linked to the morphological variation of the fans. In fact, the areas affected by the debris flows have migrated towards the plain as a consequence of the channel formation and of the "telescopic" development of the fans (Aleotti *et al.*, 1999).

From these considerations it is clear that the geomorphic evolution of the area has been controlled by slope movements, therefore the entire lowlands in front of the calcareous massif are intrinsically characterized by conditions of natural hazard. Moreover, several historical documents testify to the frequent occurrence of slope movements. In the last century alone, 34 landslide events have been recorded in the region (Del Prete *et al.*, 1998).

In previous centuries, during the Kingdom of Naples, before the unification of Italy, some slope instability preventive measures were carried out in the area. The channel systems of Regi Lagni, built mainly in the 14th century in order to accommodate the accumulation of material from debris flows, are worthy of note (Figure 12). Up to 50 years ago, the urbanization of the lowland area was limited to the more stable areas, where no apparent gullies were present. Rapid urban growth in the post-war period, and especially in the 1970s and the first half of the 1980s, led to a rapid, uncontrolled, expansion over areas exposed to high hazard. The damage caused by the 1998 event entirely affected the more recent suburbs of the towns (Figure 13). In recent years, the rapid increase in the vulnerability and the exposure of the elements at risk has been combined with an increase in the hazard level due to the excavation of a network of paths, built to facilitate access to nut plantations on the hill slopes (Del Prete *et al.*, 1998).

Figure 13. Map of Episcopio (suburb of Sarno) showing the age of buildings and the areas affected by debris flow propagation in 1998 (Aleotti et al., in press)



The case of Sarno is an illustrative example of lack of preventive measures associated with uncontrolled urban expansion. Minimal attention to the requirements of sound urban planning and some basic geological investigations could have greatly reduced the impact of this event.

4. EMERGENCY PLANNING

An emergency plan should be prepared for all those areas exposed to an unacceptable level of risk, based on the socio-economic and cultural context of the territory. An emergency plan refers to a homogeneous area characterized by a defined landslide mechanism and should cover a sufficiently large area encompassing all the possible direct and indirect consequences. The key elements for the planning of emergency measures are scenario analyses and warning systems (Figure 14).

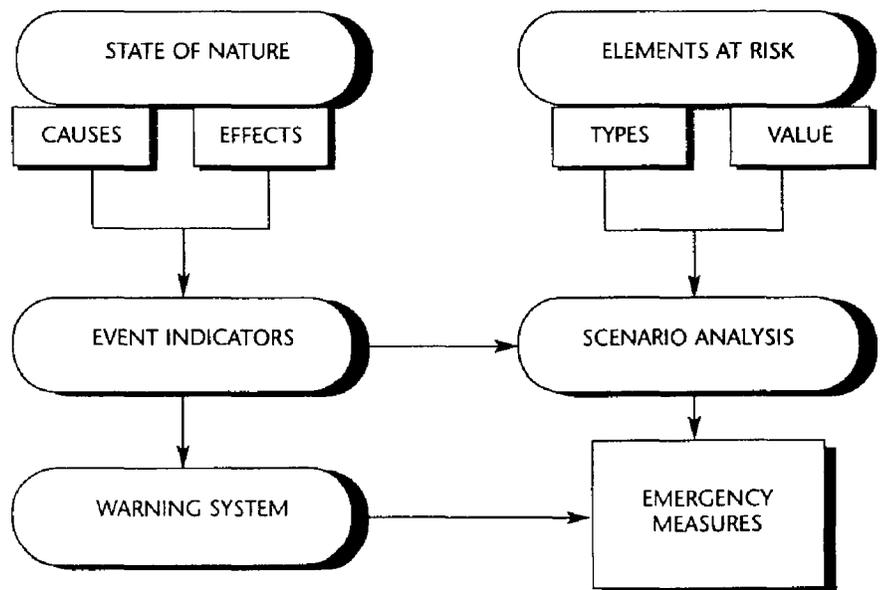


Figure 14. Formal framework for emergency management planning.

A scenario consists in a series of hypotheses which simulate the occurrence of the expected event, aimed at forecasting and preventing all the possible consequences, direct or indirect. Each scenario should be characterized by a set of measurable or observable physical parameters, defined as event indicators, which describe the relevant aspects of the state of nature. Possible event indicators include parameters which characterize the causes of the expected phenomenon (e.g. rainfall amount or intensity, seismic intensity or acceleration, external water stage), or its effects (e.g. rate of displacement, areal extension, expansion limit, mobilized run-out volume, mechanism of movement). A scenario analysis consists of a set of simulations, based on different event indicators and on the current exposure of the elements at risk. In general, several scenarios are examined with reference to situations of increasing severity up to the worst-case hypothesis (maximum expected scenario). Each scenario should include:

- (a) the possible landslide mechanisms and the delimitation of the areas potentially affected by landslide evolution (retrogression limits, run-out distance, lateral spreading, etc.);
- (b) the event indicators and the control points where the indicators should be observed or measured during the emergency phase;
- (c) the prediction of all possible consequences, both direct (e.g. loss caused by the landslide itself) and indirect (e.g. blockage of a river channel, sliding into a reservoir, pollution produced by damage to industrial plants, escape of inflammable gas or liquids).

A successful scenario analysis requires detailed site investigations for the choice of the relevant event indicators, and powerful simulation tools for the prediction of landslide evolution and its consequences. Great advances have been made in the last few years in the numerical analysis of slope stability: limit equilibrium analyses have become routine, and more sophisticated stress-strain analyses, based on finite-element, finite-difference or distinct-elements, are today possible, given the advances in computer capabilities. Models for the prediction of landslide run-out and travel distances are becoming more and more realistic and reliable. As far as loss prediction is concerned, GIS technology provides fundamental tools for the spatial analysis of the effects of landslides on complex systems of elements at risk, making socio-economic analyses of landslide effects possible. Further research is required for a better definition of landslide mechanisms and triggering thresholds, as well as on quantitative vulnerability analyses of buildings and infrastructures.

Once defined, each scenario can be associated with a warning system, related to the monitoring of one or more of the event indicators. The warning system must include a control device of the selected relevant event indicators, so that the evolution of the expected event towards a parossistic phase can be forecast with sufficient accuracy. In general, two different control strategies are possible:

- (a) monitoring of the causes of the event. regional weather forecasts, local rain gauges, piezometers, seismometers, gauges of external water levels, etc.;
- (b) monitoring of the effects of the event. periodic surveys in the field, topographic surveys, fissurimeters, inclinometers, surface or deep-wire extensometers, tiltmeters, electric crack gauges, etc.

In both cases it is necessary to develop predictive models in order to choose the thresholds to be used as warning levels, taking into account, on one hand, the expected frequency and magnitude of the landslide and, on the other, the vulnerability and value of the elements at risk.

The rapid development of technology in recent years has had important effects on landslide monitoring and control. Besides making traditional methods and instrumentation much more effective and easily manageable, innovative technology is starting to produce accurate and reliable monitoring systems. Traditional equipment can now be effectively and conveniently coordinated by central units capable of acquiring, storing and managing all the collected data. GPS (Global Positioning System) technology has been successfully applied to the monitoring of landslides of different types and is gradually replacing traditional topographic surveying techniques. Radar interferometry and laser technology

have been applied for the accurate monitoring of surface displacements and for the production of high-definition digital terrain models. New telecommunication technologies permit data acquisition from remote workstations, via radio or telephone modem (cable, cellular, satellite), on-line real-time alarms, remote management of the data acquisition system, real-time transmission of data and information to decision and policy makers through telematic networks.

After accurately defining the loss scenario and selecting an appropriate warning system, the operational phase of the emergency plan can be scheduled. In a successful emergency strategy, the following points should be carefully planned:

- (a) measures for the prevention of the consequences described in the expected scenario, such as evacuation plans, identification of alternative transportation facilities and lifelines, removal of sources of induced risk, etc.;
- (b) selection of the areas for temporary accommodations, as well as for the rescue and assistance structures;
- (c) inventory of the technical, human and logistic resources to be used in the implementation of the emergency plan;
- (d) information and dissemination activities on the correct conduct that the population should adopt in case of an emergency.

4.1 LA JOSEFINA LANDSLIDE DAM:
AN EXAMPLE OF SUCCESSFUL
EMERGENCY MANAGEMENT

On 29 March 1993, at about 22.00 hrs, a rockslide dammed the course of the Rio Paute, about 20 km northeast of Cuenca in Ecuador. The rockslide killed 35 people and produced a dam with an estimated volume of $25 \times 10^6 \text{ m}^3$, which caused the upstream flooding of over 1 000 ha of land (Figure 15 and Figure 16). As a consequence of the event, an international scientific commission was established to manage the emergency linked to the possible failure of the landslide dam.

Both the upstream and downstream regions are densely urbanized, with major railways and highways, lifelines, productive and agricultural activities. Moreover, the Amaluza reservoir (with a total capacity of $120 \times 10^6 \text{ m}^3$) lies about 60 km downstream, impounded by an arch-gravity dam on the Rio Paute. The emergency measures put into effect were aimed at mitigating the effects of the landslide dam breaching, considered unavoidable after a careful scenario analysis. The lake level was lowered by excavating a channel over the dam crest (Figure 17). The outflow through the channel started on 24 April and reduced the lake volume by $130 \times 10^6 \text{ m}^3$, avoiding the upstream flooding of an additional 250 ha of land (Plaza-Nieto and Zevallos, 1994). The Amaluza reservoir was emptied to receive the flood wave and more than 20 000 people were evacuated from the area exposed to the flood.

Figure 15. Map showing La Josefina landslide and the impounded lake (after Plaza-Nieto and Zevallos, 1994).

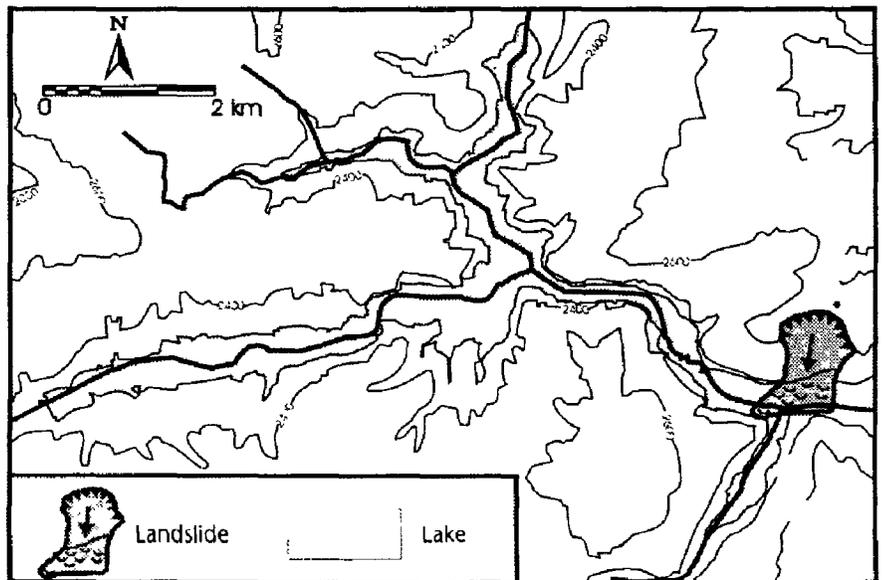


Figure 16. La Josefina rockslide and the impounded lake