INFORMATION SYSTEM ON HISTORICAL LANDSLIDES AND FLOODS IN ITALY

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1. Introduction

There is accumulating evidence that the impact of natural catastrophes is increasing. For climatically induced natural hazards (e.g., soil erosion, floods, landslides, droughts, hurricanes, show storms, etc.) climate change is commonly recognized as the primary cause for the increase in the number and the magnitude of catastrophic events. Scientists have measured a generalized increase in sea and air temperature, and changes in the amount and regime of precipitation are observed everywhere.

The risk posed by climatically induced natural hazards is a function of the frequency (or probability) of occurrence and the magnitude of the event, and the vulnerability, i.e., the number and value of the elements at risk (e.g., people, structures and the infrastructure). In urban areas the question is not if natural events are increasing in number or magnitude, or how many vulnerable elements exists. The question to ask is: are casualties and economic losses due to climatically induced events increasing? Records of air temperature, rainfall quantity, river discharge, ice thickness and sea level spanning a sufficient number of years are available, allowing climatologists to quantify the pattern, trend and amount of climate change. Demographers have shown not only that the population has increased word wide, but also that the distribution of the population has changed significantly. What remains largely unknown is the extent to which the damage caused by climatically induced events is increasing. Records of the damage caused by landslides and floods are rare, and often lack sufficient detail or the temporal coverage to properly answer this question.

Italy has a long history of climatically induced natural catastrophes. Inundations, landslides, droughts, snow or hail storms occur every year, causing significant economic damage and social distress. Systematic records of daily air temperature, rainfall, and river discharge are available since about 1910-1920. For a few stations the record extends back into the 19th century. In Italy the population has increased from about 13 millions in 1700, to 34 millions in 1900, to 57 million in 2000. However, the population has not increased at the same rate everywhere; from 1950 to 1980 the average increase was 19 percent, but the increment in the urban areas was 63 percent. The number of potentially vulnerable elements has also increased. In 1865 roads were limited to 89,000 kilometers that increased to 300,000 kilometers by 1984, of which 100,000 kilometers were built between 1950 and 1985. For Italy a catalogue of landslide and flood events for the period 1918-1998 was completed by the National Research Council (CNR), Group for Hydrological and Geological Disasters Prevention (GNDCI). The catalogue is a unique source of information on the damage caused by landslides and floods, and can be used to evaluate the risk posed by climatically induced events.

In this paper we provide a brief description of the most damaging events occurred in Italy since 1950; we present the AVI database, a bibliographical and archive inventory of landslides and floods in Italy, and its successor SICI, an information system on historical landslides and floods in Italy; and we show examples of the application of the historical information to the assessment of geo-hydrological hazard and the associated risk.

2. Landslides and floods in Italy

Figure 1 shows a debris flow inundation in the village of Castel Sant'Angelo sul Nera, in Marche Region, on 27 July 1906. The same area was visited 300 years before by Ambosio Magete, an engineer sent to investigate the causes of the recurrent flooding. Magete explained damage the rivers were causing in the area with: 1) the local climatic and meteorological conditions; 2) the morphological and geological settings; 3) the grading action of animals; and 4) the abuse of agricultural practices. These are, more or less, the same causes a geologist or a hydrologist would identify today, i.e., high intensity rainfall, steep slopes, easily eroded rocks, and inappropriate land management.

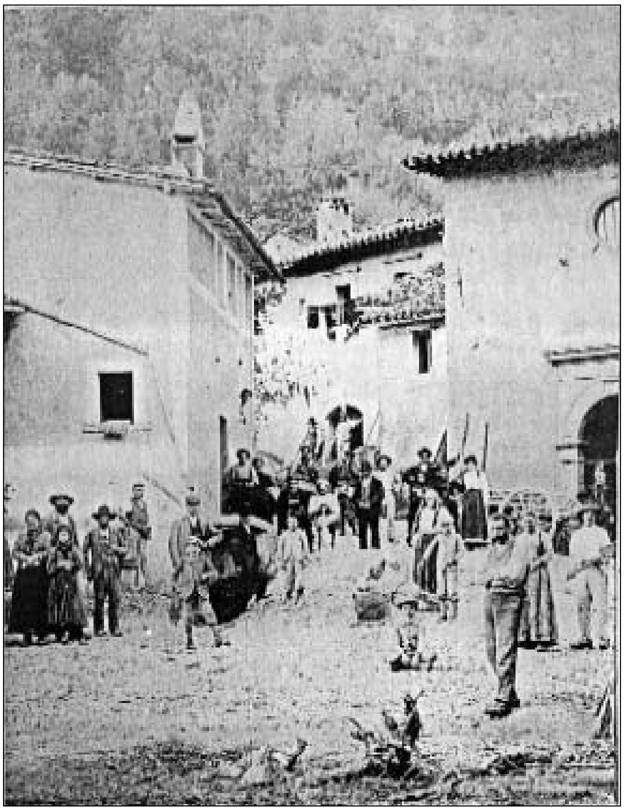

Figure 1. The village of Castel San'Angelo sul Nera inundated by a debris flow on 27 July 1906.

The impact of flooding and mass movements is heavy in Italy. In the 20th century the toll amounts to: more than 10,000 dead or missing people; more than 350,000 homeless people; thousands of houses and bridges and hundreds of kilometers of roads and rails destroyed or damaged [1-2]. Impact on the cultural heritage is also high. Figure 2 shows a painting by Cimabue severely damaged by the Arno river flood, on November 1966 [3]. Only in the last two decades of the 20th century floods, debris-flows and landslides have killed more than 300 people.

In the following we provide a brief description of some the most damaging events occurred in Italy since 1950. Far from being a comprehensive list of catastrophic events, it is meant to provide an historical perspective of the impact of floods and landslides in Italy.

On 18 November 1951, following prolonged and intense rainfall in the Alps and the Northern Apennines, the Po River broke the left banks at Occhiobello, Malcantone and Paviole (Polesine, Rovigo Province) causing the largest inundation of the 20th century (Figure 3). The water inundated the city of Rovigo, several towns (including Adria, Loreto and Cavarzene), and about 980 square kilometers of farmland in 38 municipalities. The toll amounted to 100 casualties, 170,000 homeless people, 52 bridges destroyed, 1,200 houses and 9,000 farming structures damaged or destroyed, and as many as 13,000 farm animals lost, together with 100,000 tons of wheat, and 21,000 hectares of farmland [1]. The inundation occurred in an area already economically very poor, forcing the population to immigrate to other Italian Regions.

On 25-26 October 1954, muddy debris flows triggered by high intensity rainfall inundated the city of Salerno (Campania Region) and five neighboring towns (i.e., Cava dei Tirreni, Maiori, Minori, Tramonti and Vietri) causing extensive damage. The toll amounted to 297 dead or missing people, and 113 injured people. Roads and the railway connecting Naples to the south of Italy were disrupted at several locations [1,2].

On 9 October 1963, at 10:39 pm, 240 millions cubic meters of rock detached from Mount Toc, in Veneto Region, and slid into the Vajont Lake. The rockslide pushed the water against Casso and Erto, two small hamlets on the slope in front of the slope of Mount Toc that failed in the disaster, and then over an artificial dam. A water wave several meters high overtopped the dam and reached the town of Longarone at 10:46 pm, destroying it (Figure 3). The Vajont landslide killed at least 10 people at Erto and at least 40 at Casso, 7 were killed at San Martino, an imprecise number at Pineda, Prada, Marano and Spesse, 47 at a temporary construction camp near the dam, and at least 1,759 among the town of Longarone and the area downstream along the Piave valley. News about the Vajont disaster, the worst landslide catastrophe in Europe in historical time, reached the United States; the Herald Tribune titled: "Vajont Dam: Warning Ignored" [1,2].

Three years later, on 3-4 November 1966, Florence (Tuscany Region) was inundated by a severe flood of the Arno River. The flood killed 35 people, caused severe damage throughout the basin, and produced a tremendous impact on the cultural heritage. Many masterpieces of the Italian Renaissance, including the church of Santa Croce and its square (Figure 3), the Christ by Cimabue (Figure 2), paintings by Vasari, Paolo Uccello and Botticelli, together with 3,000 art-pieces and 1,500,000 historical documents in the Museum of Santa Croce and at the National Library were damaged or destroyed. The 1966 inundation was the last in a series of more than 50 flooding events occurred in Florence since 1177, of which the most severe occurred in 1177, 1269, 1288, 1333, 1380, 1589, 1740, 1844 and 1864 [3].

What it is usually unreported is that the same meteorological event that caused the inundation in Florence dropped high intensity rainfall in the Western Alps, causing extensive inundations and numerous landslides in the Veneto and Friuli Regions. Casualties caused by landslides and floods were reported in the Provinces of Belluno (24), Treviso (3) Vicenza (4) Udine (12) and Pordenone (2). At least 137 square kilometers of land were inundated. Damage was reported in 209 municipalities. In the Belluno Province more than 4,300 buildings, 528 bridges, and 1,346 roads were destroyed or damaged. Venice experienced one of the highest high standing water (i.e., "*acqua alta*") of the 20^{th} Century [1].

Figure 2. Soldiers rescuing the famous Christ by Cimabue damaged by the 3-4 November 1966 flood of the Arno River in Florence.

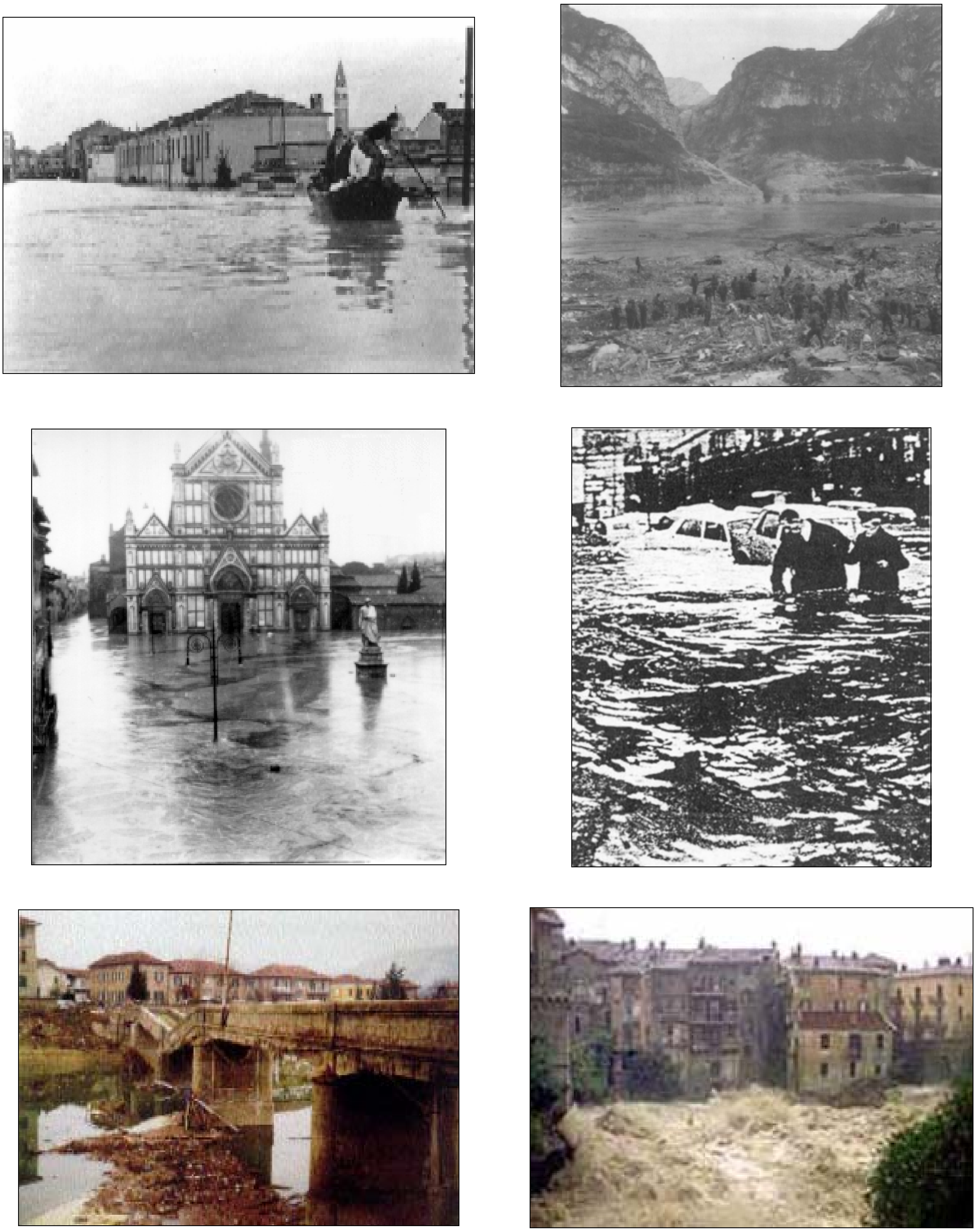

Figure 2. Effects of landslides and floods in urban areas in Italy. Upper Left: Polesine flood (Veneto Region) of 18 November 1951. Upper right: The village of Longarone (Veneto Region) destroyed by the water wave caused by the Vajont rockslide, on 9 October 1963. Center left: Florence, the church and square of Santa Croce inundated by the flood of the Arno River, on 3-4 November 1966. Center right: a street inundated by the Bisagno river in Genoa, on 7-8 October 1970. Lower left: Clevesana, Piedmont region, a bridge destroyed by the flood of the Tanaro River, on 2-6 November 1994. Lower right: Ivrea, Piedmont region, inundation caused by the Dora Baltea River, on 13-16 October 2000.

On 7-8 October 1970, Genoa (Liguria Region) was inundated by the Polcevera, Leiro and Bisagno rivers that went over the banks at several locations. A localized, but very intense rainstorm dropped more than 900 mm of rain in 24 hours; about 90 percent of the mean annual precipitation. The city of Genoa suffered the most severe loss, but damage was reported in other 20 municipalities in the Province. Major roads and two railroads were interrupted by flooding and landslides at various locations. The toll amounted to 25 casualties and more than 500 homeless people. The economic loss in Genoa was estimated at € 65 million. Damage to the cultural heritage was also severe. The lower floors of tens of historical buildings in the medieval centre of Genoa (the largest in Europe) were inundated [1,4].

On 13 December 1982, at 10:45 pm, a large, deep-seated landslide occurred at Ancona (Marche Region). The single slope failure involved the movement of 342 hectares of urban and suburban land, damage to two hospitals and the Faculty of Medicine at Ancona University, damage to or complete destruction of 280 buildings with a total of 865 apartments, displacement of the main railway and coastal road for more than 2.5 km, one (indirect) death, and the evacuation of 3,661 people. At least 500 people were left temporarily unemployed [1-2,5]. The economic loss was estimated at € 770 million [6].

On 19 July 1985, at 12:24 am, two artificial mine ponds near Tesero (Trento Province) failed producing the largest single mud flow in Italy in historical time. More than 230 millions cubic meters of muddy debris flowed at high speed along the Stava stream, reaching in 7 minutes the town of Tesero, where 269 people were killed and 70 buildings were destroyed or damaged [1].

Two years later, on 17-19 July 1987, in Valtellina (Lombardy Region) heavy rainfall produced flooding along the Adda river and its tributaries, and triggered several hundreds debris flows, a few deep-seated landslides, and a catastrophic rock avalanche 35 millions cubic meters in volume (on 28 July). The toll amounted to 27 dead and 20,000 evacuated people. Damage was reported in 162 Municipalities in 4 Provinces (Sondrio, Como, Lecco, and Bergamo). The economic loss was estimated at € 1100 million [7].

On 2-6 November 1994, the Piedmont Region (north-western Italy) suffered a severe event. Extensive inundation and numerous landslides killed 70, injured 86, and left more than 2,200 homeless people. At least 496 municipalities suffered damage that was particularly severe to the infrastructure. Ten bridges were destroyed and more than 100 were damaged. At several locations roads were destroyed by shallow and deep-seated landslides for several hundreds meters, leaving towns and villages isolated for weeks. Ten thousands people were left temporarily unemployed. The Tanaro River caused the largest damage, particularly in and in the vicinity of Alba, Asti and Alessandria [8]. Estimates of the economic loss ranged between € 8,000 and 13,000 million, 1.2 percent of GDP.

On 5 May 1998, secondary lahars (i.e., debris flows involving volcanic soils) were triggered by rainfall on the steep slopes of Pizzo d'Alvano, east of Naples (Campania Region). Several pulses of mud and debris inundated the towns of Episcopio, Siano, Bracigliano and Quindici, killing 153 people in five different sites and leaving hundreds of homeless people. The event caused a tremendous impact nation-wide which included unprecedented coverage by the mass media, and prompted a new legislation on landslide risk assessment procedures [2].

On 13-16 October 2000, the Valle d'Aosta, Piedmont and Liguria Regions (north-western Italy) suffered the last severe inundation of the century. In the western Alps, rainfall in excess of 600 mm in 48 hours produced a large flood of the Po River and of its northern (i.e., left) tributaries. In Torino the river was only a few centimeters from the top of the levees. The toll amounted to 35 deaths or missing people (18 in Valle d'Aosta, 4 in Piedmont, 3 in Liguria, and 10 in Ticino Canton, Switzerland), 40,000 evacuees, and 3,000 homeless people. Economic damage was estimated at € 5000 million.

3. The AVI Project

On 23 June 1989, the Italian Minister of Civil Protection requested the Italian National Research Council (CNR), Group for Hydrological and Geological Disasters Prevention (GNDCI), to compile an inventory of sites historically affected by landslides and floods in Italy, for the period 1918-1990. The minister's request followed several meetings of a government committee on natural and human-induced risks (the *Commissione Grandi Rischi*) that urged the Ministry of Civil Protection to complete an inventory aimed at defining the geological (i.e., caused by landslides) and hydrological (i.e., caused by floods) risk for the entire nation.

The idea of collecting historical information on natural catastrophes was not new. Toward the end of 19th century natural scientists collected a wealth of information on a variety of natural disasters including epidemics (Corradi in 1865-1894), earthquakes (Mercalli in 1883 and Baratta in 1901), floods (Bottoni in 1873), and landslides (Almagià in 1906-1910). More recently large and expensive efforts were made to collect historical information on earthquakes and their effects [9-14].

To respond to the Minister request, CNR-GNDCI in 1990-92 designed and completed an inventory of historical information on landslides and floods in Italy. The project became known as the "AVI project". Between 1991 and 1992 seventeen teams collected information on mass-movements and floods occurred in Italy in the 20th Century. A total of 22 journals were systematically searched and 350,000 newspaper issues were screened. About 150 experts were interviewed and 1,000 published and unpublished technical and scientific reports were reviewed [15-16].

Since 1992 considerable effort has been made to keep the database updated, and to search for new data on historical landslide and flood events. The inventory was updated for the period 1991-1996 by searching 55 local or regional journals, for a total of more than 120,000 newspaper issues screened. The update for the period 1997-1998 is currently in progress and it involves the systematic search of 59 local and regional newspapers, the review of tens of technical and events reports, and of the scientific papers published by CNR-GNDCI. In the attempt to perform a quick (i.e., non systematic) update of the database for the most recent years, since 1999 we check daily the web pages of regional and national journals searching for information on landslides and floods. An average of 1,000 newspaper articles is found every year.

The three main sources of information used to complete the inventory are newspapers, interviews, and the review of the technical and scientific literature. The various sources of information provide data of different quality and in different amounts. About 70% of the total information comes from newspapers, 25% from technical and scientific documents, and the remaining 5% from interviews. Journals emphasize large-magnitude events that occurred in urban areas or that caused damage to well-known or easily recognizable structures. They underreport events of low magnitude or those that do not cause extensive or well-defined damage. The bias limits the definition and the full extent of the hazard in agricultural and rural areas. Newspapers also emphasize the reactivation and repetition of mass movements and floods [15].

The amount and reliability of information found in newspapers improved after Word War II. It increased during the 1950s when several journals introduced regional and local chronicles, and markedly increased in the 1990s when many more journals were searched. The review of newspaper articles provides quality data on the date (but rarely the time) and the general triggering mechanism (rainfall, earthquake, etc.) of occurrences. The exact location is rarely reported and only for single, large events. Commonly, large areas are described where numerous landslides or bank overflows occurred. Economic estimates of the type and extent of damage is provided in a few articles, but technical data, such as the type of movement and the kind and volume of material involved, are seldom reported.

Review of technical and scientific documents provides a wealth of high-quality data for a small number of events. These documents supply information on the geological, morphological, and geotechnical characteristics of a single mass movement, and the hydrological and meteorological characteristics of a particular flooding event. Most of them contain maps and drawings describing in detail the location and the geometrical characteristics of landslides and the extent of inundated areas. Scientific papers rarely describe the types and extent of damage; such information is more abundant in the technical or events reports and in the rare books or monographs written on particular, highly catastrophic events. Social and economic considerations are limited.

Interview with experts in the fields of mass movements and floods provide general information on a limited number of hydrological events. The interviews are useful in giving a comprehensive overview of the areas historically affected by landslides or floods and in defining the awareness of the scientific and technical communities to the problem of geo-hydrological hazards in each region.

In spite of the limitations due to the complexity of the Italian territory, the different awareness of the impact of landslides and floods on the territory, and the limited resources available for the inventory and its maintenance and upgrade, the result of the inventory represents the most comprehensive source of information on mass-movements and floods ever prepared for Italy. The database contains 22,723 information on 23,606 landslide events occurred at 15,956 sites (equivalent to a density of 1 landslide per 20 sq. km) and 7,861 information on 25,078 inundation events at 13,494 sites. Stored in the database are about 100,000 newspapers articles with information on hydrological or geological catastrophes; 20 percent of them are available in digital format through the Internet (http://sici.gndci.pg.cnr.it) [17-19]. The importance of the AVI database as a source of valuable information to ascertain landslide and flood hazards and the associated risk has been recently recognized by the Italian legislator. A new legislation on landslide risk assessment procedures (Law 267/1998) specifies that the AVI database is a mandatory source of information for the assessment of landslide and flood hazards and risk in Italy.

4. Information system on geo-hydrological catastrophes

The large amount of available historical data, the complexity of the AVI database, and the increasing requests of information from the national, regional and local governments, from scientists, geologists, engineers and planners, from civil protection personnel and concerned citizens, has guided the transition of the AVI database from a simple storage of historical data into an information system on landslide and flood events, capable of responding to the requests of different users. SICI (an Italian acronym for Sistema Informativo sulle Catastrofi Idrogeologiche, Information System on Geo-Hydrological Catastrophes) is a collection of databases containing historical data and bibliographical information on landslides and floods in Italy. Instead of embarking into a troublesome and error prone effort to merge the various databases into a single archive we decided to keep all the databases separate, and to treat them as different sources of information within a single information system.

SICI presently contains 5 modules:

- AVI, the database of the AVI project described before;
- GIANO, a database of information on landslides, floods and snow avalanches in Italy from 1700 to 1900, originally prepared by SGA Storia Geofisica e Ambiente for ENEA, in the late eighties;
- ABPO, a database on landslides and floods in the Po River basin compiled by the Po River Basin Authority;
- LOMBARDY, a database on landslides, debris flows and floods for the Valtellina and Val Chiavenna areas, in the Lombardy Region;
- REFERENCES, a set of bibliographical catalogues.

The AVI database remains the largest and most important module of SICI, at least for the 20th century. It contains 22,723 information (records) on 23,606 landslide events, and 7,861 information on 25,078 flooding events. The AVI module also contains a bibliographical database with 1966 references.

The GIANO module contains information on landslides, floods and snow avalanches occurred in Italy from 1700 to 1900, including the original sources of information, derived from an historical investigation completed in the eighties by SGA Storia Geofisica e Ambiente for ENEA (www.enea.it). Information for the period 1700-1900 refer to almost 800 flooding events (388 in the 18th century and 405 in the 19th century) and more than 350 landslide events (56 in the 18th century and 300 in the 19th century). Testimonies (i.e., "information") on landslides are more than 2,100, 884 for the 18th century and 1248 for the 19th century. Testimonies on floods are more than 500, 126 for the 18th century and 402 for the 19th century. The information was collected form 177 bibliographical references, including catalogues, repertoires, historical sources and scientific reports. The value and information content of the GIANO module are still to be fully investigated. At present we can say that the major contribution of the GIANO module to the SICI information system is the extension back in the past of two centuries of the AVI database, mostly limited to the 20th century. The GIANO database, even if it lacks the completeness and accuracy of the AVI database due to the difficulty in collecting information from historical sources and testimonies, it provides a multi-secular perspective on the extent of landslides and floods in Italy. The GIANO module could be further extended back in the past to cover the period 1000-1700.

The ABPO module contains information on landslides and floods in the Po Basin, the largest river basin in Italy (~ 75,000 square km^2). Data were collected and stored in the database by the Po River Basin Authority during the production of the basin master plan ("Piano di Assetto Idrogeologico"). Information was collected from a variety of sources, including historical and archives documents. The ABPO module contains 4,171 records that refer to 5,990 sites affected by 1,647 floods, 1,995 landslides and 536 snow avalanches. For a few sites information on damage is available.

The LOMBARDY module provides information on historical landslides, debris flows and floods in Valtellina and Val Chiavenna (Sondrio Province, Lombardy Region). The database contains data on more than 1,600 sites affected by mass movements, including debris flows, or by inundations originally collected by Mario Govi and Ornella Turitto and published by the CNR-IRPI in 1992. The information was obtained searching 590 bibliographical and archive references. This is presently the only module of the SICI information system that refers to a relatively small geographical area (~ 3,200 km^2) and that was prepared through a very detailed analysis of the available historical sources.

The REFERNCES module contains bibliographical information, including the AVI project reference list, and the list of publications, maps, and reports published by CNR-GNDCI.

The SICI information system is accessible through on the World Wide Web at the internet URL http://sici.gndci.pg.cnr.it.

5. Applications

We present three examples of the use of the historical information for the assessment of landslide and flood hazard and risk in Italy.

5.1 Distribution of landslides and floods

For many sites affected by landslides and floods the exact or the approximate location is known or can be inferred. The geographical coordinates of these sites were obtained through a long and difficult work that involved: careful reading of the original source of information (i.e., newspaper article, technical report, scientific publication, etc.), locating the site affected by the damaging event on topographic maps or road atlases, mapping the location of the landslide or the inundated site as a point on topographic maps at 1.100,000 or 1:25,000 scale, and obtaining the geographical coordinate through digitization.

The availability of geographical coordinates allowed to prepare synoptic maps of the distributions of the 15,956 sites affected by 23,606 landslide events and of the 13,494 sites affected by 25,078 flooding events. Maps were published at 1:1,200,000 scale and distributed to all the Italian Senators and Chamber Representatives [16-17]. A book, in two volumes, with the national catalogue of sites historically affected by landslides or floods, and a CD-ROM built with GIS technology capable of showing the distribution of damaged sites, were prepared and distributed to National and local civil protection authorities, planners and decision makers, and private consultants involved in civil defense planning [18-19].

Comparison of the geographical distribution of landslides and floods with the Italian administrative boundaries shows that all the 105 Italian Provinces experienced recursively landslides or floods. Of the total number of 8,103 Italian municipalities (in 1998) 4,528 (51 percent) have experienced at least once a landslide, and 4,220 (52 percent) have experienced at least once a flood [17]. Analysis of the historical catalogue shows that many sites were affected by landslides or floods more than once (i.e., recursively). Figure 4 shows, for the period 1900-1998, the annual frequency of inundations in the 12,991 sites that were affected by a total of 23,426 flooding events. The plot shows that for a large number of sites (9,216) only one event is recorded in the catalogue, and that a few sites were inundated several times (up to 59). The annual frequency of inundations obeys a power law fit with exponent $\alpha = -0.42$.

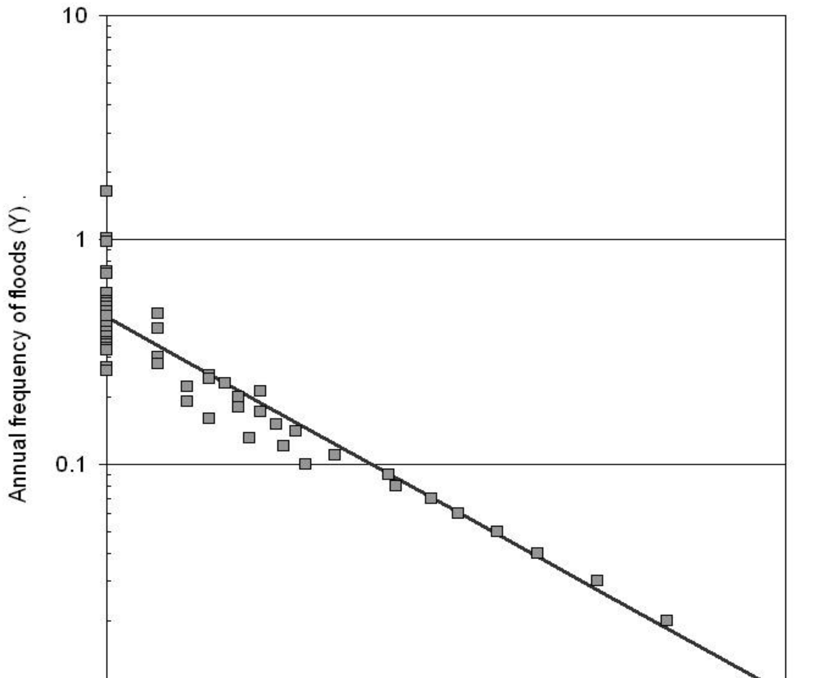

Figure 4. Annual frequency of floods for the period 1900-1998. The thick line is a power-law fit.

5.2 Landslide fatalities and landslide risk in Italy

A catalogue of landslides that have caused dead, missing, injuries and homeless people in Italy was assembled in 1999 from a variety of different sources including existing catalogues and archives on landslides, reports of meteorological and seismic events that triggered slope failures, and accounts or descriptions of individual landslide events [2].

The main source of information was the AVI database, which contains 1,442 records that provide information on mass movements with human consequences, such as numbers of deaths, injuries or homeless people. In addition to the AVI database, several other publications and reports were used to compile the database of landslides that had given rise to human consequences. Their content, temporal extent, date of issue and geographical coverage varied considerably. Some of the publications were the result of detailed historical investigations. These include the two volumes by Almagià, who published information on several hundred landslide events in the Apennines that had occurred over the period 1100-1908 [11-12]; the work of Catenacci, who reported landslides, floods and other natural disasters in each Italian region for the post-World War II period (1945-90) [1]; the work of Eisbacher and Clague on historical landslides in the Alps [20]; and the historical catalogues of landslide events prepared by Migale and Milone for the Sorrentine Peninsula (Campania Region) [21], by Monticelli for the Valli di Lanzo (Piedmont Region) [22], and by Troisi for the Canavese area (Piedmont) [23]. Some reports gave detailed descriptions of individual meteorological events that triggered landslides; other reports described landslides at a single site [2].

The historical catalogue spans the 720 years that extend from 1279 to 1999 and lists a total of 995 landslide events that caused casualties, including events for which the number of casualties is unknown. This is equivalent to a landslide disaster every 0.7 years, or an annual frequency of 1.38. Selecting only the events that caused 3 or more deaths or missing people the number of landslide disasters falls to 303 and the frequency reduces to one every 2.37 years. Between 1410 and 1999 landslide disasters resulted in at least 12,421 casualties comprising 10,447 deaths, 108 missing persons and 1,866 injured people. This is equivalent to an average of about 18 deaths or missing persons per year.

In the 20th century the catalogue reports at least 7,799 casualties, comprising 5,831 deaths, 108 missing persons and 1,860 injured people. This represents an average of 59.4 deaths or missing persons each year, a value three times higher than the one given above, due to a better completeness of the catalogue. The 227 landslide disasters with 3 or more deaths correspond to a frequency of about 2.3 events per year. The number of homeless or evacuated people is uncertain, but the total exceeds 100,000 in the 20th century alone.

Using the catalogue of landslide fatalities, the probability of occurrence of damaging landslides was calculated, and the frequency of landslides was compared with their consequences. In risk analysis it is common practice to plot frequency against consequences in F-N diagrams. In the case of landslides, F-N plots are graphical representations of the cumulative probability per year that landslides will cause N or more fatalities, versus the number of fatalities resulting from landslides, on a log-log scale. The advantage of using F-N plots is that F-N curves are available for several types of disasters, which facilitates comparison of the effects of natural disasters with established or acceptable criteria for societal risk assessment.

Figure 5 shows the curves of frequency against consequences for landslides that have caused deaths or missing people in Italy. Four F-N are shown: for the entire catalogue (1410-1999); for the 19th and 20th centuries (1800-1999); for the 20th century (1900-99); and for the post-War period (1950-99). Due to the different time intervals (590, 200, 100 and 50 years, respectively), which reflect varying degree of completeness and reliability of the catalogue, the annual frequency of events varies by about one order of magnitude. It is worth noting that the curves for 1950-99 (open diamonds) and for 1900-99 (black squares) are very similar. They differ significantly only for the less destructive events (fewer than six fatalities), which reflects the more complete historical catalogue compiled for the second half of the 20th century with respect to events that caused few deaths or missing people. For very large intensity events the difference between the two curves is due only to the 1963 Vajont rockslide (1917 casualties) [2].

Figure 5 shows that the frequency of landslide casualties in Italy is higher than that proposed for Canada (3). The Italian curve is also higher than those computed for the Alps (4) for low intensity events (< 5-10 fatalities). However, this highlights a bias in the Alpine catalogue, which lacks comparable coverage of low-intensity events. The Hong Kong curve (5) covers the period 1948-96 and is as much as one order of magnitude lower than that proposed for Italy for a comparable time interval (1950-99). Even when the catastrophic Vajont disaster is excluded, Italy experienced five times more casualties than Hong Kong did over the period after 1950. F-N curves for Japan and China are higher than the curves computed for Italy, even for the shortest time intervals. This indicates that the former countries experience a higher landslide risk, with a larger number of catastrophic events that result in several tens or hundreds of deaths. It should be noted that the Japanese curve is based on landslide events that caused 10 or more deaths, and the Chinese curve on events that caused at least 100 deaths. The higher number of low intensity events (≤10 fatalities) recorded in Italy in comparison with the Japanese and Chinese curves, and the resulting larger frequency, reflects the incompleteness of the Japanese and Chinese catalogues for the low intensity events [2].

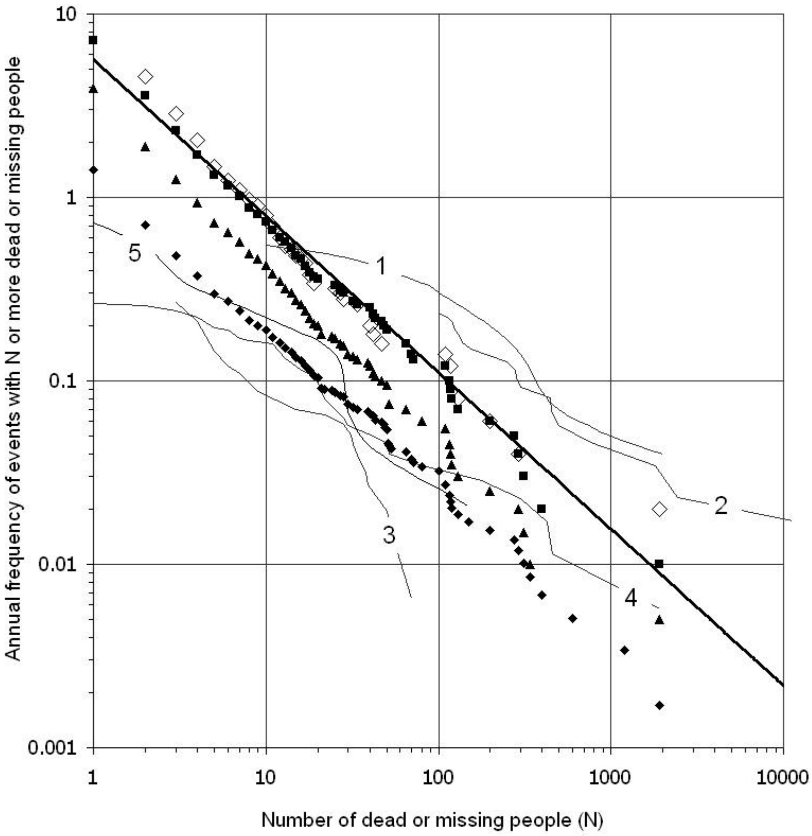

Figure 5. Frequency vs. consequences (F-N plot) curves for landslides with human consequences in Italy. Open diamonds (1950-1999); squares (1900-1999); triangles (1800-1999); black diamonds (1410-1999). The heavy black line is a power law fit to the 1950-1999 series ($y = 5.6x^{-0.85}$). Also shown are the frequency vs. consequences curves for landslides with human consequences in: 1- Japan (1948-1996); 2- China (1900-1987); 3- Canada (1860-1996); 4- the Alps (1800-1974); and 5- Hong Kong (1948-1996). Modified after [2].

5.3 Frequency and magnitude of meteorological events with consequences

For single landslides and floods there is no clear measure of their magnitude, or intensity. This is a limitation because frequency-magnitude relationships, similar to the well known Gutenberg–Richter relation linking the frequency and magnitude of earthquakes [24], cannot be established. Most of the landslides and floods stored into the AVI database are climatically induced, i.e., they were caused by meteorological events. We argue that a first order measure of the intensity of a meteorological event resulting in landslides and floods is given by the number of landslides and floods it produces.

The catalogues of landslides and floods in the AVI database contain information on the date of occurrence of the events. For the period 1900-1998 the catalogues list 15,128 landslide events and 23,426 flood events for which the date is known. Analyzing jointly the two catalogues, we have computed the cumulative (total) number of landslides and floods for different sampling intervals, ranging from 1 to 7 days. Figure 6 shows the annual frequency of geo-hydrological events (i.e., landslides or floods) against the magnitude of the events measured by the number of sites affected by landslides and floods. Regardless of the sampling interval, the annual frequency obeys a power-law relation for magnitude larger than about 10 affected sites (i.e., 10 landslides or floods). Deviation from the power-law fit for events of smaller magnitude is attributed to the incompleteness of the catalogue.

This is a first step toward the definition of a quantitative measure of the impact of damaging meteorological events. The information on the frequency-magnitude relationship of damaging events can prove very important in the assessment of geo-hydrological hazard and the associated risk.

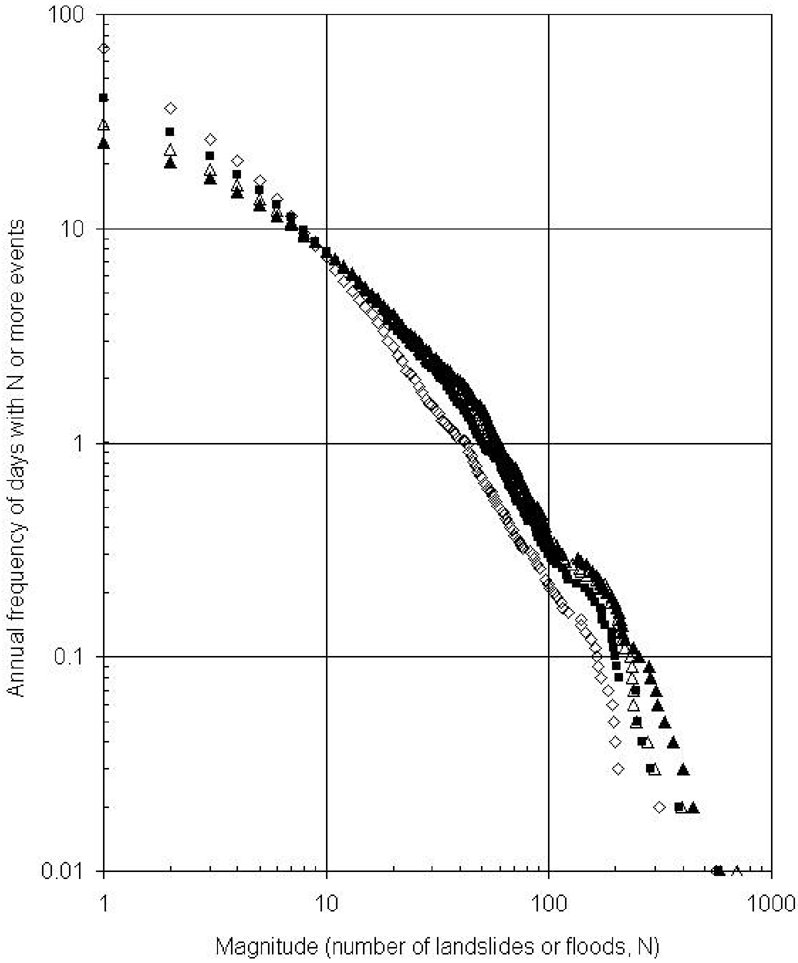

Figure 6. Annual frequency of events against their magnitude, expressed by the total number of sites affected by landslides and floods. Events of different time interval (from 1 to 7 days) are shown. Open diamonds, 1 day; black squares, 3 days; open triangles, 5 days, black triangles, 7 days.

6. Concluding remarks

A modern society may be willing to invest resources where a problem is recognized, but it is unwilling to spend where a problem exists but is not known. This is why the AVI project and the SICI information system are so important. In spite of several limitations SICI is the most comprehensive source on information on landslides and floods ever prepared for Italy. It contains thousands of documents and historical information on landslides and floods, on the locations that suffered damage, and on the type of damage. Exploitation of this information content has only begun.

Appropriate information on geological catastrophes cannot prevent natural events, but it can certainly limit their damage, preventing casualties and economic losses. Hopefully, understanding our history will help us survive in a safer world. We should always keep in mind that a measure of the degree of civilization is given by our ability to protect human life.

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8.0 Biographies

Fausto Guzzetti, a senior research scientist at the Italian National Research Council, leads the CNR-IRPI Applied Geology group in Perugia. He has worked on: landslide mapping in different morphological and climatic environments, methods for landslide hazard assessment using GIS and statistical techniques, evaluation of landslide risk, use of historical information on landslides and floods for hazard and risk assessment, and frequency-magnitude statistics of landslides. Guzzetti is the project leader of the Italian national project on the acquisition and use of historical data for landslide and flood hazards assessment (AVI project).

Francesco Cipolla, Oliviero Lolli, Stefania Pagliacci and Claudio Sebastiani, Geologists, have been involved in the AVI project since the beginning in 1990. They participated to the original inventory and have contributed to the update and maintenance of the archive. They are currently completing a new update, and they are involved in the production of a catalogue of the most damaging geo-hydrological events.

Gabriele Tonelli, Engineer, is a consultant for data-bases, GIS and web-based distributed hydro-geological information system. He has contributed to the design and the implementation of SICI and its web interface. Tonelli is a part-time Professor for Computer Graphics Design at the University of Milano and at the University of Ferrara, Italy.

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