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Relations between rainfall and triggering of debris-flow: case study of Cancia (Dolomites, Northeastern Italy)

M. Bacchini[1] **and A. Zannoni**[2]

[1]Basin Authority of Isonzo, Livenza, Tagliamento, Piave and Brenta-Bacchiglione Rivers, Venice, Italy
[2]CNR-IRPI – Research Institute for Hydrological and Geological Hazard Prevention, C. so Stati Uniti 4, 35127 Padua, Italy

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Abstract. Debris-flows occurring in the area of Cancia (Dolomites, Northeastern Italy) in recent years have exposed the population to serious risk. In response to the recurring hazard, an alarm and monitoring system was installed to provide a sufficient level of safeguard for inhabitants and infrastructures. The data recorded at three rain gauges during debris-flow events has been analysed, taking into consideration the different elevation of the gauges to delineate the storm rainfall distributions. Rainfall data is compared with the occurrence of debris-flows to examine relations between debris-flow initiation and rainfall. In addition, the data is compared with that recorded during debris-flows which occurred under similar or different geological settings in the Eastern Italian Alps, in order to define triggering thresholds.

A threshold for debris-flow activity in terms of mean intensity, duration and mean annual precipitation (M.A.P.) is defined for the study area The normalised rainfall and the normalised intensity are expressed as a per cent with respect to M.A.P. This threshold is compared with thresholds proposed by other authors, and the comparison shows that a lower value is obtained, indicating the debris-flow susceptibility of the area. The threshold equations are:

$$R/M.A.P. = -1.36 \cdot \ln(I) + 3.93 \qquad \text{where } I > 2\,\text{mm/h}$$
$$I/M.A.P. = 0.74 \cdot D^{-0.56}.$$

The determination of a debris-flow threshold is linked to the necessity of a fast decisional phase in a warning system for debris-flow protection. This threshold cannot be used as a predictive tool, but rather as a warning signal for technicians who manage the monitoring/warning system.

1 Introduction

Rainfall intensity and duration of storms has been shown to influence the triggering of debris-flows. The close relationship between intense rainfall and debris-flow initiation has been widely analysed and documented in literature in a number of different settings and environments throughout the world (e.g. Caine, 1980; Govi and Sorzana, 1980; Innes, 1983; Cancelli and Nova, 1985; Govi et al., 1985; Wieczorek, 1987; Cannon, 1988; Ceriani et al., 1992; Larsen and Simon, 1993; Wilson et al., 1993; Ceriani et al., 1994; Wilson and Wieczorek, 1995). Some authors have investigated the relations between mean intensity and duration, in order to define the triggering thresholds of the phenomena.

The large number of debris-flows that were triggered by rainstorms in the Dolomites in recent years points to the need to improve the knowledge of the triggering mechanism of these types of mass movements. In particular, the value of peak and accumulated precipitation that occurs before the flow, and the analysis of critical precipitation in relation to the time and the triggering mechanism of the debris-flow represent the first level of investigation which detailed models could follow. In the case of Cancia debris-flow (Dolomites, Northeastern Italy), particular attention has been paid to the values of maximum precipitation, the peculiar hydrological settings of the area and the heterogeneous, coarse and permeable character of the soil. These parameters indicate a quick development of the conditions necessary for failure. In addition, the high-permeability soils of the Cancia region suggest that the period of necessary previous rainfall may be extremely short or the amount of necessary antecedent rainfall may be supplied by the early part of a storm (Wieczorek, 1987). The case study represents a unique example in terms of both geomorphological evolution and risk analysis due to the long record of repeated events. The first recorded and historically documented event occurred in 1868, and in the last ten years debris-flows have been produced at an average rate of 1–2 events every year. The last destructive event that reached the village of Cancia occurred in 1996, and the increasing hazard situation led to the immediate installation of an alarm and monitoring system to defend the local road network. The establishment of a rain gauge network and the development of new studies were carried out to ensure a suf-

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Correspondence to: A. Zannoni:
(andrea.zannoni@irpi.pd.cnr.it)

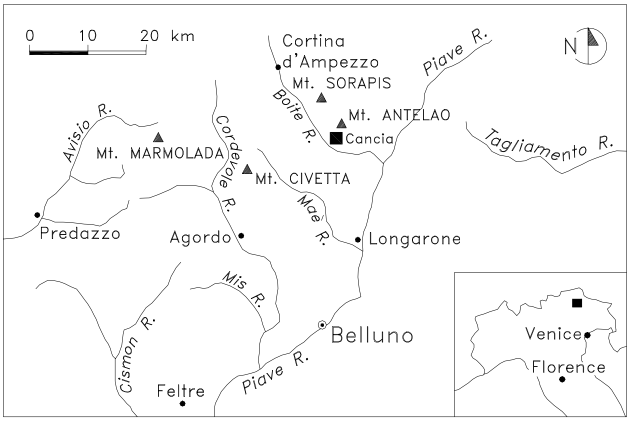

Fig. 1. Location of the Cancia debris-flow.

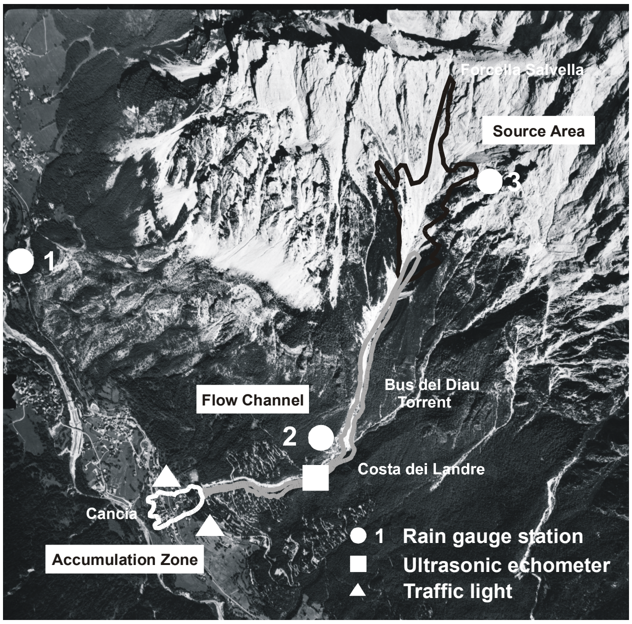

Fig. 2. Elements of the Cancia debris-flow and its monitoring system. The monitoring system is installed along the debris-flow track and consists of three rain gauges, an ultrasonic echometer and two traffic lights. Location of the rain gauge stations: (1) Villanova (since 1985, 975 m a.s.l.); (2) Cancia Bassa (since 1996, 1335 m a.s.l.); (3) Cancia Alta (since 1998, 2260 m a.s.l.).

ficient level of safeguard for the inhabitants.

In order to calculate the triggering rainfall threshold for debris-flows, an historical recording sequence of rainfall data would be necessary to give statistic reliability to the analysis. In this specific case we can consider data from three rain gauge stations located near and inside the landslide area. Unfortunately, none of these rain gauges have a long historical sequence of data to allow for a correct statistic analysis; so only single event studies have been carried out. However, the three rain gauges set at different elevations allow an analysis of the rainfall behaviour that results in debris-flow between the bottom of the valley and mountaintop. Many other rain gauges located near the study area are also examined. The resulting data is used to characterise conditions throughout the entire area, but does not allow for the definition of relations between rainfall and triggering of debris-flow, since the gauges are located some distance from the debris-flow source area. In order to research differences or analogies among triggering conditions and to determine thresholds on a regional basis, a comparison between the study case and other situations in Northeastern Italy has been made. We consider locations both with similar geological and geomorphological settings (Rio Chiesa, Rio Acquabona and Rudavoi; Dolomites, in an area about 50 km from Cancia), and with different settings (Moscardo Torrent; Carniche Alps, 200 km from Cancia). The use of simple methods in this case study could be adequate for a fast decision phase in a warning system for debris-flow protection that is usually required by civil protection authorities.

2 The study area

The Cancia debris-flow is included in the area of Borca di Cadore (Belluno, Italy) in the Eastern Dolomites (Fig. 1). The area, developing at the base of Mt. Antelao (3264 m a.s.l.), stretches from the high altitudes of Forcella Salvella (2451 m a.s.l.) to the bottom of the valley (900 m a.s.l.).

The study area is set on the left side of Boite torrent (hydrographic basin of the Piave River) and is strongly characterised by instability phenomena, in particular debris-flow, due to both geological structure and high mountain energy. The mechanical weathering of Triassic and Jurassic dolomites has resulted in the establishment of a detrital area, modified by numerous landslides. Landslides have caused the greatest changes in land morphology, starting from the post-glacial age (Panizza, 1973) and have often obscured the previous deposits.

The Cancia debris-flow is characterised by a distinctive source area, flow channel and deposition area (Fig. 2). The basin that drains this area covers a surface of about 1.8 km^2 and the altitude of the basin outlet is at 1150 m a.s.l. The source area is characterised by a detrital deposit area equal to 0.17 km^2 and a rock basin surface equal to 0.21 km^2. The flow channel has a length of about 2400 m with a mean steepness of 20°. The debris fan area is about 0.6 km^2. The gradient of the head of the basin near Forcella Salvella is about 30° (Fig. 3); near the valley in the area of possible triggering of landslides, the steepness increases until 35°, then in the confluence of the channel with the downstreaming from the Bus del Diau it decreases to 25°, and it continues to decrease progressively to about 15° in the bottom area. The flow channel appears remarkably incised, ranging from 3–5 m, coupled with much detrital material and banks that have risen. Its pattern follows a north-south direction in the upper part below Forcella Salvella, then it diverts westwards in the direction of the urban area, starting from the confluence with the torrent descending from Bus del Diau.

The rain gauges used in this study are located in Villanova

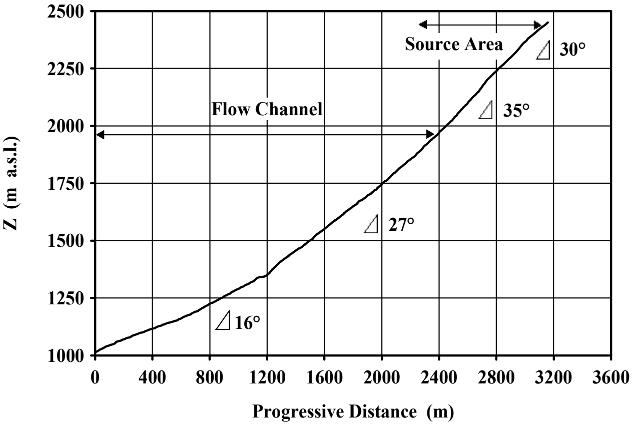

Fig. 3. Longitudinal profile of the flow channel, the upper part of the source area and mean slope angles in the different sectors of the channel.

Fig. 4. Damages from the debris-flow that occurred on 27 July 1868 (a volume of material equal to 100 000 m^3 was deposited from this event).

(bottom of the valley, altitude 975 m a.s.l.), Cancia Bassa (also called Borca di Cadore; confluence Salvella – Bus del Diau, altitude 1335 m a.s.l.) and Cancia Alta (below Forcella Salvella, altitude about 2260 m a.s.l.) (Fig. 2). These sites are located in the deposition area (Villanova), the transport area (Cancia Bassa) and the source area (Cancia Alta).

2.1 Geological and geomorphological settings

Pre-Quaternary terrains in the study area range from Triassic to Jurassic and they represent the typical dolomitic stratigraphic sequence (Viel, 1979; Bosellini, 1989; De Zanche et al., 1993; Loriga Broglio and Neri, 1995) from Fernazza Formation (Ladinian) to Calcari Grigi Formation (Lias). In the Cancia area dolomitic and calcareous walls are remarkably high with morphological benches connected with less competent nearly-argillaceous formations. This sequence has been changed according to a rigid behaviour by faulting, which has modified the geometric relationship among the different formations, especially during the Tertiary when two different regional tectonic phases occurred (Dinaric phase and Neogenic phase – Doglioni, 1987; Bosellini, 1989; Castellarin et al., 1992). All the structures deriving from these tectonic movements, at lower altitude and in the bottom of the valley, are hidden due to the abundant quaternary detrital deposits (talus, debris fan, morainic deposits and conglomerates).

The most unique and characteristic quaternary deposits are some clastic conglomerates, clearly discordant with the underlying limestone and dolomites formations, usually involved in the flow by erosional processes. The conglomerates are deeply incised along the flow channel. In the source area the erosion is promoted by the steepness of the slope. Towards the valley, reducing the gradient, it is easier to find this quaternary formation. The conglomerates outcrop at Costa dei Landre, which acts as barrier for the flow, favouring the flow channel turning in the W–SW direction.

In the area of Borca di Cadore, in the northwestern part of the slope, a debris avalanche phenomenon of a remarkable extent is observed, which, however, represents a high instability of this area, even if it is historically, but not genetically, different from the debris-flow phenomenon.

The hardly fractured dolomitic rock mass favours the formation of talus deposits, which have caused the development of many landslide phenomena (Panizza et al., 1998). The flowing materials have been classified as gravels with low content in sand and fine particles, with an abundance of pebbles and blocks (grain size laboratory analysis and grain size distribution by transept-line).

2.2 Climatic setting

Storms are typical meteorological events during the summer in the alpine area. The area of Borca di Cadore has a climate of alpine type, moderated cold, class D of Köppen classification, with vertical diversification in microclimates. The temperatures have an annual mean of 5°C, and summer maximums are between 10° and 15°C. Spring and autumn are moderately cold, and winter mean values, at low altitudes, are just below 0°C. The annual thermal excursion is comprised between 15° and 20°C (Panizza et al., 1998; Panizza and Zardini, 1986). Diagrams of the yearly rainfall activity show a medium distribution of precipitation of 1000 mm, with maximums in spring and summer (the highest values have been recorded during the months of June and August and medium values in autumn). The snow is distributed in winter and spring and at higher altitude it is preserved until late spring, while on the valley bottom March is the month of melting. The summery storms tend to locate precipitation next to the M. Antelao and M. Sorapis, which act as barriers that intensify and localise the stormy cells, thanks to the forcing effect (forced raising of the air mass saturate).

2.3 Historical sequence and urban development

The debris-flow of Cancia has been a recurrent phenomenon during the last centuries. The first documented recording is dated 1868 (Fig. 4); at that time more than 100 000 m^3

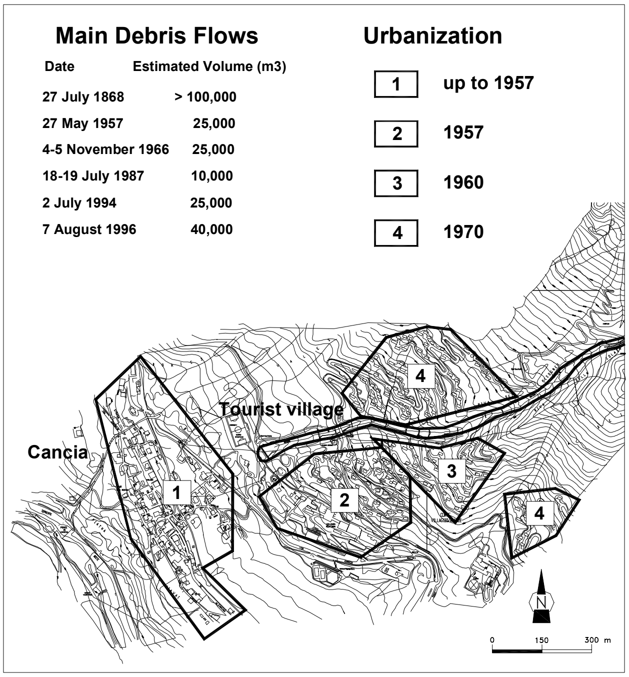

Fig. 5. Urbanization in debris-flow deposition area of Cancia.

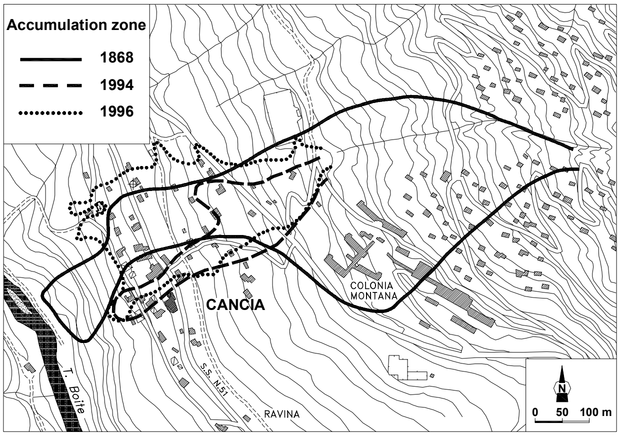

Fig. 6. Accumulation zones of the debris-flows that occurred in 1868, 1994 and 1996.

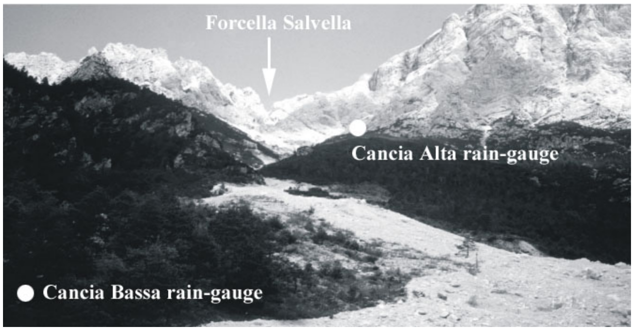

Fig. 7. The source area and the highest part of the flow channel.

of material was deposited (deposition area 203 000 m^2). This is supposed to be the largest event. The most recent events occurred in 1994, when 25 000–30 000 m^3 of material was deposited (deposition area 43 000 m^2), and in 1996 which produced 40 000–45 000 m^3 of material (deposition area 64 000 m^2). However, other smaller events have taken place between 1868 and 1994 and in some cases these events caused damage only to infrastructures and accumulated detrital material along the flow channel. Events in 1957, 1966, 1973, 1987 (two events), 1992, 1993, 1994, 1995, 1996, 1997 and 1998 (three events) have been documented.

Despite the increasing recurrence of the phenomenon, the village of Cancia continued to develop in the hazardous area. In particular, a tourist village was built between the 50's and 60's in the deposition area, including the area affected by the event of the XIX century. The 50's and 60's represented the apex in terms of urban development (Fig. 5). According to a multitemporal study of the aerial photographs, the historical nucleus of Cancia grew until 1957. At the beginning of 1957 the urban structure changed little, while the expansion in the fan area began with the gradual construction of the tourist village "Corte", which ended during the 60's. Cancia has an almost linear development, due to the road network; only the second phase of the development has made it to the mountain. During the 80's and 90's, some of the houses damaged mainly by the events in 1987, 1994 and 1996 were reconstructed. They are set along the road that connects the main valley road to the tourist village.

The increasing risk situation as a consequence of the rising hazard level of the phenomenon and the wrong urbanisation is well documented by the analysis of the deposition zones of debris-flows on the fan. The boundaries of these zones for the debris-flows that occurred on 27 July 1868, 2 July 1994 and 7 August 1996 have been determined by aerial photographs (Fig. 6). It can be observed that in all three cases, the historical nucleus of Cancia is involved; however, the possible occurrence of a similar event, like the one in 1868, would seriously impact even part of the tourist village. As a consequence of this risk, it was necessary to set up a monitoring and alarm system to safeguard the population, infrastructures and buildings (Fig. 2). The alarm system consists of the three rain gauges stations previously mentioned, of an ultrasonic echometer installed in the mid-part of the flow channel, to measure the changing depth of the channel and two traffic lights to stop vehicles on the road when debris-flow occurs.

3 The debris-flow and its triggering mechanism

The triggering area of the Cancia debris-flow is the upper part of the catchment basin (Fig. 7). This area is almost without vegetative cover and strongly affected by selective and/or wide runoff processes. The high gradient, about 30°, and the abundant unstable detrital material contributes to its instability. The grain size distribution is extremely heterogeneous with a greater presence of frequently cemented blocks and

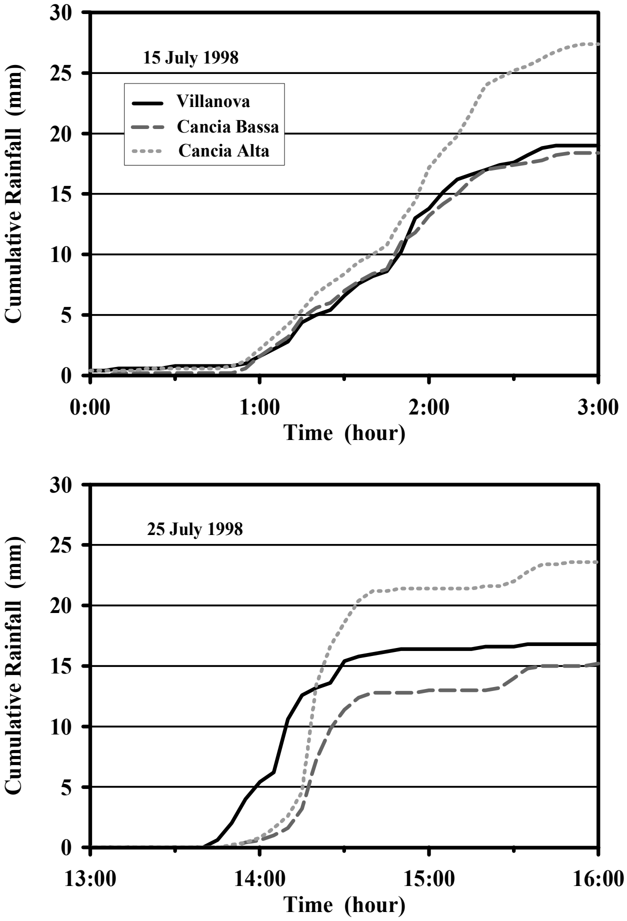

Fig. 8. Cumulative rainfall diagram of the debris-flows that occurred on 15 and 25 July 1998 recorded at the rain gauge stations of Villanova, Cancia Bassa and Cancia Alta. The debris-flow triggering time is unknown.

pebbles (conglomerates), which are affected by erosion processes as well. Towards the valley, at the beginning of the flow channel, there is a detrital deposit whose steepness can be compared with the angle of repose of the loose material (Di Silvio, 1999). These materials are easily mobilised during periods of heavy precipitation. Since the gradient of the whole area is high, two situations are presumed to occur:

- during periods of high intensity and short duration precipitation (less than one hour), pore pressure can react quickly to heavy rainfall (Sidle and Swanson, 1982), and superficial landslides of detrital materials could increase the amount of material in the deposit, thus causing remobilisation in subsequent events;
- connected with heavy rainfall, cumulative precipitation in the source area could cause the debris-flow triggering, thus remobilising at the same time the accumulated material in the deposit and the one in the upper part of the basin.

The debris-flow has a great erosive power which can be observed in the remarkable downcutting of the flow channel and in the morphologic feature of the bank erosion with the resulting addition of material during mass flow events. The flow channel is usually dry without surface runoff, also during periods of high precipitation. The high permeability of the detrital cover favours hydrogeological paths that allow subsurface runoff, and there is no track from the end of the flow channel to the Boite torrent. Valuable surface runoff occurs only during debris-flow events and higher intensity flows, thus increasing the hazardous nature of the debris-flow.

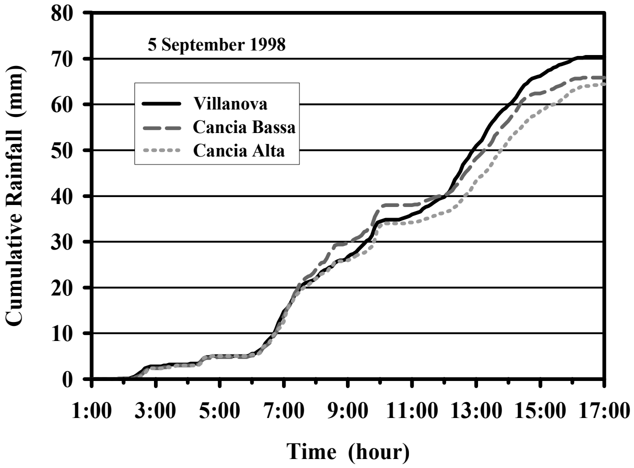

Fig. 9. Cumulative rainfall diagram of the debris-flow that occurred on 5 September 1998 recorded at the rain gauge stations of Villanova, Cancia Bassa and Cancia Alta. The debris-flow triggering time is unknown.

4 Results

This study is intended to characterise the empirical relations between rainfall and landslides, without analysing the hydrogeological and geotechnical aspects, such as the piezometric level and the conditions of the pore pressures in the terrain (Cascini and Versace, 1986). As for high-precipitation events, the recorded trend at the three stations shows a gradual increase in rainfall from the valley to the mountain. The Villanova station usually records values and intensities that are lower than those of Cancia Alta and Cancia Bassa (Fig. 8). However, this cannot be considered as a rule; in fact during the debris-flow event which occurred on 5 September 1998 (Fig. 9), the opposite happened, with lower values at higher elevations than those recorded at the bottom of the valley. This is due to the behaviour of the stormy cells, because the rainstorm began in the area of the Villanova station, thus developing from the valley to the mountain. In addition, the data analysis has enabled us to underline that the rainfall trend of the cumulative rainfall that is recorded at the Villanova station is “smooth”, usually with a lower gradient than Cancia Bassa and Cancia Alta. These rain gauges show high recurrent storms, thus involving a fast increase in cumulative rainfall and intensity that is an important factor for

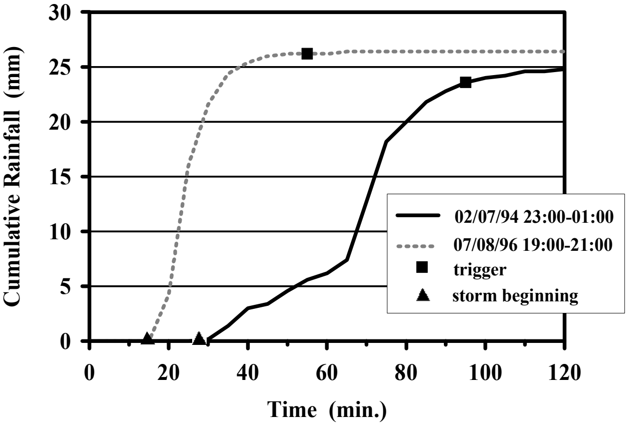

Fig. 10. Cumulative rainfall diagram of the debris-flows that occurred on 2 July 1994 and 7 August 1996 recorded at the rain gauge station of Villanova.

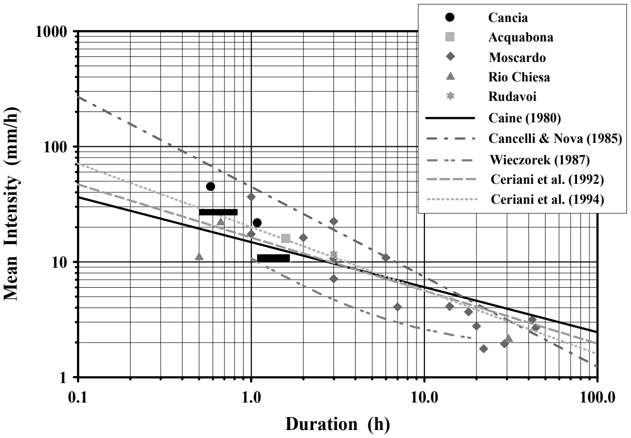

Fig. 11. Rainfall intensity vs. duration and debris-flow correlation. Cancia debris-flows are represented with a point when the triggering time is known (1994 and 1996 events) and with a rectangle that considers the intervals of possible intensity and duration when the triggering time is uncertain (July 1998 events).

debris-flow triggering (Fig. 8). However, the behaviour of the stormy cells in the area has an important role in defining cumulative rainfall and intensity that causes debris-flow initiation. The comparison among the three rain gauge records could be decisive in identifying a representative station, even if its existence cannot be known for certain. Unfortunately, there is not enough data referring to the Cancia Alta and Cancia Bassa stations due to their short period of use linked to debris-flow events. This fact has reduced the possibility of identifying a representative station, even if the Cancia Alta rain gauge could be the most representative due to its closeness to the triggering area. Data recording in the next few years will be important to determine if data from a representative station could be used for threshold computation. However, the role of stormy cells seems more decisive for debris-flow triggering for the study case, and case-by-case situations should be considered for the rain gauge network, in order to better understand the triggering mechanism with respect to the cumulative rainfall and intensity of rainstorms.

Concerning the five events that could enable a correct analysis of the phenomenon (2 July 1994, 7 August 1996, 15 July 1998, 25 July 1998 and 5 September 1998), reliable information about the triggering time is only available during 1994 and 1996, because the events were very destructive and reached the village of Cancia (Fig. 10). The debris-flows that occurred in 1998 stopped before the ultrasonic echometer and no information about the triggering time is available, but day-after surveys of technicians managing the monitoring system ensured that the debris-flow was triggered. As for the two events in July 1998, it is possible to determine the time when the debris-flow occurred, thanks to the short rainfall duration linked with possible moments when the debris-flow was triggered. Unfortunately, this process cannot be used for the event occurring in September due to rainfall duration, because the obtained interval is too long. On the basis of the analyses carried out, a comparison with other cases of debris-flow occurred in the north-eastern alpine area in different or similar geologic settings has been made. The analysed data has been used to plot an intensity-duration graph (Fig. 11) in which it is possible to check the data behaviour in comparison with critical lines suggested by different authors in the literature (Caine, 1980; Cancelli and Nova, 1985; Wieczorek, 1987; Ceriani et al., 1992, 1994). According to this analysis, a homogeneous behaviour in the Cancia case has been recorded that can be compared to the cases of the Dolomites. The available data underlines that the triggering rainfall does not have very high values (usually between 20 and 30 mm in 1–2 h), but does have a short duration and intermediate-high intensity. The data referring to the 1994, 1996 and July 1998 events has been used both in the graph of normalised intensity on Mean Annual Precipitation (M.A.P.) – duration (Fig. 12, Cannon, 1988), and in the graph of normalised triggering rainfall on M.A.P. – intensity (Fig. 13, Govi et al., 1985).

Normalisation of rainfall and intensity by dividing by the M.A.P. has been a common practice, and works fairly well with limited areas where the annual frequency of rain storms is fairly constant. M.A.P. normalisation fails, however, when attempted across large areas where rain frequency may vary significantly (Wilson, 2000). Considering the regional character of our research and the similar climatic settings, we can accept M.A.P. normalisation. In both cases of Figs. 12 and 13, it is clear that the data referring to 1994, 1996 and 25 July 1998 events is in the instability area for the debris-flow, just over the “debris-flow beginning line”, suggested by Ceriani et al. (1994), but also in the stability area in comparison with the one suggested by Govi et al. (1985). Even in these cases we considered the previously analysed situations, such as the one of the Rudavoi torrent (Marchi and Pasuto, 1999, drainage area 3.3 km^2), the Moscardo torrent (Deganutti et al., 2000, drainage area 4.1 km^2), the Rio Acquabona (Genevois et al., 2000, drainage area 0.3 km^2 closed

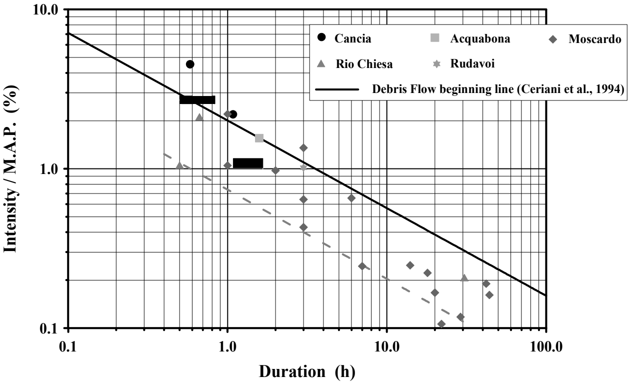

Fig. 12. Normalized rainfall intensity (intensity/M.A.P.) vs. duration and debris-flow correlation. Cancia debris-flow representation is the same as in Fig. 11. The dashed line shows the debris-flow threshold proposed for the study area.

at the beginning of the initiation area) and the Rio Chiesa (drainage area 0.65 km^2). The M.A.P. is quite similar for all sites (about 1000 mm), except for the Moscardo Torrent where it reaches 1600 mm.

According to the analysis of the whole range of studied cases, most of the events occur in the stability area, below the thresholds suggested by Govi et al. (1985) and Ceriani et al. (1994). In each graph, however, a new possible debris-flow starting line is delineated and connected with the considered cases; it is lower than the one suggested by Ceriani et al. (1994) and with an almost parallel trend. This different lower threshold can be explained by the following reasons:

- the case study we have shown concern only small basins which are particularly prone to landslides;
- the climate, very similar among our cases, is different in comparison with the one considered by Ceriani et al. (1994);
- the high predisposition and recurrence of debris-flow phenomena in the studied alpine area is due to the regional character of our research; instead, Ceriani et al. (1994) considered debris-flows which occurred in a wider alpine area (Central Alps in Lombardia region and Western Alps in Piemonte region), in very different environments from a geological, geomorphological and meteorological point of view;
- the triggering features of the analysed cases are different from those Ceriani et al. (1994) studied: debris-flow, debris torrent, debris avalanches, soil slip and other hydrological damages like floods and consequent sliding phenomena of different sizes (Ceriani et al., 1994).

The obtained data can be considered reliable enough to determine equations of the debris-flow threshold that we are proposing. The normalised rainfall and the normalised intensity expressed as per cent with respect to M.A.P. are:

$$R_n = -1.36 \cdot \ln(I) + 3.93, \qquad \text{where } I > 2\,\text{mm/h} \tag{1}$$

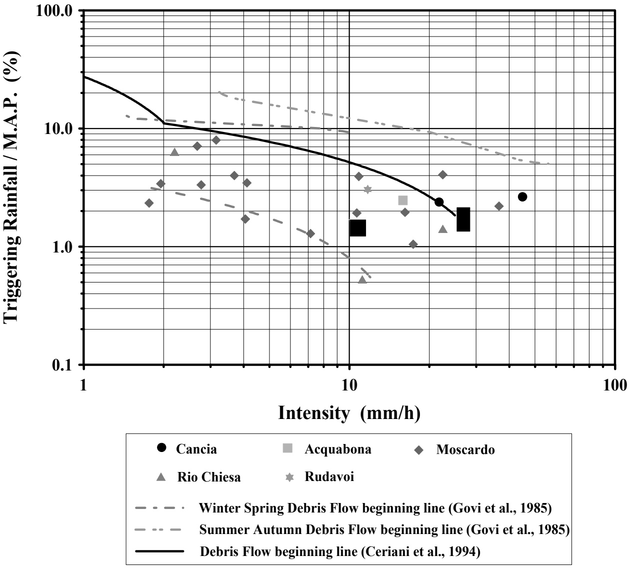

Fig. 13. Normalized rainfall (rainfall/M.A.P.) vs. intensity and debris-flow correlation. Cancia debris-flow representation is the same as in Fig. 11. The dashed line shows the debris-flow threshold proposed for the study area.

$$I_n = 0.74 \cdot D^{-0.56} \tag{2}$$

with

D	Duration (h)
I	Mean intensity (mm/h)
$R_n = \dfrac{R}{M.A.P.}$	Normalised rainfall (%)
$I_n = \dfrac{I}{M.A.P.}$	Normalised intensity (%).

However, we would like to underline that new data concerning other further events is necessary to check and to improve this threshold in the future, and after all, it cannot have a forecast-value due to the precipitation duration and the time passing between two subsequent meteorological events. The identification of such thresholds needs real-time data acquisition (Bottino et al., 1996), especially for the management of a monitoring system. It is thought that in the analysed case the identification of a minimum threshold is useful as a warning level for those managing the monitoring system, but it cannot be used to alert the population at this time.

5 Conclusions

The opportunity to install a wider network of meteorological stations, together with the monitoring of sites affected by debris-flows, enables a more and more detailed definition of the triggering conditions of these phenomena. In particular, the case study of Cancia, also in comparison with other situations in Northeastern Italy, has allowed for the determination of a debris-flow threshold that is valid in the study region. Comparison of the threshold developed here with the threshold conditions defined by others shows that this one is a lower triggering threshold. This is due to the regional character of the study, the unique meteorological, geologic and geomorphological conditions of the case studies and the features of the triggering mechanism. However, it is underlined that the studied area is particularly affected by debris-flows, and considering the urban development, there are high-risk conditions.

As for the Cancia debris-flow, the data collected by the three rain gauge stations has enabled a preliminary analysis of the precipitation trend connected with the altitude, even if the lack of data recorded in the two stations at higher altitude (due to their recent installation) has not allowed for a more detailed research. However, this network of stations has turned out to be greatly positive for the debris-flow studies, in order to improve the debris-flow threshold knowledge, to analyse the trend of stormy cells, which is important for critical rainfall forecast, triggering debris-flow, and finally to develop new technologies for the improvement of the alarm system. As our study suggests, the determination of a minimum threshold could be useful for the requirements of civil protection, which are linked to the management of the monitoring system. However, the authorities in charge for these tasks should use more sophisticated models, based on critical precipitation forecast, in order to plan the population warning.

Indirect geophysics surveying (electrical tomography) is going on in the area of Cancia with the aim of estimating the volumes of mobilised, deposited and still movable material and of delineating in detail the geomorphologic evolution of the area. Moreover, it would be necessary to calibrate the interpretative model derived from geoelectric surveying with useful drillings equipped with piezometric cells to measure the groundwater level and the pore pressure. The increase in knowledge would be useful to carry out more detailed analyses of pluviometric data and of the role that rainfall duration and intensity play in the debris-flow triggering mechanism of Cancia.

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