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DEBRIS FLOWS TRIGGERED BY THE JULY, 17-19, 1987 STORM IN THE VALTELLINA AREA (NORTHERN ITALY)

Laves torrentielles provoqués par l'ouragan du 17-19 Juillet 1987 dans la région de la Valtellina (Nord de l'Italie)

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Abstract

The results of a study on mass-movements triggered by the July 17th-19th, 1987 storm in the Valtellina area, are presented. The meteorology of the event, the geotechnical properties of soils, and the morphological characters of the failures are studied. Comparisons are made with similar findings for the May 14th-23rd, 1983 inundation in Valtellina. An attempt is made to correlate the different types of debris-flows, classified according to their morphological, topographic, hydrological and geotechnical characteristics, with the source, transport and accumulation areas of an alpine torrent system. Finally, considerations on the evolution of the different types of failures are made.

Resumé

On presente les resultats d'un étude sur les mouvements de terre provoqué par un événement catastrophique dans la Valtellina entre le 17 e le 19 Juillet du 1987. Nous avons pris en consideration les conditions météorologiques de l'ouragan, les caractéristiques géotéchniques des sols, et la morphologie des èboulements. Les resultats ont été comparés avec les observations conduites sur l'inondation du 14-23 Mai 1983 en Valtellina. On à mis en corrélation les différentes types des mouvements de terre, classés selon leur caractères morphologiques, topographiques, hydrologiques, et géotechiniques, avec les régions the source, transport et de deposition d'un torrent alpin. Enfin, on à analysé l'évolution des différents types des coulées.

INTRODUCTION

Heavy rainfalls have been recognized as the principal factor for triggering debris flows in different geological, morphological and climatological environments world-wide (CAMPBELL, 1974; GOVI and SORZANA, 1980; KOSTASCHUK *et al.*, 1986; COSTA and WIECZOREK, 1987). In the Central Alps debris flows are particularly common phenomena. Reports on inundations, floodings, and landslides go back to the 14th century (ENGELEN, 1967; AULITZKY, 1980; MOSER and HOHENSINN, 1983; EISBACHER and CLAGUE, 1984).

In the Valtellina area the latest catastrophic inundations occurred in the spring of 1983 and in the summer of 1987. These highly destructive events have produced large floods, hundreds of landslides, debris flows and debris torrents, causing extensive social and economic damages, and claiming 29 lives. In 1983, 17 people were killed in the town of Tresenda and more than 5000 were evacuated in the valley. The estimated economic loss was in the range of 60 to 240 billion 1983/Lire (BENEDINI and GISOTTI, 1985; CANCELLI and NOVA, 1985). The 1987 event claimed 12 lives; 10 of them were killed by a debris flow in a hotel in the town of Tartano. Thousands of people were evacuated from their homes located in the flooded plain of the Adda river, or on the alluvial fans, inundated by debris flows and debris torrents all over the valley. The total economic loss was estimated in excess of 2000 billion 1987/Lire.

GENERAL SETTING

Valtellina is an Alpine valley located in the South-Central Alps, in the northern part of the Lombardia region (Fig. 1). The valley extends for 2400 km^2 from the Como lake to the Stelvio pass, and constitutes the upper basin of the Adda river, a tributary of the Po river. The total relief exceeds 3800 m, from the Adda plain to the P.zo Bernina (4050 m).

Valtellina can be subdivided into two parts. The Lower valley, from the Como lake to the town of Tresenda, has a general E-W direction, and follows the Insubric line, a regional tectonic lineament that separates the Orobic Alps to the south, from the Retic Alps to the north. The Upper valley, upstream from Tresenda, can be further subdivided into a NE-SW segment, between Tresenda and Le Prese, and a N-S segment, between Le Prese and Bormio.

The morphology of Valtellina is the result of combined glacial and fluvial activity. The main valley has a U-shaped transverse profile with very steep slopes and a flat bottom up to 3 km wide. The tributary valleys, originally scoured by glaciers, as it is demonstrated by glacial cirques and hanging U-shaped valleys, show in the lower section V-shaped profiles, indicating recent down-cutting by fluvial erosion. In the area outcrop mostly metamorphic rocks (schist and gneiss) and subordinately sedimentary and intrusive rocks. Continental quaternary deposits are scattered all over the area: glacial deposits mostly above 1900 m, and alluvial deposits along the main valleys where the relief is lower.

The climate of the Alps is continental, and reflects three weather systems: one originating over the Atlantic Ocean, a second in the Mediterranean sea, and a third in the cold regions of Russia. In Valtellina precipitations concentrate during two rainy periods, on May and November. Of particular interest for debris flows are the high-intensity thunderstorms (cloudbursts) that occur in intramontane areas, such as Valtellina, during exceptionally hot summers.

METEOROLOGICAL CONSIDERATIONS

The analysis of a 60-years rainfall record shows that the annual precipitation varies in Valtellina from less than 700 mm·yr^{-1} on the valley bottom, to more than 2000 mm·yr^{-1}. The Lower valley receives more rain than the Upper valley, and the Orobic side receives more rain than the Alpine side (Fig. 2a). Precipitation is modified by local aspect and elevation; this is particularly evident if one considers the rainfall pattern of summer storms.

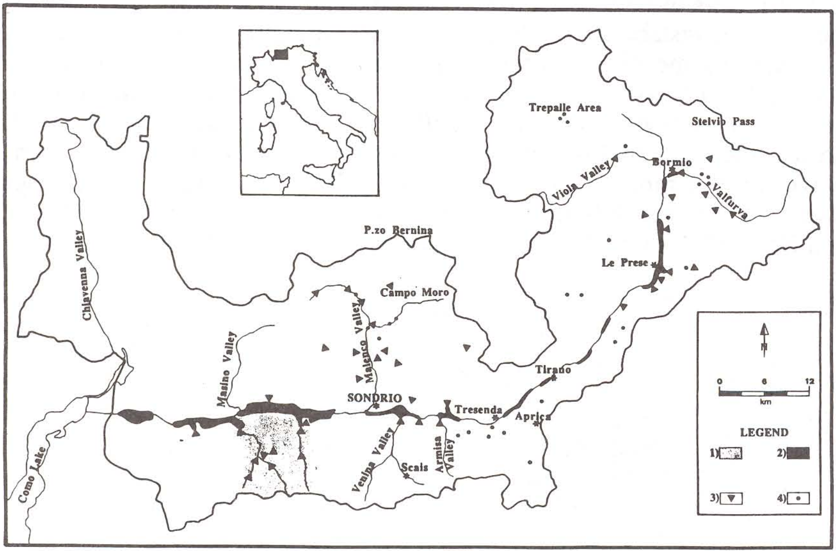

Fig. 1. Location map. 1) Tartano, Madrasco and Presio basins, 2) Areas inundated by the July, 1987 flood, 3) Major failures occurred in 1987, 4) Major failures occurred in 1983.

Fig. 1. Localization de la zone d'étude. 1) Bassins du Tartano, Madrasco and Presio, 2) Zones inundés en Juillet, 1987, 3) Principals éboulements du 1987, 4) Principals éboulements du 1983.

April and May 1983 were marked by pronounced meteorological instability. The persistence of low-pressure cells over the Atlantic Ocean and the Tyrrhenian sea, produced a series of fronts over the Alps, and consequentially meteorological disturbance and high precipitations (Fig. 3a).

In the Valtellina area two major storms were observed, respectively on May 14th-16th and on May 21st-23rd. The events were preceded by scattered precipitations. The antecedent rainfall was consistently above 100 mm, reaching 289 mm at Campo Tartano, and 267 mm at Aprica (Tab. 1). During the first storm, from 78 mm to 248 mm of rain were recorded, whereas during the second storm rainfall generally exceeded 120 mm, and locally reached 200 mm (Aprica). The cumulative rainfall ranged from 193 mm at Campo Moro, to 453 mm at Aprica, representing respectively the 19% and 34% of the total annual precipitation. The average cumulative rainfall for the whole event was in the order of 260 mm. The observed daily intensities ranged from 41 mm at Campo Tartano, to 108 mm at Aprica, and were generally recorded on the 16th and the 22nd, respectively for the first and the second storm.

During the second decade of July 1987 a stationary front, with low pressure cells moving from the Atlantic Ocean to the Alps, produced meteorological instability and heavy rainfalls throughout the Alps (Fig. 3b). In Valtellina the main rainfall event occurred on July 17th-19th and was marked by increasing rainfall intensity. The antecedent rainfall was low, ranging from few millimetres to 60 mm, with the exception of the Le Prese gauge, where 134 mm of rain were measured (Tab. 2). The cumulative rainfall ranged from 73 mm at the Trepalle gauge, in the Upper Valtellina, to over 400 mm, at Case Pizzini (410 mm), Armisa (414 mm), and Scais (512 mm). On average, 180 mm of rain fell from the morning

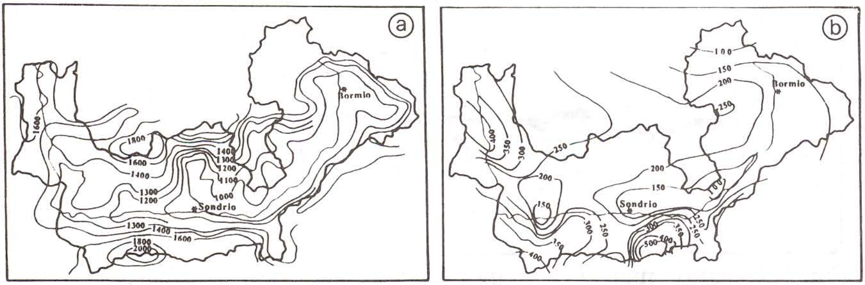

Fig. 2. Rainfall contour maps. a) Mean annual precipitation
b) Cumulative rainfall for the July 1987 storm.

Fig. 2. Cartes des isohyètes. a) Précipitations moiennes annuelles
b) Précipitations de l'ouragan du Juillet 1987.

Raingauge	Elevation a.s.l. m	Basin	April 15 May 13 mm	May 14 - 16 mm	May 17 - 20 mm	May 21 - 23 mm	Storm Total mm	Mean Annual mm	NSR %
L. di Cancano	1948	Adda	156,0	99,2	13,2	159,4	271,8	733,9	37
Premadio	1275	Adda	134,9	89,6	2,4	125,8	217,8	731,3	30
Le Prese	954	Adda	172,2	82,0	8,6	123,2	213,8	699,3	31
Teglio	450	Adda	190,8	96,4	0,0	187,7	284,1	1064,2	27
Arnoga	1870	Bormina	246,8	145,6	0,0	199,0	344,6	1118,5	31
Bormio	1225	Bormina	145,8	94,0	0,0	125,2	219,2	696,4	31
S.C. Valfurva	1710	Frodolfo	103,8	78,4	0,6	138,2	217,2	851,8	25
Aprica	1181	Belviso	267,0	248,0	0,0	205,0	453,0	1207,6	38
Campo Moro	1906	Mallero	184,0	100,0	2,0	91,0	193,0	915,0	21
Campo Tartano	1040	Tartano	289,0	125,0	27,0	53,4	205,4	1017,2	20

Tab. 1. Precipitations recorded during the May, 1983 storm in Valtellina.
Tab. 1. Précipitations du Moi 1983 en Valtellina.

Raingauge	Elevation a.s.l. m	Basin	July 1 - 14 mm	July 15 - 16 mm	July 17 - 19 mm	Storm Total mm	Mean Annual mm	NSR %
L. di Cancano	1948	Adda	38,8	22,9	114,8	137,7	733,9	19
Premadio	1275	Adda	39,6	11,0	144,2	155,2	731,3	21
Le Prese	954	Adda	134,2	20,0	118,7	138,7	699,3	20
Sernio	470	Adda	48,6	25,8	95,9	121,7	843,9	14
Arnoga	1870	Bormina	41,0	28,7	199,3	228,0	1118,5	20
Bormio	1225	Bormina	24,6	11,2	149,8	161,0	696,4	23
Trepalle	1990	Rio Torto	25,6	10,4	73,2	83,6		
Fusino	1212	Roasco	25,4	22,1	164,6	186,7	765,2	24
Livigno	1810	Spoel	10,8	11,2	87,2	98,4		
Forni S. Giacomo	2165	Frodolfo	40,8	26,8	96,5	123,3	642,2	19
S.C. Valfurva	1710	Frodolfo	59,6	23,4	166,9	190,3	851,8	22
Campo Moro	1906	Mallero		25,4	163,9	189,3	915,0	21
Lanzada	983	Mallero	12,0	27,3	164,4	191,7	842,6	23
V. Antognasco	940	Mallero	11,3	10,0	110,0	120,0		
Sondrio	298	Mallero	17,5	18,3	102,6	120,9	859,0	14
Prati di Lotto	970	Masino	18,0	17,0	138,0	155,0		
Ruschedo	755	Masino	7,4	14,0	141,0	155,0	1073,4	14
Ardenno	266	Masino	17,8	14,1	121,0	135,1	997,0	14
S.S. Armisa	1865	Armisa	10,0	20,6	414,1	434,7		
Case Pizzini	1060	Armisa	9,0	22,0	410,0	432,0	1486,3	29
Frera	1382	Belviso	48,0	17,0	203,0	220,0		
Aprica	1181	Belviso	57,0	43,0	167,0	210,0	1207,6	17
Lago Inferno	2332	Bitto	37,5	10,0	305,0	315,0	1895,6	17
Publino	2116	Livrio	25,0	31,0	134,0	165,0		
Campo Tartano	1040	Tartano	43,0	35,0	271,0	306,0	1017,2	30
Lago Venina	1800	Venina	29,0	41,0	183,0	224,0	1234,9	18
Scais	1500	Venina	23,0	32,0	479,0	511,0	1417,8	36
Vedello	1060	Venina	23,0	32,0	218,0	250,0	1254,4	20

Tab. 2. Precipitations recorded during the July, 1987 storm in Valtellina.
Tab. 2. Précipitations du Juillet 1987 en Valtellina.

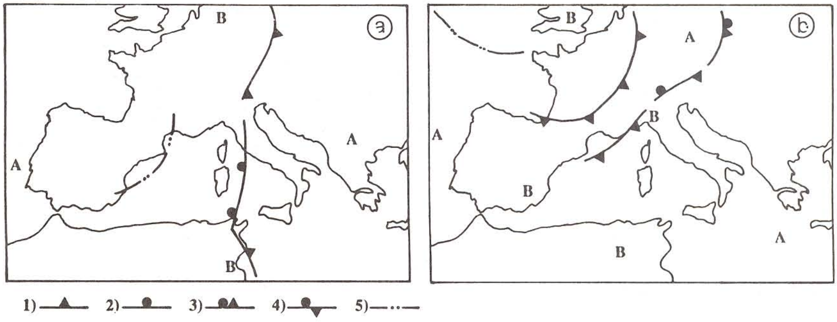

Fig. 3. Meteorological maps. a) May 23rd 1983 b) July 18th, 1987.
1) Cold front, 2) Warm front, 3) Occluded front, 4) Stationary front, 5) Line of instability.

Fig. 3. Cartes météorologiques. a) 23 Mai 1983 b) 18 Juillet 1987.
1) Front froid, 2) Front chaud, 4) Front stationnaire, 5) Ligne d'instabilité.

of the 17th to the late afternoon of the 19th (Fig. 2b). Locally, some rain was recorded also on the 20th. Hourly intensities measured at 23 recording stations, were in the order of 11 mm·h^{-1}. Extreme values were observed at Le Prese (24 mm·h^{-1}), Venina (36 mm·h^{-1}), and particularly at S. Stefano, where on the evening of July 18th, 47 mm in 1 hour, 129 mm in 4 hours, and 170 in 7 hours were measured.

GEOTECHNICAL SOIL CHARACTERISTICS

The mobilization of a soil into a debris flow depends on rainfall characteristics, such as intensity and duration, as well as on mechanical properties of the material, such as the grain size distribution and the clay content, the liquid limit and plasticity index, the natural water content, the angle of internal friction and cohesion (ELLEN and FLEMING, 1988; MOSER and HOHENSINN, 1983). To assess the susceptibility of soils to flow it is important to measure such geotechnical properties. In Valtellina soil samples were collected after both the 1983 and 1987 events. CANCELLI and NOVA (1985) sampled mostly sandy soils in the Tresenda area; CROSTA (1990) sampled 32 scars of soil slips and debris flows in the Tartano basin, as well as a debris-torrent deposit at Fusine.
Well-graded soils were found in the source area of soil slips and debris flows; whereas poorly-graded coarse soils marked the source area of debris avalanches and were found in debris-torrent deposits. The coarser fraction was generally constituted by angular metamorphic blocks of tabular shape, cobbles, and gravel. More rounded blocks were found in debris flow and debris-torrent deposits. The finer fraction was mostly sandy or silty, with a clay content rarely exceeding 14%, and with an av-

erage value of 5%. The dry unit weight ranged from 16 to 19 KN/m^3, and the total weight ranged from 18 to 21 KN/m^3. The natural water content was between 16% and 35%, with an average value of 24% (CANCELLI and NOVA, 1985; CROSTA, 1990).

According to the USCS soils were classified as SM, SW, SG, GM, GP-GM, and subordinately as CL and SC. The plasticity index and liquid limit, measured on a total of 13 samples, ranged from 4% to 22%, and from 18% to 32% respectively (CROSTA, 1990; POLLONI *et al.*, 1992). Values of the angle on internal friction and cohesion, for both undisturbed and reconstructed samples, ranged from 17° to 43°, and from 5 to 43 KN/m^2 respectively (CANCELLI and NOVA, 1985).

The analysis of soil properties for different types of failures revealed that soil texture, and in particular the clay content, influences the susceptibility of soils to mobilize. Soils with a high clay content (> 14%) produced shallow and less mobile soil-slips (Trepalle area), whereas silty and sandy soils with a lower clay content, gave rise to fast moving flows (Tartano area). This is because small quantities of clay may help to maintain high pore pressures facilitating flows, but large percentages of clay prevent mobilization by providing cohesion that inhibits remolding (ELLEN and FLEMING, 1988). This is confirmed by the values of the Approximate Mobility Index. AMI, the ratio of saturated water content of an undisturbed soil to its liquid limit, devised by ELLEN and FLEMING (1988) as an indicator of the likelihood that a soil will mobilize, was found less than 1 for shallow, slow moving soil slips, and greater than 1 for debris flows on silty, sandy soils.

DEBRIS FLOWS

A comprehensive inventory of failures for the entire Valtellina area was not completed, mainly because of time and resource constrains. Aerial photographs flown after the 1987 event were limited to a narrow strip along the Adda river and some tributary valleys. The investigation was therefore concentrated to the areas where debris flows were found particularly abundant, during a preliminary reconnaissance survey carried out immediately after the July 1987 inundation.

In the Tartano, Madrasco and Presio basins, three left tributaries of the Adda river in the Lower Valtellina, an inventory of debris flows was completed. In the 80 km^2 area, 503 debris flows were mapped through the interpretation of colour aerial-photographs and field surveys (CROSTA, 1990). According to their morphological, hydrological, and geometrical characteristics, debris flows were subdivided into 4 groups: soil slips in unchannelled, zero order basins; debris flows in channelled basins; debris avalanches, and debris torrents (CROSTA *et al.*, 1990).

This data-set was combined with information on other debris flows triggered by the July 1987 and May 1983 storms in Valtellina, to produce the schematic diagram of Figure 4. The diagram shows the relative position of the 4 types of debris flows with respect to the source, transport and accumulation areas of a torrent system (EISBACHER and CLAGUE, 1984). The different groups of failures were tentatively placed on the diagram according to qualitative estimates of the slope gradient in the source area, the stream order, the velocity of flow, the relative concentration of sediment and water, the volume of mobilized material and its grain size.

Soil slips, originating in the hollows up-slope of the channel network (RENEAU and DIETRICH, 1987), are placed in the source area of the torrent system, in the upper-central part of the diagram. In the source area are placed also debris avalanches detached from steep, forested terrain in the interfluves. Debris flows, originating as shallow slides in channelled basins, are placed at the centre of the diagram, equally distributed between the source, transport and accumulation areas. Finally, debris torrents, the less frequent but volumetrically more abundant features, are located in the lower-right side of the scheme, mostly in the accumulation area, close to the flood field.

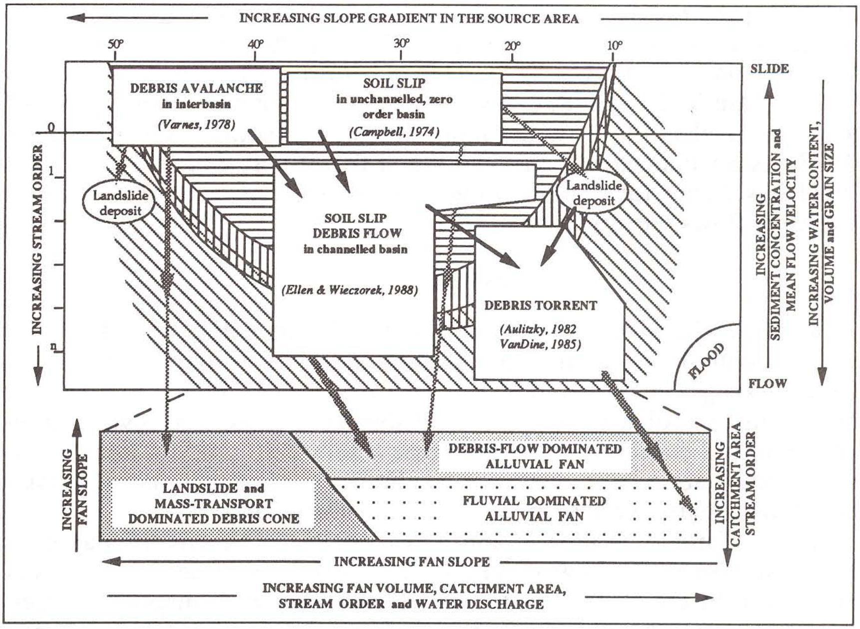

Fig. 4. Evolutionary scheme for the different type of failures. Horizontal, vertical and oblique patterns represent respectively the source, travel and accumulation areas.

Fig. 4. Evolution des differents types des laves torrentielles. Les lignes horizontales, verticales et obliques représent les zones d'alimentation, de transport et de deposition.

The diagram reports also, with black arrows, the most frequent evolutions of debris flows, and with gray arrows their preferred depositional areas within the drainage network and on the different types of fan. Soil slips, that did not completely mobilize, stopped shortly after failure, leaving small landslide deposits. Where they were able to reach the drainage network picking up enough material, they evolved into debris flows. Both soil slips and debris flows deposited material along low-gradient sections of the drainage network, mainly as laterl levees, and on debris-flow dominated fans. Debris avalanches deposited coarse material on small debris cones at the foot of steep slopes, and subordinately at the mouth of steep channels, along the drainage network. In places they formed minor landslide deposits.

Debris torrents were caused by the breaching of landslide or debris dams, by lateral erosion or under-cutting of the toe of large slides, or through the coalescence of other debris flows. They deposited large quantities of debris along high-order sections of the drainage network, or, more frequently, on alluvial fans. Debris was deposited from the fan apex to the more distal areas, with some degree of sorting of the material. Diversions of the flow, caused by natural or man-made blockages and structures, were common. Locally, up to 5 meters of debris were deposited in several pulses by a single debris torrent (Fusine and T. Ravione).

DISCUSSION

Regional meteorological conditions for the 1983 and 1987 events were similar. In both cases high-intensity rainfalls were produced by meteorological instability connected to stationary fronts, that originated on the Atlantic Ocean and moved over the Alps. Both events were characterized by heavy precipitations.

In 1983 a long period of antecedent rainfall preceded two high-intensity storms, whereas the 1987 event occurred in the middle of the summer, and was not preceded by any considerable rain. Total rainfall was higher in 1983, but if one considers only the two rainfall periods that triggered extensive failures (May 21st-23rd and July 17th-19th), the cumulative rainfall in 1987 was slightly higher.

Failures were not distributed homogeneously, but concentrated in limited areas. No failure was reported in the high-elevation, glaciated terrain. In 1983 landslides were concentrated in the Trepalle area, near Livigno, (66 failures), in the S. Antonio area, east of Bormio, (44 failures), and at Tresenda, where in a 5 km^2 of terraced vineyards 61 failures were reported (CANCELLI and NOVA, 1985). 40 more scattered failures were observed in the Upper Valmalenco, the Grosina and Viola valleys, and along the central Valtellina.

In 1987 shallow landslides occurred from the late afternoon of July 18th, after ~ 30 hours of rain, to the evening of the 19th. Failures were more abundant in the Orobic basins of the Lower Valtellina, and particularly in the Tartano and Madrasco valleys where 500 failures were observed. At least 60 more failures were reported in Valmalenco; and large debris flows occurred in the Venina, Armisa, and Rezzalasco valleys. Many more small, scattered shallow-failures occurred on the slopes of the main Adda valley.

Different approaches to estimate threshold values for the mobilization of debris flows can be used. The more commonly pursued method consists in estimating some measure of precipitation (i.e., intensity, duration, cumulative storm rainfall, normalized storm rainfall), and to relate it to the observed distribution or timing of failures.

The analysis of rainfall records for the 1983 and 1987 storms shows that locally precipitations exceeded the threshold found by CAINE (1980) studying more than 70 cases world-wide. CANCELLI and NOVA (1985) analysing the duration and intensity for the two May 1983 storms, found that both fell above the threshold proposed by MOSER and HOHENSINN (1983) for Carinthia. The same was observed for the 1987 event. For the last storm precipitations were also found in the range of values for "abundant debris-flows activity" established by CARSON and ELLEN (1987) for the San Francisco Bay Region. Finally, normalized storm rainfall, the ratio of the cumulative storm rainfall to mean annual rainfall (GOVI and SORZANA, 1980), averaged 29% (16% for the second storm), and 21% respectively for 1983 and 1987.

A criticism to the application of such approach in the Valtellina area is that high intensity precipitations exhibit an extremely large spatial variability, limiting the reliability of thresholds based only on rainfall data. During the 1987 storm, for example, the Upper valley received less rain than the Lower valley. Basins on the Orobic side of the valley received more than 270 mm of rain, with peaks well over 400 mm (Venina and Armisa basins); whereas the alpine side of the valley received only 130-160 mm of rain (Mallero basin).

The mobilization of soils into debris flows depends not only on rainfall, but also on the geotechnical properties of soils, as well as on the morphological, vegetational, and hydrogeological setting of the source area. All these parameters show a considerable natural variability, and are difficult to determine over large areas. Considering only precipitation as a measure of the likelihood of debris-flow occurrence may lead to erroneous results.

A different approach for the estimation of debris-flow initiation thresholds, consists in analysing the stream-flow discharge of rivers and torrents. Discharge is the result of a complex, at to some degree unknown, series of events. It is in fact controlled by meteorological (rainfall pattern, duration, intensity) conditions, and by geological (soil texture, grain size, clay content, infiltration rate), morphological and vegetational characteristics of a drainage basin. Averaging out all local variability discharge constitutes an accurate and reliable measurement of the hydrogeological behaviour of a catchment during a storm. Thus, it might represent a better parameter for the estimation of debris-flow initiation thresholds. This approach is less investigated mainly because of the lack of discharge measurements compared to the availability of rainfall data. In Valtellina only 2 river-level gauges were active in 1987, both along the Adda river, compared to 40 raingauges.

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