Geogr. Fis. Dinam. Quat.
32 (2009), 157-166, 10 figg., 6 tabb.

GUIDO NIGRELLI (*) & CHIARA AUDISIO (*)

THE MAY 2008 EXTREME RAIN EVENT IN THE GERMANASCA VALLEY (ITALIAN WESTERN ALPS): PROCESSES AND EFFECTS OBSERVED ALONG THE HYDROGRAPHIC NETWORK AND VALLEY SLOPES

ABSTRACT: NIGRELLI G. & AUDISIO C., *The May 2008 extreme rain event in the Germanasca Valley (Italian Western Alps): processes and effects observed along the hydrographic network and valley slopes*. (IT ISSN 0391-9838, 2009).

This article describes an extreme rain event (28-30 May 2008) in the Germanasca Valley. It gives details on rainfall data and on the processes and effects observed along the hydrographic network and valley slopes. The recent event data were compared with those of previous events (1728-2008). The analysis was carried out using a GIS application specifically designed to identify areas of major hazard, for geo-hydrologic risk mitigation and civil protection, as well as to define rainfall threshold values that could be useful for activating local warning systems. The data analysis showed that major risk situations are associated with rock fall, complex landslides and bank erosion and that the basin areas and the type of damage are consistently the same in extreme rainfall events. With improved identification of hazard and risk scenarios, more effective interventions in an area could be undertaken to mitigate hydraulic and geologic risk.

KEY WORDS: Rain events, Landuse planning, GIS, WebGIS, Germanasca Valley, Piedmont (NW Italy).

RIASSUNTO: NIGRELLI G. & AUDISIO C., *L'evento pluviometrico del Maggio 2008 in Val Germanasca (Alpi Occidentali): processi ed effetti osservati lungo il reticolo idrografico e sui versanti*. (IT ISSN 0391-9838, 2009).

In questo lavoro si analizza l'evento meteorologico del 28-30 Maggio 2008 in Val Germanasca, con particolare riferimento ai caratteri pluviometrici, ai processi ed agli effetti lungo la rete idrografica e sui versanti. Le informazioni raccolte sono state comparate con gli eventi pregressi, considerando un intervallo temporale compreso fra gli anni 1728 e 2008. Mediante l'utilizzo di un sistema informativo territoriale appositamente sviluppato per la mitigazione del rischio geo-idrologico e per scopi di protezione civile, è stato possibile individuare aree a maggior pericolosità e rischio, nonché definire alcuni valori pluviometrici di riferimento utili per l'attivazione a livello locale di procedure di attenzione.

Dai dati elaborati emerge che le situazioni a pericolosità maggiore sono in prevalenza legate alle frane di crollo, alle frane complesse ed alle erosioni spondali. Per gli eventi a magnitudo più elevata, gli areali coinvolti sono sempre gli stessi e così anche le tipologie di danno. Gli scenari di pericolosità e di rischio identificati, consentono di effettuare interventi sul territorio più efficaci ai fini della mitigazione del rischio idraulico e geologico.

TERMINI CHIAVE: Eventi pluviometrici, Pianificazione territoriale, GIS, WebGIS, Val Germanasca, Piemonte (Italia).

INTRODUCTION

The 28-30 May 2008 rainfall event was most intense in the western alpine sector between the Stura di Demonte and the Lanzo valleys, where it caused major property and environmental damage and claimed some lives. Within this sector lies the catchment of the Germanasca Stream. Studied repeatedly by the Consiglio Nazionale delle Ricerche, Istituto di Ricerca per la Protezione Idrogeologica (CNR-IRPI) Torino, the Germanasca is noted for numerous shallow landslides, debris flows, alluvial fan re-activation, and overbanking with erosion and widespread flooding, all of which have led to highly critical situations similar to those that have developed in the basins of the Dora Riparia, Chisone and Pellice rivers (ARPA Piemonte, 2008d; Tropeano, 2008). This article describes the 28-30 May 2008 rainfall event recent in the Germanasca Valley and gives details about rainfall data, the processes and the effects the torrential rains had on the hydrographic network and slopes. The information collected during post-event surveys was compared with descriptions of previous events by

(*) *CNR - Istituto di Ricerca per la Protezione Idrogeologica, UOS di Torino (www.irpi.to.cnr.it).*

We wish to thank Dr. Tropeano (IRPI, UOS di Torino) for his useful suggestions during revision of the manuscript. Special thanks are due to anonymous reviewers for their helpful comments and suggestions.

means of a GIS application specifically designed for land-use planning and advance warning for civil protection agencies. The results of this study are presented here.

THE GERMANASCA VALLEY

The Germanasca Valley lies in the central sector of the Cotian Alps (western Piedmont, NW Italy), bordering to the north, west and east with the Chisone Valley and to the south with the Pellice Valley. The Germanasca valley (approximately 197 km^2 in area) terminates at the confluence of the Germanasca and the Chisone rivers. The Chisone River is the main tributary of the Pellice River which flows into the upper Po River. Orographically, the catchment has two principal valley heads (Salza-Massello and Prali branches), which differ in morphology and the development of the hydrographic network, and converge near the town of Perrero to form the terminal valley segment of the branch of the Germanasca (fig. 1). The valley sides are mainly characterized by steep slopes, particularly those near the thalwegs, making the valley floors narrow and deeply seated along several segments. The hydrographic network has a convergent dendriform pattern (Nigrelli, 2005).

Geologically, the basin is seated in the internal crystalline massif of the Dora-Maira and is mainly composed of orthogneiss, gneiss, metabasites and metatonalites (Briançonnais Zone), micashists and calceshists (Piemonte Zone) and by fluvial and glacial deposits (Borghi & *alii*, 1984). The main soil types identified at the level of Great Groups, according to the Soil Taxonomy (Soil Survey Staff, 1999; USDA-NRCS, 2006) are: Udifluvents in the main valley bottoms and in the flood zones (land-use class III) (Regione Piemonte, 1982); Dysthrochrepts, Euthrochrepts and Hapludalf on the wooded or pasture slopes (land-use classes V and VI), and Udorthents, where the vegetation cover is sparse, at various elevations and on the steep slopes, sometimes with outcroppings (land-use classes VII and VIII).

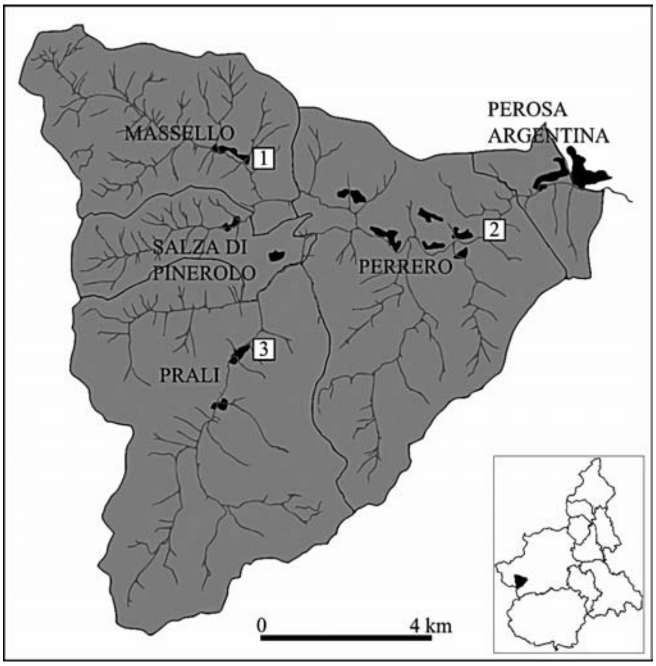

FIG. 1 - The Germanasca river basin: municipal names and borders (black color lines), built-up areas (black color), main river channel (grey color) and location of the three AWS: 1. Massello (elevation 1388 m a.s.l.; UTM-WGS84 4980319N, 347375E); 2. Perrero (662 m a.s.l.; water-gauge zero 649.190 m a.s.l.; 4978654N, 355064E); 3. Prali (1385 m a.s.l.; 4974207N, 346645E).

The chief morphogenetic processes that have modelled the landscape are the result of glacial-nival action, surface or subterranean streams and gravity. The resulting forms are closely connected with the local lithology, the climate (particularly the thermo-pluviometric regime) and the type and distribution of vegetation cover. The most common gravitational phenomena are deep-seated gravitational slope deformations, rock falls, and rock/debris slides (Turner & Schuster, 1996). Slide activation usually follows extreme rainfall or flood events. During flood events, bank erosion often causes undermining of the slope foot near the valley floor, thus triggering complex gravitational movements. Local brief, intense rainfall events, frequent in summer, can trigger shallow slides involving soil cover and eluvial desposits. The eluvial deposits, in turn, can unleash debris flows and mudflows, with the deposition of huge amounts of sediment on the alluvial fans where some hamlets are located. The most common type of events may be classified as bank and bed erosion associated with flooding and overbanking. Flooding is generally limited to the stream bed and ordinarily remodels the discharge channel and sediment deposits. Widespread anthropic intervention characterizes the valley floors and the mid-lower slope areas where villages are located and agro-silvo-pastoral activities are chiefly carried out. Talcum mines and quarries are also present.

RAINFALL EVENT PROPERTIES AND COMPARISON WITH PAST DATA

The pluviometric parameters ordinarily taken for meteo-hydrologic study are rainfall total and maxima (annual, seasonal or monthly), precipitation during brief but intense rainstorms, maximum rainfall over several consecutive days and peak rainfall within temporal units (minutes, hours, days). The data of some of these parameters may be derived from various different events. In studies on geohydrologic risk mitigation and advance warning for civil protection, it is important to evaluate how much rain and how it falls.

An analysis of the evolution of precipitation over time can provide better suitable information for computer analysis than with conventional methods in studying types of phenomena such flood. The study method used for these needs, and applied to other alpine basins, considers a rainfall event as a defined meteo-climatic variable and defines it as a rainfall day, preceded and succeeded by a day in which no rain is recorded. The rainfall event acts directly on landscape modelling. Depending on duration, total amount of rainfall, peak amount of rainfall, and the way and season in which it occurs, a rainfall event may trigger natural phenomena carrying high hazard and risk. However, the tenuous correlation between total rainfall and flood events indicates that, particularly in mountain basins, hydrologic response to precipitation will vary, depending on a host of variables which arise and interact differently.

With the aims to improve instruments for better land-use planning, a historical series of rainfall events in an alpine basin can be analyzed to identify the most frequent class of event, and correlate it with floods and usually affected areas. The May 2008 extreme rainfall event in the Germanasca Valley was analyzed using data recorded at official rain gauge stations located throughout the basin. For further analysis, these data were compared with past rainfall event data including those recorded at rain gauges (SIMN-UIPO).

These rain stations went out of operation after the regional authorities took over meteo-hydrographic monitoring services, according to a national-regional agreement. The new, more modern stations operated by the regions can record and put on line the acquired data, with real-time transmission (ARPA Piemonte, 2008a, 2008b, 2008c). The historical data published in the hydrologic annals show notable gaps in the old SIMN-UIPO station records of the study area; for example, data from the entire period between 1942 and 1950 are missing. Given these circumstances, complete data sets covering 41 years are available for Massello (1919-2007), 66 years for Perrero (1913-2007), and 68 years for Prali (1915-2007). Archiving, validation and processing of the climatic data were done using dedicated software applications (Nigrelli & Marino, 2008).

In 2008 late-spring and early-summer seasonal rainfall began on 10 May and continued nearly uninterrupted until 13 June in several distinct phases. The first phase ended on 22 May and was characterized by light rain, with 71.8 mm recorded at Massello and Perrero and 70 mm at Prali (approximately 5 mm/day). Though not substantially influencing network runoff, these rains saturated the ground in some areas, creating favorable conditions for subsequent rainfall to trigger soil slips. No rainfall was recorded on 23 May, but atmospheric conditions strongly reduced water drainage, evaporation and evapotranspiration. On 24 May rainfall resumed with increasing intensity, culminating in a paroxysmal event on 29 May. Rainfall began to subside on 30 May, with less than 1 mm recorded on 31 May.

Between 1 and 13 June the following rainfall values were recorded: 169.8 mm (13.0 mm/day) at Massello; 126.4 mm (9.7 mm/day) at Perrero; and 132.2 mm (10.2 mm/day) at Prali. The heavy rains hindered emergency operations and road use throughout the valley. For the purposes of this study, the week between 24 and 30 May was taken as the reference period for a detailed analysis of the 2008 rainfall event in the Germanasca Valley.

Table 1 illustrates the daily rainfall values for the study period. Peak values were recorded on 29 May, the 6th day with rain, with lower rainfall amounts recorded at Perrero (92.2 mm) than at either Massello (196.2 mm) or at Prali (218.8 mm), indicating that the low pressure system mainly affected the internal sectors of the Alps. Unseasonably higher daily values were measured at Massello in May 2008 compared with October 2000 (146.4 mm), whereas the total rainfall in both the 2008 and the 2000 events was nearly the same (418 mm vs. 423 mm, respectively). A comparison between the May 2008 and the October 2000 values also shows significantly different amounts of precedent rainfall calculated over a 10-day or a 20-day period.

TABLE 1 - Daily total rainfall (aggregation 0÷24) of the May 2008 and October 2000 rain events recorded at the Massello, Perrero and Prali stations. Mean annual total rainfall is given in parentheses next to the geographic name. May 2008 rainfall amounts greater than those of October 2000 (bold). First day of the 2008 event, 24 May; first day of the 2000 event, 10 October; Rtot, total rainfall amount; Rmax, peak day total rainfall; R10, rainfall during previous 10 days; R20, rainfall during previous 20 days (Data: ARPA Piemonte, 2008c)

		Massello (1127.9 mm)		**Perrero (994.0 mm)**		**Prali (1044.2 mm)**	
		2008	**2000**	**2008**	**2000**	**2008**	**2000**
Event day number	1st	22.6	1.4	11.2	1.8	17.0	2.2
	2nd	23.2	13.8	21.4	7.4	16.6	20.6
	3th	34.8	5.4	37.2	1.8	24.2	4.6
	4th	81.2	39.2	25.0	29.8	54.4	35.2
	5th	34.8	190.2	38.6	190.6	29.2	167.8
	6th	**196.2**	146.4	92.2	146.6	218.8	244
	7th	24.6	26.6	30.6	35.2	28.4	17.0
	8th	0.6			1.6	0.6	
	9th				0.2		
	10th				0.2		
Rtot	(mm)	418.0	423.0	256.2	415.2	389.2	491.4
Rmax	(day)	6th	5th	6th	5th	6th	6th
R10	(mm)	59.8	120.6	50.6	106.6	54.0	71.8
R20	(mm)	71.8	260.6	73.2	252.8	70.4	209.8

The October 2000 event was characterized by intense rainfall between 28 and 30 September, with substantially greater differences. The trend in rainfall amounts reflects this aspect (fig. 2). The event may be divided into two distinct phases of increasing rainfall that differed at the three rain gauge stations. The first phase includes rainfall recorded in the 20 days prior to the event. In contrast, the trend of the May 2008 event has a different shape, with an initial phase substantially unaffected by precedent precipitation, followed by an increasing phase which ended less markedly.

In both events, the main difference between precedent rainfall and inflow throughout the entire basin is the amount of surface runoff, as shown by the rainfall amounts recorded at Perrero (fig. 3). During the May 2008 event, the Perrero station recorded a peak of 3.83 m on 29 May at 9.30, whereas the peak amount during the October 2000 event was 5.56 m recorded on 15 October at 12.00. Some peaks in rainfall intensity recorded at different time points were higher during the May 2008 event than the October 2000 event (tab. 2). Ten-minute interval values higher than the corresponding 2000 values were recorded at Perrero and Prali; 60-minute interval values were also higher than the corresponding 2000 values recorded at Massello and Prali. The rainiest day was 29 May (204.8

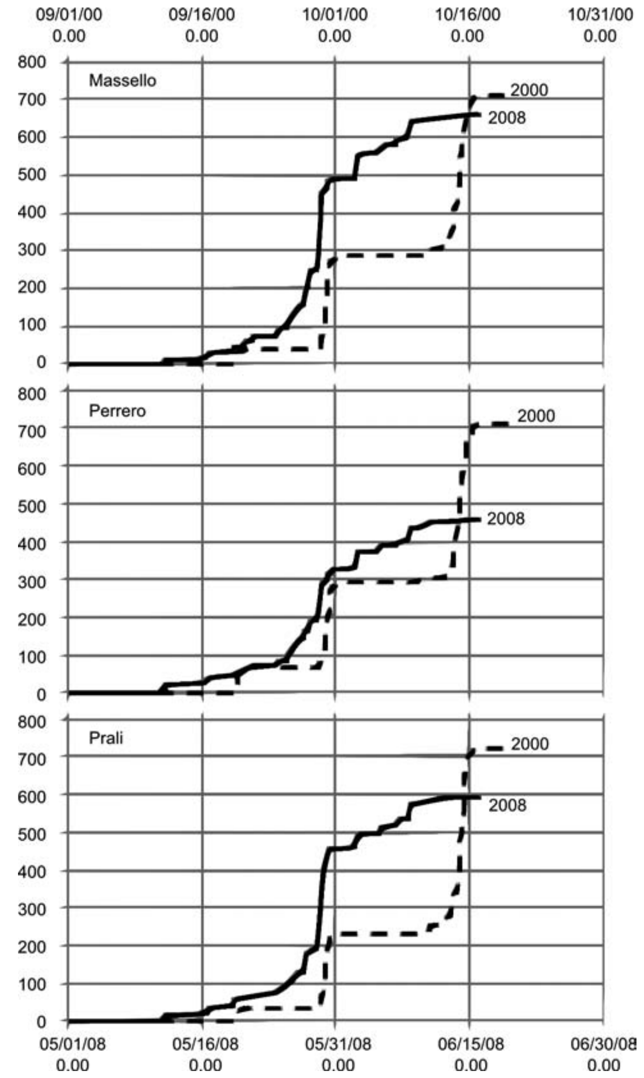

FIG. 2 - Cumulative rainfall amount trend (mm) of the May 2008 event (lower axis) and the October 2000 event (upper axis) at the Massello, Perrero and Prali station (Data: ARPA Piemonte, 2008c).

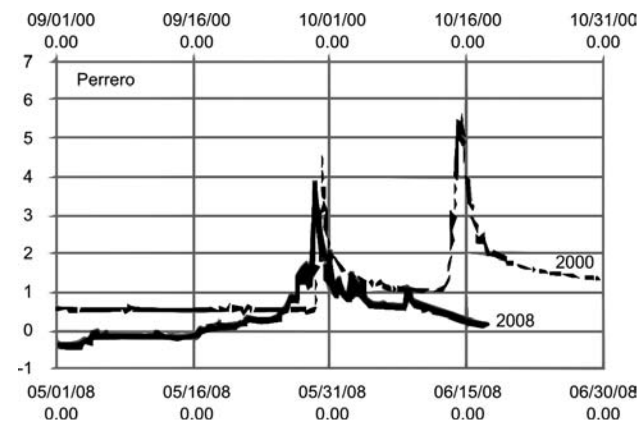

FIG. 3 - Water level (m) of the May 2008 event (lower axis) and the October 2000 event (upper axis) at the Perrero station (dati ARPA Piemonte, 2008c).

TABLE 2 - Maximum rainfall intensity recorded over different time periods, in the May 2008 and the October 2000 rain events, at the Massello, Perrero and Prali stations. In bold, May 2008 rainfall amounts greater than those of October 2000 (Data: ARPA Piemonte, 2008c)

		10 minutes		1 hour		24 hours consecutive		1 day (0÷24)	
		2008	2000	2008	2000	2008	2000	2008	2000
Massello	(mm)	9.4	10.0	**36.6**	16.8	209.4	211.2	**196.2**	190.2
	(data)	May, 29	Oct., 14	May, 29	Sep., 30	May, 28	Oct., 14	May, 29	Oct., 14
	(hour)	9:10	6:20	8:00	5:00	22:40	3:20		
Perrero	(mm)	**10.4**	8.4	27.6	31.8	104.8	229.0	92.2	190.6
	(data)	May, 29	Oct., 14	May, 29	Oct., 14	May, 28	Oct., 14	May, 29	Oct., 14
	(hour)	7:20	6:20	7:00	6:00	22:40	4:20		
Prali	(mm)	**8.6**	6.6	**36.8**	30.2	231.0	329.8	218.8	244.0
	(data)	May, 29	Oct., 15	May, 29	Oct., 15	May, 28	Oct., 14	May, 29	Oct., 15
	(hour)	8:30	10:50	8:00	10:00	22:30	13:50		

mm); the maximum total 24-h rainfall was 207.8 mm, starting from 9 pm on May 28. Rainfall events with total rainfall amount >100 mm recorded since 1913 at Massello, Perrero, and Prali are 82 mm, 158 mm, and 126 mm, respectively. The number of extreme rainfall events (total rainfall >250 mm) recorded since 1913 are 11 at Massello and 16 at Perrero and Prali (tab. 3÷5). Within this class of events, the May 2008 event ranks third and fourth for Massello and Prali, respectively, in terms of total rainfall, and represents for both locations the first late-spring season event of the two series analyzed in this study. When these events are analyzed in relation to maximum daily rainfall amount, the May 2000 event still ranks third and fourth for Massello and Prali but not the first late-spring season event at either location, since the total daily rainfall recorded during the April 1934 event at Massello and the April 1926 event at Prali was higher (283.9 mm and 246 mm, respectively).

In the hydrographic basins of the European Alps, well-defined meteorological configurations of several consecutive days duration give rise to extraordinary rainfall events. In the Germanasca basin, events with total rainfall amounts

TABLE 3 - Main characteristics of extreme rain events (Rtot>250 mm) recorded at Massello, listed in decreasing order in relation to total rainfall. Bold, May 2008 values; *, flood; Rtot, total rainfall amount; D: number of days of the event; Rmax, peak day total rainfall; Pd, peak day of the event (Data: ARPA Piemonte 2008c and SIMN-UIPO, period 1919÷2008 with gaps)

data	Rtot		Rmax	
	(mm)	(D)	(mm)	(Pd)
1941/09/28	441.0	9	175.0	3th
2000/10/10*	429.4	8	188.4	6th
2008/05/24*	**418.0**	**8**	**196.2**	**6th**
1934/04/30	323.9	2	283.9	2nd
1938/09/26	318.0	5	105.0	5th
1957/06/08*	300.0	10	93.0	6th
2001/04/30	299.4	10	84.0	6th
1953/10/13	291.0	11	117.0	7th
1937/10/22	272.0	13	57.0	7th
1926/04/23	264.0	5	160.0	3th
2000/09/29	252.8	4	210.4	2nd

TABLE 4 - Main characteristics of extreme rain events (Ptot>250 mm) recorded at Perrero, listed in decreasing order in relation to total rainfall. Bold, May 2008 values; *, flood; Rtot, total rainfall amount; D: number of days of the event; Rmax, peak day total rainfall; Pd, peak day of the event (Data: ARPA Piemonte 2008c and SIMN-UIPO, period 1913÷2008 with gaps)

data	Rtot (mm)	(D)	Rmax (mm)	(Pd)
1981/03/29	577.2	8	241.6	4th
1962/11/05*	468.6	8	222.0	4th
2000/10/10*	417.6	9	196.0	6th
2001/04/30	386.2	13	95.0	6th
1941/09/30	379.0	6	166.0	1st
1977/05/17*	377.6	6	171.2	4th
1978/01/12	356.0	7	102.6	6th
1976/10/25	320.6	6	80.4	3th
1928/10/28	295.0	7	95.0	4th
1985/05/05	289.6	11	60.4	3th
1957/06/10*	286.0	9	91.0	8th
1977/03/21	273.2	5	128.0	4th
1937/10/26	270.0	9	105.0	4th
1982/11/28	263.6	7	70.2	4th
1914/05/24	262.5	7	114.0	4th
2008/05/24*	**256.2**	**7**	**92.2**	**6th**

TABLE 5 - Main characteristics of extreme rain events (Ptot>250 mm) recorded at Prali, listed in decreasing order in relation to total rainfall. Bold, May 2008 values; *, flood; Rtot, total rainfall amount; D: number of days of the event; Rmax, peak day total rainfall; Pd, peak day of the event (Data: ARPA Piemonte 2008c and SIMN-UIPO, period 1915÷2008 with gaps)

data	Rtot (mm)	(D)	Rmax (mm)	(Pd)
2000/10/10*	488.2	8	220.2	6th
1962/11/05*	459.0	8	229.6	4th
1941/09/03	432.0	6	180.0	1st
2008/05/24*	**389.2**	**8**	**218.8**	**6th**
1926/04/24	387.0	5	246.0	2nd
1953/10/13	356.5	11	162.3	7th
1957/06/08*	306.9	11	120.0	6th
1961/09/30	286.2	9	122.4	4th
2000/06/10	279.0	6	107.8	3th
1919/10/02	272.0	4	155.0	4th
1918/04/08	266.6	8	92.0	7th
1959/05/19	266.6	8	160.0	5th
1995/04/20	261.0	8	63.8	6th
1953/06/06	255.0	5	149.5	4th
1920/09/16*	252.9	9	150.0	8th
1960/12/15	251.2	7	152.0	4th

>100 mm last 5 days on average (var. 2.32, c.v. 43.6%, n 366) and peak on day 3 of the event (var. 1.92, c.v. 56.5%, n 366). Extreme rainfall events last 8 days on average (var. 2.32, c.v. 30.3%, n 43) and usually peak on day 5 (var. 1.72, c.v. 37.6%, n 43). These events occur most often during the autumn (47%) and spring (37%) seasons. Both types of events are frequently caused by low pressure areas over Corsica and Sardinia (most often), the Balearic Islands and Spain, and the Gulf of Lyons (Nigrelli, 2005; 2007). Table 6 shows the meteorological configuration and generating depression system of recent extreme rainfall events, ranked by season and in data decreasing order. Fig. 4 com-

TABLE 6 - Meteorological configuration and generating depression system of recent extreme pluviometric events, ranked by season and in data decreasing order. * denote a flood event

Season and data	Depression type	Geographical centre
Spring:		
2008/05/24*	Mediterranean	Ligurian Gulf
2002/05/01	Mediterranean	Balearics-Spain
2001/05/01	Atlantic	France
1995/04/20	Atlantic	France
1985/05/05	Atlantic	British Isles
1981/03/29	Mediterranean	Corsica-Sardinia
1977/05/17*	Mediterranean	Balearics-Spain
1926/04/24	Mediterranean	Corsica-Sardinia
Summer:		
1957/06/08*	Mediterranean	Corsica-Sardinia
1953/06/06	Mediterranean	Cote Azure
Autumn:		
2000/10/10*	Mediterranean	Gulf of Lyons
1976/10/25	Mediterranean	Balearics-Sardinia
1962/11/05*	Mediterranean	Gulf of Lyons
1961/10/01	Atlantic	British Isles
1959/05/19	Mediterranean	Ligurian Gulf
1953/10/13	Mediterranean	Corsica-Sardinia
1941/10/01	Mediterranean	Corsica-Sardinia
1938/09/26	Mediterranean	Balearics-Spain
1920/09/16*	Mediterranean	Gulf of Lyons

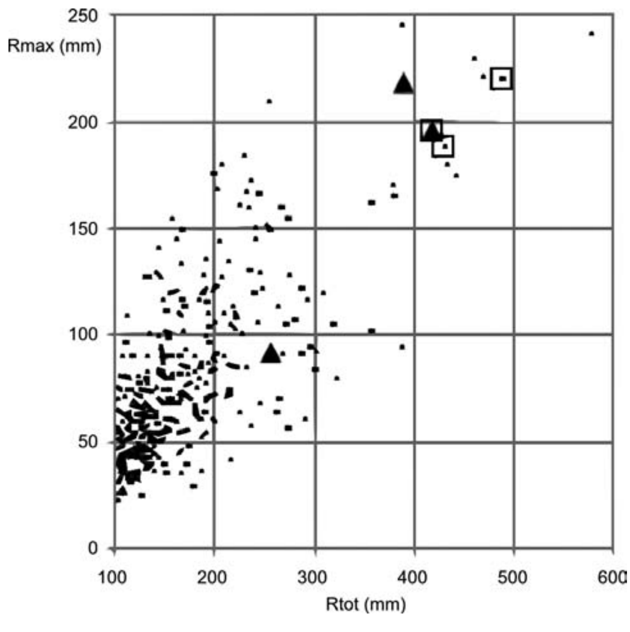

FIG. 4 - Rainfall events (Rtot >100 mm) in the Germanasca Valley. Data ARPA Piemonte 2008c and SIMN-UIPO (1913÷2008 with gaps, 366 cases). Total rainfall of each event (Rtot) in relation to peak day rainfall (Rmax). The triangles denote the May 2008 event, the squares the October 2000 event.

pares the total rainfall amount recorded for each event in relation to the peak day value. The correlation between these values (y = 0.429x + 8.572; r^2 0.551; n 366) does not reach statistical significance because of the high degree of data dispersion. Even so, this correlation may provide civil protection agencies with useful information for forecasting and monitoring rainstorms (Regione Piemonte, 2001). Specifically, it may aid in developing forecast models or be merged with information derived from fitting curves and recurrence curves of precipitation maxima. During a rainstorm, when the civil warning system is ordinarily in full operation, this information can be integrated with rainfall data correlated with flood hydrograms in order to more closely monitor flow-discharge trends. This type of information is also useful for studies on solid transport in rivers (Tropeano, 1991).

LANDSLIDES AND FLOODS ANALYSIS

Metodology

A detailed analysis of the main interactions between a rainfall event, the natural phenomena it causes and the resulting damage was conducted using a methodology developed by the CNR-IRPI, Torino. The methodology uses a GIS application decision-making support named «Sistema Informativo Territoriale Rischio Idraulico e Geologico (SIT-RIG)». The SIT-RIG works extremely well for supporting decision-making processes in geo-hydrologic risk mitigation in relation to civil protection and local and basin-wide land-use planning. With this GIS application, vast amounts of georeferenced data can be managed quickly and accurately to generate new information. Fig. 5 illustrates a flow chart of the method procedure. The SIT-RIG uses ESRI ArcView GIS software within which an extension was developed to facilitate the entry of data collected from historical and contemporary documentation sources. The applied methodology has already been illustrated in Audisio & *alii* (2009). Multilevel data processing generates spatiotemporal correlations between a point theme called «event-phenomenon-damage» and various basin landscape features that highlight high-risk and hazardous areas.

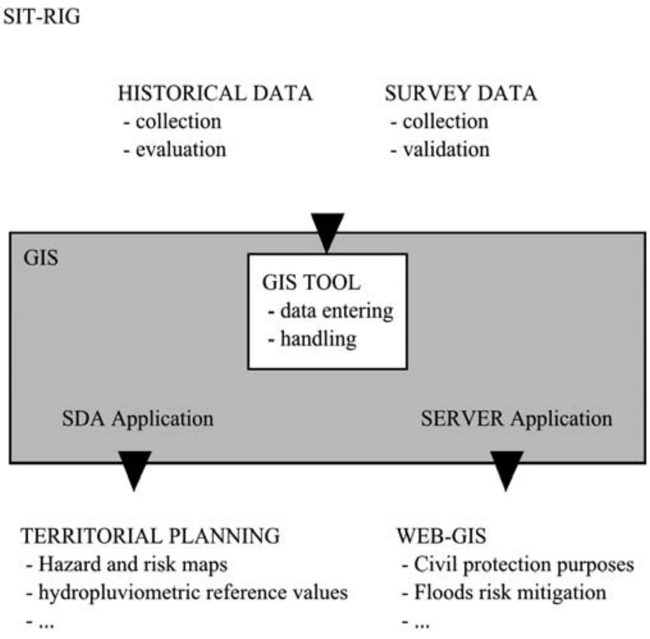

FIG. 5 - Flow chart of the «Sistema Informativo Territoriale Rischio Idraulico e Geologico» (SIT-RIG).

Many different types of analyses can be done using this method and the SIT-RIG:

- Analysis of frequency and distribution of events, phenomena, and reported damage;
- Identification of areas where events and phenomena occur repeatedly and/or with greater intensity;
- Study on the most frequent types of events and phenomena;
- Single event/phenomenon and multiple event/multiple phenomenon analysis;
- Damage analysis;
- Analysis of interventions and efficacy evaluation.

The study basin database covers the period from 1728 to 2008, with some records dating as far back as 1600, for a total of 351 cases described. The SIT-RIG of the Germanasca Valley can also be accessed online using WebGIS.

Main processes and effects of the May 2008 event

Analysis revealed a number of phenomena along the stream trunk, its tributaries and on basin slopes. Along the main stream network, effects of bank erosion and flooding were assessed. Specifically, in the Germanasca of Prali branch, between Borgata Ribba and Ghigo di Prali, erosion of the right and left banks was noted. Bank erosion partially damaged road infrastructures and defense works, some of which had been built after October 2000 event. Near the Molino Bridge, just downstream from Borgata Ribba, intense flooding reactivated an abandoned channel on the left side of the main stream. The bridge itself remained undamaged, but the road crossing was blocked and damaged. At Prali widespread bank erosion was noted, together with major flooding effects in the stream bed. Upstream from Prali Villa, on the left stream bank, erosion damaged bank defense works and swept away part of the provincial road. In the Germanasca of Massello branch, extensive right bank erosion seriously damaged the road junction where secondary roads lead to the towns of Massello and Salza di Pinerolo. Here, part of the slope between the stream and the road bed failed, forming a scarp approximately 20 m high. Near the bend in the road to Salza di Pinerolo, the road bed was washed away (fig. 6). Transport of floating material (tree trunks and branches) was greater in this reach of the stream than in the other rivers of catchment. Near Perrero, bank erosion and flooding were noted, with deposition of sediment. In this seg-

FIG. 6 - Intense bank erosion involving the provincial road near the junction of the road leading to Salza di Pinerolo and Massello.

ment the deposited sediment was composed chiefly of sand and gravel. At Pomaretto, along the stream segment that runs opposite the town hall, there was bank erosion with partial damage to the defense works on the right bank. The phenomena observed along the tributaries were attributable to fairly high solid transport. These phenomena were concentrated within an area of about 25 km^2 encompassing the towns of Massello and Perrero. In many instances the processes were triggered by slope dynamics (rock falls, slides and soil slips). Soil cover washed down from the slope into the stream was carried to the valley floor, creating hazards and causing substantial damage. Of the most critical situations, the one near Pomeifrè, just upstream from Perrero, was notable: two streams transported material variously consisting of sand, gravel and pebbles which blocked or damaged the road network at various points. These processes mobilized several tens of cubic meters of deposit, even though they originated from streams fed by small catchments (approx. 100 m^2) Similar situations were noted along the right-sided tributaries of the Prali segment of the Germanasca and on the left bank of the Massello segment of the stream.

Mass solid transport in the Rio Iclo near the chair lift station at Prali (Ghigo) was one of the largest in terms of area involved and of damage to man-made works on the alluvial fan (fig. 7). Mass solid transport also reactivated an old stream bed on the left side of the fan which had been filled in to build an access road to several houses. Near the fan apex, the material overtopped the natural banks of the stream, damaging the right side of a weir and depositing some of the material transported (fig. 8). The material carried to the valley floor measured from approximately a centimeter to several centimeters in size and was contained in a clay-sand-gravel matrix. The small granulometric size of the transported sediment is given by the basin lithology, which consists of micashist layers. In this process, the major damage occurred to the chairlift station and service buildings on the alluvial fan. The houses on the left side of

FIG. 7 - Stream transport on the alluvial fan of the Rio Iclo (Photo courtesy of G. Lollino).

FIG. 8 - Apex of the alluvial fan of the Rio Iclo. Deep erosion; the right shoulder of the weir has been completely washed away. Just downstream from the weir, to the left, note the differences in rock size: scattered large rock masses and a fine matrix composed of sand and gravel.

the fan sustained external damage when they were hit by debris and uprooted trees carried by the old stream bed.

Nearly all slope failure processes were classifiable as landslides involving soil cover, of which 60% were classified as soil slips and the remaining 40% as rotational slides. The majority of soil slips occurred on the left slope of Prali valley; the rotational slides occurred in all three branches of the basin. A 300 m stretch of the road running below the houses at Campo la Salza was blocked at four points; detachment niches were observed at two points along the slip surface of the slope on which some houses are located (fig. 9). The processes involved a vast portion of the slope, blocking the road and damaging the sewer system. One landslide also interacted with the hydrographic network.

Two other major landslides related to soil cover fluidification occurred near Pomeifrè just after the road fork where one road leads to the Rodoretto valley. In the former, the landslide triggered between 7.30 and 8.00 the morning of 29 May, involving a front about 35 m long and mobilizing masses on an estimated magnitude of over several cubic meters. The latter, which took place between the road fork leading to Rodoretto and the bridge over the Rio Rodoretto, was probably triggered by stream phenomena that developed along the town road running above the site. The detachment niche was observed just downstream from the road, where the phenomenon was much smaller since it involved only soil cover deposits and exposed the underlying rocky outcroppings. The material blocked the road and spilled into the Germanasca below.

Rock falls were few and occurred along the rocky scarps in the valley heads, accounting for about 10% of the total landslide phenomena observed in the basin. None caused direct damage.

Background analysis

A comparison between the information collected about the May 2008 event and the information about previous events contained in the SIT-RIG database evinced some similarities in situation and phenomena. One example is mass solid transport in the Rio Iclo. During the October 2000 event, the basin and the stream were affected by a similar phenomenon and the alluvial fan was also partially reactivated. Most likely, the processes originated in the middle-upper part of the basin following surface instability phenomena that mainly involved the soil cover and eluvial deposits. The stream banks on the fan were involved by erosion processes. The ways in which the old stream bed were reactivated were the same in both the October 2000 and the May 2008 events. Following the October 2000 event the town administration planned a series of interventions, including building a retention weir at the fan apex, construction of rock walls, and regulation of the stream by placing rock platforms in several places. The bank erosion phenomena along the stretch of the road between Borgata Ribba and Ghigo di Prali during the May 2008 event occurred in exactly the same places, though less intensely than during either the October 2000 or the June 1957 event. Portions of the defense works builted after the October 2000 event were damaged during the May 2008 event.

FIG. 9 - Rotational landslide near Campo la Salza. Note the sewer pipe exposed by the landslide.

The same situation occurred along the segment between Ghigo di Prali and Prali Villa, where left and right-sided bank erosion was observed. During the 2000 event, the road on the left bank was damaged, whereas during the 2008 event, most of the damage occurred to the cross-country ski trail on the right bank. The Molino Bridge, downstream from Borgata Ribba, was washed away in the June 1957 event and partially damaged in the May 1977 event. While the bridge was not damaged by erosion and flooding during the October 2000 event, the road upstream from the bridge was washed out after the streamflow had diverted to the left. In this instance, as in October 2000, the phenomenon occurred just as in May 2008, though less intensely. Mass solid transport along the two streams downstream and upstream from Pomeifrè was observed in the events of May 1977, November 1993, and October 1994.

CONCLUSIONS

Since 1970 studies on the Germanasca catchment have focused mainly on describing major rainfall events (Anselmo, 1978), flow-discharge ratio in small mountain basins (Anselmo & *alii*, 1982), hydrogeologic hazard analysis (Govi & Turitto, 1994), landslide monitoring (Lollino & *alii*, 2004), and processes and effects following floods (Tropeano & *alii*, 1995, 1999, 2002). In this last field of enquiry, IRPI Torino has collected a noteworthy amount of information from site surveys and archive research that has gone into the creation of a database. Various methodologies applied to the database have provided a fairly accurate picture of the spatiotemporal evolution of major events over the past two centuries in relation to the damage the events have caused. With the use of the SIT-RIG tool we were able to identify areas at higher hazard and risk and estimate reference rainfall values that could be useful for civil protection agencies.

The problem with defining rainfall threshold values for this type of natural phenomena is largely connected with the so-called basin response and the effect of precedent rainfall. The best orientation for prevention forecasting and civil protection is to call attention to lower rainfall values since they, too, may be potentially dangerous. Based on our estimates, a daily rainfall amount of 70-80 mm could be taken as a reference value for municipal agencies. Studies on precipitation patterns in the basin could be improved with the use of data from other rainfall stations installed in locations for specific local purposes. For example, weather stations at the catchment head of the Germanasca of Prali and the Germanasca of Massello streams within the municipal territory of Salza di Pinerolo could be extremely valuable for such studies and could help to better define the evolution of summer season events. A hydrometric station upstream from the confluence of the two streams could provide data on discharge from the two subbasins and thus aid in planning the size of hydraulic defense works to be built upvalley.

Based on calculations using the SIT-RIG tool, area sectors were accurately defined which, because of the higher frequency of phenomena and damage, may be considered as being at higher risk (fig. 10). High-risk sectors may be classified into two different types: areal and linear. The high-risk areal sectors are those most subject to the effects of slope dynamics (e.g., rock falls and complex falls), as in the case of the accumulation talus on which the town of Perrero is built. In the upper valley at Ghigo di Prali, reactivation of alluvial fans by debris flows or massive solid transport is more prevalent. Events occurring in this area have been recorded since 1921. Activated several times in the past, the only critical point related to slope dynamics is near Campo la Salza, along the slope portion between the buildings and the provincial road. The area sectors more vulnerable to linear risk are affected by phenomena related to fluvial dynamics such as bank erosion: the most frequent sites were observed at the Molino Bridge (Borgata Ribba, upstream from Ghigo di Prali), Borgata Giordano (just upstream from Ghigo di Prali), Prali Villa (upstream and downstream), Campo la Salza, at the confluence of the Germanasca of Prali and Germanasca of Massello streams, downvalley at the bridges at the hamlets of Trossieri and Chiotti Superiore, and at Pomaretto on the right bank of the stream.

Damage assessment documented between 1728 and 2008 shows that some types of man-made works are struck more frequently than others, roads (51%) and bridges (18%) being the two infrastructures most often damaged, followed by buildings, hydraulic works and defense works (9% each), farmland (3%) and factories (<1%). The results of this study show which types of man-made structures are more vulnerable to damage during an above average rainfall event. The economic value of these infrastructures constitutes one of the starting points for defining the risk to which the Germanasca stream basin is exposed. The cases assessed in relation to the May 2008 event all lie within the critical areas a SIT-RIG analysis had already identified. From our knowledge of the areas at higher risk, measures can be undertaken to mitigate hydraulic and geologic risk in the basin.

FIG. 10 - The Germanasca river basin: municipal names and borders (black color lines), built-up areas (black color), main river channel (grey color) with hazard and risk areas (white).

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(Ms. presented 1 April 2009; accepted 30 September 2009)