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RAINFALL INITIATION OF DEBRIS FLOWS IN CAMPANIA (ITALY): A TWO-PHASE ANALYSIS

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ABSTRACT

Debris flows in Campania begin as soil slides within the pyroclastic mantle that blankets the steep local hill slopes, which are, in turn, composed largely of carbonate bedrock. The historical pattern appears to be that clusters of debris avalanche-flows occur after intense rainstorms that follow an accumulation of a certain amount of pre-storm seasonal rainfall.

Soil moisture appears to show a seasonal pattern of summer drying and winter wetting that is typical for the Mediterranean climate of the region. The physical analysis of the interaction of rainfall with the pyroclastic mantle requires two-phase approach. Phase 1, early in the rainfall season, concerns the accumulation of the retention water in the soils, up to field capacity, whereas the second phase of the analysis examines the accumulation of surplus moisture from intense rainfall, leading to the development of positive pore pressures and debris flow initiation. Rainfall data analysed cover also the last decade characterised by no debris-flow activity in the Sarno area

Key words: *rainfall, debris flow, Campania*

INTRODUCTION

Debris avalanche-flows occurred many times in western Campania, involving thin pyroclastic layer mantling steep limestone slopes, some steeper than 40°. These deadly events occur generally when periods of prolonged rainfall are followed by intense rain storms, triggering hundreds of initial instabilities, such as debris slides, some of which then evolve into debris avalanches and debris flows, causing devastation in the lower zones.

The most catastrophic events were those of October 1954 along the Salerno coast (Penta *et alii*, 1954) and that of May 1998 (Del Prete *et alii*, 1998; De Riso *et. alii*, 1999; Guadagno & Perriello Zampelli, 2000; Brancaccio *et alii*, 2000; Pareschi *et alii*, 2000; Revellino *et alii*, 2004; Guadagno *et alii,* 2005) that struck Sarno, Quindici, Siano and Bracigliano. Other catastrophic events occurred along the Sorrento peninsula in February 1963 (Mele & Del Prete, 1999), March 1969 (Civita *et alii*, 1975), January 1997 (Calcaterra & Santo, 2004). In December 1999 catastrophic debris flows occurred at Cervinara, along the northern ridge of Mt. Partenio (Fiorillo *et. alii*, 2001), and in March 2005 debris flows occurred at Nocera.

Fiorillo & Wilson (2004) analysed rainfall data from the (Italian) National Hydrographic Service from the principal storms that triggered debris flows in Campania area up to 1998, supplemented by unpublished hourly rainfall data from specific storms.

Rainfall data have been analyzed to understand the hydrological process that leads to debris flow initiation, and two main stages were proposed about rainfall accumulation in the soil:

- Early wet season recharge of unsaturated soil moisture, reducing the moisture deficit (soil suction) induced by the long dry season, without de-

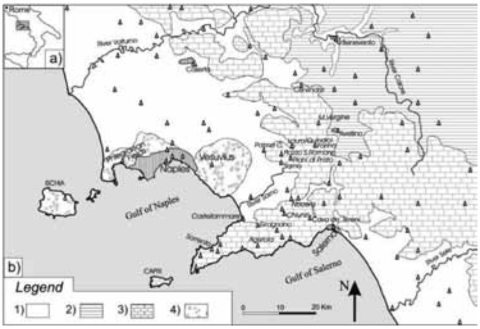

Fig. 1 - (a) Italian peninsula and area location; (b) Geological sketch map of the western side of the Campanian Apennines (modified from Fiorillo & Wilson, 2004). 1) Alluvial and other continental deposits (Plio-Pleistocene); 2) Marine terrigenous sequences (Mio-Pliocene); 3) Carbonate unit (Trias-Paleocene); 4) Volcanic area (Quaternary); Rain gauge network is shown by triangles

Level	Gs (-)	clay (%)	silt (%)	sand (%)	gravel (%)	γ_d (kN/m^3)	n (-)	n_{eff} (-)
B_w	2,55	5	20	54	21	10,8	0,57	0,05÷0,07
C	2,55	-	2	52	46	8,1	0,68	0,33÷0,37
B_t	2,55	15	25	60	-	8,3	0,67	0,05÷0,06

Tab. 1 - Porosity and some geotechnical characteristics of the pyroclastic soil. Bw, weathered and remoulded ash deposits; C, pumice level; Bt, weathered ash level; n, total porosity; neff, effective porosity (extracted from Fiorillo & Wilson, *2004)*

velopment of positive pore pressure.

- Storm rainfall retained in open pore spaces later in the wet season, after the soil moisture saturation is restored, with consequent development of positive pore pressures.

In this study we analyse hydrological data up to December 2008, providing further 10 years of records, which allow us to verify a previous hypothesis on the soil moisture accumulation into the soil. In particular, we focused the analyses in the Sarno area (P.zzo d'Alvano), where a high-elevation rain-gauge is available since May 1998, which allows also to compare data with low-elevation rain gauges. The topic assumes particular significance in this case, because the storm of May 1998 didn't show exceptional rainfall at any of the rain gauge stations, to justify the high number of debris flows produced.

Besides, some details will be further given about the process of water accumulation into the soil which can lead to instability, controlled by the evapotranspiration processes and daily rainfall distribution.

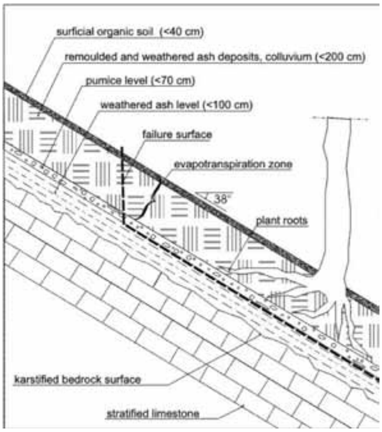

Fig. 2- Schematic profile of a typical slope of high-elevated zones of the Sarno area (overlapping and thickness of the levels are schematised)

SOME ASPECTS OF MATERIALS, DEBRIS FLOWS AND STORM EVENTS

Complex system of highlands surrounding the Campania Plain characterises the western sector of Campania, and along the coast volcanic structures of Vesuvius and the Phlegrean Fields are present (Fig. 1).

The highlands are formed predominantly by limestone sequences (Mesozoic age), bounded by faults of Quaternary tectonic activity, forming high ridges and steep slopes (Brancaccio *et alii*, 1978).

Volcanic activity of Vesuvius and the Phlegraean Fields (Rosi & Sbrana, 1987; Santacroce, 1987) has produced air-fall tephras, deposited in function of the wind direction and accumulated progressively onto the steep limestone slopes. As a consequence of intermittent eruptions and pedological alteration between deposition events, the pyroclastic mantle is generally composed of several irregular, ashy pumiceous layers, alternating with buried soil

Esposito & Guadagno (1998) stressed the peculiar physical characteristics of the pumices, characterised by interconnected internal voids controlling water accumulation. Besides, being thixotropic, all soils have high water retention values and low values of dry bulk density (γ_d); then the weight of retained water can be higher than dry soil weight (Terribile *et alii,* 2000).

Figure 2 provide a schematic profile of these slopes, and table 1 shows some geotechnical characteristics of the pyroclastic mantle.

Some instabilities develop along gullies, due to erosion of the colluvial deposits (reworked pyroclastic), while a large proportion originate as translational

Date	Main locality	Death Nr.	D. Fls Nr.	2 days rainfall (raingauge); mm
26 Oct '54	Salerno	318	>100	504 (Salerno)
8 Dec '60	Nocera	-	2	128,3 (Nocera)
17 Feb '63	Gragnano	-	>10	238,8 (Gragn.)
20 Dec '64	Forino	-	>5	109,2 (Lauro)
24 Nov '66	Vico Equ.	3	1	182,5 (Gragn.)
9 Jan '68	Sarno	-	1	24,2 (Sarno)
15 Mar '69	Agerola	-	>10	178 (Agerola)
2 Jan '71	Gragnano	6	1	176 (Gragnano)
6 Mar '72	Nocera	1	1	115 (Nocera)
16 Feb '73	Termini	9	1	62 (Turro)
22 Feb '86	Palma C.	8	4	43 (Palma C.)
23 Feb '87	Castellam.	-	1	80 (Castellamm.)
3 Octr '92	Bracigl.	-	1	102,6 (Sarno)
10 Jan '97	Castellam.	5	>50	163 (Castellam.)
5 May '98	Sarno	180	>100	157,8 (Lauro)
16 Dec '99	Cervinara	5	>10	321,2 (Cervin.)
3 March 2005	Nocera	2	1	167 (Nocera)

Tab 2 - Debris flow events occurred in Campania since 1954

slides of pyroclastic mantle as complex landslides (Cruden & Varnes, 1996), from debris slide, to debris avalanche, to debris flow (Fiorillo *et alii*, 2001). Following classification by Hungr *et alii* (2001), these landslides may be classified as debris avalanches and debris flows.

The initial movement occurs mainly above and below discontinuities along the slopes, such as trackways (Del Prete *et alii*, 1998; Guadagno & Perriello Zampelli, 2000; Fiorillo *et alii*, 2001; Guadagno *et alii*, 2003-2005), and the sliding surfaces were located prevalently within a pumice level (Del Prete *et alii*, 1998; Calcaterra *et alii*, 1999; Fiorillo *et alii*, 2001; Del Prete & Del Prete, 2002; Guadagno *et alii*, 2005; Crosta & Dal Negro, 2003). Following detachment, the landslide progressively involves the pyroclastic mantle of the slope, transforming the landslide into a debris avalanche, with increasing velocity and volume. At the base of the slopes, the material can reach long distances (Revellino *et alii*, 2004), and causes the major damages. Table 2 lists the principal debris flow events that have occurred in Campania since 1954

Some of the storms that led to numerous debris flows involved a wide area (up to 100 km^2) that included at least one rain gauge. In these cases, the rain gauge network was able to record the heaviest rainfall. In other cases, such as single debris-flow events, the amount of rainfall associated with the debris flows activity is more difficult to ascertain.

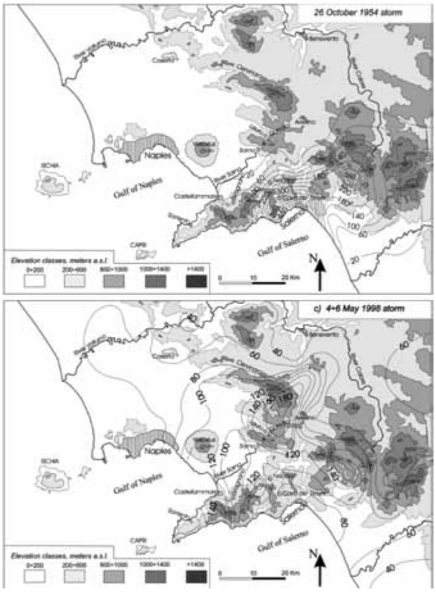

Fig 3 - Isohyets of the storms inducing the main debris flow phenomena

Isohyets for the two main rainfall induced debris flow storms (Fig. 3) have been produced by Kriging interpolation. High-elevation rain gauges include those located (Fig. 1) west of Avellino (M.Vergine, 1287 m a.s.l.), at Vesuvius (Osservatorio, 610 m a.s.l.) and on the Sorrento Peninsula (Agerola, 691 m a.s.l.; Chiunzi, 617 m a.s.l.). The role of the topography appears very important in controlling the distribution of the rainfall of the 1954 storm, but it seems minor for the 1998 storm. In any case, the rain gauge network describes the spatial rainfall distribution of the rainfall.

The 26 October 1954 occurred after a long dry summer, and was characterised by a very concentrated cell located on the Salerno town. No rainfall (or just few millimetres) was recorded several kilometres in the northern (Vesuvius area) and southern (Sele plain) sector, highlighting the "tropical" character of this storm. The maximum was recorded at Salerno rain gauge with 504 mm (locally the annual mean rainfall is 1250 mm). The storm had a duration of about 16 hours; however, more than 75% of the total amount occurred in only 7 hours (data in SIMN, 1954).

The May 1998 storm was less intense than other storms (Tab. 2), but caused numerous large-scale debris flows. Braca & Onorati (1998) described the singular characteristics of this storm, such as the unusual presence of heavy and sustained precipitation at the beginning of the month of May (9 rainy days). They pointed out that this heavy spring rainfall was the his-

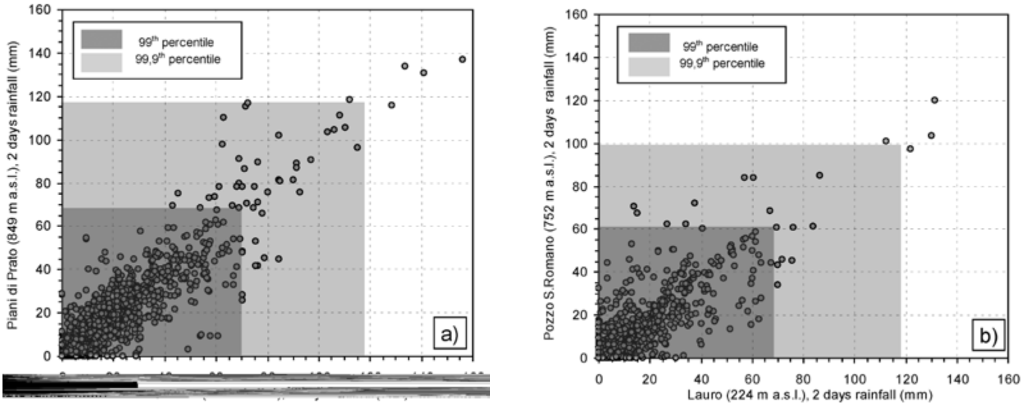

Fig. 4 - Comparison between rainfall (2-days) recorded by rain gauges located at different elevation. a) Quindici and Piani di Prato (3,1 Km spaced), period 1998-2008; b) Lauro and Pozzo S.Romano (3,5 Km spaced), period 1971-1977

torical maximum for this time of year. Other authors suggested that the rain gauge network might have been insufficient in defining the characteristics of the storm (Mazzarella *et.alii*, 2000).

After the debris flow event of May 1998, a high-elevated rain gauge was located on the upland of Piani di Prato (849 m a.s.l.), above the detachment of the landslides of May 1998. Besides, between 1971 and 1977 a high-elevation rain gauge was in operation (Pozzo S.Romano, 752 m s.l.m), sited along the water divide between Lauro and Sarno villages. Figure 4 shows the scatter plot of 2-days rainfall of the low-elevated rain gauges (Quindici and Lauro) and the high-elevated rain gauge (Piani di Prato and Pozzo S.Romano). The scatter plot indicates that data not dispersed, and provide two main considerations on the rainfall spatial distribution:

- rainfall doesn’t increase with the elevation;
- extremes values (higher than 99,9 percentile) appear well correlated.

HYDROLOGICAL ANALYSES

The Campania area is characterised by a typical Mediterranean climate, with dry season between June and September and wet season from October to May. The storms that occur at the beginning of the rainy season (Sept.-Oct.) can be characterized by a very high peak of hourly intensity, possibly linked to heat and local disturbance; the autumn-winter rainfalls appear connected to storms characterized by either high hourly intensity or long duration, and the spring season, on the other hand, is characterized by more evenly distributed rainfall (Fiorillo &Wilson, 2004).

The first rainfall at the beginning of the wet season occurs in conditions of minimum soil water content and consequently, a high soil moisture deficit. Thus, early seasonal rainfall is mainly absorbed into the soil, increasing the soil moisture. Some intense historical storms, extracted from the historical series, failed to induce debris flows. In particular, heavy storms occurred in January 1973 and November 1985 failed to trigger debris flows, although they induced floods and erosion in many places. The same amount of rainfall occurring later in the wet season, when the soil moisture

content is closer to saturation, would interact with the soil in a much different way, with the rain water now free to flow down into deeper layers or to move downslope as runoff or throughflow.

Until field capacity is reached, the water retained within the soil layer reflects the balance between cumulative rainfall and water loss by evapotranspiration. Once this moisture level is reached, however, any additional infiltration from rainfall is subject also to drainage, either directly into the underlying bedrock (percolation) or laterally along the hillslope (throughflow). Positive pore pressures may be created if the rate of rainfall infiltration exceeds the rate of drainage, either because of intense rainfall or reduced permeability in an underlying "perching" layer.

To restate the above in a different way, the water content of the soil may be divided into two different components

PHASE I: ANTECEDENT SOIL MOISTURE

Fiorillo & Wilson (2004) fixed the soil undergoing evapotranspiration at h=100 cm, because plant

Main storm		P_{storm} (mm)	θ (%)	ΔP (mm)	P_{exc} (mm)
Nov	1985	203,2	39,86	111,4	91,8
May	1998	157,6	51	0	157,6
Dec	2004	156,2	51	0	156,2
Nov	1986	155,8	32,8	182	-26,2
Sep	2002	141	27,0	240	-229
Dec	2000	133,6	46,0	50	83,6
Nov	1975	131,4	45,7	53	78,4
Jan	1973	130	40,6	104	26
Mar	2005	128,6	50,7	3	125,6
Dec	1964	126	50,76	2,4	123,6
Jan	1987	124,8	50,2	8	-116,8
Dec	1988	117,8	41,2	98	19,8
Sep	2006	115,2	27,0	240	-124,8
Feb	1984	113,2	51	0	113,2
Nov	1989	109,8	32,8	182	-72,2
May	1963	109	48,6	24	85
Sep	1998	106	27,0	240	-134
Nov	1980	103,6	42,3	87	16,6
Apr	1978	100,8	51	0	100,8
Mar	1972	98,4	50,5	5	93,4
Nov	1978	97,4	27	240	-142,6
Nov	1992	91	44	70	21
Nov	1979	89,6	38,7	123	-33,4
Dec	1960*	88	51	0	88
Dec	1959	84,5	51	0	84,5
Nov	1991	81,4	51	0	81,4
Nov	1997	63,4	46,13	48,7	14,7

Tab. 3 - Some hydrological parameters of the main storms (Lauro/Quindici rain gauge) occurred in the area analysed: P_{storm}*, 2-days cumulative rainfall of the storm; θ, antecedent soil moisture;ΔP, minimum rainfall needed to reach*θ_{max}*;* P_{exc}*, rainfall excess and useful to induce positive pore pressure*

roots reach depth between 80 and 120 cm in the Sarno-Quindici area. Plan roots are unable to cross the pumice layers (Fig. 2); these levels act as a drainage sheet, and break the root grooving deeply. As consequence, the evapotranspiration processes occur prevalently in the upper part of the pyroclastic mantle, deeply limited by the first pumice level. In situ suction measurements (Versace *et alii*, 2005) highlight the increasing of the suction toward summer, the decreasing towards autumn; below pumice level the suction tends to be constant during the year. For a thickness of 100 cm of the zone subject to evapotranspiration processes, and based on the technical characteristics of the soil mantle, the following parameters have been estimated (Fiorillo & Wilson, 2004):

- soil storage capacity, *m*, 240 mm;
- (volumetric) water content at field capacity, θ_{max}, 51%
- minimum (volumetric) water content reached at the end of dry season (summer), θ_{min}, 27%;
- thickness of the soil, *H*, 1000 mm.

The soil generally reaches peak moisture (θ_{max}) by December and remains at or near that level until April. During this period, any additional rainfall percolates down, recharging the water table of the carbonate aquifer, or runs off as surface stream flow. Between July and September, the moisture content of the pyroclastic cover is reduced to its minimum level (θ_{min}).

To increase the water volumetric content from θ_{min} up to θ_{max}, an amount of 240 mm of water is needed, corresponding to soil storage capacity, m. Due to evapotranspiration processes, this amount of water corresponds to an higher amount of rainfall, up to 400-500 mm, depending on the its temporal distribution.

In order to examine the antecedent soil moisture conditions before several important storms, the path of the soil moisture was computed from daily rainfall and temperature, and a hydrological balance of the pyroclastic cover (Fiorillo & Wilson, 2004).

Table 3 shows the main storms (2 days cumulative rainfall) extracted from a historical series of the Lauro rain gauge (Quindici rain gauge after May 1998), for which antecedent volumetric water content, θ, was calculated.

The value ΔP is the minimum rainfall needed to reaches θ_{max}, and it depends on the soil moisture conditions and thickness of soil involved as below specified:

$$\Delta P = H\ (\theta_{max} - \theta)$$

The value ΔP makes up the minimum quantity to be subtracted from Pstorm since runoff, especially during high intensity rainfall, leads to an increase of such an amount. Thus, the excess of rainfall, P_{exc} useful to induce positive pore pressure is given by:

$$P_{exc} = P_{storm} - \Delta P$$

Table 3 shows that at the Lauro rain gauges the highest Pexc values refer to the storms of May 1998 and Dec 2004. The other storms were less intense or occurred in conditions of $\theta < \theta$ max and show up lower values for $P_{exc.}$

The storm of May 1998 is the powerful in term of rainfall exceed, P_{exc}, but other recent storms (December 2004 and March 2005) appear intense and will be analyzed in the following section.

PHASE II: POSITIVE PORE PRESSURE AND CONDITIONS LEADING TO DEBRIS FLOW INITIATION

Detailed in situ measurements (Pierson, 1980, Sidle & Swanston, 1982; Reid *et alii*, 1988; Johnson & Sitar, 1990; Wilson & Wiezoreck, 1995; Fannin & Jaakkola, 2000) demonstrated that positive pore pressures develop during heavy storms.

Wilson & Wiezoreck (1995) noted that positive pore pressures might be highly transient, decreasing

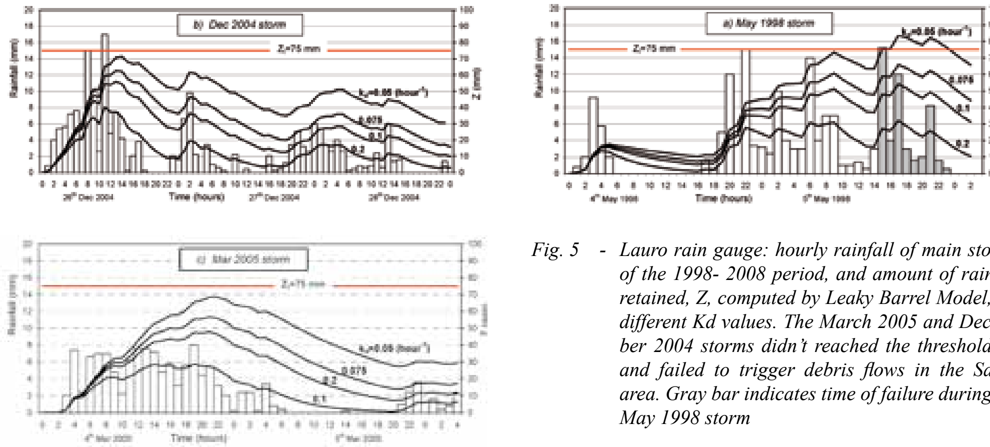

Fig. 5 - *Lauro rain gauge: hourly rainfall of main storms of the 1998- 2008 period, and amount of rainfall retained, Z, computed by Leaky Barrel Model, for different Kd values. The March 2005 and December 2004 storms didn't reached the threshold Zt, and failed to trigger debris flows in the Sarno area. Gray bar indicates time of failure during the May 1998 storm*

quickly after the cessation of heavy rainfall. This could make it difficult to measure or observe positive pore pressures without automatic data recording of rapid-response piezometers. Furthermore, in hillslopes with stratified and/or lenticular soil layers with different hydraulic conductivities, higher pore pressure will develop in locations where more conductive zones pinch out or are constricted (Reid *et alii*, 1988). Johnson & Sitar (1990) concluded that, because of the highly variable nature of the pore pressure response, both in space and time, and the close association with specific characteristics of the rainfall record, a traditional hydrological model cannot completely explain the hydrologic response leading to debris-flow initiation on the upper portion of the slope.

Although instrumental data about positive pore pressures during debris flow initiation have not yet been collected in the Campania pyroclastic mantle, it is probable that positive pore pressures do form during intense rain storms (Fiorillo & Wilson, 2004). Because of the high permeability of the Campania pyroclastic cover and the steep hill slopes, however, possible positive pore pressure would rapidly decrease after each storm. Below, the role of positive pore pressure has been evaluated by the "leaky barrel" model described by Wilson & Wiezoreck (1995). This model cannot explain the real hydrologic phenomena into the soil mantle, but it is useful to evaluate the power of each storm in function of its rainfall time-distribution.

The LB model describes the drainage characteristics of a hydrological system, such as a slope, by introducing a new parameter, the drainage coefficient, K_d, with dimensions of inverse time (hour^{-1}). During a storm, the amount of retained rainwater, Z, increases or decreases, depending on the balance between rainfall intensity, I(t), and drainage rate, K_dZ. The net rate of change in the water level retained in the system may be expressed as a linear first-order differential equation (Wilson & Wiezoreck, 1995):

$$dZ/dt = I(t) - K_d Z$$

Fiorillo & Wilson (2004) compared the main storms occurred in Campania using hourly rainfall data, and found the minimum value of retained rain water, Z_t, needed to induce a failure. Here, the analyses has been extended to further 10-years records of rainfall to verify the model used. As shown in Tab.3, during this recent decade, the storm of December 2004 and March 2005 are comparable to May 1998 storm. Figure 5 shows the values of the retained rainwater, Z, induced by the storm of May 1998 and December 2004. The value of K_d was deduced observing the starting time of landslide initiation (gray bar of Fig.5a). In this time, a higher value of Z must not have been reached previously, nor exceed after all landslide initiations. The minimum retained rainfall needed to debris flows initiation, Z_t, has been fixed at 75 mm for Lauto rain gauge gauge and for K_d=0,05 (Fiorillo & Wilson, 2004). This value has not been reached during the December 2004 and March 2005 storms (Fig.5b-c), which failed to trigger debris flows in the Sarno area, instead, the 4 March 2005 storm induced a debris flows in Nocera, where it was more intense (Tab. 1)

DISCUSSION

Based on the historical rainfall data (daily and hourly data) and the occurrence of the main debris flow events since 1954, the hydrological conditions leading to debris flows in Campania can be connected to two main principal factors:

- a long antecedent period of rainfall, which recharge the pyroclastic mantle after the water deficit accumulated during the dry and summer;
- a storm characterised by high intensity in term of retained rainwater.

Conditions of soil moisture close to field capacity are reached during the winter season, and can be maintained also during the spring season. Minor is the soil moisture conditions of the pyroclastic mantle previous the storm, and higher has to be the intensity of the storm to induce debris flows.

The storm of May 1998 and October 1954 reflect the two extreme records which lead to debris flow initiation.

The storm of October 1954 occurred after a long dry season (ΔP, the minimum rainfall needed to reach $\theta_{\max}$ was at the maximum value, 240 mm) and was intense in the Salerno Area (fig.3) and induced rainfall excess, P_{exc}.

Viceversa, the storm of May 1998 wasn't particularly intense. It singular characteristics appear connected to the previous hydrological conditions. To stress this point some considerations will be given on the capacity of the soil to retain water. We have fixed a value of soil moisture storage capacity of 240 mm, which refers to 1 m thick evapotranspiration zone. However, soil moisture storage capacity cannot be assumed as a constant, depending mainly on the thickness of soil, and in particular on the depth of the first pumice level.

Higher is the soil moisture storage capacity, higher will be the amount of rainfall needed to reach the field capacity. Besides, the effects of the storm tends to increase as the antecedent soil moisture increase.

As consequences, any specific storm, characterised by a definite hourly rainfall distribution, induce different pore pressure into the soil, in function of the soil moisture storage capacity of the soil.

In situ thickness measurements of the pyroclastic mantle, carried out in the scar zones, are somewhere higher than 1 m, and can reaches a value up to 2 m. If the thickness of the pyroclastic mantle subject to evapotranspiration is considered higher than 1 m, a higher values (>240 mm) of the soil moisture storage capacity, *m*, has to be assumed. Based on this hypothesis, the value of the rainfall excess, P_{exc}, has been re-computed for different values of the soil moisture storage capacity (Fig. 6). Initial horizontal segment indicates that antecedent rainfall and temperature conditions are able to maintain field capacity also considering a value of the soil moisture storage capacity, *m*, higher than 240 mm. Whereas, decreasing trend indicates a diminution of the soil moisture condition, which reduces the "power" of the storm, in term of $P_{\mathrm{exc.}}$

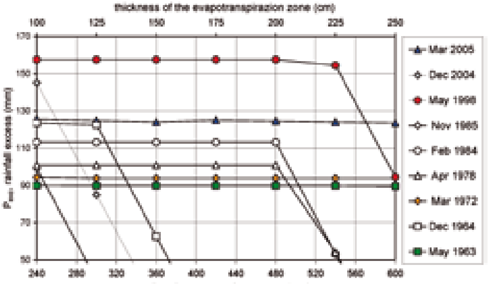

Fig. 6 - Rainfall excess, Pexc, as function of soil moisture storage capacity, m, for the main storms occurred at Lauro rain gauge extracted from table 3

The value of P_{exc} of the May 1998 storm remains constant up to a value of the soil moisture storage capacity, m=480 mm. Also the May 1963, February 1984 and March 2005 storms present similar path, but they were characterised by minor value of rainfall excess, Pexc. The March 2005 storm was more intense at Nocera rain gauge (167 mm, Tab.1) and locally induced some debris flows. The rainfall excess of other storms drop rapidly for values of the soil moisture storage capacity, *m*, higher than 240 mm, indicating that storm rainwater was partially retained by the pyroclastic mantle as retention water.

CONCLUDING REMARKS

This study extends the hydrological analyses on debris flows in the Campania area carried out by Fiorillo & Wilson (2004), integrating data with further 10-years of records.

Two main aspects have been discussed:

- the possible rainfall amount in the high elevation zones during the May 1998 storm;
- the role of the antecedent rainfall controlling the amount of the rainfall excess during intense storm.

The first point has been analysed by high elevation data available after the May 1998 storm, and by another rain gauge during the seventieths. The analysis shows that rainfall doesn't increase with the elevation, and the singularity of the May 1998 storm has to found in the characteristics of the antecedent rainfall and soil moisture storage capacity.

The second point has been discussed by the Fig.6: zones characterised by high values of the soil moisture storage capacity are sensible to powerful storm only after abundant antecedent rainfall recharge.

These characteristics help to understand the catastrophic effects induced on the slopes by the May 1998 storm, although it had unexceptional characteristics in term a total amount of rainfall. The singular characteristics of the hydrological condition before the May 1998 storm lies in the particular distribution of the antecedent rainfall, in a way that soil could maintain field capacity condition up to a high value of the soil moisture storage capacity.

The spatial distribution of different values of the soil moisture storage capacity can have a strong control on the location of the landslide initiation. This suggests that landslide initiation in Campania is also controlled by the characteristics of the storm and by antecedent hydrological conditions, as well as geomorphological and stratigraphical features of the slopes.

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