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RELATIONSHIPS BETWEEN MASS WASTINGS AND RAINFALL IN THE PARMA VALLEY (NORTHERN APENNINES)

ASTRACT: PEREGO S. & VESCOVI P., *Relationships between mass wastings and rainfall in the Parma Valley (Northern Apennines)*. (IT ISSN 0391-9838, 2000).

In the ambit of a historic research, 31 landslide reactivations and 79 soil slips were dated. The correspondence between rainfall and the development of mass wastings, distributed over periods with annual rainfall above the average and especially in periods with monthly rainfall clearly above the average, was evident. The highest concentration of mass wastings was found during the hydrological year 1959-'60.

An examination of cumulative rainfall over a period of 60 days prior to the landslide revealed values which, in the majority of cases, were between 300 and 450 mm, with at least 200 mm 30 days before reactivation.

The landslide phenomena are distributed over the Spring and Autumn-Winter periods, peaking in April and December. The Spring landslides are reactived in correspondence with the secondary maximum annual rainfall, while the Autumn-Winter landslides are approx. one month in delay with respect to the principal maximum rainfall.

Moreover, the cumulative rainfall measured over the 60-day period necessary for the Spring landslides appears to be lower than that necessary for the Autumn-Winter landslides, when the initial degree of saturation of the soil is lower, following the lack of rain over the Summer.

The soil slip phenomena are concentrated in the months of March, April, October and December, with a distribution which does not entirely correspond with monthly rainfall peaks. In relation to these instability events, we consider the presence of intense precipitation events which, in these conditions of greater permeability, can rapidly increase the saturation level and trigger instability, to be a determining factor.

KEY WORDS: Mass movements, Historical data, Rainfall, Parma Valley, Northern Apennines

RIASSUNTO: PEREGO S. & VESCOVI P., *Relazioni tra dissesti e piovosità in Val Parma (Appennino settentrionale)*. (IT ISSN 0391-9838, 2000).

Con una ricerca storica sono stati datati in Val Parma 31 riattivazioni di frana e 79 fenomeni di instabilità superficiale assimilabili alle colate di terra. Risulta evidente la corrispondenza tra la piovosità e lo sviluppo dei dissesti che si distribuiscono in periodi con precipitazioni annuali superiori alla media e soprattutto in periodi con precipitazioni mensili nettamente superiori alla media. La massima concentrazione dei dissesti è stata riscontrata nell'anno idrologico 1959-'60.

Esaminando le piogge cumulate in un periodo di 60 giorni precedenti il movimento franoso sono emersi valori che, nella maggior parte dei casi, risultano compresi tra 300 e 450 mm, con valori di almeno 200 mm a 30 giorni dalla riattivazione.

I fenomeni franosi si distribuiscono nei periodi primaverile e autunnale-invernale, con due massimi in Aprile e Dicembre. Le frane primaverili si riattivano in corrispondenza del massimo secondario di piovosità annuale, mentre quelle autunnali-invernali mostrano uno sfasamento di circa un mese con il massimo delle precipitazioni. Per le frane primaverili sembra inoltre sufficiente un'altezza delle piogge cumulate dei 60 giorni inferiore a quella dell'Autunno-Inverno, periodo in cui le condizioni di relativa saturazione del terreno vengono raggiunte più lentamente, dopo la scarsa piovosità estiva.

I fenomeni di instabilità superficiale indagati si concentrano nei mesi di Marzo, Aprile, Ottobre e Dicembre con una distribuzione che non trova completa corrispondenza con i massimi di piovosità mensile. Per questi dissesti che si sviluppano nella parte più superficiale della coltre detritica eluvio-colluviale, si ritiene infatti determinante la presenza di eventi piovosi concentrati che, in questi contesti di maggiore permeabilità, possono aumentare velocemente il livello di saturazione, innescando l'instabilità.

TERMINI CHIAVE: Precipitazioni, Dati storici, Movimenti di massa, Val Parma, Appennino settentrionale

INTRODUCTION

In the Parma Valley, many reactivations of old landslides are found; in many cases, these mass wastings are distributed over periods with abundant rainfall. The relationship between rainfall and landslides is analysed by dating the largest possible number of mass wastings which developed in comparable geologic and geomorphologic settings and by examining daily rainfall data from the nearest raingauge stations. The goal of this work is to find a correlation between particular rainfall situations and landslide

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reactivations, without going into the problem of analysing hydrogeological conditions or defining the threshold rainfall values required to trigger the landslides.

Bibliographic research on mass wasting dates was restricted to the last century because pluviometric data from Parma Valley raingauge stations are available only from 1913 onwards. Historical sources were gathered from Internet catalogues (Guzzetti & *alii*, 1994) and from the archives of the *Gazzetta di Parma*, the local daily newspaper; some information was found in Dall'Olio (1975). The information gleaned from the local press was particularly useful for the postwar period but is, unfortunately, fragmentary for the first half of the century and especially during the wars. Information was also obtained from technical reports supplied by the Ufficio di Coordinamento Provinciale di Parma del Corpo Forestale di Stato.

We do not consider landslides where exact dating is not possible or those for which the dating is precise but the location unsure. The historic data that we have collected have enabled us to reconstruct a sequence of landslide events which is certainly incomplete; nevertheless, these data provide indispensable study material. Bibliographic research has also drawn our attention to the recurrence of mass wastings which are not reactivations of old landslides. For these mass wastings, which we distinguish, we have the dates, but their exact delimitation remains uncertain. The information we have gathered concerning these mass wastings, nevertheless, indicates that they involved significant portions of the soil cover even though they are not mappable as landslides.

The daily rainfall data we have used come from twelve raingauge stations in the Parma Valley and were gathered between 1913 and 1996; they are, in part, published in the *Annali Idrologici* of the Ufficio Idrografico del Po di Parma (Ministero dei Lavori Pubblici, 1913-1990) and, were kindly supplied by the same office for the period from 1990 onwards.

The diffusion and importance of slope movements in the Parma Valley have been known (Almagià, 1907; Sgavetti, 1972; Papani & Tellini, 1974; Perego, 1992; Pellegrini & *alii*, 1998). In general, one could say that the valley has characteristics which favour the development of slope movements (Clerici & *alii*, in press).

GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

The study area is situated in the basin of the River Parma over a surface of approx. 320 km^2, stretching from the Apennine ridge (M. Marmagna, 1852 m) to the edge of the high plain, downstream of Langhirano (200 m) (fig.1).

In order to analyse the distribution of mass wastings in the valley, we have subdivided the River Parma basin into different sectors, each characterised by a fairly uniform lithological and geomorphological setting (fig.1). The following sectors are distinguished: 1 Backbone, 2 Upper Valley, 3 Inner Middle Valley, 4 Outer Middle Valley, 5 Lower Valley.

The Backbone sector lies on a Tuscan sequence Macigno arenaceous unit, affected by an overturned anticline which is structurally uplifted in relation to the northeastern allochthonous units (Bartolini & *alii*, 1982; Bernini & *alii*, 1991; Bernini & *alii*, 1997). This sector is characterised by steep slopes, notable frost action and a landform controlled by rock structures except in the till deposits, which are fairly localised. Landforms produced by glacial abrasion during the last glaciation are also evident. (Losacco, 1949; Federici, 1977; Federici & Tellini, 1983). The rocks outcropping in this sector are highly resistant and mass wasting is not very frequent.

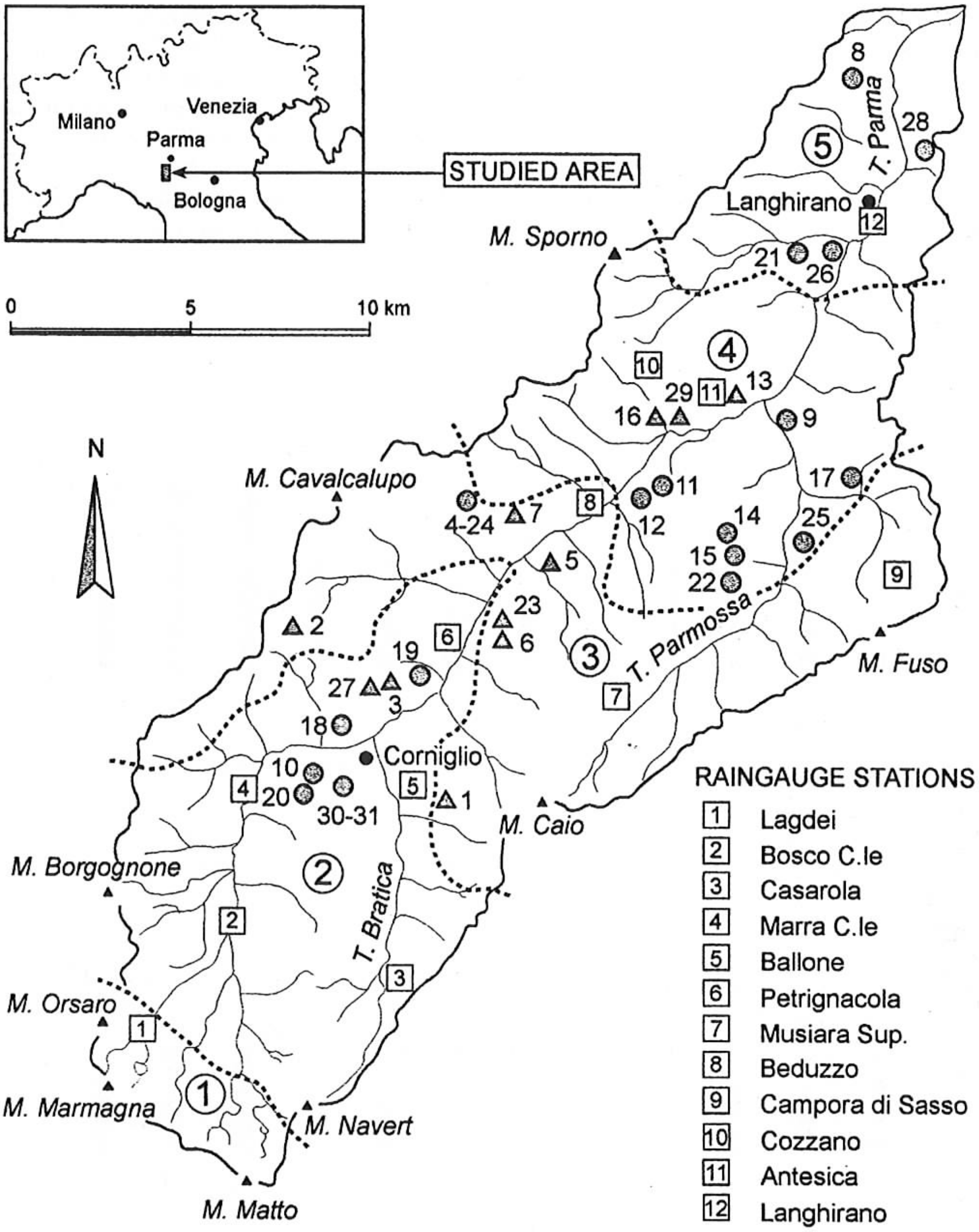
The Upper Valley sector features gentle slopes and is, therefore, much wider and largely covered by glacial and periglacial drifts which reach their greatest extension here. The substrate is made up of Subligurian units (Barbieri & Zanzucchi, 1963; Plesi, 1975; Vescovi, 1998), composed mainly of shale and limestones and, locally, of sandstones (Bratica Valley). These lithological features and the extent of the deformation of these units restrict the structural control of the landforms and favour the development of frequent landslides widespread in this sector, which often involve large bodies of helminthoid flysch along the northwestern and eastern borders of the sector.

The Monte Caio Flysch (predominant lithology: marly limestones and calcareous marlstones) (Ghelardoni, 1961) constitutes the substrate of the Inner Middle Valley sector; in a limited area in the eastern part of the Parma basin (Parmossa Valley), Epi-Ligurian sequence formations with predominantly arenaceous and marly lithology are present (Papani & *alii*, 1987). The well-defined bedding and the strong lithologies exercise notable structural control over landform evolution (Perego & Vescovi, 1991) and the development of mass movements which are less frequent than in the previous sector. The structural control exercised by the bedding is particularly evident on the left side of the valley, showing short steep slopes because of N and NW dipping of the Flysch endowing this part of the valley with notable dyssymetry.

The Outer Middle Valley sector presents gentle slopes; the «Marne rosate di Tizzano» marlstones and the M. Sporno Flysch, here essentially composed of marly lithology (Petrucci & Barbieri, 1966; Cerrina Feroni & *alii*, 1990), exercise low structural control. Only in the northern part of the sector, on the left side, the thick-bedded flysch forms steep slopes, thereby limiting landslide development and giving the area characteristics which resemble the previous sector and favour a dyssymetry of the valley that is, however, reversed, compared with the dyssymetry further upstream.

The Lower Valley sector is characterised by its openness and the extent of the alluvial deposits of the River Parma, which, especially on its right side, are present over wide terraces (Clerici & *alii*, 1979). The outcropping formations are predominantly marlstones and clays, they belong to the Epi-Ligurian and «Neoautochthonous» sequences (Gasperi & *alii*, 1986) and are covered with Quaternary deposits (Di Dio & *alii*, 1997). The lithologic features of the clay-rich substrate, favour the development of mass wastings even in a context of gentle slopes.

FIG. 1 - The Parma river basin and the location of the landslides reactivated during the last century. Triangles show landslides on flysch debris and small rings those on shales and marlstones. The circled numbers show sectors with fairly uniform geologic and geomorphologic characters: 1. *Backbone*, 2. *Upper Valley*, 3. *Upper portion of the middle Valley*, 4. *Lower portion of the middle Valley*, 5. *Lower Valley*. The 12 rain gauging stations are shown.



GENERAL RAINFALL CHARACTERISTICS

Data from twelve raingauge stations in the Parma Valley area were analysed (fig. 1). The stations have been operative discontinuously for periods of various lengths over the last century, but a few of them have provided continuous data for periods of over thirty years.

The plots of monthly average rainfalls of fig. 2, showing precipitation conditions in the three sectors into which the basin in question may be subdivided, were constructed on the basis of daily pluviometric data from three raingauge stations representing the upper, middle and lower parts of the valley.

Rainfall performance of the upper portion of the Parma River basin is shown in the diagram relative to the Bosco Centrale raingauge station (784 m), active for over 70 years; the Lagdei raingauge station (1245 m) (fig. 1) would be more representative of this sector but was not used as it was inactive for extended periods. The middle portion of the river basin is represented in the diagram relative to the Petrignacola raingauge station (630 m), which was active for 64 years; other stations in this sector are unusable because they have only functioned for brief periods. The lower portion of the valley is represented by the Langhirano raingauge station (262 m), which is the only station in the area to have functioned for a long enough period (27 years).

In the upper valley, annual average rainfall is approx. 2000 mm, with values of over 2500 mm in the ridge zone; in the middle portion of the valley, average annual rainfall is 1100 mm, and 850 mm in the lower portion.

The monthly average rainfalls reveal a trend with two peaks and two lowpoints, which is typical of the so-called «sublitoraneo-appenninico» climate (Rossetti, 1975). The autumn peak is higher than the spring peak, with November as the rainiest month. The summer lowpoint is always lower than the winter lowpoint; moreover, as can be seen in the Bosco Centrale and Petrignacola diagrams, the winter lowpoint is not particularly marked, with monthly averages similar to the Autumn and Spring figures. In fig. 2, the monthly means of rainy days are illustrated, where rainy day stands for at least 1 mm of rain; the values show a similar trend to the monthly averages with peaks in

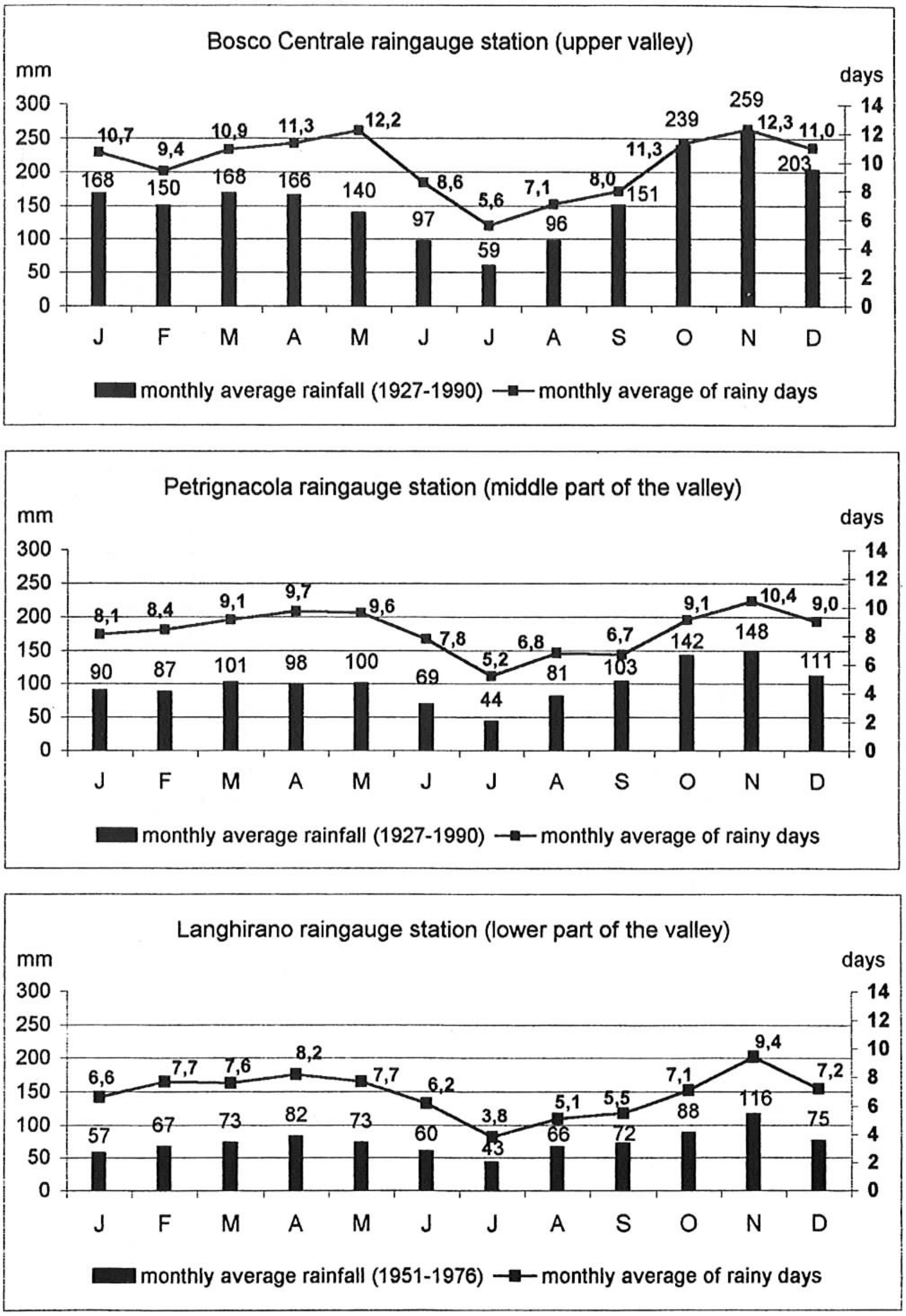


FIG. 2 - Monthly average rainfall and monthly average of the rainy days at the three rain gauging stations of the upper, middle and lower Parma Valley.

Spring and Autumn. April, May and November are the months with the highest average number of rainy days, for all stations.

Daily average rainfalls are higher in Autumn (about 20 mm at Bosco Centrale, 15 mm at Petrignacola and 12 mm at Langhirano), compared to Spring (about 15 mm at Bosco Centrale, 10 mm at Petrignacola and 10 mm at Langhirano).

The temperature regime of the basin reveals average annual temperatures of 7° in the upper sector and 13° in the area north of Langhirano. Temperature distribution is fairly homogeneous, except for the Petrignacola area, where an isotherm of 13° is present (Rossetti, 1975).

Snowfalls mainly occur between December and March, with permanence on the ground reaching a top value of 180 days a year in the backbone area, 63.4 days a year at the Bosco Centrale station, 57.6 days a year at the Petrignacola station and 43 days a year at Langhirano. The thickness of the snowpack varies, on average, between 8.8 cm at Langhirano and 70 cm at Lagdei (Rossetti, 1975).

RAINFALL PARAMETERS AND MASS WASTING TYPES

RAINFALL PARAMETERS

When choosing the rainy periods to relate to the landslides discussed in this paper, we took into account the fact that most of the landslide reactivations in Emilia Romagna affected units characterised by low permeability due to their high clay content, and that cumulative rainfall has an important role on these units over long periods (Galliani & *alii*, in press). These observations are confirmed by other research which, in different regional contexts, highlights the importance of cumulative rainfall in the development of landslide phenomena in low permeability lithologies (Govi & *alii*, 1985; Sorriso-Valvo & *alii*, 1994; Corominas & Moya, 1999; Flageollet & *alii*, 1999). In conditions of higher permeability, it would, on the other hand, appear that severe rainfall events over several days (Mele & Del Prete, 1999) which are statistically analysable have a decisive role (Canuti & *alii*, 1985; Cascini & Versace, 1986; Garland & Olivier, 1993). In some cases, the influence of cumulative rainfall over a very long period is proposed; in the Southern Apennines, in a similar geological context to ours, Corbi & *alii* (1999) presume that mass wastings form after a preparatory phase of rainfall periods on a pluriannual scale.

Total annual and monthly rainfall related to the average rainfall of the same period, the cumulative rainfall and the distribution of rainy events before mass wastings are the parameters which we have taken into consideration for the purposes of this work.

For most of the period we analysed, hourly intensity parameters are not available, but we consider that, in the Parma Valley units, almost always with slow infiltrations, heavy precipitations probably do not play a decisive role, while they are very important in units with high permeability, characterised by fast increases of the interstitial pressures (Ikeya, 1989; Au, 1993; Crozier, 1996; Wieczorek, 1996; Regione Piemonte, 1998).

The aim of this work is to show any eventual relationships between rainfall conditions and landslide reactivations; this work doesn't define the threshold rainfall values required for landslide triggering.

In choosing the period of antecedent precipitations in connection with the landslides, we calculated the relationship between the precipitation in the months preceding the landslides and the respective average values, in order to highlight eventual periods with clearly above average rainfall. This ratio is shown in tab.1 for the month preceding the reactivations (R1) and for the second preceding month (R2).

These comparisons with average values suggest that it would be worthwhile to investigate cumulative precipitation over 60 days prior to reactivations (*antecedent precipitations*).

This length of time might not be enough only in the case of landslide n. 30 (tab. 1); Galliani & *alii* (in press) consider a seventy day period for this landslide. Using the daily data provided by the raingauge stations situated close to the individual landslides, we have, for every single landslide reactivation, reconstructed cumulative curves for the 60 days preceding the event, with the aim of analysing their evolution over time and highlighting any eventual common features.

For each landslide we have also highlighted the presence of an *antecedent event*, in the sense of a rainfall event immediately preceding the reactivation date, i.e. the continuous series of rainy days contemporaneous with the landslide or in the period immediately preceding it, including events which terminate one or two days before the reactivation date but which are closely related to the triggering of the landslide.

MASS WASTING TYPES

Our bibliographic research enabled us to date many mass wastings: 31 reactivations of landslides and 79 soil slips.

- *Landslide reactivations*

All dated landslides are reactivations of dormant landslides which were partially or entirely reactivated in the last century; they are distributed all over the Parma Valley. The present geomorphological context suggests that the dated slope movements were predominantly landslides with rotation and traslation in the main body and flows in the foot, as is the case for the majority of landslides currently active in the Parma Valley. We distinguish the landslides on marly limestones flysch debris (debris slide) and those on clay-rich lithologies (earth slide - earth flow) (Cruden & Varnes, 1996).

In order to highlight the overall morphological setting in which the landslides developing, landslide areas and average slopes («travel angle» sensu Cruden & Varnes, 1996) are shown in the graph of fig. 3. The majority of landslides have an area under 0.40 km^2; only two are particularly wide, with areas of 0.80 km^2 (landslide reactivations n. 4 and 24 in tab. 1) and over 3 km^2 (landslide reactivations n. 30 and 31 in tab. 1). The average slope of the main body of the landslides is between 7° and 19° and it is worth noting that the landslides developing on flysch debris have steeper slopes than those situated on units with high clay content (fig. 3).

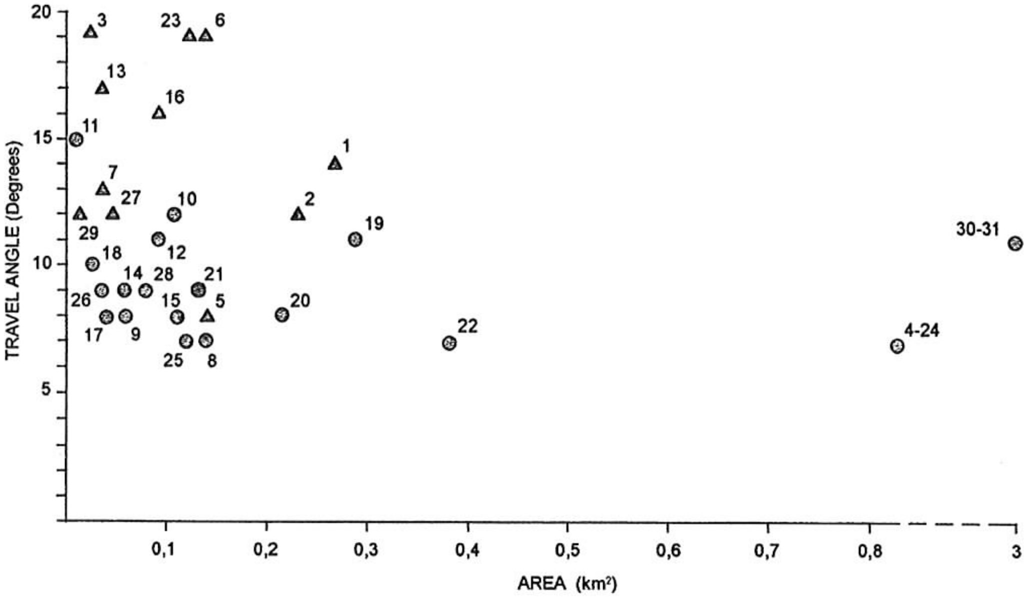
- *Soil slips*

This term defines all mass wastings which develop within the soil and the eluvial-colluvial deposits. These mass wastings cannot be precisely mapped owing to the lack of current evidence; they have been defined solely on the basis of historical data. In the majority of cases one can presume that these phenomena developed as shallow slides, which were possibly rapid. These mass wastings are clearly distinguishable from the deeper landslides and have been examined separately.

HISTORICAL DATA REGARDING MASS WASTINGS

The cluster of dated mass wastings in the Parma Valley occurring during the last century and rainfalls divided by hydrological years (from September to August) recorded at the Bosco Centrale raingauge station are shown in fig. 4.

FIG. 3 - The graph shows the travel angle and the area for each landslide. For the symbols see fig. 1.



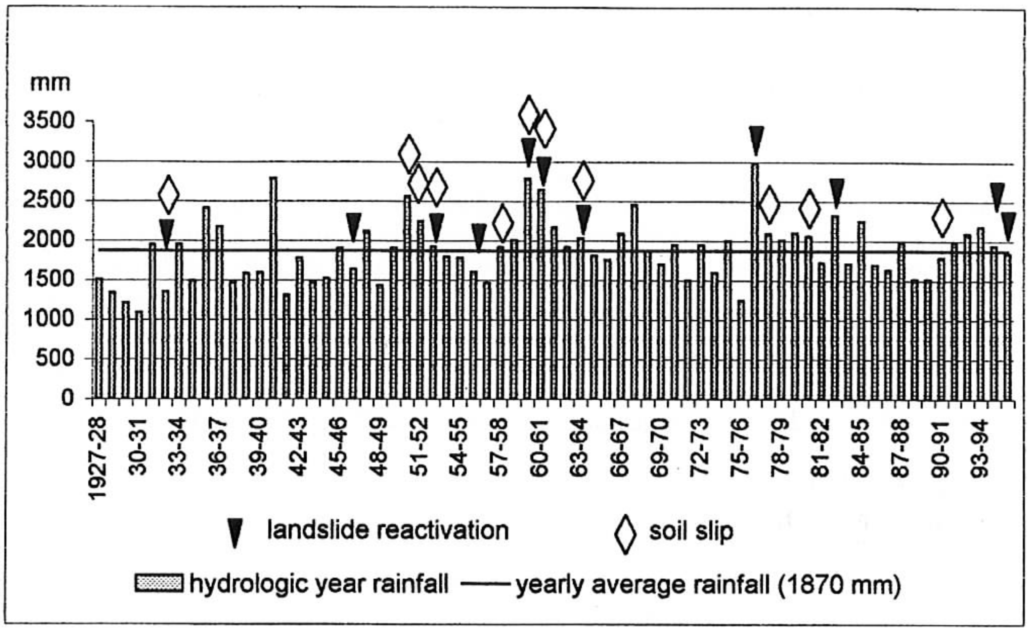


FIG.4 - Mass wastings distribution and hydrologic year rainfall (Bosco Centrale raingauge station).

TABLE 1 - Time sequence of the landslide reactivations. For each landslide the *antecedent event* and 60-day cumulative rainfall (*antecedent rainfall*) are shown. R1 is the ratio between the monthly rainfall and the monthly average rainfall of the last month before reactivation, R2 is the same ratio for the second month before reactivation

N°	date of the landslide reactivation	antecedent event (mm)	cumulative rainfall (60 days) (mm)	R1	R2
1	may 2 1915	112.5	413.5	2.2	1.4
2	feb 15 1933	no daily data	no daily data	1	1.2
3	mar 4 1933	no daily data	no daily data	1.2	1
4	mar 8 1947	no daily data	no dally data	1.5	0.9
5	nov 20 1952	88	440	2.3	0.9
6	may 9 1956	no event	203	1.3	0.7
7	dec 11 1959	70.6	489	1.3	0.7
8	dec 12 1959	29.4	328.4	1.3	0.5
9	dec 14 1959	25	353.4	1.3	0.5
10	dec 15 1959	173.4	924.8	1.7	1.2
11	mar 15 1960	6	198	1.8	0.8
12	mar 15 1960	48.8	329.8	1.8	0.8
13	apr 1 1960	62	255.8	2	2
14	apr 19 1960	95	350.4	2.1	1.8
15	apr 19 1960	95	350.4	2.1	1.8
16	apr 21 1960	135	309.6	2.1	1.8
17	apr 21 1960	135	309.6	2.1	1.8
18	apr 22 1960	169.8	377.2	2.1	1.8
19	may 1 1960	51.8	400.4	1.8	2
20	nov 10 1960	74	723.8	2.8	2
21	nov 30 1960	45.6	357	1.6	2
22	mar 29 1964	68.4	257.4	2.3	0.6
23	apr 1 1964	116.4	303.8	2.3	0.6
24	jan 1 1977	29.2	369.6	1.7	1.1
25	jan 10 1977	no event	389.7	1.7	1.1
26	jan 13 1977	70.8	405.7	1.2	1
27	jan 16 1977	10.2	415.9	1.7	1.1
28	dec 3 1982	138.2	559	2.1	1.6
29	dec 7 1982	no event	492	2.1	1.6
30	nov 15 1994	no event	398.8	0.8	7.8
31	jan 1 1996	14	282	1.3	0.6

The station was chosen because of the length of time during it functioned and the correspondence of the maximum annual rainfalls recorded there with those of the other stations in the valley. Fig. 4 shows the total precipitations measured in hydrological years, which are more meaningful than solar years in respect of the distribution of mass wastings which is continuous from October to May.

The majority of mass wastings occurred during years with higher than average rainfalls (fig. 4); 1940-'41 seems to be an exception, but the information about landslides provided by the press during wartime was scarce and does not allow a sure assessment.

In tab. 2, the number of mass wastings per hydrological year is reported, in order to provide a fuller picture of their distribution. The highest concentration of landslide reactivations occurred between 1959 and 1960, during which period the total annual and total monthly rainfalls were higher than average (figs. 4, 5).

The monthly distribution of mass wastings in the Parma Valley is shown in fig. 6, illustrating the monthly average rainfalls recorded at the Bosco Centrale raingauge station and the number of mass wastings per month. We note that landslides were reactivated in two periods: the first, in spring (March-April-May), in correspondence with the second highest annual rainfall; the second, in late autumn, early winter (November-December-January), with a delay of about a month between the rainfall peak and landslide reactivations. The months with the highest number of reactivations are April and December, which corresponds with the situation in the neighbouring province of Reggio Emilia (Bertolini, 2000).

In respect of soil slip phenomena, the highest distribution occurred in March, April, October and December (fig. 6) which is not in perfect correspondence with the monthly rainfall peaks.

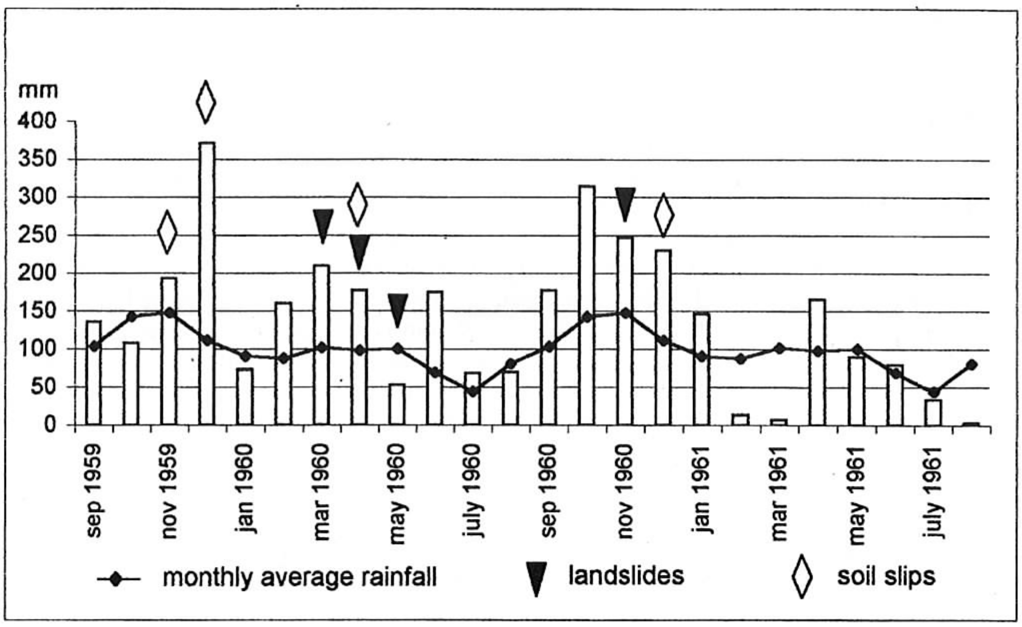


FIG. 5 - Mass wastings distribution (15 landslides and 26 soil slips in all) and monthly rainfall during hydrologic years 1959-'60 and 1960-'61 (Petrignacola raingauge station).

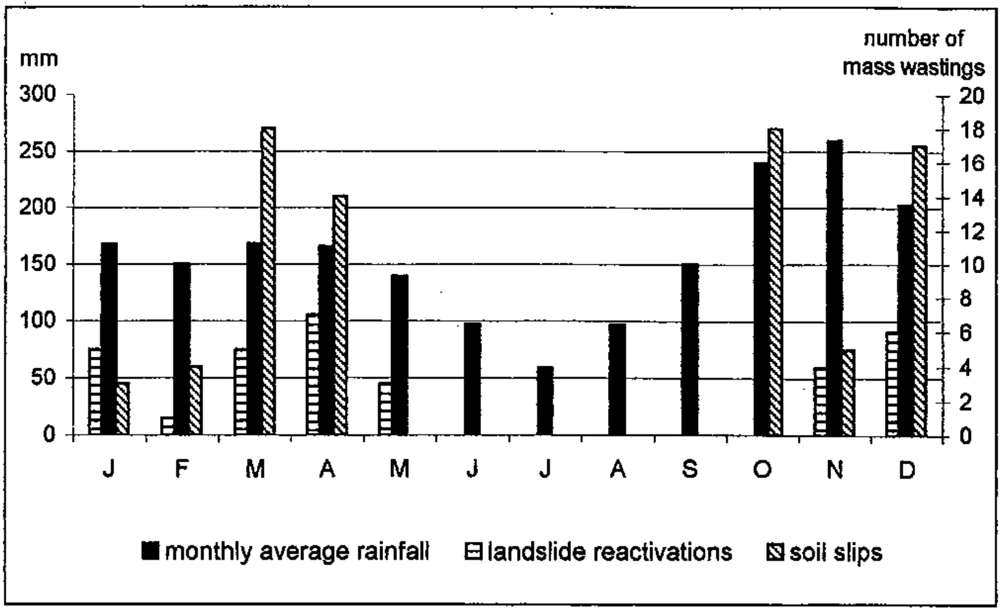


FIG. 6 - Monthly distribution of the mass wastings (monthly average rainfall at the Bosco Centrale raingauge station).

RAINFALLS AND MASS WASTINGS

RAINFALL PRECEDING LANDSLIDE REACTIVATIONS

The majority of landslide reactivations we analysed (29 of the 31 landslides), occurred after a period of at least one month with higher than average rainfall, between 1.2 and 2.8 times the monthly average (R1 in tab. 1); in 50% of the 31 dated landslides, R1 value is greater than 2. Moreover, the ratio between the total rainfall for the second preceding month and the average of the same period (R2 in tab. 1) has values close to 2 in 30% of the landslides.

By examining the cumulative curve of rainfall in the 60 preceding days, we have analysed rainfall amounts which are likely to be connected with the mass wastings.

The cumulative values of landslides n° 2, 3, 4, reactivated in February and March (tab. 1), were not calculated because of a lack of daily rainfall data regarding 1933 and 1947. 20 out of the 28 reactivations show a cumulative rainfall of between 300 and 450 mm over a period of 60 days, with values of at least 200 mm 30 days prior to reactivation, fig. 7A provides a good example of this typical situation; 5 landslides do not fit into this group, presenting a low cumulative rainfall of between 300 and 200 mm (fig. 7B), while 3 landslides have a very high cumulative rainfall, between 500 and 900 mm (fig. 7C). The latter develop on the shale and limestone units of the Upper Valley and on the marlstone and clay units of the Lower Valley (fig. 1), while 4 of the 5 landslides with cumulative rainfalls lower than 300 mm (fig. 7B) are located on the flysch debris in the middle valley sectors.

Many uncertainties remain, however, in the determination of the true influence of the lithological nature of the substrate; in fact, all landslides here considered originate from the reactivation of old landslides and can develop in very weathered lithologies. In the case of some landslides with low antedecent precipitations (landslides n. 31, 6, 11 in tab. 1) it is very difficult to attribute reactivation to rainfall. In the case of landslide n. 31 (the Corniglio landslide), Pellegrini & *alii* (1998) suggest that reactivation may have been triggered by the earthquake of 12/31/1995; on the other hand, Galliani & *alii* (in press) consider the cumulative rainfall value over the five preceding months to be a decisive factor.

The presence of an *antecedent event* seems to characterise nearly all the landslides developing on debris derived from flysch and on steep slopes, whereas these events are not found in the landslides with shale and limestone lithologies in the Upper Valley (tab. 1; figs. 1, 3).

THE SIGNIFICANCE OF ANTECEDENT RAINFALL MONTH BY MONTH

To highlight the role of antecedent rainfall on a month by month basis, cumulative rainfall values over 60-day periods are recorded in fig. 8 for every landslide reactivation, arranged by month, in the period from November to May. The distribution of these data allows us to make some comments which may prove helpful in linking rainfall trends and the triggering of mass wastings.

Fig. 8 provides an indication of the minimum quantities of cumulated rainfall that necessary to influence landslide reactivation. Although the figure is not sufficient to define trigger thresholds, it shows that lower cumulative rainfall values are associated with spring landslides than with autumn-winter ones. The higher cumulative rainfall

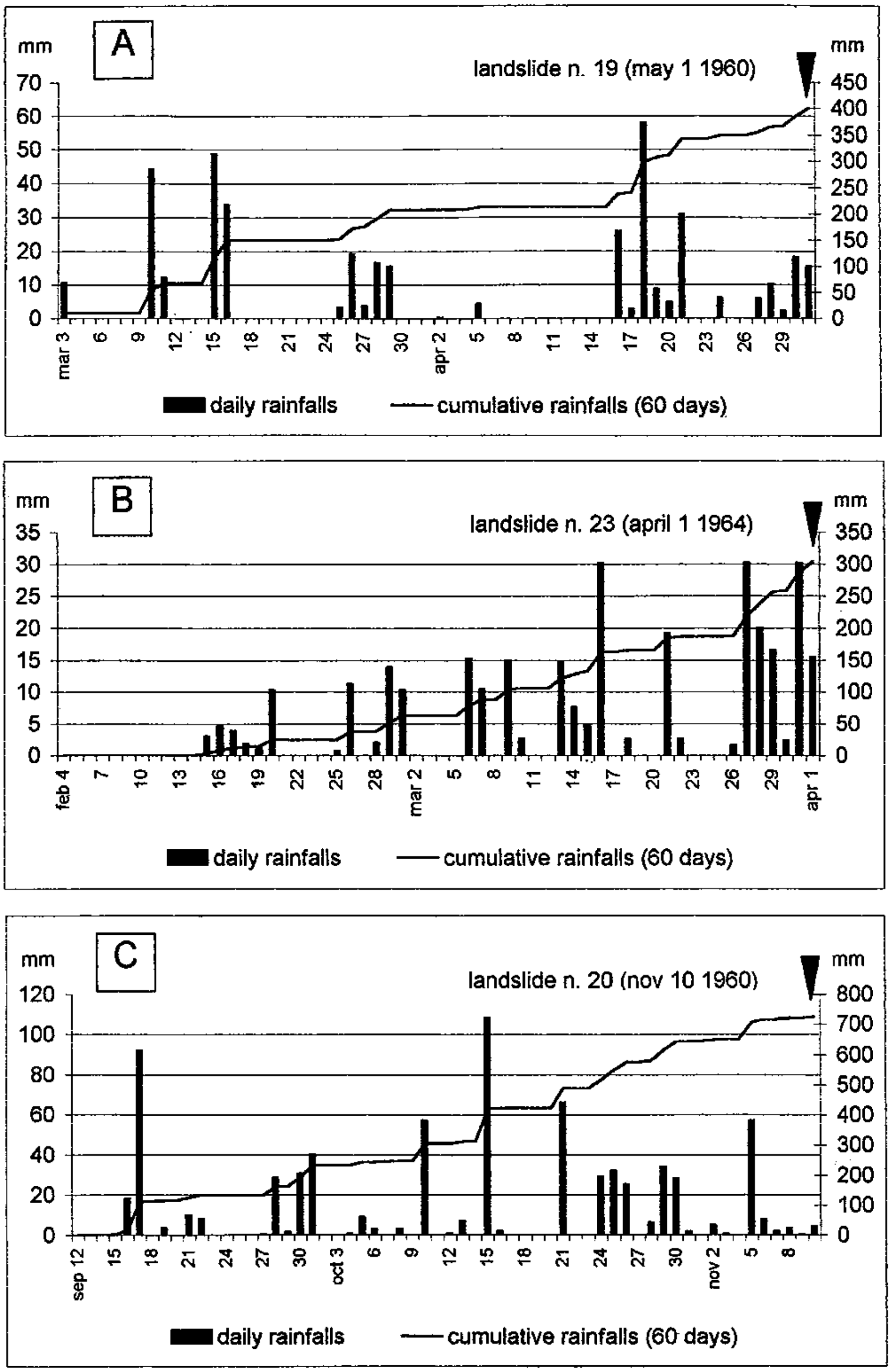


FIG. 7 - 60-day cumulative rainfalls for the landslide reactivations. A: landslide n.19 (Petrignacola raingauge station data); B: landslide n. 23 (Petrignacola raingauge station data); C: landslide n. 20 (Marra Centrale raingauge station data).

values in November and December may be justified by the low substrate permeability characterising the majority of these landslides. In fact, in low permeability units, the autumnal supply may be slow after a summer period with low precipitations.

In Spring, it is fair to presume that conditions of relative saturation of the soil and regolith are reached more quickly, especially considering the likely contribution of the snowmelt (Bertolini, 2000). These conditions certainly favour the development of slope movement and landslides

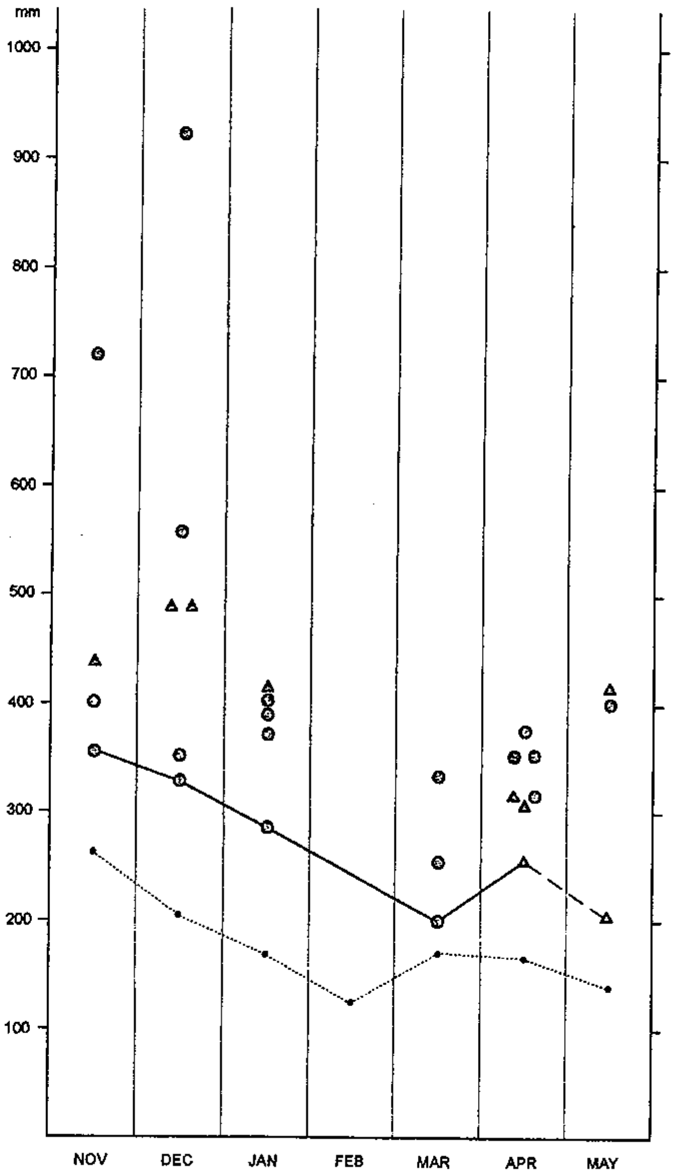


FIG. 8 - 60-day cumulative rainfall in relation to the dated landslides; the upper line shows the minimum values of the cumulative rainfall for each month. The lower line shows the monthly average rainfall at the Bosco Centrale raingauge station. For the symbols see fig. 1.

can be reactivated with lower cumulative rainfall values (approx. 200 mm in March). As far as May goes, any comments are bound to be cloaked in uncertainty since the landslide with a cumulative rainfall value of approx 200 mm recorded in fig. 8 (landslide n. 6 in tab. 1), as we have already emphasised, has a very unsure relationship with rainfall.

RAINFALL PRECEDING SOIL SLIP PHENOMENA

The cumulative curves for the 60-day periods were also reconstructed for dated soil slip phenomena in the Parma Valley (tab. 2). The curve trends highlight the presence of a daily or pluridaily rainy event that is contemporaneous with or immediately prior to these mass wastings (*antecedent event*). The latter could be decisive for triggering soil slip phenomena; in fact, in 76% of the 79 cases we examined, the depth of rainfall characterising the event equals or is greater than the monthly average values. Fig. 9 shows daily rainfall and the 60-day cumulative curve relative to two groups of mass wastings dated 10/21/1952 and 10/18/1980. In 1952, after a rainfall period in which 230 mm accumulated in the 59 days before the mass wastings, on 21st October there was a rainy event producing 170 mm in 24 hours. This value is over ten times the daily mean value in autumn at the raingauge station under consideration.

In 1980, after cumulative precipitations of 150 mm in 57 days, there was a pluviometric event producing 258.2 mm in three days, of which 165.6 mm on 16th October, 50 mm and 42.6 mm on the two following rainy days. The soil slip phenomena of fig. 9 may be attributed to these heavy pluviometric events, although the influence of antecedent precipitations that may have weakened the slope and increased saturation cannot be excluded a priori. These mass wastings do in fact develop on the shallow part of the soil cover where there are higher permeability conditions than in the substrate and where there is a faster increase of interstitial pressure. Heavy rainfalls, even if they are brief, can, by infiltrating soil and weathered rocks, notably reduce their strength.

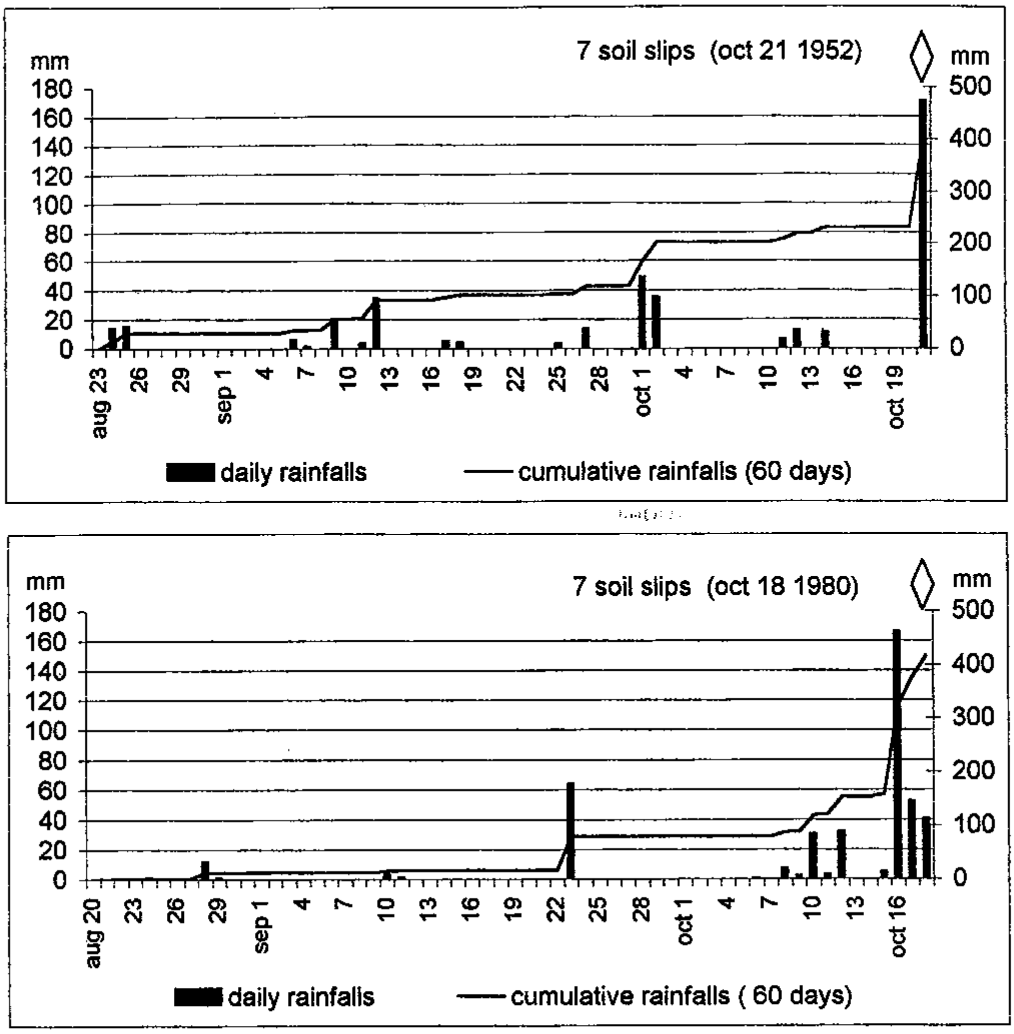
TABLE 2 - Distribution of the soil slips and landslides for each hydrologic year

hydrological year	soil slips	landslides
1914-1915	0	1
1932-1933	1	2
1946-1947	0	1
1950-1951	1	0
1951-1952	2	0
1952-1953	8	1
1955-1956	0	1
1957-1958	2	0
1959-1960	25	13
1960-1961	1	2
1963-1964	19	2
1976-1977	5	4
1977-1978	3	0
1980-1981	11	0
1982-1983	0	2
1990-1991	1	0
1994-1995	0	1
1995-1996	0	1

CONCLUSIONS

In the case of dated landslides and soil slips in the Parma Valley, there is a clear connection with rainfall. In fact, the 31 lanslide reactivations occurred in correspondence with hydrological years with above average rainfall and/or

FIG. 9 - 60-day cumulative rainfall for two clusters of soil slips. Petrignacola raingauge station daily rainfall.



above average monthly totals. The highest concentration of mass wastings occurred in the hydrological year 1959-'60.

Almost all the landslides we examined present a rainfall total in the preceding month which is clearly above average and for 1/3 of the landslides this is true in the two preceding months.

We therefore analysed cumulative rainfall over the 60 days preceding reactivation (*antecedent precipitation*) in order to pinpoint common features.

The majority of landslides presents a 60-day cumulative rainfall between 300 and 450 mm, with values of at least 200 mm 30 days before reactivation. The landslides are distributed over spring (March-April-May) and autumn/winter (November-December-January), with two peaks in April and December. In the case of the springtime landslides there is a good correlation with the second highest annual rainfall peak, whereas in the case of the autumn/winter ones there is a delay of approx. one month in respect of the rainfall peak.

The values of the 60-day cumulative rainfall period for the spring landslides differ from those pertaining to the autumn landslides; in spring reactivations with lower antecedent precipitation values can occur because it is believed that high saturation of the soil is reached more rapidly.

Considering the 79 cases of soil slips, we observe that they are concentrated into groups which are distributed over March, April, October and December, but which are not in perfect correspondence with monthly rainfall peaks.

We consider that the presence of a concentrated rainfall event which is either contemporaneous or immediately antecedent is a decisive factor where this kind of mass wastings is concerned, when the values of the event are equal or greater the monthly average. Nevertheless we do not exclude the possibility of the influence cumulative rainfalls favouring soil slips and increasing the saturation level.

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