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AN ESTIMATE OF THE SEDIMENTS VOLUME ENTRAINABLE BY DEBRIS FLOW ALONG STROBEL AND SOUTH PEZORÌES CHANNELS AT FIAMES (DOLOMITES, ITALY)

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ABSTRACT

The area of Fiames is located on a narrow and flat valley, 2 km north to Cortina d'Ampezzo, and is bounded on the right side by the Pomagagnon and Pezorìes peaks. At the transition between rock vertical cliffs and talus, about twenty debris channels originate and affect the talus till the bottom of the valley. The Strobel and South Pezorìes channels were recently routed by debris flows in 2004 and 2006. Field surveys, topographical and geo-morphological measurements were carried out to recognize the sediments volume that the debris flow can entrain during triggering and routing phases. The estimate of the erodible sediment volume was obtained through the measurements of the geo-morphological and sediments features of source areas including their locations (channel bank or bottom). The resultant estimate can help in the design of the input debris flow hydrographs for dynamic modelling of debris flow and retain basins.

Key words: *sediment volume, geo-morphological measurements, triggering, debris flow, field survey.*

INTRODUCTION

Land management, using risk or hazard maps, requires knowledge of the volumes of water and sediments mobilized during a flood events. So, the estimation of sediment volumes potentially trasportable in a basin, during particularly intense rainfall, is the starting point for analyzing an intense sediment transport (hyperconcentrated flow) or a debris flow event.

In literature there are descriptions of different methodologies applied to different environments and contexts for the estimation of sediment volumes mobilized by debris flow. These methodologies, for streams or torrents characterized by debris flows, can be divided into two groups: the first, empirical or semi-empirical, carries out a statistical analysis of historical data of measured sediment volumes in the deposition area (D'Agostino, 1996; Bovis & Jakob, 1999; Rickenmann, 1999; Bianco & Franzi, 2000; D'Agostino & Marchi, 2001; Brochot *et alii,* 2002; Gartner *et alii,* 2008), while the second is based on geomorphological survey, verifying the availability of sediment along the channel routed by debris flow (Hungr *et alii*, 1984; Thouret *et alii*, 1995; Spreafico *et alii*, 1999; Bovis & Jakob, 1999; Brochot *et alii*, 2002; D'Agostino & Marchi, 2003; Gartner *et alii*, 2008; Santi *et alii*, 2008).

There are many factors involved in defining the volumes that are mobilized during a flood event: the basin and stream's slope, the drainage area and in particularly that part which is a potential source of sediments, the intensity of rainfall and thus runoff, the land cover, the type of sediment (cohesive or not), the geology and stratigraphy of soil layers, and many others. However, in a geomorphological approach, some of these become more important and require a very detailed survey.

From an operational standpoint, the geomorphological approach must be economical, fast, safe for technicians but also sufficient to define with some pre-

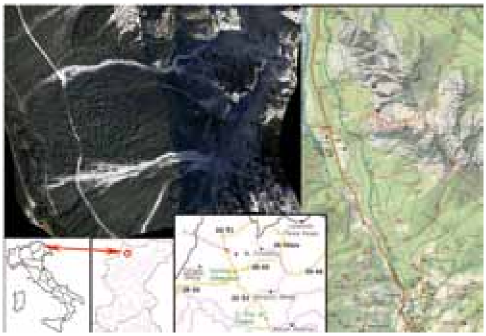

Fig. 1 - Test bed area: Fiames (Eastern Dolomites)

Fig. 2 - Overview of the two debris flow channels at Fiames

cision the areas and volumes of sediment.

This paper will present a methodology adopted for geomorphological field surveys, taking inspiration from those proposed by some authors (Hungr *et alii,* 1984; Thouret *et alii,* 1995) but differs from these for the topographic approach and hydraulic considerations. This methodology will be applied to estimate the volume of sediments in two debris flow channels at Fiames, Eastern Dolomites. The results will be compared with the volumes obtained from application of empirical and semi-empirical formulas

GENERAL SETTING

TEST BED AREA LOCATION.

The test bed area is in north to Cortina d'Ampezzo (upper Boite River Valley, Eastern Dolomites, Italy) on the western side of Pomagagnon and Pezorìes peaks (Fig. 1).

Two channels, routed by debris flow, were surveyed in summer 2010: "Strobel" channel (c06), which runs almost linearly on a well developed fan, and "South Pezorìes" channel (c07), north to Strobel channel, that runs along the intersection of two fans with a meandering path (Fig. 2).

catchment area of debris flow triggering zone	0.166841 km^2
catchment area of total basin	0.199309 km^2
maximum elevation of the catchments	2351 m a.s.l.
elevation of the triggering section	1677 m a.s.l.
fan apex elevation	1693 m a.s.l.
fan foot elevation	1348 m a.s.l.
channel length in triggering area	0.4 km
mean channel slope in triggering area	43.5 ° (about 95%)
channel length in routing area	0.6 km
mean channel slope in routing area	30 ° (about 58%)

Tab. 1 - Morphometric characteristics of channel c06 "Strobel"

TEST BED AREA GEO-LITHOLOGICAL CHARACTERISTICS

Both channels born at the transition between rock walls and talus and run on a non-cohesive soil with limestone scree. The area covered by vegetation is very small and is restricted to Mugo Pine (*Pinus mugo*) upstream and, by Scots Pine (*Pinus sylvestris*) and Mugo Pine, downstream.

From the geological point of view, the study area is covered by a pre-Quaternary formations in an interval between the Carnian and Early Miocene. The stratigraphic succession, from oldest to most recent, is as follows:

· Saint Cassian formation with intercalations of marls, shales and calcarenites;

· Cassian Dolomite that represents the massive white-gray crystalline dolomite and is the basis of the Pomagagnon and Pezorìes peaks;

· Durrenstein formation (upper Carnian) consists of white dolomite with sandstone purposes, siltstones and silty limestones;

· Raibl formation consists of sandstone and marl and thin intercalations of gypsum;

· Main dolomite consisting of white and gray massive dolomite representing the most developed outside of the cliffs;

From a geomorphological point of view, we can say that the weathering of limestone and dolomite develops a thick debris layer, formed by particle size ranging from sand to large boulders, which is easily and often entrained by debris flows during the roaring storm from July to October. Both the channels were routed by debris flows the 19th of July 2004 and the 5th July of 2006 (Gregoretti & Dalla Fontana, 2008).

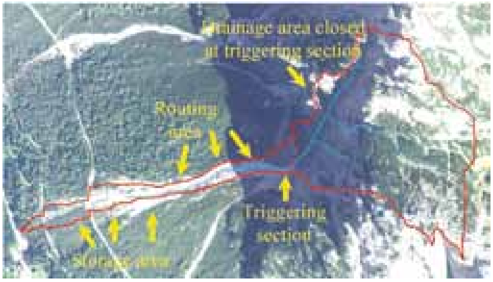

Fig. 3 - View of the "Strobel" channel (c06)

TEST BED AREA MORPHOMETRIC CHARACTERISTICS

The morphometric analysis of Strobel channel (Tab. 1) shows that slopes along the channel are very high (up to 48%): the deposition area is generally very limited in length and is positioned at the end of the fan (mean slope 31%), at its confluence with the Boite river where the slope decrease too. Often, debris flows can deposit in the upper part of the channel (slopes between 40-48%) due to a strong enlargement of the channel bed: indeed, it's not unusual to find large deposits of debris flow with slopes larger than 40%. Strobel channel is very small in length (about 1 km from the source at the end of the fan); the catchment area can be divided into two parts: the upstream drainage area closed to triggering section of the debris flow (approximately 0.16 km^2) almost in rock and, downstream the routing area, that is limited to the path occupied by the flow, consist of scree with some small piece of outcrop rock

The catchment area has a very small portion of plant cover composed exclusively of *Mugo pine*.

Figure 3 shows the drainage basin closed at triggering section and the fan area incised by Strobel channel. The basin has undergone a thorough hydrological and morphological analysis by applying a numerical model on a GIS support (Geographic Information System – AdBToolBox, 2010): a crucial problem, when using a distributed hydrologic model, is that the drainage area on the downstream part of the fan allows more outlets preventing the software to close the catchment area properly.

In the following, Figures 4, 5, 6 show three sections of the Strobel channel relative to the triggering area, to the middle part and downstream respectively: in the upstream part (Fig. 4) it can be observed the large detrital grains and clusters that constitute the source areas of sediment. Figure 5, with a classic V-shape, shows a large bank erosion, fine debris and boulders in riverbed, residues left by the tails of previous debris flows. Figure 6 shows the channel enlargement degree and the massive accumulation of detritus consisting of gravel and small pebbles

Fig. 4 - Upstream part of "Strobel" channel (c06)

Fig. 5 - Middle part of "Strobel" channel (c06)

Fig. 6 - Downstream part of "Strobel" channel (c06)

Very similar is the situation for the second channel, South Pezorìes (Tab. 2), with the difference that the channel runs along a more tortuous path characterized by two wide bends. Even in this case the average slope of the channel is quite high (usually more than 35%). In respect to the Strobel channel, the storage area is very long and narrow (mean slope 32%) because debris flows tend to entrench too much with-

catchment area of debris flow triggering zone 0.083948 km^2
catchment area of total basin 0.105897 km^2
maximum elevation of the catchments 2351.4 m a.s.l.
elevation of the triggering section 1602.0 m a.s.l.
fan apex elevation 1671 m a.s.l.
fan foot elevation 1365 m a.s.l.
channel length in triggering area 0.44 km
mean channel slope in triggering area 46 ° (about 104%)
channel length in routing area 0.6 km
mean channel slope in routing area 23 ° (about 42%)

Tab. 2 - Morphometric characteristics of channel c07 "South Pezorìes"

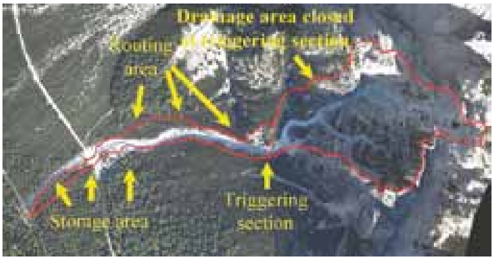

Fig. 7 - View of "South Pezorìes" channel (c07)

out overflowing the banks. South Pezorìes channel is very small like Strobel channel and the basin can also, in this case, divided in two parts: the upstream drainage area closed to triggering section of debris flow (approximately 0.08 km^2) is mostly rocky with the presence of *Mugo pine* (20%). Downstream, in the routing area, there is only scree, and at the foot of the fan there are also *Mugo pine* and *Scots pine*.

Figure 7 shows the drainage basin closed at triggering section and the fan area incised by South Pezorìes channel.

Also in this case, the hydrological analysis presents several problem for the inability to define a unique flow path along the fan. Figg. 8, 9 and 10 show three representative sections of the South Pezorìes channel: in the upstream part (Fig. 8) it can be observed that there are boulders and large detrital areas that are the source areas of sediments. Figure 9, with a classic V-shape, shows a narrow bank erosion, and a large sediment deposition. In the downstream part (Fig. 10) it is evident the channel minor enlargement rate andm the massive accumulation of detritus consisting of gravel and small pebbles also in this case.

METHODOLOGY FOR THE ESTIMATION OF SEDIMENT VOLUMES

The geomorphological approach emphasizes the role of the field survey in the sense that sediment vol-

Fig. 8 - Upstream part of "South Pezorìes" channel (c07)

Fig. 9 - Middle part of "South Pezorìes" channel (c07)

Fig. 10 - Downstream part of "South Pezorìes" channel (c07)

ume, potentially erodible and transportable during an event, should be determined through observations, and hydrologic and hydraulic considerations.

The methods proposed by other authors provide the definition of a channel type (eg. A, B, C, D, ..) and a minimum or a range of values for yield rate (m^3/m) that is distributed along all the channel length (Hungr *et alii,* 1984; Spreafico *et alii*, 1999; Brochot *et alii,* 2002). The proposed values are the result of assessments, in torrents, which bring the geological substrate, the average channel slope and some qualitative stability conditions (eg. stable, unstable, eroded,...) but, anyway, they don't consider directly the hydrological and hydraulic aspects.

The approach taken in this work can be summarized in the following six stages:

- before carrying out a field survey, it's necessary to compute the runoff hydrograph corresponding to

some return periods (2, 5, 10, 100, 200 years) and transform it in a debris flow hydrograph. Runoff is computed by the hydrological model proposed by Gregoretti & Dalla Fontana (2008) which runs on GIS platform (AdBToolBox, 2010). The transformation of runoff hydrograph into debris flow hydrograph is carried out using the triggering model of AbBToolBox (see also Deangeli *et alii*, 2010). The computed peak discharge of debris flow is then transformed in an equivalent debris flow depth using the formula proposed by Hungr (1984). In this way it's possible to get an idea of debris flow discharge, strength and velocity along the channel (see formulas in HUNGR *et alii* 1984). Present methodology assumes a correlation between the volume mobilized by a debris flow and the return time of the runoff that trigger it. The initial hypothesis is that the increase of precipitation (related to the return period) in mountainous areas with steep slopes corresponds to an increase in runoff and, consequently, of its erosion capacity. The increase of erosion capacity means an higher mobilized solid volume. The results are clearly approximated but are very useful to assess the erosive capacity of debris flow;
- the second step is the analysis of the geo-lithological and geomorphological mapping corresponding to the area with technical data available in literature. This work provides information about cohesion, permeability, stability, erodibility of debris piles and rock structures. All the maps data should be checked by a preliminary survey of the entire basin. The preliminary survey allows the knowledge of the real situation which can help in the planning the following surveys;
- third step is the field analysis along the channel. The channel must be walked up to its beginning (the limit beyond which point you can no longer walk) and the main morphological features investigated. From the upper point, the channel is walked down: topographic and morphological measurement are carried out using the following instruments.
  - GPS (Global Position System) to make a detailed survey into the channel to improve the DEM building. GPS was used also to capture several points for geo-referencing the border of the source areas (Fig. 11). We used GRS-1 TOPCON GPS with real time differential correction (horizontal error less than 0.03 m and vertical error less than 0.2 m) and TOPCON system, rover and base, with vertical error less than 0.02 m used on storage areas;
  - laser rangefinder to measure the lengths and slopes of the source areas located along the banks or in the slope overhanging the banks (eg. local landslides).
  - a camera to photograph each source area: you must have a feedback image for data analysis that, some times, is made long after the event;
  - sampler for sediment grain sizes (numeral method);
  - sheets, prepared 'ad hoc', for the survey data of source.areas of sediment.

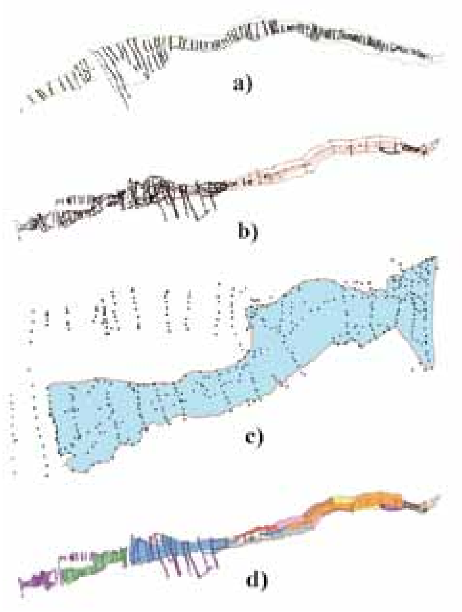

Fig. 11 - Measured GPS points in South Pezorìes channel (a), in Strobel channel (b,) a detailed view (c) of source sediment area and its many GPS points and different homogeneous source sediment areas in Strobel channel with proposed methodology

- fourth step is to identify source areas of sediment, homogeneous for litho-morphological, geotechnical characteristics and for erosion phenomena (erosion/deposition) These areas will be corrected or modified during data processing;
- fifth step is the collection of soil samples along the channel for geotechnical analysis (eg. grain size with weight method, cohesion, friction angle, etc.)
- sixth step is the digital input of all the collected data in a GIS database in order to have georeferenced information and carry out the calculations. After that, it's possible to make all the computations regarding

the basin characteristics and the source areas and then, the estimation of sediments volume.

Figure 11 shows the GPS points measured in field survey: 983 points were taken in South Pezorìes channel (Fig. 11.a) and 1031 points were measured in Strobel channel (Fig. 11.b). The distribution of measured GPS points allows us to build a DEM of the channels and of the source sediment areas (Fig. 11.c and 11.d).

The survey must proceed from top to downstream because, during the ascent, the operators must carefully observe the channel, banks, sediment in the channel, the erosions or the landslides present along the channel, in order to define with some precision homogeneous traits of source area (not the channel; this aspect differs from that proposed by previous authors). In fact, we assume that the source area of sediment should be homogeneous for geomorphological characteristics and phenomena to which is subjected (erosion, deposition) and not for the trait of channel. In a same channel trait we can have one or more source areas. In fact in a channel trait we can distinguish one or more source areas of sediment on the right bank, idem on the left bank and idem on the bottom (Fig. 11.d).

This methodology is original and differs from those proposed in literature; the formula proposed by previous authors has the following form (Hungr *et alii,* 1984; Spreafico *et alii*, 1999; Brochot *et alii*, 2002; D'Agostino & Marchi, 2003):

$$V_{tot} = \sum_{1}^{n} V_i = \sum_{1}^{n} \left(k_i \cdot d_i \cdot b_i \cdot L_i \right) = \sum_{1}^{n} \left(k_i \cdot d_i \cdot A_i \right) \qquad (1)$$

where n = source areas; V_i = erodible sediment volume of the single homogeneous trait of channel; V_{tot} = the total volume. The volume V_i is the result of the product of the following factors: a reduction coefficient k, the thickness of erodible layer d (m), the bottom width b (m) and the length of the homogeneous channel trait L (m). The product of the last two parameters is the erodible area in homogeneous channel trait $A = b \cdot L$ (m^2).

We propose the following relationship for the sediment volume estimation:

$$V_{tot} = \sum_{1}^{n} V_i = \sum_{1}^{n} \left(As_i \cdot d_i \right) \qquad (2)$$

in which the total volume V_{tot} is obtained by the product of As_i , that is the source area numbered i along the channel from upstream (m^2), with the corresponding thickness d_i .

The thickness of the sediment layer in the source area d_i is determined through the following procedure:

- computation of the surface delimited by the GPS points which border it;
- estimation of the minimum, average and maximum values of slope of the source area (estimated directly in field or more accurately using GIS if GPS points are enough);
- estimation of the impact angle, i.e. the angle between the prevailing direction of flow and the surface area (even this estimation can be done directly in the field or more precisely by GIS operations);
- estimation of the average slope of the channel trait adjacent to source area;
- computation of the average bottom width;
- estimation, with the most possible accuracy, of the debris flow depth, velocity, force and impact force (Hungr *et alii*, 1984) based on elaborated field data collection, for events with different return times in order to define the erodible thickness for different situations.

The first two operations provide the range of debris thickness of the source area while the remainders are necessary to define the specific thickness corresponding to the flow erosion power. In fact, we distinguish two thickness of source area: the first, called erodible depth (d_e) represents the erodible thickness by an event with return period of ten years; the second, called potentially erodible depth (d_p) represents the erodible depth for an event of 100 years return time. Furthermore, at the purpose of limiting the subjectivity anddiscretion, each of the thickness was further subdivided into aminimum, av erage and maximum thickness.

The parameters that affect the determination of the erodible or potentially erodible thickness are the following:

- the erodible thickness increases with bank slope (up to 40°) while, for larger bank slope values there is a slight and progressive reduction of thickness.
- flow erosion power: it is evaluated through the average slope of the channel, the debris flow depth, the impact angle between flow and source area, the cross section of channel. The erodible thickness increases with the increasing of impact angle and flow

	Strobel channel	South Pezories channel
$V_{e\,min}$ =	1629	936
$V_{e\,m}$ =	2908	1834
$V_{e\,max}$ =	4705	3034
$V_{p\,min}$ =	8014	4007
$V_{p\,m}$ =	10249	5296
$V_{p\,max}$ =	12537	6739

V_e is calculated with d_e (retun time 10 years) while V_p is calculated by d_p(retun time 100 years) and subscript min = minimum, m = average, max = maximum

Tab. 3 - Erodible sediment volumes (m³) obtained using equation (2)

discharge (and its related parameters, eg. velocity, cross section, water level, impact force, etc.).

- the susceptibility to erosion (Hungr *et alii,* 1984): it is evaluated considering vegetation cover, grain size, sediments cohesion, location of the area, the causes which leads to instability and stability conditions. The erodible thickness increases from soils covered with vegetation to bare soil, from cohesive to not cohesive sediments, from large to small grain size. The instability for foot erosion produces more sediment than an uniformly distributed erosion and, erodibility of deposited sediments is easier than surface bank erosions.

The influence of these parameters on the erodible thickness has been overall considered. In other words the erodible depth is subjectively estimated considering all the aspect above. The average debris thickness computed by the first two operation is assumed as the average thickness $d_{e\,m.}$ This value is then modified according to the influence of the parameters listed above to have the erodible and the potential erodible depths.

ESTIMATION OF SEDIMENT VOLUMES FOR THE SURVEYED CHANNELS USING THE PROPOSED METHODOLOGY

The sediment source areas number 14 for the Strobel channel and 11 for the South Pezorìes channel. Their surfaces range between 194 and 2167 m² for the first channel and between 108 and 576 m² for the second channel. The corresponding average erodible thickness ranges between 0.1 and 0.7 m in the case of Strobel channel and between 0.2 and 1.0 m for South Pezorìes channel.

The values of the erodible and potential erodible depths were estimated for all the source areas in the two surveyed channels and the corresponding sediment volumes of the numbered source areas were computed using equation (2). The results are shown in Table 3.

For the debris flow event that occurred in July 2006 on both the channels, being distinguishable deposits, there were carried out measurements of sediment deposit thickness in the terminal part of the fan. In this case, for each point detected by GPS in the storage area, it was evaluated the thickness of the deposit. The estimation of sediment deposit volumes is carried out through the difference of the DEM obtained from the surface of the GPS points and the subsurface corresponding to the quote of GPS points minus the estimated debris thickness. The areal average difference between the two surfaces multiplied by the surface area itself provides the overall volume of the deposit

Volumes obtained by topographic survey of sediment deposit after 2006 event for Strobel and South Pezorìes depositional fans are. 3415 and 3058 m³ respectively. These values can be compared with those computed by equation (2) to check the reliability of the proposed methodology. In the case of the Strobel channel the deposited volume (3415 m³) has an intermediate value between the mean erodible (2908 m³) and the maximum erodible volumes (4705 m³); In the case of the South Pezorìes channel the deposited volume (3058 m³) coincides with the maximum erodible volume (3034 m³). These results assure the reliability of the proposed methodology.

COMPARING THE RESULTS WITH SEDIMENT VOLUMES COMPUTED BY EMPIRICAL RELATIONSHIPS OF PREVIOUS AUTHORS

The method proposed and applied in this work tries to compensate on the one hand the economic aspect and from another the quality of data (that must be georeferenced) in order to make findings with past events and/or future, ones.

The volumes obtained by present geomorphological methodology, are then compared with those obtained from the application of empirical or semi-empirical relationships available in literature. In Table 4, the relationships are listed with their references. These formulas use morphometric parameters and indices that must be derived for each of the catchments shown in figure 3 and 7. The formulas are presented in the following:

$$V = \frac{k_1}{e^{k_2 \cdot A}} \cdot A \cdot i \qquad (3)$$

$$V = 29000 \cdot A^{0.67} \qquad (4)$$

$$V = 211 \cdot A \cdot i^{1.3} \tag{5}$$

$$V = 667 \cdot e^{-0.005 \cdot A} \cdot A \cdot i \tag{6}$$

$$V = 39 \cdot A \cdot i^{1.5} \cdot IG \cdot IT^{-0.3} \tag{7}$$

$$V = 45 \cdot A^{0.9} \cdot i^{1.5} \cdot IG \tag{8}$$

$$V = 334 \cdot A \cdot i^{1.3} \cdot IT^{0.6} \tag{9}$$

$$V = 70 \cdot A \cdot i^{1.28} \cdot IG \tag{10}$$

$$V_{max\ available} = 70 \cdot A \tag{11}$$

$$V = 65000 \cdot A^{1.35} \cdot i^{1.7} \tag{12}$$

$$V = 18000 \cdot A^{1.16} \cdot i^{1.3} \cdot IG \tag{13}$$

$$V = 13000 \cdot A^{-0.4} \tag{14}$$

$$V = 14000 \cdot i^{1.5-i} \cdot IG^{1+0.1 \cdot IG} \pm 13000 \cdot A^{-0.4} \tag{15}$$

$$V = 5107 \cdot A^{1.16} \cdot i^{1.3} \cdot Igv \tag{16}$$

where k_1 and k_2 are coefficients relative to sediment production and for the surveyed channels assume the values 1150 and 0.014 respectively; A is the catchment area (km^2); i is the average slope along erodible channel (%); IG is the geological index (1-5) that for the surveyed channel assumes the value 1.66; IT is an index depending on the mass transport phenomenon (debris flows = 1, hyperconcentrated = 2 and bed-load =3); *Igv* is a geolithological index (1-6) that for the surveyed channel is 3 (dolomite rock and scree). In the equations (12) and (13) *i* is expressed in m/m.

Eq.	Authors	Strobel	South Pezories
(3)	Kronfellner-Kraus, 1984	13257	5107
(4)	D'Agostino, 1996	9876	6465
(5)	D'Agostino, 1996	8246	2880
(6)	D'Agostino, 1996	7703	2965
(7)	D'Agostino, 1996	5700	2219
(8)	D'Agostino, 1996	7728	3204
(9)	D'Agostino, 1996	13054	4559
(10)	D'Agostino & Marchi, 2001	4187	1750
(11)	D'Agostino & Marchi, 2001	13952	7413
(12)	Marchi & D'Agostino, 2004	18521	13504
(13)	Marchi & D'Agostino, 2004	9312	8020
(14)	Bianco & Franzi, 2000	24782	31915
(15)	Bianco & Franzi, 2000	40098	44296
(15)	Bianco & Franzi, 2000	9465	19533
(16)	Rickenmann & Koschni, 2010	4774	3459

Tab. 4 - Erodible sediment volumes (m^3) obtained by empirical and semiempirical formulas application

The values computed according to equations (3) to (16) are in a wide range of value: from 4187 to 40098 m3 in the case of Strobel channel and from 1750 to 44296 m^3 in the case of South Pezories channel. The average erodible volume Ve m computed for the Strobel channel is always overstimated by equation (3)-(16) while that of South Pezorìes channel not. In this last case the value of $V_{e\,m}$ nearly coincides with that given by equation (6) given by D'Agostino (1996). The average potential erodible volume $V_{p\,m}$ computed for the Strobel channel is next to value given by equation (15) given by Bianco & Franzi (2000) while that of South Pezorìes is next to the values computed by equation (3) given by Kronfellner-Kraus (1984). These results are of no use for a comparison due to their high variability explainable by the lack of homogeneity in data used by the previous authors. The lack of homogeneity mainly regards the use of data of volumes deposited by debris flows corresponding to different return periods of runoff that triggered them. There are two confirmations of this, one direct and the other one indirect. The direct is that equation (16) obtained by Rickenmann & Koschni (2010) using data with the same return period, approximates the maximum erodible volume values of both the channels. The indirect confirmations is given by the results of equation (15) that imputes larger volumes to the South Pezorìes channel characterized by minus sediment production.

The fact that equation (16) provides a set of values somehow in agreement with those computed here could be a confirm of the reliability of the proposed methodology.

CONCLUSIONS

A new methodology for the estimation of sediment volume that can be mobilized by debris flows is presented and used in two channels of Dolomites (Italy). Both the channels were surveyed and the source area of sediments were identified and measured (surface and thickness). These data were used to provide an estimate of the erodible sediment volumes in the two channels. The reliability of this approach was checked by comparing the results with the deposited volumes due to antecedent debris flows and with the results of an empirical equation obtained through data characterized by the same return period.

Nevertheless, this approach should be tested in other channels toassess its validity.

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