Hydrological and sediment trends between 1982 and 2011 in the long term research basin *Valle della Gallina*, Italy

F. Maraga, M. Arattano and S. Chersich

Hydrologische und sedimentologische Trends der Jahre 1982 bis 2011 im Forschungseinzugsgebiet *Valle della Gallina*, Italien

Introduction

The study area is a sub-basin located in the upper Po river catchment and regarded as a pristine or undisturbed mountain landscape of volcanic bedrock (rhyolite) outcrops in the foothills of the northwest Italian Alps. It was selected to investigate surface water balances, assess sediment transport and erosion of the volcanic bedrock. Previous hydrological studies have been undertaken since the 1970s to collect data on the runoff/precipitation ratio, flood generation and erosion processes that are discharged into the *Marchiazza* basin (5,36 km^2 in area; Biancotti, 1981; Caroni & Tropeano, 1981; Anselmo et al., 1982; Anselmo et al., 1987).

The regional climate is continental Mediterranean with an isohyet range between 1.100 mm and 1.600 mm from the Po river alluvial plain to the Alpine range (Caroni, 1979). Sub-basin surface water data (rainfall and a runoff stations) and sediment discharge (sediment trap) have been continuously collected for nearly 30 years (1982 to 2011) to record small scale hydrological responses in the context of global climate change.

The records provide a reasonable characterisation of local climatic responses, which are assumed to be representative of hydrological variability at the regional scale. Experimental data elaboration after 2008 are still in progress. Field observations of sediment transport were made during flood events (bed load mechanisms, Govi et al., 1993) as well as

Zusammenfassung

Seit 1982 werden im Testgebiet *Valle della Gallina* in den westlichen Italienischen Alpen sedimentologische und hydrologische Untersuchungen durchgeführt. Das Gebiet beinhaltet meteorologische und hydrologische Messeinrichtungen inklusive einer Sedimentfalle. Der mittlere Abfluss beträgt 0,02 m^3/s, Hochwässer überschreiten oftmals 1 m^3/s (Maximalwert 1996: 6,4 m^3/s). Sedimenttransport findet vorwiegend als Geschiebe statt mit Jahresfrachten von 0 bis 74 m^3. Oberflächenabfluss und Sedimenttransport nehmen seit 2002 kontinuierlich ab. Die Ursachen liegen in abnehmenden Niederschlägen und zunehmendem Bodenwasserrückhalt infolge von Aufforstungen im Gebiet.

Schlagworte: Abflussverminderung, Wasserbilanz, Grobgeschiebetransport.

Summary

Sediment and hydrological monitoring were conducted in a small basin on the western Italian Alps along an experimental reach of 120 m located upstream of a sediment trap. A meteorological station located at the ridgeline and a monitoring station at the outlet have been recording hydrological and sediment flows since 1982. The mean subbasin discharge is 0.02 $m^{3\ s-1}$ (maximum: 6,4 $m^{3\ s-1}$, 1996) and flash floods occur with several peak flows higher than 1 $m^{3\ s-1}$. Sediment transport is mainly bed load with sediment discharges ranging between zero and 74 m^3. Surface runoff and sediment transport have been decreasing since the year 2000, commensurate with reduced annual rainfall and increased soil water retention attributed to forest revegetation across the basin. There has been no land use or anthropogenic disturbance during the period of sediment monitoring.

Key words: Runoff decrease, water balance, coarse sediment transport.

measurements of annual sediment volumes to assess rates of erosion and transport delivered to the outlet sediment trap (CARONI et al., 2000). Since 1992 researches carried out in the basin have been presented at the Experimental and Representative Basins (ERB) international conferences to show results on water and sediment release from the mountain region (GODONE & MARAGA, 1992; MARAGA et al., 2000, ANSELMO et al. 2011). The data collected in the research basin have indicated a reduction in annual rainfall, runoff and sediment delivery between 1999 and 2011.

The river tributaries from the northwest Alpine slopes have compounded the reduction in sediment supply from the spread of vegetation cover, similar to the situation described in France (PIÉGAY et al., 2004). The study sub-basin defines the intermediate mountain area in the Italian Alps that slope down towards the alluvial plain of the Po River (the largest in Europe) and are typical for landscape processes in homogeneous impervious bedrock (alkaline rhyolites).

1 Characteristics of the small Research small basin

The small research basin *Valle della Gallina* (1,08 km^2; 522 m max, 330 m min a.s.l.) belongs to the Po river system at the border of the Alpine range in north-western Italy (Fig. 1a and b).

The sub-basin is representative of the hydrological patterns and sediment supply in the foothills of the northwest Italian Alps. The mean temperature is 11 °C. Channel sediment is from soil erosion of the steep slopes (basin mean slope is 0.49; the main channel length is 1.57 km and slope 0.06). Soil cover is a regolithic evolution of the bedrock *eluvium* and *colluvium* with rock fragments.

Some bedrock outcrops appear on the ridgelines and in the channel network. Erosion has been the dominant process. Since the 1970s the channel network has deepened and the colluvial flux has concentrated in the main channel. Erosion has cut down to the bedrock in the channels. The vegetation cover in the sub-basin increased since 1975 (75 % cover) through forest and scrub revegetation to cover most of the basin by the year 2000. The progression of the revegetation pattern has been from the channel network to the ridgeline, involving four recorded species: *Quercus pubescens, Castanea sativa, Betula pendula, Pinus sylvestris* (PELISSERO et al., 2009).

1.1 Soil cover

Soil profile analyses (BIANCOTTI & AJASSA, 1979, BIANCOTTI, 1981) show that the dominant soil fraction is sand (60–70 %), followed by silt and clay. The soils were surveyed using a sample of 57 pits equally distributed through-

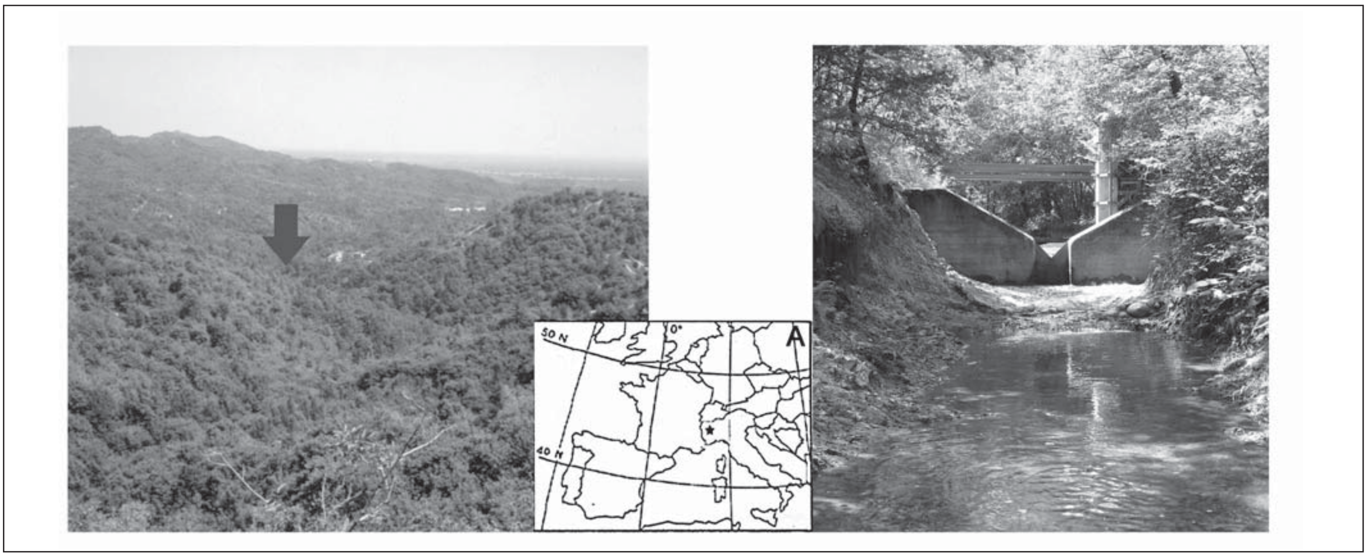

Figure 1: *(a, left)* south-eastern view from the headwaters towards the research sub-basin *Valle della Gallina*, in the background can be seen the Po river alluvial plain (see red star in cartographic map). The red arrow indicates the location of the basin outlet with the sediment monitoring station, which is shown from the downstream outlet in Figure 1 *(b, right).*

Abbildung 1: (A, links) südöstliche Ansicht des Testgebiets *Valle della Gallina*. Im Hintergrund erkennbar die Ebene des Po-Flusses. Der rote Pfeil zeigt die Lage des Testgebietsauslasses mit der Sedimentbeobachtungsstation. Abb. B (rechts) zeigt die Detailansicht flussaufwärts out the basin (1.08 km^2; BELLINO et al., 1993). They have an average thickness of 0.7 m (range: 0.20 m to 2 m) and derive from the weathering of homogeneous bedrock on the slopes, the local colluviums and limited overbank alluvial deposits in the main channel of the basin. Field work (CHERSICH, 2003) has confirmed that regosols are the predominant soil (cf. World Reference Base for soil resources, I.U.S.S., 2007). These soils are composed of unconsolidated materials with minimal profile development and absence of identifiable horizons.

The Available Water Content (AWC) has been calculated for the soil profiles according to the Soil survey of England and Wales (HALL et al., 1977), using spatial variability to find the relationship between soil morphology and terrain features. The AWC shows an average water content from very low (AVC of 6 mm) to low (AVC of 113 mm). The low soil water content is consistent with the rapid flow of rainfed water from the ridgeline rain gauge station to the basin outlet gauge.

2 Field experiences

An experimental channel reach upstream of the hydro-sedimentary station (Fig. 2) was used, with dimensions of 120 m length, 5 m width and an approximate slope of 1 %. A set of nine benchmarks were used to record changes in the channel bed level before and after the floods at the scale of decimetres, and to survey the bed level development as a sediment transport wave.

A sediment trap (5 m width, 8 m length, 1 m depth) was cemented into the bedrock of a natural pool at the channel outlet. Located on the downstream side is a water weir that forms part of the hydrometric station. On the upstream wall is an innovative investigation system (2001) using a computerized balance for continuous and simultaneous monitoring of water and sediment.

A swinging steel plate (5 m W x 1 m L) was attached as a platform for load sensors. Both the width of the sediment trap and steel plate are the same dimensions as the width of the channel bed (5 m). The simultaneously-monitored data were calibrated by the hydrometric station up to 1 m of the water level in the trap (LOLLINO et al., 2006).

2.1 Seismic surveys (1990–1991)

The channel bed was equipped with five seismometers installed in the channel banks (S1–S5) and one seismometer in the channel coarse bed just upstream of the sediment trap (S). Continuous micro-seismic records from the seismometers allowed the separation of water and sediment transport during seven flood events, of which five were associated with coarse sediment delivery into the trap (GOVI, MARAGA

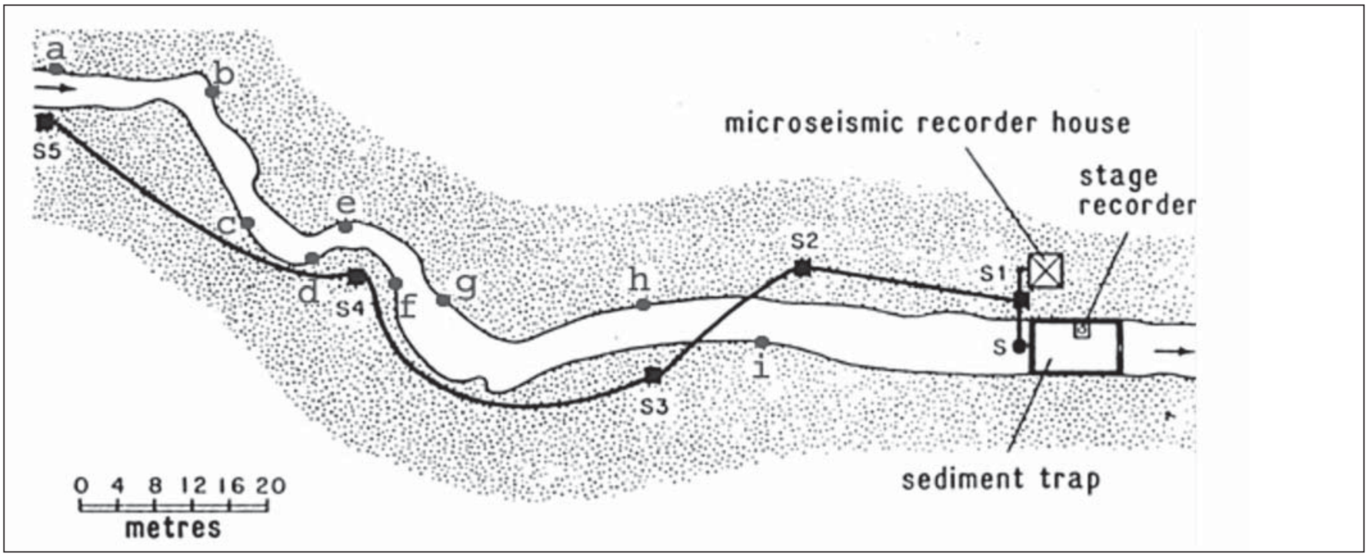

Figure 2: Plan of the experimental reach (120 m L) upstream from the sediment trap. Lettering indicates the nine benchmarks for the bed level topographic survey. Six seismometers (S, S1 to S4) measured the coarse sediment transfer noise

Abbildung 2: Karte des instrumentierten Flussabschnitts (120 m) oberhalb der Sedimentfalle. Die Buchstaben zeigen neun Messbereiche der Sohlhöhen, die Symbole S und S1–S4 zeigen sechs Seismometeranlagen zur Erfassung des Grobgeschiebetransports

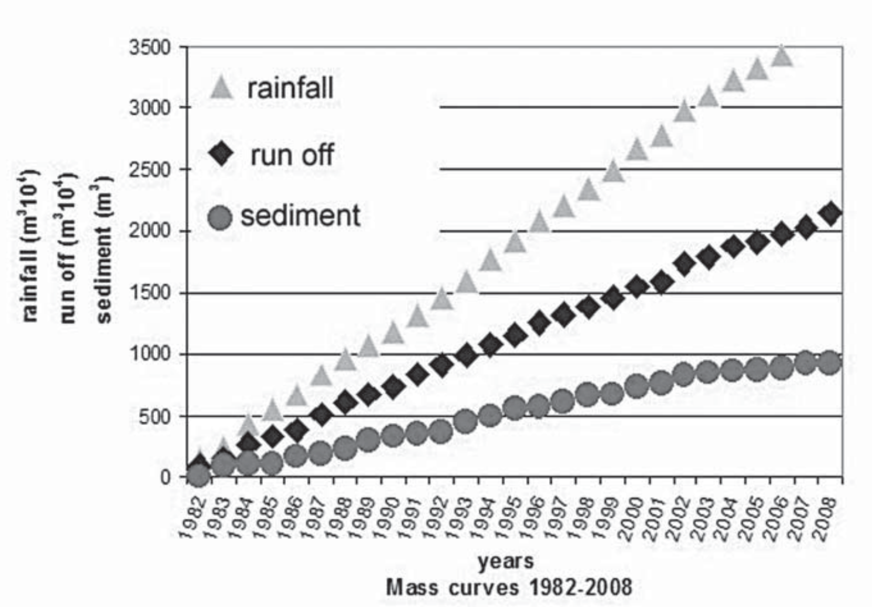

Figure 3: *Valle della Gallina* research basin: rainfall, runoff and sediment variability in yearly data. Accumulated annual mass curves for the 1982–2008 period

Abbildung 3: Beobachtungsdaten des *Valle della Gallina*-Testgebiets: Akkumulierte Jahressummen von Niederschlag, Abfluss und Sedimenttransport der Periode 1982 bis 2008

& MOIA, 1993). The discharge threshold for triggering the initial motion was 0.3 m^3s^{-1} for coarse sediment. The experience highlighted the mechanism of transport. In fact two or three micro-seismic impulse peaks were recorded during the flood event and they occurred before and after the water peak flow, proving the pulsing activity of the coarse transport. The experience gathered with the seismic tests carried out in the Valle de Gallina basin were subsequently exploited in the debris flow monitoring through seismometers in the Rio Moscardo (Arattano, 2003; Arattano et al., 2012).

2.2 Tracers movements (1985–2007)

Cobble material originating from the gravel channel bed itself were selected as tracers to measure the distances travelled by coarse sediment (29–123 mm grain size). An experiment was started in 1985 with 300 painted cobbles at the beginning of the experimental reach by surveying travelled distances and collecting the tracers arriving at the trap. The measurements revealed a fair agreement between the mean distance of displacements and the peak flows that were linked by an exponential relationship (ANSELMO et al., 1987; GODONE & MARAGA, 1989).

An experiment was carried out using nuclear-activated cobble tracers (sand and gravel) which are easy to detect, even if buried by several centimetres of sediment. The experiment showed that the longest distances were travelled by the larger cobble tracers (GIUSSANI et al., 1992). Peak flows involve sediment distance travels while flow duration involves sediment volumes delivery in the sedimentary trap. Discharges of 0,1 m^3s^{-1} transported only sandy sediment.

3 Hydro-sedimentary variability 1982–2008

Annually decreasing trends were observed in the water and sediment data, with the highest decrease in the last decade (Fig. 3). Runoff and sediment showed greater decreases, depending on the presence of extensive wood cover. The volumes of the sediment transport have decreased at the sediment trap due to the loss of the soil erosion.

The lack of sediment flux in the collector main channel has involved selective sediment transport of the finest grain size fractions and protruding cobbles in the channel bed.

Consequently the range of sediments transported has been narrowed to the coarse sediment fraction, as represented by the change in sediment grain sizes in the sediment trapped after 2002. For example, the earlier grain size distribution of 0.06–128 mm (measurement period 1982–2001) is now a larger grain size class of 128–256 mm.

3.1 Sediment delivery

The sediment trap is coupled with the water stage station at the basin outlet to evaluate as basin soil losses, represented by sediment delivery from the channel network.

The trapped sediment is periodically moved downstream and measured in volume by elevation surveys using a grid of 0.50 x 0.20 m, as referred to the top wall of the sediment trap.

Maximum annual sediment yield is 74 m^3 and the mean is 34 m^3 between 1982 and 2008.

3.2 Rainfall-runoff variability

The mean annual precipitation of 1,279 mm ranges between a maximum of 1923 mm (2002) and a minimum of 929 mm (1983). The most seasonal rainfall occurs in spring (May), with a maximum monthly mean of 185 mm, and in autumn (November or October), with a maximum monthly mean of 176 mm. Summer rainstorms are frequent and generate soil erosion on the local bare slopes and in the channels bed, contributing to the sediment transport.

The annual runoff shows a mean value of 734 mm and varies between 375 mm (2007) and 1341 mm (2002). The monthly occurrence of runoff has changed the maximum monthly position from October (1982–1998) to May (1999–2008), due to the absence in early spring of leaf canopy in the deciduous species. The annual runoff data show a maximum in the period 1982–2008 and suggest a decreasing trend after the year 2000, despite an extreme value of nearly 1,400 mm in 2002. This trend in the research basin corresponds with the estimated flow patterns projected as long term climate change for headwaters in the Czech Republic (BENČOKOVA et al., 2011).

3.3 Water balance

The mean runoff coefficient is 56 %/year, and ranges from a maximum of 0.82 (1988) to a minimum of 0.39 % (2007). The subsurface water system in the soil is fed only by rainfall (i.e. soil porosity of 35–40 % in sandy dominant soils, having 28 % and 34 % of efficacy). The variable water content in the soil of the slopes generates variability in the annual runoff coefficients (from 40 to 80; ANSELMO et al., 2011). Soil saturation effects were shown in winter 1991, indicated by runoff coefficients higher than 1 (BELLINO & MARAGA, 1995).

4 Final remarks and regional significance

The sediment yield at the outlet of the representative basin *Valle della Gallina* in the northwest Italian Alps is supplied by soil erosion that is undergoing a decreasing trend due to the revegetation of its previously bare slopes. Climate change trends in the form of decreasing rainfall and increasing revegetation are found to correspond with decreasing 1) water runoff; 2) soil erosion of the slopes and headwaters. The existing natural changes to the sub-basin environment are modifying the water balance by promoting rainfall infiltration on the slopes and water retention in the soils. Forest and bush revegetation has prevented soil erosion processes and colluvial fluxes in the channel network and consequently the delivery of sediment to the basin outlet. The hydrological and sediment adjustments in the small research basin under investigation are consistent with river dynamics observed in the upper Po basin along the Alpine range in north-western Italy. Shortening and deepening of the river channels are occuring contemporaneously with sediment losses in the channel beds due to the reduction in sediment supplied from the associated mountain basins.

Acknowledgments

Collaborators in field data collection and elaboration: Di Nunzio (formerly), F. Godone, R. Massobrio, G. Rivelli, E. Viola (formerly), Cnr-IRPI (http://www.irpi.to.cnr.it).
Field logistic assistance by local Municipality of Lozzolo (VC).

References

ANSELMO, V., E. CARONI, F. MARAGA and C. PELISSERO (2011): Tendencies in the hydrological budget of a Prealpine small basin. Die Bodenkultur, 62 (1–4), 9–15.

ANSELMO, V., F. DI NUNZIO and F. GODONE (1982): Hydrological investigation in a small catchment. Proc. of Intern. Symposium "Hydrological Research basin", Bern (Switzerland), Sept. 21–23 1982.

ANSELMO, V., F. MARAGA, F. BUFFA and V. VILLI (1987): Sediment yield and bedload movement in mountain torrents in the Italian Alps. Proc. of IUGG General Assembly, Vancouver (Canada), Aug. 9–22 1987, Abstract V.3, IAHS HW6, 978.

ARATTANO, M. (2003): Monitoring the presence of the debris flow front and its velocity through ground vibration detectors. In: Rickenmann, D. and C.L. Chen (eds.): Debris-flow Hazard Mitigation: Mechanics, Prediction and Assessment, Millpress, Rotterdam, 719–730.

Arattano, M., L. Marchi and M. Cavalli (2012): Analysis of debris-flow recordings in an instrumented basin: confirmations and new findings. Nat. Hazards Earth Syst. Sci., 12, 679–686.

Bencovocà, A., J. Hruscka, P. Kram and E. Stuchlik (2011): Future and recent changes in flow patterns in the Czech headwater catchments. Die Bodenkultur, 62 (1–4), 17–22.

Bellino, L., F. Maraga and R. Massobrio (1993): Caratterizzazione granulometrica dei terreni superficiali del bacino sperimentale della Valle della Gallina (VC). Cnr-IRPI, Torino, Internal Report M.I. 93/9, 9.

Bellino, L. & F. Maraga (1995): Temps de saturation en bassin versant. Proc. of 2nd Intern. meeting for young researchers in applied geology, Peveragno (CN)(Italy) Oct., 1995, 11–13.

Biancotti, A.(1981): Morfologia, suoli ed erosione in Valle Marchiazza. Geogr. Fis. Dinam. Quat., 4, 30–38.

Biancotti, A. & R. Ajassa (1979): I suoli della Valle Marchiazza (Biellese). Cnr-IRPI, Torino, Internal Report RI.

Caroni, E. (1979): Pluviometria del Biellese orientale. Boll. Ass. Min. Sub., XVI (4).889–9009.

Caroni, E., M. Arattano and F. Maraga (2000): Results from bed load measurements in a small catchment (Valle della Gallina, Italy). Quaderni Idronomia Montana, 20, 99–110.

Caroni, E. & D. Tropeano (1981): Rate of erosion processes on experimental areas in the Marchiazza basin (north-western Italy). IAHS Publ. n. 133, 457–460.

Chersich, S. (2003): Study of forestall humus and of their roles in the evolution of the soils of forest ecosystem" (In Italian). Palermo University, Dept. Agronomia, Coltivazioni Erbacee e Pedologia (ACEP) (Italy), PhD thesis on Soil Science, 258 pp.

Giussani F., F. Maraga, E. Pirastru and G.M. Zuppi (1992): Use of activated sediment in field measurements of bed load transfer in a mountain stream. Proc. of "Isotope techniques in water resources development 1991", IAEA-UNESCO, Wien 11–15 March 1991, 753–757.

Godone, F. & F. Maraga (1989): Distances de transport par charriage en milieu préalpin. Quaderni Idronomia Montana, 9, 83–102.

Godone, F. & F. Maraga (1992): Topographic changes at gravel stream bed induced by sediment transfer in the Valle della Gallina experimental basin, Alps, Italy, Conference on Methods of Hydrologic Basin Comparison, Oxford, 1992.

Govi, M., F. Maraga and F. Moia (1993): Seismic detectors for continuous bed load monitoring in a gravel stream. Hydrological Sciences Jour., 38 (2), 123–132. Quad. Idronomia n. 9.

Hall, D.G.M., M.J. Reeve, A.J. Thomasson and V.F. Wright (1977): Water retention, porosity and density of field soil. Techn. Monograph 9, Harpenden, Soil survey of England and Wales.

I.U.S.S. (International Union of Soil Science) Working Group WRB (2007): World reference base for soil resources 2006, report 103.

Lollino, G., P. Allasia, M. Arattano and F. Maraga (2006): Experimental method for water flow and sediment transport automatic measurements, European Geosciences Union, General Assembly, Geophisical Research Abstracs, vol 8, 07190.

Maraga, F., F. Di Nunzio, F. Godone, R. Massobrio and E. Viola (2000): Sixteen years field monitoring of debris supply from an incised stream channel network. Proc. of ERB Conf., Liblice (Czec Republic), 22–24 Sept. 1998, IHP-V Techn. Docum. N. 37, 131–138.

Pelissero, C., F. Maraga, F. Di Nunzio, F. Godone, R. Massobrio and G. Rivelli (2009): A new trend in streamwater balance and sediment delivery induced by increasing vegetation cover in a small basin. In Chelmicki and Siwek (eds.): Proc. of ERB 2008 12th International Conference "Hydrological extremes in small basins", Krakow, Poland, 18–20 Sept. 2008, IHP-VII UNESCO, Technical Documents in Hydrology, 84, 91–98.

Piégay, H., D.E. Walling, N. Landona, Q. He, F. Liébault and R. Petiot (2004): Contemporary changes in sediment yield in an alpine mountain basin due to afforestation (the upper Drome in France). Catena 55, 183–212.

Address of authors

F. Maraga *formerly*, **M. Arattano**, National Research Council of Italy (Cnr), Department of Earth and Environment, Research Institute for geo-hydrological protection (IRPI), Unit of Turin, Italy (http://www.irpi.to.cnr.it)
S. Chersich, University of Pavia, Department of Earth Sciences, Italy.
silvia.chersich@gmail.com

Corresponding author
Franca Maraga, franca.maraga@gmail.com