Tendencies in the hydrological budget of a pre-alpine small basin

V. Anselmo, E. Caroni, F. Maraga and C. Pelissero

Trends in den hydrologischen Bilanzgrößen eines kleinen Einzugsgebiets in den Voralpen

Zusammenfassung

Die hydrologischen Beobachtungen im kleinen, alpinen Testeinzugsgebiet *Valle della Gallina* (1.08 km^2) im Nordwesten Italiens begannen im Jahre 1982. Die Ergebnisse wurden zur Abschätzung der Variabilität der Wasserhaushaltsgrößen für die Periode 1992–2008 herangezogen. Unter Bezugnahme auf die Niederschlagsmuster im Nordwesten Italiens wurden die Abflussbeiwerte und ihre Schwankungsbereiche analysiert. Die saisonalen Niederschlagsmaxima treten in dieser Region im Herbst (Oktober-November) sowie im Mai auf und spiegeln das typische Verteilungsbild des kontinental-mediterranen Klimas wider. Das Testeinzugsgebiet mündet in den Fluss Po, in dessen Einzugsgebiet sich eine signifikante Abnahme des Jahresniederschlags und der Nasstage und eine Zunahme der Gewitterintensitäten zeigten. Die Forstnutzung nimmt in den alpinen Lagen zu.

Der Abflusskoeffizient nahm in der Beobachtungsperiode deutlich ab, wobei die Abflusshöhe stärker abnahm als die Niederschlagshöhe. Die monatliche Variabilität des Abflusskoeffizienten nahm zu, die Niederschlagsintensitäten während der Hochwasserereignisse nahm zu.

Schlagwörter: Hydrologisches Regime, Abflussabnahme im Italienischen Alpenvorland.

Summary

In 1982 hydrological observations were started in the small mountain basin of *Valle della Gallina* in north-western Italy (1.08 km^2). The results were analysed to evaluate variability in the water balance during the period between 1982–2008. Variations in the ratio of runoff to rainfall at yearly and monthly scales were considered, with reference to the rainfall pattern in the north-western Italian environment. In that region the seasonal rainfall maxima are recognized in autumn (October-November) and late in spring (May). The seasonal rainfall distribution is typical of the zone encompassing the basin and is considered representative of the continental-Mediterranean climate. This small basin contributes to one of the Alpine tributaries of the River Po, whose basin has seen a decrease in the amount of annual precipitation and number of wet days, together with increasing storm intensities. Forest cover is increasing in mountain lands.

In the *Valle della Gallina* small research basin, the annual runoff coefficient is observed to have decreased during the last period 1999–2008, with the runoff decrease being higher than the rainfall decrease.

Variability in monthly runoff coefficients showed increasing values in the summer season. At the same time, rainfall intensity related to flash flood events increases, being characterized by higher hourly values.

Key words: Hydrologic change, research basin, rainfall – runoff decrease, pre-alpine environment, Italy.

Introduction

In climate change analysis, some efforts have been made to assess trends or variations in hydrologic variables as measured in the field. In particular, changes were investigated in the rainfall regime related to drought duration or extreme precipitation. Within the geographic area extending from the Mediterranean Sea to European Russia, rainfall has noticeably decreased up to 20% in the period ranging from 1960 to 1999 (Piervitali et al., 1998). The analysis of annual rainfalls in Italy, over the last two centuries (1800–2006) has shown an estimated decrease of only 5% per century on an annual basis (BRUNETTI et al., 2006). Over the same time period, the number of rainy days was observed to have decreased considerably and a perceptible increase in average rainfall intensity was therefore detected as well in northern regions of Italy (NANNI et al., 2004; BRUNETTI et al., 2004, 2006; NANNI and PRODI, 2008).

In the Po River basin (northern Italy), rainfall records from the middle of the Po plain that date back to 1830 (LOMBROSO and QUATTROCCHI, 2002) showed a noticeable decrease in annual rainfall, estimated at 84 mm per century. Regarding rainfall distribution, high intensity rainfalls became more frequent and an evident increase in summer rainfalls was recognized in the last 10 years, so that summer became the most rainy season in that area. The well-known rainfall pattern during summer 2002, with heavy rainfalls extending over most of Europe, confirmed the change in seasonal and spatial distribution of rainfalls (Deutscher Wetterdienst, 2002; Regione Piemonte, 2002; JAMES et al., 2003; Risk Management Solution, 2003).

The present paper describes the annual and monthly rainfall variability measured in the *Valle della Gallina,* a small research basin within the upper Po River catchment. This basin is considered to be representative of a pre-alpine environment in north-western Italy, and its hydrology has been monitored with instruments since 1982. From the end of the 1990s, varying hydrological patterns were recorded in the annual rainfall and decreasing trend in the runoff mass curve (MARAGA and PELISSERO, 2008; PELISSERO et al., 2009).

Research basin observations

The *Valle della Gallina* research basin is a small hydrographic basin located in a mountain region between the upper plain of the River Po and the north-western Alps main relief. The basin has an almost circular shape with an area of 1.08 km^2 and maximum elevation of 522 m a.s.l. The basin outlet is located at 45°38’28”N, 8°18’48”E at an elevation of 330 m a.s.l. (Figure 1).

Main physiographic and hydrological parameters of the basin are summarised as follows: average slope (49%); main channel length (1.57 km); average main channel slope (4.8%). Mean temperature is 11°.The stream network is a well-developed dendritic drainage pattern, incised in the bedrock. Stream density (as measured from aerial photographs at 1:2000 scale) is of the order of 52 km per km^2. The channel width varies from a few decimetres in the headwater channels to 7 m in the main channel at the basin outlet. A rain gauge located on the northern ridgeline boundary has made continuous observations since 1982 and similarly for the gauging stations at the basin outlet for flow and sediment.

The hydrological regime of the research basin is characteristic of the pre-alpine environment, pertaining to a Mediterranean rainfall type. This is characterised by two

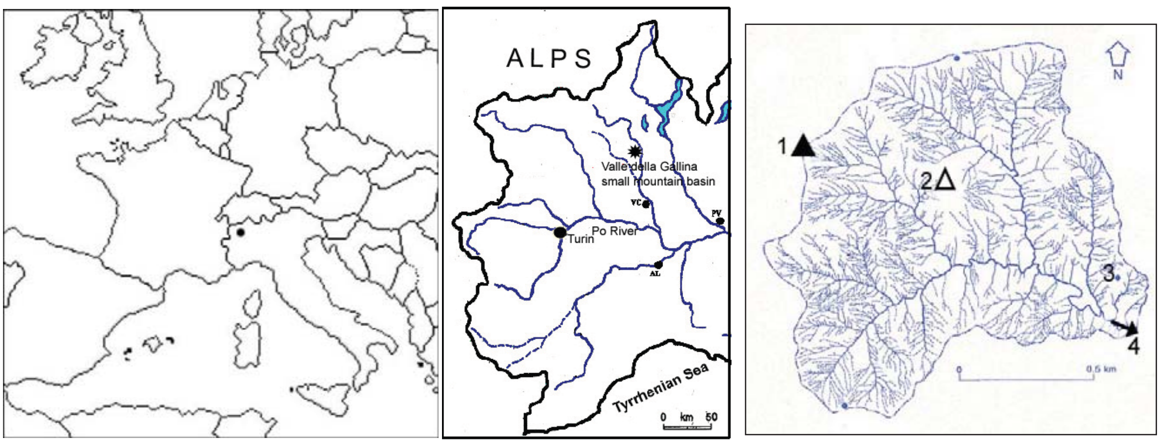


Figure 1: Location map of the *Valle della Gallina* research basin (asterisk), NW River Po system, Italy. Explanation of the right frame (basin channel network): 1) max. elevation 522 m a.s.l.; 2) Mount *Gallina* – elevation 450 m a.s.l.; 3) rain gauge (370 m m a.s.l.); 4) hydrometric gauge and sedimentary station at the basin outlet (330 m a.s.l.)

Abbildung 1: Lageplan und Höhen des Ursprungsgebiets des Flusses Po und des *Valle della Gallina* Testgebiets. 1) Maximale Seehöhe 522 m ü.A.; 2) Mount *Gallina* – Seehöhe 450 m ü.A.; 3) Niederschlagsstation 370 m ü.A.; 4) Abflussstation am Gebietsauslass 330 m ü.A.

relative maxima (May and October–November) and minima (January and July), according to records from the 20 rain-gauge stations during the 1924–1973 period. This is related to the pre-alpine sub-zone between the Alps and the Upper Po Plain (Caroni, 1979). This hydrological regime is congruent with the western sub-littoral regime which Perosino and Zaccara (2006) attributed to the north-western part of the Po River basin. Mean rainfall of the research basin (1982–2008) is 1279 mm $year^{-1}$. Occasional snowfall contributes less than 10% of the precipitation of January and February. Mean runoff is 734 mm.

Human activity is limited to two trails (i.e. cart-roads): one follows the basin watershed, the other develops along the bottom of the valley. No ground water contribution has been detected as the watershed is characterized by an impervious, homogeneous, volcanic bedrock (rhyolites). Consequently the hydrological budget at the mouth is dependent on the rainfall pattern. Soil cover is represented by an irregular regolithic sheet (maximum depth 2 m). The vegetated land cover of the basin's steep slopes is coppiced chestnut trees and underbrush.

Decreasing rainfall trends are recognized in the concomitant decreasing runoff trends for monthly and annual data over the time period 1999–2008. This trend occurred despite the unexpected increase in rainfall pulses for years 2002 and 2008.

Hydrological Variability

Over the time period 1982–2008, there was an average annual rainfall of 1,279 mm. The rainfall variability range was 350mm, with a minimum of 929 mm (1983) and a maximum of 1,923 mm (2002). The latter was the last big hydrological event in the upper Po river basin as well in Europe. Between years 2002 (1,341 mm) and 2007 (375 mm), the annual average runoff was 734 mm.

In Figure 2a, rainfall after the year 2000 shows a pattern of more frequent minimum values compared with the previous period and a higher amount in 2002 (Figure 2a). It is worth noting that 2002 was recognized through-out Europe as an extreme rainfall and flood event period. In Figure 2b, the annual runoff after 2000 shows a pattern of decreasing values below the average, notwithstanding the higher amounts recorded in 2002 and 2008. This trend influences the average value for the 1999–2008 period, which decreases from 734 mm to 706 mm of the 1982–2008 observation period. No significant change is detected in rainfall averages.

The 1999–2008 rainfall variability relates to six times the occurrence of values below the average. The runoff decrease is more important than the decrease in rainfall. For the period 1999–2008 it reaches – 4% versus the 1982–2008 average of 734 mm. Over the last ten years the recorded lower runoff values are approximately 400 mm for 2001, 2005 and 2007, which is 50 mm less than the lowest values ob-

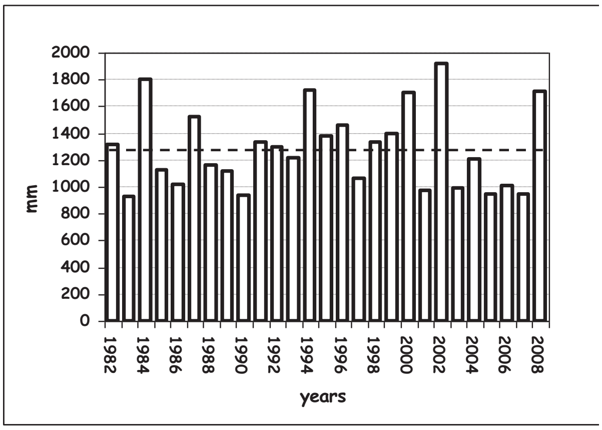


Figure 2a: Annual pattern for rainfall

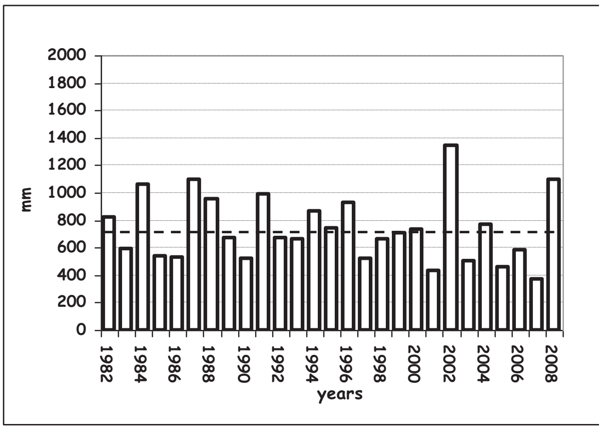


Figure 2b: Annual pattern for runoff

Figures 2a, 2b: Annual patterns for rainfall and runoff between 1982–2008. Mean values for rainfall and runoff are 1,279 mm and 734 mm respectively (dashed line). Maximum for 2002 and 2008 are shown, as well as the minimum occurring after 2000

Abbildungen 2a, 2b: Jahresgang des Niederschlags und des Abflusses 1982–2008. Mittelwerte (strichliert): Niederschlags 1.279 mm, Abfluss 734 mm served in the previous period (1985, 1986, 1997). Runoff records also show that several flash floods were quickly generated by intense storms, indicating a pulsed flood regime. Within the observed time period, there were more than one hundred events with a peak flow exceeding $1 m^3 s^{-1,}$ compared with the average annual flow of 0.020 $m^3 s^{-1}$ (ANSELMO et al., 2008). The peak flow average is almost $2 m^3 s^{-1}$, with a maximum of 6.44 $m^3 s^{-1}$ in 1995.

Annual rainfall and runoff amounts indicate decreasing changes after the year 2000. At the same time, changes in the monthly rainfall patterns were also observed and compared with the monthly runoff. With respect to the rainfall pattern between 1999–2008, the maximum on 01 May was 185 mm (versus 177 mm). The second maximum occurred in November (176 mm), instead of October (127 mm), showing higher values and quite comparable in spring and autumn (see Figure 3). Both the spring and autumn seasonal maxima achieve better and incisive settlement and reflect a shift towards an initial maximum in the autumn. Spring and autumn are representative of higher rainfall seasons, even though the 1999–2008 rainfall was concentrated in the two months of May and November.

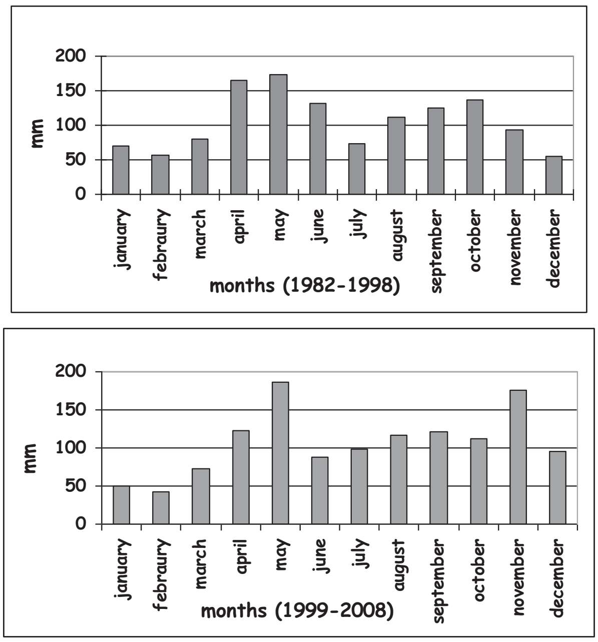


Figure 3: Monthly rainfall patterns in 1982–1998 (left) and 1999–2008 (right)
The patterns show a seasonal change in 1999–2008 interval versus higher May and November values, incidentally the first maximum and the second maximum instead of October

Abbildung 3: Monatlicher Niederschlag für 1982–1998 (links) und 1999–2008 (rechts)

Comparative monthly runoff patterns are presented in Figure 4 to show maximum seasonal runoff change. The comparison highlights the 1999–2008 period, raising the May maximum over the 1982–1998 maximum for October. Spring has the highest runoff concentration over the 1999–2008 period. related to May and June, with the latter connected to storms and flash floods.

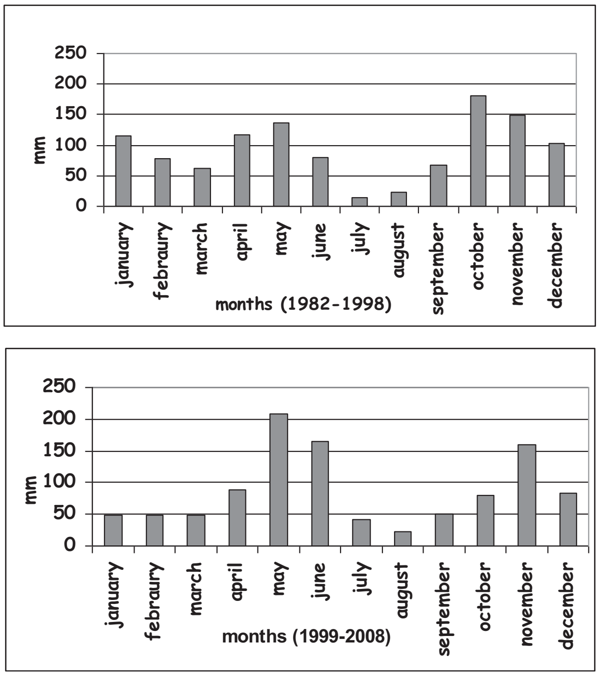
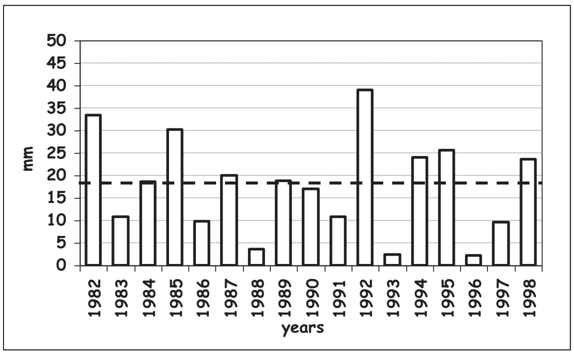


Figure 4: Monthly runoff patterns in 1982–1998 (left) and 1999–2008 (right)
The patterns show a seasonal change in 1999–2008 interval versus higher May first maximum value and versus higher June and November second maximum value instead of October.

Abbildung 4 Monatliche Abflussspenden für 1982–1998 (links) und 1999–2008 (rechts)

Frequent flash floods of over $1 m^3 s^{-1}$ (an average of four events per year) are generated by the storm rainfall regime. Rain shower variability of the storm is analysed hourly with extended rainfall generating the flash peak flow. The hourly rainfall values higher than average value 1982–2008 (19 mm) range between 20 mm (1987, 2004) and 46 mm (2001). The maximum values per year are presented in their distribution for 1982–2008 and selecting the time period 1999–2008 (Figure 5). In 1999–2008, the occurrence of maximum hourly rainfall heights per year exceeding the average of 19 mm is 60% instead of 41% in the 1982–1999 period.



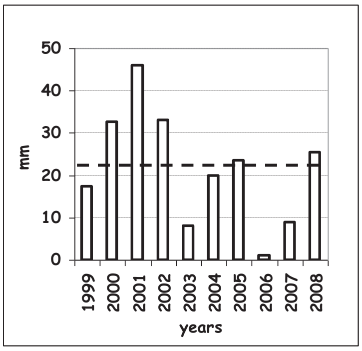


Figure 5: Maximum hourly rainfall values per year in 1982–1998 (left) and 1999–2008 (right) with related averages (dashed line). The mean value in 1999–2008 is 22 mm compared with 17 mm in 1982–1998

Abbildung 5: Maximale Stundenniederschläge in den Jahren 1982–1998 (links) und 1999–2008 (rechts) und deren Mittelwerte (strichliert). Diese sind 22 mm für 1999–2008 und 17 mm für 1982–1998

Runoff coefficients

Yearly runoff coefficients are presented in Figure 6 together with four years moving average, representing their evolutionary trend. The runoff coefficient variability indicates lower values, even though a step of inversion change appears in the 1999–2008 decade, related to 2002 and 2008 maximum events. The 1982–2008 coefficient average is 0.56. The maximum value is related to the 1988 coefficient (0.82) and the minimum is recorded in 2007 with a runoff coefficient value of 0.39.

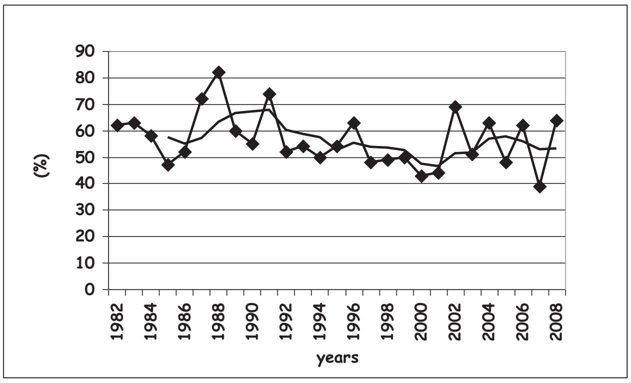


Figure 6: Yearly runoff coefficients and four years moving average trend line between 1982–2008, the mean is 56%)

Abbildung 6: Mittlere, jährliche Abflussbeiwerte für die Periode 1982–2008 und gleitendes Mittel (Gesamtmittelwert ist 56%)

The decreasing pattern in runoff coefficients reflects the change in land cover shown in aerial photographs between 1975 and 2009, vegetation cover has been developing in the small basin, with 77% vegetation cover shown in the 1975 aerial photo, then reaching nearly 100% cover in 2009. This increase represents a corresponding evapotranspiration water loss condition (BUCHTELE et al., 1998). Over the 1982–2008 period, the annual coefficient there is a decrease of 17%. The distribution of monthly runoff coefficients also appear to have changed during the 1999–2008 period. In 1982–1998 the monthly maxima characterised the spring and autumn response (March, 0.59; December 0.56), whereas the monthly maxima for 1999–2008 correspond with January (0.39) and June (0.24), which characterise the winter and summer seasons.

Results

Evolutionary changes in observed annual amounts during 1982–2008 mark variability towards a weak decrease in rainfall versus a significant decrease in runoff. Over the 1999–2008 period the rainfall average is comparable to average values for 1982–2008 (rainfall 1279 mm, runoff 734 mm respectively), but the runoff average is 706 mm (approximately -4%). This is clearly represented from the beginning of 2000, with some change in seasonal rainfall also being observed in the same period, with the autumn maximum shifting in November (1999–2008) instead of October (1982–1998). The annual maximum remains in May, although with significantly increased values. As related to the comparative runoff seasonal variability, a noticeable change occurred in the first 1999–2008 maximum, which is May instead of October (1982–1998), in combination with the observed rain storm frequency and intensity shifting from autumn to summer.

Final remarks

Over the 1982–2008 observation period, the *Valle della Gallina* small research basin showed variability. In particular for trends in runoff values toward lower annual amounts, starting from 2000, with a decreasing average for the 1999–2008 period.

The seasonal rainfall and runoff events recorded in the research basin suggest hydrological evolution towards changes in monthly event distribution. In fact monthly amounts happen to be higher in late spring instead of autumn. Moreover, changes in the seasonal hydrological regime are developing towards a typical plain regime, rather than the mountain regime that was typical pre-2000 for a pre-alpine zone bordering the upper Po river plain. The comparison between data stresses that the decrease in runoff has exceeded the decrease in corresponding rainfall.

This comparative difference between runoff and rainfall variability is related to changes in regional environmental factors. For example the development of forest vegetation on mountain slopes in recent years at the scale of the western Alps covering the previously exposed mountain divides in the research basin (PELISSERO et al., 2008). Therefore an evapotranspiration component, due to the vegetation cover, must be involved in the reduction of the runoff coefficient in the *Valle della Gallina* research basin, which enhances the decrease in the runoff response.

Collection of further data in the future is expected to assess whether the variation trend is permanent, especially during the period 1999–2008. This will provide a more consistent sample for statistical trends in order to validate the heuristic observations presented above.

Acknowledgements

Logistical assistance was provided by the Local Authorities of Sostegno, Villa del Bosco and especially the Community of Lozzolo. Cooperation by the following is acknowledged with appreciation: M. Arattano, for data processing since 2008; F. Di Nunzio for hydrologic observations and data processing in 1982–2008; G. Rivelli for hydrologic observations and data processing since 2008; and P.G. Trebò (CNR-IRPI, branch of Turin) for image management. This research was developed within the framework of RSTL 560 project, promoted by the Italian National Research Council.

References

ANSELMO V. DI NUNZIO F. and MARAGA F. (2008): Peak flow modelling related to a small river data in mountain region. In: XXII Biennial International Conference of ERB, Cracow, Poland, 18–20 Sept. 2008, *Extended Abstracts,* 21–22.

BRUNETTI M., MAUGERI M., MONTI F. and NANNI T. (2004): Changes in daily precipitation frequency and distribution in Italy over the last 120 years. J. Geophys. Res., 109.D05102.

BRUNETTI M., MAUGERI M., MONTI F., and NANNI T. (2006): Temperature and precipitation variability in Italy in the last two centuries from homogenised instrumental time series. Int. J. Climatol., 26, 345–381.

BUCHTELE J., HERMANN A., MARAGA F. and BAJRACHARYA O.R. (1998): Simulation of effect of lad use change on runoff and evapotranspiration. In: Proc. Head water'98 Conference, Merano, Italy, 20–23 April 1998, *IAHS Publ.;* 248, 99–106.

CARONI E. (1979): Pluviometria del Biellese Orientale. *Boll. Ass. Min. Subalpina*, XVI. 4, 889–909.

DEUTSCHER WETTERDIENST (2002): Extreme precipitation amounts in Central Europe from 1–13 August 2002. Deutscher Wetterdienst, Ofenbach. http://www.meteo.uni-koeln.de/content/downloads/rr_extreme200208_germany.pdf

LOMBROSO L. and QUATTROCCHI S. (2002): *Il clima e le misure meteo-climatiche a Modena.* Proc.of Dipartimento Ingegneria dei Materiali e dell'Ambiente. Osservatorio Geofisico. Università degli studi di Modena e Reggio Emilia, 1–10.

MARAGA F. and PELISSERO C. (2008): *Charge de fond et débits en comparaison dans un petit cours d'eau équipé des Alpes piémontaises (Italie).* La Houille Blanche, N. 5, 123–129.

NANNI T., BRUNETTI M. AND MAUGERI M. (2004): *Variazioni nella frequenza e nell'intensità delle precipitazioni giornaliere in Italia negli ultimi 120 anni.* In: Proc. Clima e cambiamenti climatici: le attività di ricerca del CNR, 229–232.

NANNI T. and PRODI F. (2008): Cambiamenti climatici: la situazione in Italia. *Energia*, 1/2008, 66–71.

PELISSERO C., MARAGA F., DI NUNZIO F., GODONE F., MASSOBRIO R. and RIVELLI G. (2009): A new trend in stream-water balance and sediment delivery induced by increasing vegetation cover in small basin. In: Proc. XXII Biennial International Conference of ERB "Hydrological extremes in small basins", Cracow, Poland, 18–20 Sept. 2008, *Technical Documents in hydrology*, 84, Unesco, Paris, 141–147.

PIERVITALI. E., COLACINO, M. and CONTE, M. (1998): *Rainfall over the central-western Mediterranean basin in the period 1951-1995.* Part I: precipitation trends. Il Nuovo Cimento, 21C, 331–344.

PEROSINO GC. and ZACCARA P. (2006): *Elementi climatici del Piemonte*. In: Proc. Centro Ricerche in Ecologia e Scienze del Territorio, 1–17.

P. JAMES, A. STOHL, N. SPICHTINGER, S. ECKHARDT and C. FORSTER (2003): Climatological aspects of the extreme European rainfall of August 2002 and a trajectory method for estimating the associated evaporative source regions. *Natural Hazards and Earth System Sciences,* 2004(4), 733–746.

REGIONE PIEMONTE (2002): Il rapporto sullo stato dell' ambiente 2002, Event report , Torino 1–72.

RISK MANAGEMENT SOLUTIONS (2003): Central Europe flooding, August 2002. Event Report, 1–22.

Address of authors

V. Anselmo, Anselmo Associati, Chieri-Turin, Italy
E. Caroni, University of Trieste, Civil and Environmental Engineering Dept., Trieste, Italy
F. Maraga and C. Pelissero, National Research Council of Italy, Geo-hydrological Research Institute (IRPI), Branch of Turin, Turin, Italy