Severe storm cases in Italy: hydrological and ground effects in the Tiber Basin

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Abstract

The determination of the river discharge as a function of precipitation is a well known basic problem in Hydrology. The relationship among the observable and the typical parameters characterising the basin, may be obtained by means of a deterministic, physically-based, modelling system. This allows the simulation of all major hydrological processes of the land phase of the hydrological cycle. An example of this type of approach is provided by the MIKE-SHE model (Abbot et al. 1986) possibly coupled with an event oriented additional river model. Nevertheless the application of physically based models requires the provision of a large amount of parametric and input data. A preliminary "black box analysis", which, independently from the underlying physics, provides an operator capable of transforming rainfall into discharge, may be a useful tool to gather possible clues to simplify the conceptualization of the considered physical system. In this study the latter approach is pursued.

1 DATA

The study is referred to the forty-year period from 1959 to 1998. In this time span 23 cases are recorded in which the Tiber peak discharge (TPD) at Rome reached or surpassed the threshold of 1400 m^3/s. The intent is to investigate on possible soil and atmospheric conditions favouring large TPD cases.
Rainfall data were collected at 55, uniformly distributed rain-gauge stations (Bencivenga et alii,1998; Bersani et alii, 1999) which operated without interruptions in the period under consideration. The area is divided in 13 sub-catchments which are listed in Table A/1 of the Appendix. In the present river bed conditions (Bersani et alii, 1999) it is deemed correct considering a main Tiber section from the source up to the Paglia river and a next segment from the Paglia confluence to the mouth. In fact the river segment upstream of the Paglia-Tiber junction is controlled by the Corbara reservoirs.
The events are distributed throughout the months of September (1), November (5), December (8), January (2), February (6), April (1), while TPD highest values are more frequent in February.
In the Appendix the list of considered cases is presented (Table A/2).

2 FIRST ANALYSIS STEPS

The relationship between precipitation and runoff in the Tiber Basin has been considered by several authors (Bencivenga et al.,1998; Bersani et al., 1999, Alessandroni et al. 1998, Calenda et al. 1997). There is agreement among them on the fact that 4-6 day total rainfall is an effective parameter controlling the river discharge in the final section of the Tiber. Nevertheless the "peak" discharge value does not show a marked correlation with the 4-6 day precipitation, supporting the view that other variables (such as Basin's previous conditions) play a role in determining the stream flow maximum.
As a preliminary analysis very simple indicators of the recent weather history in the Basin are considered. Monthly rainfall at 15 stations are determined in the three months preceding those in which the severe discharge event occurred, indicated as P(-1), P(-2), P(-3). In Table 1 correlation coefficients between P(-1), P(-2), P(-3) and peak discharge (TPD) are reported.

Station	1st month	2nd month	3rd month
Petrelle	-0,11	-0,10	0,20
Perugia	***-0,62***	-0,08	-0,09
Torgiano	***-0,63***	-0,11	0,01
Nocera U.	***-0,51***	-0,09	-0,06
Todi	***-0,58***	-0,14	0,03
Proceno	***-0,44***	-0,18	0,25
Bagnoregio	-0,38	-0,09	0,22
Terni	***-0,49***	-0,18	0,21
Balze S.Lucia	-0,41	-0,15	0,22
Tagliacozzo	***-0,60***	-0,35	0,16
Ronciglione	-0,27	-0,03	0,36
Abb. Farfa	-0,39	-0,13	0,24
Subiaco S.Scol.	-0,23	-0,09	0,28
Roma S.I.	-0,30	-0,11	0,23
Abeto	-0,35	-0,08	0,36

Table 1. Correlations between P(-1), P(-2), P(-3) and peak discharge (TPD)
(statistically significant values are highlighted)

Negative values, such as those appearing in the first column, indicate that, *within the sample being considered*, below average values of P(-1) tend to be associated to large TPD values. Sign homogeneity for all stations provides a further support to this result.
The second column on its turn, shows, beyond any doubt, the absence of any correlation between precipitation in the last but one month, and TPD. On the other hand, rainfall occurred in the third month before that of the event, presented in the last column of Table 1, shows a weak correlation with TPD values. The sign is now positive, indicating that above average values of P(-3) tend to be coupled with large TPD.

Before attempting any interpretation of these results, it is deemed useful to analyse the space patterns of the found correlation.

3 CORRELATION PATTERNS

The correlation field between P(-1) and TPD is shown in Fig.1. A well defined negative maximum centre appears in the northern part of the Basin, identified by the stations of Perugia, Torgiano, Nocera Umbra and Todi. Values are gradually decreasing moving southward.
Correlation field of P(-3) and TPD (Fig.2) presents a large area of small values centred in proximity of Perugia and Torgiano, while weak but significant positive values appear in the southernmost part of Basin, particularly over Nera and Aniene catchment.

4 DISCUSSION OF RESULTS

The clear empirical relationship between monthly precipitation anomaly in the *month preceding the storm* and TPD is very likely related to soil conditions and evapotranspiration. Negative anomalies appear in the second half of December and increase gradually to reach their climax in February. In the heart of Winter, deciduous vegetation falls in a "quiescent" stage (trees without leaves) , while cultivated seeded areas are in the earliest stage: water is exported to the atmosphere solely by direct evaporation from ground. On the other hand soil keeps the "memory" of the previous rainy Autumn and its water content is generally high. Moreover the reduced riparian vegetation eliminates the retarding frictional effect along river banks. In a situation of this kind nearly all the precipitated water tend to be converted into runoff.
On early Autumn, evapotranspiration is very effective, ranging around 3-4 mm/day (Siani & Palmieri, 1988). A non negligible amount of water is exported from ground to the atmosphere preparing soil for hosting more rain water. At the same time the ground, after the summer, has a considerable water capacity available. Riparian vegetation is prosperous and operates as an effective brake for the river flow. As a consequence, surface runoff is reduced.
The P(-3) pattern suggests a rather different interpretation: the soil in eastern (Nera) and southeastern catchments (Aniene) is mainly composed of carbonate rocks in which water percolates quite easily. The mean time required for the water to reach the springs is estimated to be about two-three months (Boni et al. 1993, Giuliano & Sciotti 1981). Positive rainfall anomalies in the third month before the peak discharge, indicate that the increased underground water flow, very probably contribute to the extreme event.

5 PRECIPITATION INTENSITY

Precipitation intensity is considered a possible factor influencing runoff. A possible relation between rainfall intensity and peak discharge is investigated considering the following variables, determined in the southern portion of Tiber Basin: (a) the total precipitation (TP) during the six days preceding the peak discharge and (b) the number of days with rainfall equal to, or greater than 10 mm (NP) within the same six day period. TP/NP is assumed as a crude indicator of the convective activity of the storm. The result is presented in Fig. 3. Obviously TP/TN is linearly increasing with TP. Nevertheless the considered storms tend to form two main clusters: that labelled "*marked convection*", involving cases in which most of the six day precipitation occurred in three days, and the other indicated by "*limited convection*", in which total rainfall was distributed in a 4 day period. The two largest cases of peak discharge (2050 and 1900 m^3/s) occurred on Feb 17th, 1976 and Feb 2nd, 1986 respectively, are both associated to marked convection, supporting the concept that precipitation intensity has an impact on the peak discharge.

6 STATISTICAL MODELLING

The development of a stable statistical model based on a limited set of cases is obviously a too ambitious task. Nevertheless the exercise may be useful to throw some light on the relationship among those variables which show a statistically significant level of correlation with the observed peak discharge, and particularly to identify clues of non linearity.
To this purpose "spline" or threshold non linear variables are introduced using the mean value as breakpoint (Taliani et al. 1996). They may assume the following forms:
[P(-x)*-P(-x)] or [P(-x) – P(-x)*], where P(-x)* is the mean precipitation value (within the sample under consideration), P(-x) is the rainfall observed in the xth month before that in which storm occurred. Spline variables are switched on when their value is positive, otherwise they are set to zero. After a thorough screening the following regression model was obtained:

(2) TPD = 1465.935 + 0.641*[104-A] + 0.372*[B – 77]
- 0.439*[C-114] – 0.168*[D-100]
+ 0.583*[B – 77]* [C-114]* [D-100]

where A = P(-1) at the station of Torgiano, B = P(-3) at Abeto, C = P(-3) at Ronciglione, D = P(-3) at Proceno. The numbers within square brackets are the respective P(-x)* of each station. Note that data at one station (Torgiano) are effective in describing the last-but-one month conditions, while a third order interaction among splines is fruitful to deal with the longer term effects. The contribute of P(-3) is more active when the whole southern part of the catchment experiences the same conditions The last term in eq. (2) provides a correlation increase from 0.880 to 0.919.

7 CONCLUSION

Result obtained in this preliminary investigation appear encouraging. They indicate the possibility to develop more realistic physical models to describe the conditions leading to severe hydrological events.
Further development of the study require, from an observational point of view, the improvement of the hydro-meteorological network in the northern part of the Basin to allow a better estimate of soil moisture and evapotranspiration together with a monitoring of vegetation changes over the area.
From a modelling point of view, the development of an operational atmospheric boundary layer model is considered necessary to take into account the interactions between ground properties and atmospheric boundary layer. Moreover a realistic simulation of major hydrological processes of the land phase of the hydrological cycle is necessary.

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APPENDIX

SUBCATCHMENT	AREA (km^2)	%	RAINGAUGE STATIONS
1 - Tiber upstream of Chiascio	2.184	12,7	Montecoronaro, Toppole, Pietralunuga, Petrelle, Perugia Isa, Torgiano, Castel Rigone
2 - Chiascio	724	4,2	Gubbio, Sorgenti Scirca, Bastia Umbra, Assisi
3 - Nestore and Trasimeno	1.034	6,0	Perugia Isa, Tuoro, Monte del Lago, Corciano, Fratta Todina
4 - Topino – Maroggia	1.230	7,2	Assisi, Nocera Umbra, Spoleto
5 - Tiber upstream of Paglia	905	5,3	Fratta Todina, Prodo, Todi, Casalina
6 - Chiani and Paglia	1.338	7,8	Prodo, Castelluccio di Pienza, Proceno, Acquapendente, Orvieto
7 - Tiber upstream of Aniene	3.383	19,7	Bagnoregio, Attigliano, Calvi, Ronciglione, Civita Castellana, Abbazia di Farfa, Nepi, Riano
8 - Nera	501	2,9	Terni
9 - Corno and Nera upstream of Velino	1.454	8,5	Abeto, Albaneto, Arrone
10 – Velino	742	4,3	Terni e Monte Terminillo
11- Salto and Turano	1.592	9,3	Posticciola, Balze S.Lucia, Tubione, Pereto, Scurcola, Verrecchie
12 –Aniene	1.446	8,5	Affile, Subiaco S.Scolastica, Licenza, Castelmadama, Settecamini, Pantano Borghese, Zagarolo, Frascati
13 – Tiber urban Rome area	621	3,6	Roma Millerose, Roma S.I., Roma Tre Fontane, Castel di Leva
Whole Basin	17.156	100	

Table A/1. The 13 subcatchments of the Tiber Basin

Date	River height (m)	Peak discharge (m^3/s)
03-12-1959	11,75	1400
26-12-1959	11,88	1400
23-12-1960	12,10	1400
06-01-1961	12,10	1400
30-12-1964	12,46	1550
03-09-1965	12,65	1600
06-02-1969	11,30	1550
17-02-1969	11,43	1600
19-11-1975	11,26	1450
17-02-1976	12,72	2.050
16-04-1978	10,74	1.400
18-02-1979	11,90	1.650
17-01-1980	10,76	1.450
08-11-1980	11,10	1.500
15-11-1980	10,83	1.450
23-12-1982	11,55	1.600
27-02-1984	11,81	1.750
02-02-1986	12,40	1.900
27-11-1987	10,70	1.400
10-12-1987	11,08	1.500
11-12-1990	10,63	1.400
22-11-1991	11,77	1.600
09-12-1992	11,39	1.550

Table A/2. The 23 cases with TDP > 1400 m^3/s