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HYDROLOGICAL ANALYSIS OF A RAINFALL EVENT IN CALABRIA

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ABSTRACT

Between 12th and 13th November 2004 a considerable rainfall event occurred in the Calabria region (southern Italy). This event started in the south part of Calabria and during its evolution it interested the entire region with remarkable damages.

The analysis of the cumulate precipitation recorded during the event, from 6:00 a.m. of the 12th November to 6:00 a.m. of the 13th November, and the evaluation of the return period for the maximum rainfall of 1 hour, 3 hours, 6 hours, 12 hours and 24 hours stored in some rain gauges were performed.

The hydrologic model WRROOM (Watershed Rainfall Runoff Object Oriented Model) was applied to study rainfall-runoff transformation in four of the principal basins of Calabria region: the Neto River at the closing section of Rocca di Neto and the Tacina River at the closing section of Serrarossa for the Ionian side, the Mesima River at the closing section of Sbarretta and the Petrace River at the closing section of Gonia for the Tyrrenian side.

Results of the hydrological analysis of the rainfall event occurred in Calabria in November 2004 are presented.

1. INTRODUCTION

Two of the main problems in hydrology are to estimate the magnitude of an event with a given return period and to determinate the rainfall-generated runoff. The first problem has been overcome by the use of some statistical distribution such as the Two Components Extreme Value (TCEV) distribution (*Rossi et al.*, 1984). In order to obtain a robust estimation of the parameters, statistical distributions need a large data set which is difficult to find, for this reason such kind of distributions are often used on regional basis. In Calabria a regionalized procedure has been developed in the VAPI project, based on the TCEV distribution (*Versace et al.*, 1989). The knowledge about the mechanism of transformation of rainfall in runoff is very important because it permits the integration of the runoff information, usually more limited than those on precipitation and often completely missing.

In literature there are several rainfall-runoff transformation models, and different classifications (*Maione,* 1977; *Moisello,* 1985). Among the various models, of remarkable interest are the "mathematical models of distributed type". A rainfall-runoff simulation improvement can be obtained by taking into consideration models of physically based distributed type which allow accounting for the heterogeneities of the topography, the vegetation and the soil, and the non uniform distribution of the precipitation inside a basin. The growing availability of cartography in digital form (DEM) and the coming of Geographic Information Systems (GIS) together with the development of more and more progressive and powerful calculation means has directed the research toward this type of models in which the representation of the variables concerning the input and the basin features can be assumed as changing in time and space. In the mathematical modelling a simplification is made by identifying elementary cells in which these features are considered as uniform. However, the restrict description and simplification of the various hydrologic processes have put in evidence, in real cases, the limits of the applicability of these models both for the complexity of the calculations and for the information necessary to an acceptable knowledge of the morphological features of the basin and of the spatial and temporal distribution of the precipitation. For this reason, in the last few years, hydrologic studies of distributed type directed towards the analysis of special aspects of the hydrologic cycle (infiltration, propagation of flood in the network) have taken start.

2. METHODOLOGY

2.1 Two Components Extreme Value

The TCEV model (*Rossi et al.*, 1984; *Fiorentino et al.*, 1987; *Ferrari and Versace*, 1995; *Versace and Ferrari,* 1997; *Gabriele and Iiritano,* 1994; *Versiani and Carneiro* 2000), considers that there are two independent series of independent and identically distributed variables $Z_{1i,j}$ (j = 1,...,K_1) and $Z_{2i,j}$ (j = 1,...,K_2), generated by two Poisson processes, with respective parameters $\Lambda_1 = E\{K_1\}$ and $\Lambda_2 = E\{K_2\}$, with $\Lambda_1 > \Lambda_2$.

The cumulative distribution function (cdf) of the TCEV (Two Components Extreme Value) probability law is:

$$F_X(x) = \exp\left[-\Lambda_1 \exp(-x/\theta_1) - \Lambda_* \Lambda_1^{(1/\theta_*)} \exp(-x/\theta_*\theta_1)\right] \tag{1}$$

The parameters θ_* and Λ_* used in the regionalization procedure are defined by:

$$\theta_* = \frac{\theta_2}{\theta_1} \tag{2}$$

$$\Lambda_* = \frac{\Lambda_2}{\Lambda_1^{(1/\theta_*)}} \tag{3}$$

The parameters θ_1 and Λ_1 describe the most frequent events (the basic series), while θ_2 and Λ_2 describe the rarest events (the outlier series). The first level of the regionalization consists in searching for homogeneous regions characterised by similar coefficients of skewness, such that they can be considered as constant. In each region the parameters θ_* and Λ_* are assumed as not changing from site to site. The second and third levels of the regionalization method consist of the search of homogeneous sub-regions. In this level we assume that homogeneous sub-regions with respect to the coefficient of variation exist within the region where the coefficient of skewness is constant. In each sub-region the parameters θ_*, Λ_* and Λ_1 are assumed not to change from site to site.

2.2 Rainfall-Runoff model

The hydrologic model used for the rainfall-runoff simulations is a semi-distributed type. It has a limited number of lumped parameters with a clear physical meaning, and his structure considers the spatial and temporal variability of the fields of precipitation and of morphological features of the basin. It is a model of the type "object-oriented" and so the basin is represented through the combination of “hydrologic objects” connected depending on the detail level of the simulation. The “objects” used in the schematization of a hydrographical basin are “sub-basin”, “reservoir”, “junction” and “channel”.

Each of these “objects” is a linear element, with a hydrologic-hydraulic behaviour definable through opportune mathematical relations of link between points of outlet of sub-basin. In particular, every component can be characterized by one or more physical processes, in turn, can be simulated through one or more alternative mathematical procedures, defined methods. The topologic connection of the elements and the determination of their features take place automatically way using the information derived from the digital terrain models (DTM) due to techniques of integration between hydrologic modelling and geographic information system.

In relation to the number and to the geographic position of the hydrometric stations present in the basin, and in relation to the hydrologic features and to the level of detail of the rainfall-runoff simulation, it is possible to realize different topologic analysis schemes for the same network. Furthermore, the system is equipped with a calibration procedure totally automatic which is implemented on every hydrometric measurement station and at the outlet of the main basin. In this case the topologic scheme used to represent the basins has been limited to the use of an element “sub-basin” and a “junction”, in the closing section, coinciding with the hydrometric station. That has been principally done to evaluate the hypothesis of using the model with pre-announcement purpose, to limit the calculation time necessary for the simulations.

2.3 Initial and constant rate loss model

The underlying concept of the initial and constant-rate loss model is that the maximum potential rate of precipitation loss, f_c, is constant throughout an event. An initial loss, I_a, is added to the model to represent interception and depression storage. Interception storage is a consequence of absorption of precipitation by surface cover, including plants in the watershed. Depression storage is a consequence of depressions in the watershed topography, water is stored in these and eventually infiltrates or evaporates. This loss occurs prior to the onset of runoff. Until the accumulated precipitation on the pervious area exceeds the initial loss volume, no runoff occurs.

2.4 SCS Curve Number loss model

The Soil Conservation Service (SCS) Curve Number (CN) model estimates precipitation excess as a function of cumulative precipitation, soil cover, land use, and antecedent moisture. This method is based on two parameters, the Initial Abstraction value and the Curve Number. The first one depends on the infiltration; the second one depends on the type and the use of the soil and on the antecedent moisture conditions. CN values range from 100 (for water bodies) to approximately 30 for permeable soils with high infiltration rates (*USACE*, 2000). Publications from the Soil Conservation Service (1971 and 1986) provide further background and details on use of the CN model.

2.5 Modified Clark model

The method schematizes the way between sub-zone k and the closing section through a combination of a channel and a reservoir, both linear, which describe the translation and the store phenomena. This method is based on two parameters, the mean velocity value V_m, supposed constant, in each cell of the basin, and the value of the ratio between the delay time of the hypothetical linear reservoir at the closing section and the total resident time of the rainfall, β, inside the basin.

2.6 Diffusive model

For this scheme the function of answer $h_k(t)$, concerning the way which joins the generic cell of the DTM to the basin outlet, is obtained through a statistical distribution of the type "first-passage-time distribution". This method is based on two parameters, the mean velocity value V_m, in each cell of the basin, and the Peclet number of the cell. In this method so far considered it is assumed that the relationship $Pe=V_p l_p/d_p$ defined as number of Peclet of the single cell, remain constant in the entire basin (*Calabretta et al.*, 2000) and therefore it can be used as parameter of calibration which allows to determine, locally, the coefficient of dispersion d_p. Based on the formulated hypotheses the unitary hydrograph can be determined by estimating the two and parameters V_m e P_e.

2.7 Base-Flow model

For the simulation of the baseflow, low-pass method (*Chapman*, 1999) was applied. The baseflow value is computed weighing the value of the flow at time t and baseflow at the time t-1, using a parameter ρ.

3. APPLICATIONS

The Calabria region is in the furthest south of Italy, with an area of 15080 km^2 and a perimeter of about 818 km. Towards the north it borders Basilicata region for about 80 km, the south-eastern side is washed by the Ionian Sea and the western one by the Tyrrhenian Sea, for a total of 738 km of coasts. Calabria has an oblong shape with a length of 248 km and a width included between a maximum of 111 km (between Punta Alice and Capo Bonifati) and a minimum of 31 km (between Squillace’s and S. Eufemia’s Gulfs). Calabria is one of the most mountainous regions of Italy, since 42% of the land is mountainous, 49% hilly and only the 9% is flat. The maximum and average altitudes are 2267 m a.s.l. and 597 m a.s.l. respectively.

In Calabria there are 36 main hydrographical basins divided into 75 secondary and into 591 elementary. Even though they are hundreds, streams of Calabria are, however, all of short length, with basins of limited extension and high slopes. Due to the morphological features of the streams and to the presence of waterproof formation, rainfall swallowed quickly and the hydrometric regime depends on the meteoric inflows. Only some of the main streams, for most coming from the Sila Mountain, have a constant hydrometric regime (*Caloiero et al.*, 1990).

3.1 Spatial and temporal evolution

The evaluation of the return period for the maximum rainfalls of duration 1, 3, 6, 12 and 24 hours observed in some rain gauges during the event, from 6:00 a.m. of 12th November to 6:00 a.m. of 13th November, was performed.

In the first six hours, from 6:00 a.m. to 12:00 a.m. of 12th November, the event localized over Aspromonte Mountain and in the territories of Gioia Tauro. Maximum precipitation values have been observed in the rain gauges of Santa Cristina d'Aspromonte (105.2 mm) and Gioia Tauro (42.6 mm) (Figure 1a).

From 12:00 a.m. to 18:00 p.m. of 12th November the event interested the other territories of the region and in particular the Amato River valley for province of Catanzaro and the middle-high Savuto River valley, the Crati River valley and the upper Ionian side for province of Cosenza. Maximum precipitation values have been observed in the rain gauges of Parenti (102.2 mm), Rogliano (74.4 mm), Tiriolo (59.2 mm), Gioia Tauro (54.4 mm) and Cropalati (47.2 mm) (Figure 1b).

From 18:00 p.m. to 24:00 p.m. of 12th November, the event interested all the territories of Catanzaro, Cosenza and Vibo Valentia with an increasing of intensity in Aspromonte Mountain and in the territories of Gioia Tauro. Maximum values precipitation have been observed in the rain gauges of Parenti (120.2 mm), Tiriolo (115.8 mm), Camigliatello (81 mm), Savelli and Cerenzia (68.4 mm), Feroleto della Chiesa (67.8 mm) and San Pietro di Caridà (67.4 mm) (Figure 1c).

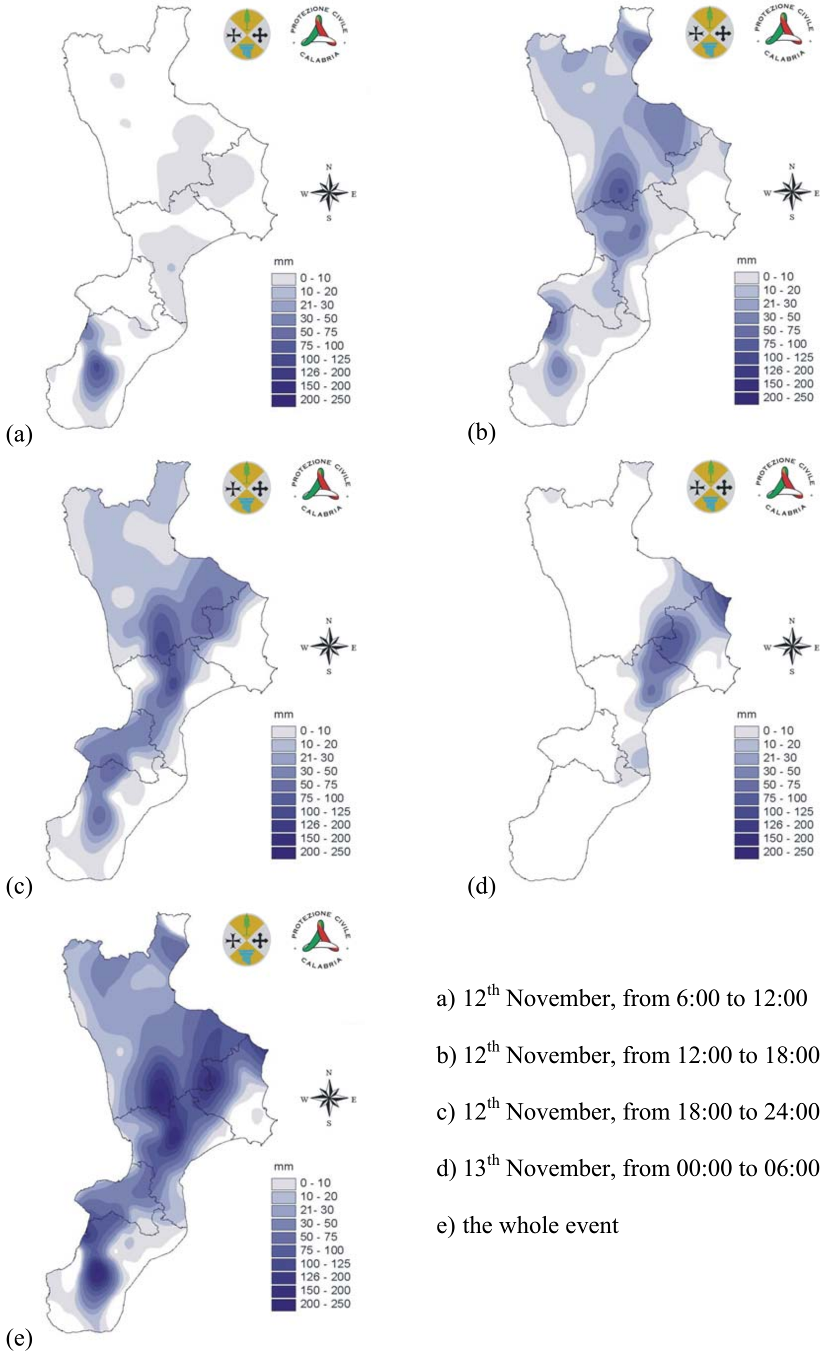
In the last six hours of the event, from 00:00 a.m. to 6:00 a.m. of 13th November, precipitations decrease mainly in Crotone territory and, to a lesser extend, in the territories of Catanzaro and Cosenza. Maximum precipitation values are stored in the rain gauges of Cirò Marina Volvito (114.4 mm), Pagliarelle (97.2 mm), Cotronei (90.6 mm), Cerenzia (72.6 mm), Catanzaro (55.4 mm) and Albi (51.0 mm). During its evolution, from 6:00 a.m. of 12th November to 6:00 a.m. of 13th November the event interested the entire region. Maximum precipitation values are observed in the pluviometric stations of Parenti (223.6 mm), S. Cristina d'Aspromonte (206.4 mm), Tiriolo (181.6 mm), Cerenzia (158.2 mm), Cirò Marina Volvito (127.6 mm) and Savelli (125.2 mm).

3.2 Determination of the return period

For the rain gauges in which, during the evolution of the event, maximum values of precipitation were stored, a statistical analysis was performed to determine the values of the return period (T) at different levels of time aggregation (1 hour, 3 hours, 6 hours, 12 hours and 24 hours). The TCEV probabilistic model has been applied to hourly data recorded in the rain gauges listed in Table 1, that also show maximum rainfall values.

Code	**Rain Gauge**	**Basin**	**Elevation** (m)	h_{1hour} (mm)	h_{3hours} (mm)	h_{6hours} (mm)	$h_{12hours}$ (mm)	$h_{24hours}$ (mm)
1410	Cariati	Tra Trionto e Neto	10	39.8	64.4	87.6	88	133.8
1455	Cirò Marina Volv.	Tra Trionto e Neto	10	67.4	77.6	114.4	115.8	133.2
1570	Savelli	Neto	964	47.8	89.2	96.0	101.8	125.6
1580	Cerenzia	Neto	663	62.6	110.8	140.8	141.6	193.4
1724	Cotronei	Tacina	530	37.6	82.2	96	96.6	124
1830	Albi	Alli	710	51.4	90.4	90.8	92.4	105.4
2540	Santa Cristina	Petraie	510	78.8	139.0	145.0	205.8	206.6
2665	S.Pietro di Caridà	Mesima	750	50.4	66.8	67.4	73.4	105.8
2740	Rosarno	Mesima	61	34.6	43.6	44.2	84.2	100.8
2890	Tiriolo	Amato	690	81.4	120.2	120.2	174.6	181.2
2990	Parenti	Savuto	830	85.4	118.6	120.2	222.4	223.6
3000	Rogliano	Savuto	650	39.2	70.6	74.4	102.6	102.8

Table 1 – Maximum rainfall values observed with different levels of time aggregation.



a) 12th November, from 6:00 to 12:00

b) 12th November, from 12:00 to 18:00

c) 12th November, from 18:00 to 24:00

d) 13th November, from 00:00 to 06:00

e) the whole event

Figure 1. Maps of the cumulate precipitations stored during the event.

The analysis with the TCEV model was performed at the first level of regionalization for the rain gauges with an historical dataset of minimum 30 years, at second level of regionalization for the rain gauges with an historical dataset of minimum 10 years. For all the stations the analysis was performed at the third level of regionalization (Figure 2).

From the analysis of the return period (Table 2), there are relevant results in Parenti rain gauge with return periods of 306 years, 220 years and 436 for aggregations of 1 hour, 3 hours and 12 hours respectively. There are other relevant results in Tiriolo rain gauge with return periods of 110 years and 87 years for aggregations of 1 hour and 3 hours respectively.

Other remarkable results point out from rain gauges of Rogliano with return periods of 84 years and 29 years for aggregations of 3 hours and 6 hours respectively and San Pietro di Caridà, Cirò Marina Volvito, Santa Cristina d'Aspromonte e Cerenzia with return periods of 65 years, 41 years, 34 years and 29 years respectively, for 1 hour aggregations.

Rain Gauge	Level	T (hours)				
		1	3	6	12	24
Albi	I	11	14	5	2	2
Cariati	III	5	6	8	3	4
Cerenzia	III	29	30	22	7	5
Cirò Marina Volvito	III	41	13	22	8	4
Cotronei	III	4	11	6	3	2
Parenti	III	306	220	52	436	75
Rogliano	I	18	84	29	22	8
Rosarno	I	4	11	2	22	4
San Pietro di Caridà	I	65	39	8	7	3
Santa Cristina	III	34	25	5	5	2
Savelli	II	11	14	5	2	2
Tiriolo	I	110	87	25	28	9

Table 2. Return period values.

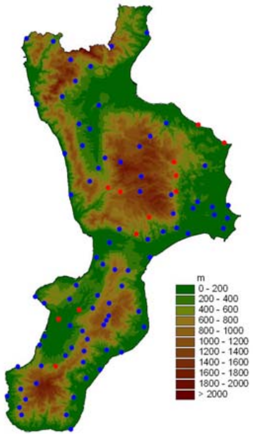


Figure 2. Maps of total rain gauges (in blue) and of rain gauges (in red) in which TCEV model was applied.

3.3 Rainfall-runoff simulation

A rainfall-runoff model was applied in four of the principal basins of the Calabria Region: the Neto River at the closing section of Rocca di Neto and the Tacina River at the closing section of Serrarossa for the Ionian side, the Mesima River at the closing section of Sbarretta and the Petrace River at the closing section of Gonia for the Tyrrhenian side. The initial and constant rate loss model, the SCS Curve Number loss model, the modified Clark model and the diffusive model were combined and applied for the simulations.

The combinations of different loss models and UH models applied with the same base-flow method are:

a. CN, Modified Clark, Low-pass;
b. Initial and Constant Rate, Modified Clark, Low-pass;
c. CN, Diffusive, Low-pass;
d. Initial and Constant Rate, Diffusive, Low-pass.

In Tables 3-6 the values of the parameters obtained by the simulations are shown:

Basin	Ia	CN	V_m	β	ρ	O.F.	EQ_{peak}	ET_{peak}	BIAS	E.C.
Neto	49.86	80.4	4.51	0.1	0.55	47.57	-3.246	-0.333	46.67	0.938
Tacina	37.01	60.52	4.61	0.61	0.99	12.25	-9.781	0.333	11.75	0.87
Mesima	0.01	39.23	4.81	0.84	0.98	11.36	-16.074	0.667	9.77	0.859
Petrace	0.01	34.43	4.72	0.1	0.5	96.03	-29.051	6.667	78.03	0.285

Table 3. Results using CN, Modified Clark, Low-pass.

Basin	Ia	CN	V_m	β	ρ	O.F.	EQ_{peak}	ET_{peak}	BIAS	E.C.
Neto	49.16	11.48	0.91	0.19	0.57	49.1	-6.419	-0.667	44.9	0.942
Tacina	28.37	19	1.53	0.66	0.99	11.17	-10.084	-0.333	10.75	0.891
Mesima	21.47	10.17	2.1	0.86	0.99	9.71	-14.307	0	8.41	0.895
Petrace	15.6	12.62	4.85	0.21	0.97	33.66	0.35	0	29.5	0.898

Table 4. Results using Initial and Constant Rate, Modified Clark, Low-pass.

Basin	Ia	CN	V_m	β	ρ	O.F.	EQ_{peak}	ET_{peak}	BIAS	E.C.
Neto	50	82.45	4.95	99.9	0.8	48.03	-4.797	-0.667	47.35	0.936
Tacina	50	77.71	0.51	94.3	0.98	12.85	-8.743	-0.333	12.86	0.844
Mesima	29.34	81.34	0.51	20.6	0.96	21.04	10.67	0	19.13	21.04
Petrace	0.012	34.67	2.99	99.5	0.5	97.06	-29.23	6.667	79.2	0.267

Table 5. Results using CN, Diffusive, Low-pass.

Basin	Ia	CN	V_m	β	ρ	O.F.	EQ_{peak}	ET_{peak}	BIAS	E.C.
Neto	50	9.2	0.54	100	0.77	95.74	-14.428	-1	91	0.764
Tacina	18.17	21.48	0.51	100	0.95	23.61	-4.463	-1	24.42	0.439
Mesima	35.71	2.18	0.51	22.4	0.97	23.14	19.051	-0.333	21.09	0.348
Petrace	21.77	10.38	2.28	30.9	0.95	24.96	-5.58	-0.333	24.48	0.93

Table 6. Results using Initial and Constant Rate, Diffusive, Low-pass.

where:

$$\mathrm{O.F.} = \sqrt{\frac{\sum_{t=1}^{n}\left[Q_{obs}(t) - Q_{comp}(t)\right]^2 \cdot \frac{\left[Q_{obs}(t) + Q_m(t)\right]}{2Q_m}}{n}} \qquad \begin{array}{l} Q_m = \frac{1}{n}\sum_{t=1}^{n} Q_{obs}(t) \text{ mean discharge observed} \\ Q_{obs}(t) \text{ discharge observed at time } t \\ Q_{comp}(t) \text{ discharge computed at time } t \end{array} \tag{3}$$

$$EQ_{peak} = \frac{Q_{peakOBS} - Q_{peakCOMP}}{Q_{ppeakCOMP}} \tag{4}$$

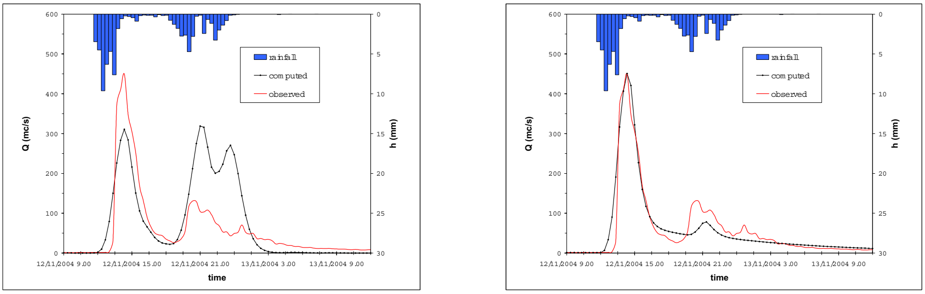
$$ET_{peak} = \frac{T_{peakOBS} - T_{peakCOMP}}{T_{peakOBS}} \cdot \frac{\Delta t}{60} \tag{5}$$

$$\mathrm{BIAS} = \sum_{t=1}^{n} \frac{Q_{obs}(t) - Q_{comp}(t)}{n} \tag{6}$$

$$EC = 1 - \frac{\sum_{t=1}^{n}\left[Q_{obs}(t) - Q_{comp}(t)\right]^2}{\sum_{t=1}^{n}\left[Q_{obs}(t) - Q_{m}(t)\right]^2} \tag{7}$$

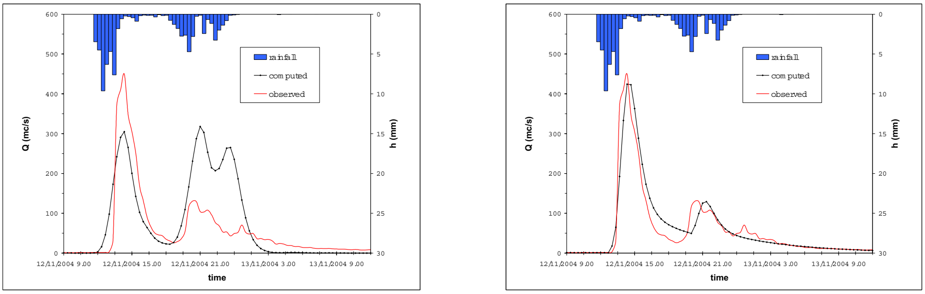
The Petrace River at the closing section of Gonia presents an area of 402.87 km^2 with a perimeter of 129.7 km and a slope of the main stream of 2.63 %. The application of the rainfall-runoff model gives good results (Figure 3) with the use of the initial and constant rate loss model. In particular the best simulation is made by using the initial and constant rate loss model and the diffusive model. The Mesima River at the closing section of Sbarretta presents an area of 461.94 km^2 with a perimeter of 141.92 km and a slope of the main stream of 0.82 %.

The application of the rainfall-runoff model gives acceptable results (Figure 4) with the use of the modified Clark model. In particular the best simulation is made by using the initial and constant rate loss model and the modified Clark model. The Neto River at the closing section of Rocca di Neto presents an area of 845.76 km^2 with a perimeter of 185.92 km and a slope of the main stream of 1.99 %. The application of the rainfall-runoff model gives good results (Figure 5) with the use of the modified Clark model. In particular the best simulation is made by using the SCS Curve Number loss model and the modified Clark model. The Tacina River at the closing section of Serrarossa presents an area of 241.17 km^2 with a perimeter of 114.88 km and a slope of the main stream of 3.74 %. The application of the rainfall-runoff model gives good results (Figure 6) with the use of the SCS Curve Number loss model. In particular the best simulation is made by using the SCS Curve Number loss model and the diffusive model.



CN + Clark

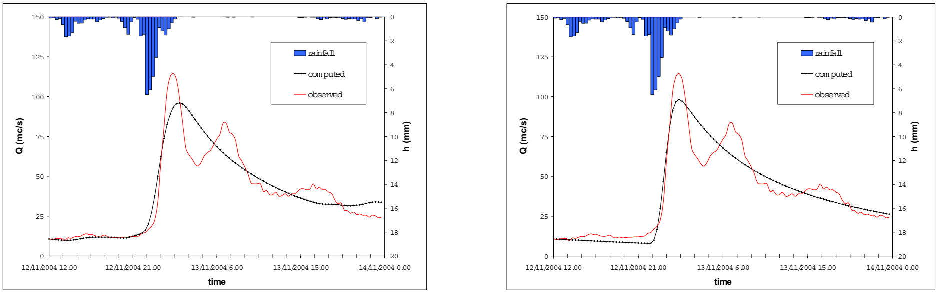
Initial and Constant + Clark



CN + diffusive

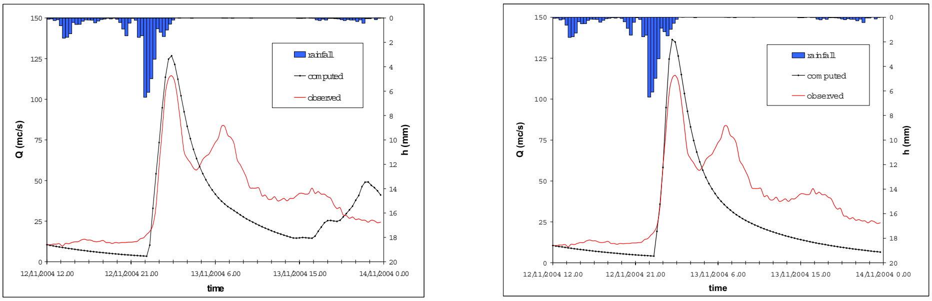
Initial and Constant + diffusive

Figure 3. Rainfall-runoff simulation on the Petrace River.



CN + Clark

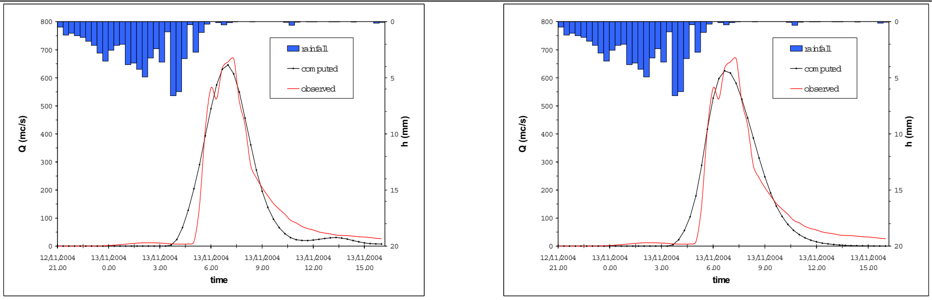
Initial and Constant + Clark



CN + diffusive

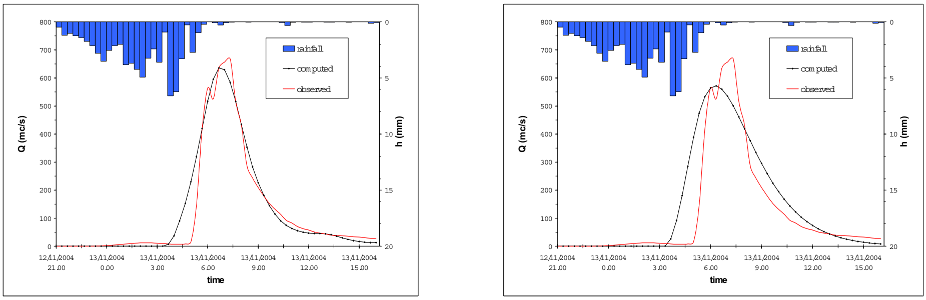
Initial and Constant + diffusive

Figure 4. Rainfall-runoff simulation on the Mesima River.



CN + Clark

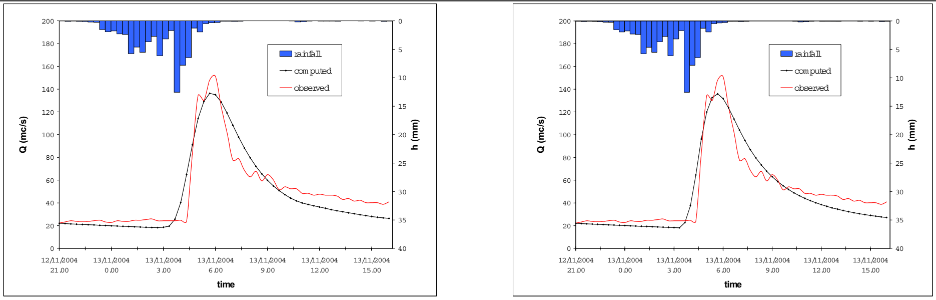
Initial and Constant + Clark



CN + diffusive

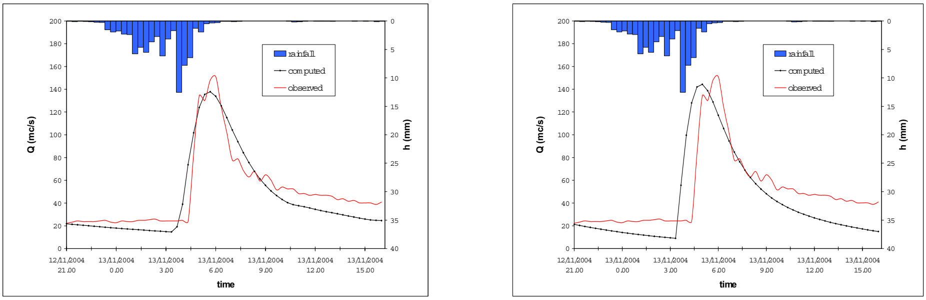
Initial and Constant + diffusive

Figure 5. Rainfall-runoff simulation on the Neto River.



CN + Clark

Initial and Constant + Clark



CN + diffusive

Initial and Constant + diffusive

Figure 6. Rainfall-runoff simulation on the Tacina River.

4. CONCLUSIONS

The analysis of extreme rainfall events is very important, in particular in territories as the Calabria region in which many basins present areas less than 100 km^2. In fact, for those basins and in condition of high soil moisture, due to a extreme rainfall event flash flood can be generated.

The rainfall event occurred in Calabria between 12th and 13th November 2004 is one of the biggest of the last years. The analysis with the TCEV model has shown high return period of the rainfall in the entire region. The rainfall-runoff simulation has generally given good results. In particular, observed and computed hydrographs are very similar and there is a good correspondence in the time of the maximum curve peak. The results allow to set the WRROOM model for the basins interested by the event.

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