Effects of soil moisture parameterization on a real time flood forecasting system based on rainfall thresholds

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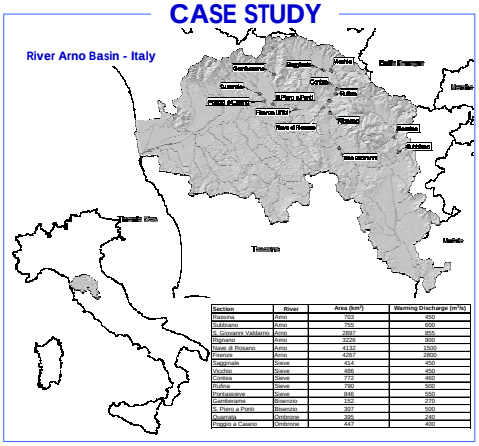
ABSTRACT: The rainfall threshold is the cumulated rainfall depth required to cause flooding flow at the basin outlet. Thresholds are used in operational flood forecasting systems as a means to provide flood warnings based on the comparison with rainfall amounts (either observed or forecasted). This approach results in a simple system to be used also by non expert technicians. It is a complementary tool to 'classical' rainfall-runoff modelling system. Despite the simple usage, a flood forecasting system based on thresholds requires great accuracy in definition of the critical rainfall. Special attention is to be kept in modelling the basin moisture condition. The aim of this paper is to assess a reliability analysis of a framework for the definition of rainfall thresholds using the distributed hydrological model FEST. The AMC value (Antecedent Moisture Condition) of conventional SCS-CN method is employed to describe the soil moisture initial condition. The case study is the Arno river basin located in Italy. A detailed investigation of the most recent flood events shows that a precise accounting for the watershed wetness based on analysis of actual soil moisture can improve the prediction accuracy of flood forecasting systems.

CASE STUDY

River Arno Basin - Italy



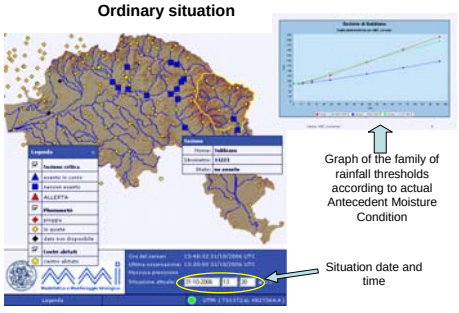
Section	River	Area (km²)	Warning Discharge (m³/s)
Rassina	Arno	703	450
Subbiano	Arno	755	600
S. Giovanni Valdarno	Arno	2897	855
Rignano	Arno	3229	900
Nave di Rosano	Arno	4132	1500
Firenze	Arno	4287	2800
Saggiolo	Sieve	414	450
Vicchio	Sieve	488	450
Contea	Sieve	772	450
Rufina	Sieve	790	500
Pontassieve	Sieve	846	550
Gamberame	Rosenzio	152	270
S. Piero a Ponti	Rosenzio	307	500
Quarrata	Ombrone	395	240
Poggio a Caiano	Ombrone	447	400

MIMI

Modello Integrato Meteo Idrologico
(Meteo Hydrologic Integrated Model)

Real time flood forecasting based on rainfall thresholds

Ordinary situation

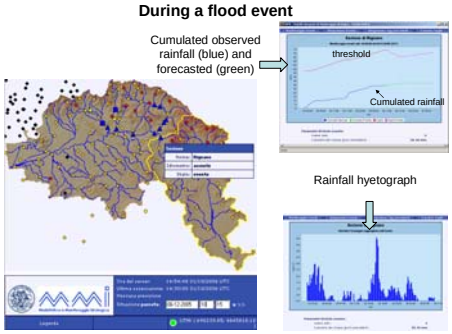


Graph of the family of rainfall thresholds according to actual Antecedent Moisture Condition

Situation date and time

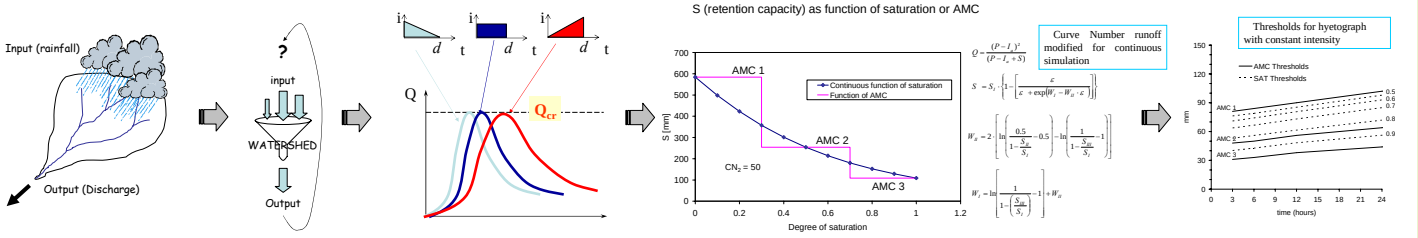
During a flood event

Cumulated observed rainfall (blue) and forecasted (green)



Rainfall hyetograph

RAINFALL THRESHOLDS ESTIMATION



Thresholds are defined as a function varying with duration, soil wetness condition and shape of the hyetograph. Wetness condition can be parameterized with classical AMC classes based on past five days rainfall, or with actual average soil moisture of the basin.

RELIABILITY ANALYSIS 1

Historical events from 1992

outcome	River Section				
	Nave di Rosano	Subbiano	Pontassieve	S. Piero a Ponti	Poggio a Caiano
hit (h)	2	2	4	0	1
false alarm (f)	1	3	1	1	0
miss (m)	1	1	1	0	0
correct reject. (c)	8	9	15	3	11
delayed hit (d)	0	2	2	0	0
Total (n)	12	17	23	4	12

index	River Section				
	Nave di Rosano	Subbiano	Pontassieve	S. Piero a Ponti	Poggio a Caiano
POD	0.667	0.667	0.800	-	1
FAR	0.111	0.250	0.063	0.250	0
CSI	0.615	0.545	0.759	-	1
CPI	0.833	0.647	0.826	0.750	1

A warning, *W*, is defined as a forecast of an occurring event, *E*. The number, *n*, of total observations consists of the occurred events *e*, and the non-events *e'*; the total number of warnings is *w*, and the number of no-warnings is *w'*. The following outcomes are defined: (1) a hit, if an event occurred and the warning was provided (*h* is the number of hits); (2) a false alarm, if an event did not occur but the warning was provided (*f* is the number of false alarms); (3) a miss, if an event occurred but the warning was not provided (*m* is the number of misses); (4) a correct rejection, if an event did not occur and the warning was not provided (*c* is the number of correct rejections); (5) a delayed hit, if an event occurred and a warning was provided later (*d* is the number of delayed hits).

The skill of the forecasting system can be represented on the basis of the probability of detection (POD) defined as $h/(h+m)$, the false alarm ratio (FAR) defined as $f/(f+c)$, the critical success index (CSI) defined as 1/(1/(1-FAR)+(1/POD)-1) and the correct performance index (CPI) defined as $(c+h)/n$.

Observations	Forecasts		
	Warning (W)	No warning (W')	Total
Event (E)	h	m	e
Non event (E')	f	c	e'
Total	w	w'	n

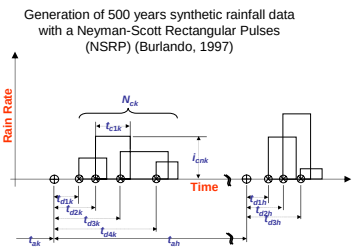
RELIABILITY ANALYSIS 2

Synthetic events (500 years)

outcome	River Section				
	Nave di Rosano	Subbiano	Pontassieve	S. Piero a Ponti	Poggio a Caiano
hit (h)	110	197	261	90	33
false alarm (f)	13	36	43	24	1
miss (m)	56	56	40	29	11
correct reject. (c)	197	331	405	116	153
delayed hit (d)	19	10	5	4	1
Total (n)	395	630	754	263	199

index	River Section				
	Nave di Rosano	Subbiano	Pontassieve	S. Piero a Ponti	Poggio a Caiano
POD	0.663	0.779	0.867	0.756	0.75
FAR	0.062	0.098	0.096	0.171	0.006
CSI	0.635	0.718	0.794	0.654	0.746
CPI	0.777	0.838	0.883	0.783	0.935

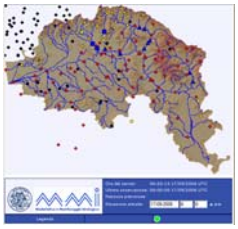
Generation of 500 years synthetic rainfall data with a Neyman-Scott Rectangular Pulses (NSRP) (Burlando, 1997)



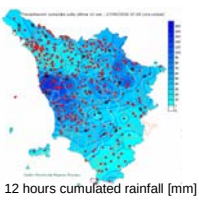
Rainfall data as input of distributed hydrological model (the same used for threshold estimation)

THE 17 SEPTEMBER 2006 FLOOD EVENT

The Summer of 2006 was dry. It was characterized by some rare and localized convective phenomena with a total precipitation of 110 mm observed from June to the 14 September 2006. During the night between Saturday 16 September 2006 and Sunday 17 September 2006, a heavy rainfall was registered over the entire Arno River basin. The greater intensity was on the southeast part, the Chiana tributary. The rain gauge at Pratomagno, Chiana subbbasin, recorded a 15-hour rainfall of 180 mm. The cumulative rainfall measured in twenty hours on the basin of Nave di Rosano was 73 mm (recurrence interval estimated to be about 10 years). As a result of the intense rainfall, flooding occurred in a less severe way than expected. The observed peak flow of the Arno river at Nave was 600 m^3/s (the flood warning is 1500 m^3/s) with a recurrence time interval lesser than two years.

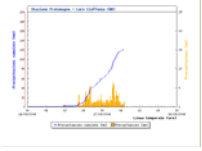


Alarms at Nave di Rosano, Rignano and S. Giovanni Valdarno according to AMC thresholds

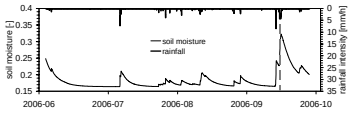


12 hours cumulated rainfall [mm]

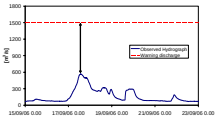
Cumulated rainfall at Pratomagno [mm]



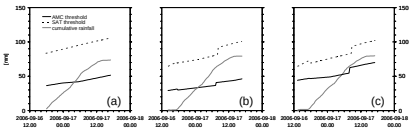
Simulation of water balance with distributed hydrological model



Observed hydrograph at Nave di Rosano



SAT thresholds perform succesfully



CONCLUSIONS: a method for the estimation of the rainfall thresholds based on the search of the solution of the inverse hydrological problem was presented. Application of the warning system to the historical and synthetic flood events of the Arno River basin showed an high degree of reliability. However, in the most recent flood event occurred on the Arno River basin, a false alarm was issued at three sections. The error is due to an incorrect estimation of the basin wetness index. The SCS method which distinguishes three AMC categories on the basis of the only past precipitation is unsuitable, if evapotranspiration has a key role in soil moisture dynamic. The use of the actual soil moisture as basin wetness index, in conjunction with a method for estimation of soil moisture at the beginning of the rainstorm, takes to an improved result.

The next step will be to extend the reliability analysis of the SAT thresholds to the historical events of the River Arno basin.

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