Mediterranean Storms
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A REAL TIME FLOOD FORECASTING SYSTEM BASED ON RAINFALL THRESHOLDS WORKING ON THE ARNO WATERSHED: DEFINITION AND RELIABILITY ANALYSIS

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ABSTRACT

The pluviometric flood forecasting thresholds are an easy method that helps river flood emergency management collecting data from limited area meteorologic model or telemetric raingauges. The thresholds represent the cumulated rainfall depth which generate critical discharge for a given section.
The thresholds are calculated for different sections of Arno river and for different antecedent moisture condition using the flood event distributed hydrologic model FEST. The model inputs are syntethic hietographs with different shape and duration.
The system reliability has been verified by generating 500 year syntethic rainfall for 3 important subwatersheds of the studied area.
The alarm system has been implemented in a dedicated software (MIMI) that gets measured and forecast rainfall data from Autorità di Bacino and defines the state of the alert of the river sections.

1 INTRODUCTION

The interest in flood forecasting systems has been heightened by recent large floods, such as those that occurred in the Elbe basin in summer 2002. The real-time flood forecasting systems help to anticipate hazardous events and allow sufficient time for action. This work concerns the settings of a flood forecasting system for some historically critical subsections of the Arno basin (Italy).

In the Mediterranean catchments the critical fluvial sections generally do not drain wide area (100-1000 km^2) which can comprehends steep slopes mountains. These small catchments often have a very short time of concentration which causes a very rapid rainfall-runoff transformation: the lonely hydrological modelling is not sufficient for the forecasting task with enough anticipation. In this case, quantitative rainfall forecasting is very useful: mesoscale circulation models can provide meteorological scenario 24-48 hours in advance.

It is then useful some *a priori* knowledge of dangerousness of precipitation fields.

A simple representation for the operative forecasting task is done by warning cumulative precipitation lines (pluviometric thresholds) which define, for a given duration and condition, the total amount of rainfall which cause flooding damages. By coupling meteorological Limited Area Model (LAM) and the pluviometric thresholds, a working operative flood forecasting system can be implemented.

This work presents:

- A framework for the estimation of warning pluviometric thresholds;
- Its application to some subbasin of the Arno watershed (Italy) and the integration in a java based client-server system for automatic monitoring of critical river sections;
- System reliability analysis based on historical and synthetic rainfall-hydrographs scenarios.

2 RAINFALL THRESHOLDS ESTIMATION

2.1 The hydrologic model

The rainfall thresholds estimation requests the solution of the inverse hydrological problem. The traditional problem of the hydrologic research is the modelling of transformation of rainfall into runoff; here the scope is, on the contrary, to define that amount of rainfall which produces a given flooding discharge in a river section.

For this work a distributed conceptual hydrologic model has been employed: the FEST98 (*Mancini*, 1990; *Mancini et al.*, 2000; *Montaldo et al.*, 2002) developed in the past years at the *Politecnico di Milano*. The choice of a distributed model was done for its capacity to represent spatial characteristics (*Rosso et al.*, 1994) of heterogenous basins as the Arno subwatersheds and to simulate hydrograph at any river sections as the critical sections often aren't coincident with the calibration ones. The FEST98 model is composed by two modules: the first computes the surface runoff for each cell according to SCS-CN method (*USDA*, 1986), the second computes the flow routing to the outlet on the hillslopes and in the river network according to Muskingum-Cunge technique. The FEST98 model has been calibrated at three subbasin outlet sections on the base of about ten years collected hydrographic and rainfall data (1992-2000).

2.2 Framework for thresholds estimation

For the solution of the inverse hydrologic problem the first assumption is the definition of the critical discharge. This is defined as that discharge which guarantees 1 meter average gap between floodplain and levees in the critical sector of the river.

A simple assumption has been made about the spatial distribution of the rainfall: infact, it was considered uniformly distributed over the basin. Considering variable spatial pattern in the rain fields, infact, would lead to increase the degree of freedom of the problem and as a consequence to find infinite solutions. This assumption may lead to the overestimation of rainfall thresholds: in fact spatial uniform rainfall is rare in the reality so, for local extreme rainfall events, you can observe a great discharge increment but a little amount of global rainfall over the entire basin.

The differentiation of rainfall temporal variability is considered by 3 types: constant intensity, linear increasing intensity and linear decreasing intensity.

A further variability factor is the initial state of the system, the antecedent moisture condition of the terrain. It is parameterized with the AMC index of the Soil

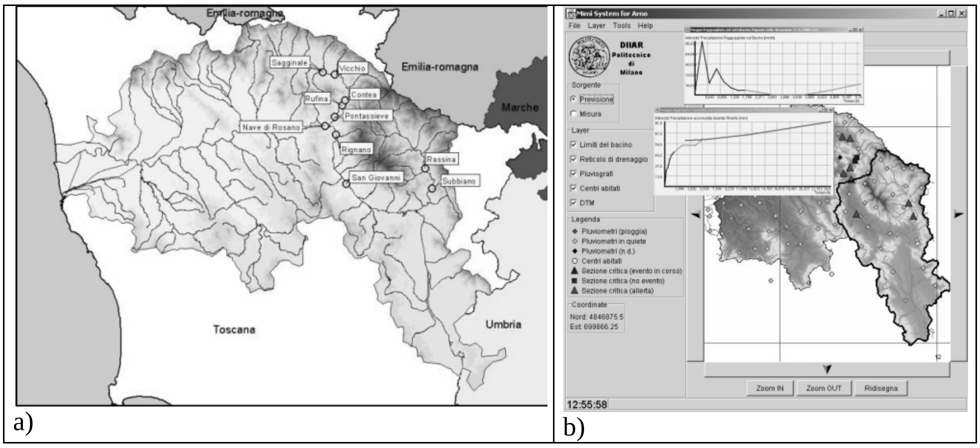

Figure 1. a) The critical river sections of the Arno basin (Italy). B) Example of analysis of an emergency situation. If a warning is encountered the warning signal is displayed at a river section (red triangle). The user can display in a plot the current situation of every critical section: measured and forecasted rainfall and pluviometric threshold are displayed

Conservation Services (*USDA*, 1986) which defines three classes of moisture content according to the precipitation amount of the past five days.

For every combination of the conditions mentioned above and for every given duration, the total amount of rainfall must be estimated using the FEST98 model. An automated iterative procedure based on a numerical optimization method (*Brent R.P.*, 1973) lead to the estimation of all the points which compound the thresholds. In figure 2.a an example of the resulting rainfall thresholds for the Subbiano section is reported: total critical rainfall is computed for the three AMC classes, for the three hyetograph types and for 3-6-12-24-48 hours duration. The value so estimated are linked together to give the critical pluviometric line.

3 SYSTEM WORKING MODALITY

For the usage of the warning system the alert watcher, as first, must choose the reference warning line by determining the type of hyetograph and the AMC class. By comparing this with the cumulative rainfall computed from the beginning of the event, the user can decide the alert status (Figure 2.b). When the cumulative rainfall line intercepts the warning line the warning is on.

The operations mentioned above may result difficult to do during an emergency situation so a dedicated automated software (MIMI, *Modello Integrato Meteo Idrologico*) has been implemented for the "*Autorità di Bacino del fiume Arno*" (The Arno Basin Authority).

MIMI is part of a wide warning system established by the Arno Authority (ARTU, http://www.arno.autoritadibacino.it/FAQ/faqartu.html).

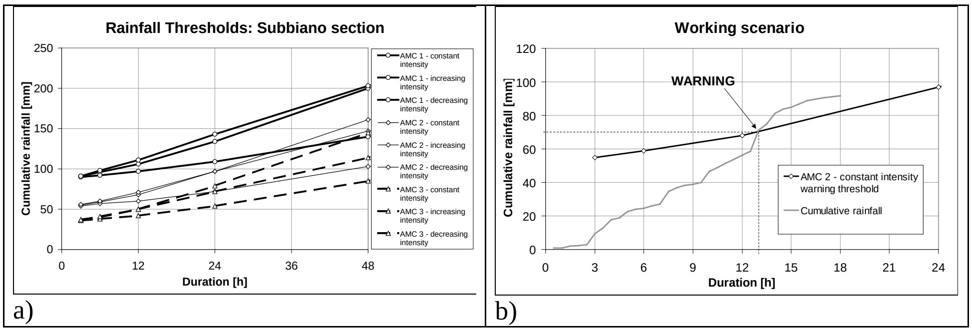

Figure 2. a) The computed rainfall thresholds for the Subbiano section. Total critical rainfall is computed for the three AMC class, for the three hyetograph type and for 3-6-12-24-48 hours duration. b) Example of usage of the warning system: after choosing the reference warning line by determining the type of hyetograph and the AMC class, the alert status is decided by comparing this with the cumulative rainfall computed from the beginning of the event.

MIMI is built up by three subsystems: the Dataserver, the Hydroserver and the mimiclient. The Dataserver collect rainfall measurements from the telemetric raingauges scattered over the basin and the forecasted rainfall data. The Hydroserver is the central unit which acts as the hydrologic model: computes cumulative rainfall, AMC class, hyetograph type and compare the warning threshold with the rainfall. The mimiclient can run on any internet connected computer: it shows to the user a graphical-GIS representation of the situation (Figure 1.b).

4 SYSTEM RELIABILITY ANALYSIS

A first reliability analysis is based on the historical rainfall and hydrograph data available for about past ten years (1992-2000). During this time we analyze the behavior of the system counting the number of times the warning system failed.
The typical encountered results are graphically shown in Figure 3.

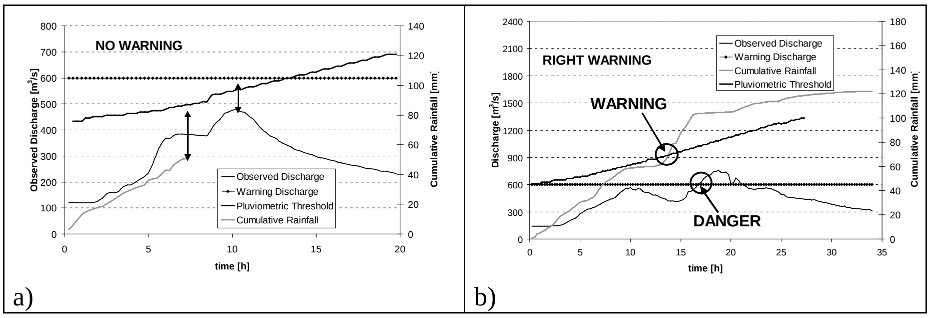

Figure 3.a. The Typical results encountered during the system reliability analysis

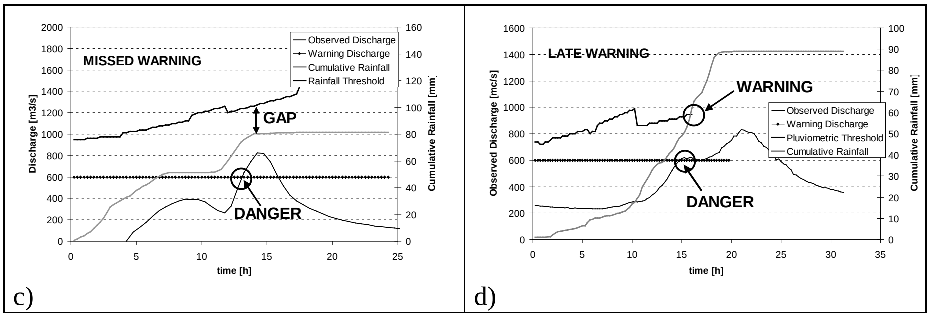

Figure 3.b. The Typical results encountered during the system reliability analysis

For the three main river section we report in Table 1 the results of the reliability analysis based on historical data. We can observe a good working degree (sum of "no warning" and "right warning") of 66.66% for the section of Nave di Rosano, 64.70% for the section of Subbiano and 78.36% for the section of Pontassieve. The wrong working degree (sum of "missing warning" and "late warning") is 16.67%, 17.64% and 13.05% respectively for the three sections.

TYPE OF ALARM	Section of Nave di Rosano		Section of Subbiano		Section of Pontassieve	
	N° events	%	N° events	%	N° events	%
NO WARNING	7	58.33	9	52.94	13	56.52
RIGHT WARNING	1	8.33	2	11.76	5	21.74
FALSE WARNING	2	16.67	3	17.65	2	8.7
MISSING WARNING	0	0	1	5.88	2	8.7
LATE WARNING	2	16.67	2	11.76	1	4.35
N°main events	12		17		23	
Good Working Degree [%]	66.66		64.7		78.36	

Table 1. System reliability analysis based on 1992-2000 historical collected data

As you can see from Table 1 the number of available historical events is not large enough for robust statistical analysis. For increasing the number of events a 500 years pluviometric data series has been synthetically generated according to Neymann Scott Rectangular Pulses (NSRP) algorithm (*Burlando*, 1989). Rainfall data have been generated for a reference fictitious raingauge for each main subbasin. Rainfall has been considered uniform distributed over the basin and a transformation into runoff has been done vith FEST98. The analysis of synthetic rainfall-runoff data gave the results shown in Table 2.

TYPE OF ALARM	Section of Nave di Rosano		Section of Subbiano		Section of Pontassieve	
	N° events	%	N° events	%	N° events	%
NO WARNING	201	46.53	295	46.46	425	52.28
RIGHT WARNING	164	37.96	224	35.28	289	35.55
FALSE WARNING	24	5.56	47	7.40	53	6.52
MISSING WARNING	34	7.87	59	9.29	41	5.04
LATE WARNING	9	2.08	10	1.57	5	0.62
N°main events	432		635		813	
Good Working Degree [%]	84.49		81.74		87.83	

Table 2. System reliability analysis based on 500 years synthetically generated data.

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