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Final Scientific Report

"Processing and hydrological analysis of the data of the November 2003 flood event in the Reno River closed at Pracchia"

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Abstract

An interesting case study for the implementation of the model was identified by the DISTART research group in the Northern Apennine Mountains, as requested by the LAMPIT research group. The identified watershed is the most upstream part of Reno river basin, at the closure section of Pracchia, located in the Tuscan part of the Reno watershed, close to the border with the Regione Emilia Romagna. Following an analysis of the rainfall and streamflow data collected from 2002 and 2007, the flood event that took place at the beginning of November 2003 (days 7-9) was identified as one of the most severe meteorological events in the whole observation period. The rainfall event was characterized by high rainfall intensities for several hours over the entire northern Apennine area and it corresponded to a significant flood hydrograph at the Pracchia cross-section. As required by the LAMPIT and CIRA, the following data, needed for the implementation of both hydrological/hydraulic and meteorological modelling, were collected, processed and delivered to either the CIRA or the LAMPIT research groups by the end of July 2009. In addition to the collection and processing of the above data, the DISTART group performed the research activities needed for issuing the following products (delivered to the LAMPIT research group on the 30th September 2009):

i) the spatially distributed hourly rainfall fields on the basis of the ground raingauge data, for each hour from 0.00, 7 November 2003 to 23.00, 9 November 2003, that is the total (or gross) hourly rainfall fields (in a matrix form, following the standards required by the LAMPIT research group, that is for cells of 20 m x 20 m) over the watershed area;
ii) an estimate of the spatio-temporal distribution of the net rainfall, that is of the part of the gross rainfall that actually becomes surface runoff (or overland flow). Net rainfall is obtained is subtracting from the gross rainfall the water losses ascribed to: interception by the vegetation, depression storage (or surface retention) and infiltration. A net rainfall map, over the watershed (plus buffer) area, was computed for each hour from 0.00, 7 November 2003 to 23.00, 9 November 2003.

Keywords: Rainfall data, hydrological analysis

JEL Classification:

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INTRODUCTION

In the latest years, spatially-distributed hydrological models have become an attractive perspective for both researchers and practitioner hydrologists, due to the increasing availability of computer power and the steady development of geographic information systems and remote sensing techniques, which help to handle the bulk of data needed as model input. Several distributed rainfall-runoff models, with a higher or lower degree of conceptualisation, have been developed in the last decade, where the internal descriptions of the various sub-processes are modelled attempting to represent the known physical processes.

In particular, as far as flood forecasting systems are concerned, recent advances have produced two-dimensional surface runoff models with direct access to large raster-based GIS data sets, like the one implemented by the LAMPIT research group: it is a single-event rainfall-runoff model that simulates flood runoff hydrographs, originated by surface runoff alone.

An interesting case study for the implementation of the model was identified by the DISTART research group in the Northern Apennine Mountains, as requested by the LAMPIT research group. The identified watershed is the most upstream part of Reno river basin, at the closure section of Pracchia, located in the Tuscan part of the Reno watershed, close to the border with the Regione Emilia Romagna.

The drainage area is not excessive (around 40 km^2), there are no reservoir upstream nor other important hydraulic structures that may modify the natural hydrological processes, of which the most important is certainly the surface runoff generated primarily through an infiltration excess type mechanism, considering also that the water tables are far from the surface and the base flow is generally low.

Detailed digital topographic information is available from the Topographic Service of the Regione Toscana, with contour lines digitalised with a vertical interval of either 5 or 10 meters for the entire watershed area.

Following an analysis of the rainfall and streamflow data collected from 2002 and 2007, the flood event that took place at the beginning of November 2003 (days 7-9) was identified as one of the most severe meteorological events in the whole observation period. The rainfall event was characterised by high rainfall intensities for several hours over the entire northern Apennine area and it corresponded to a significant flood hydrograph at the Pracchia cross-section.

As required by the LAMPIT and CIRA, the following data, needed for the implementation of both hydrological/hydraulic and meteorological modelling, were collected, processed and delivered to either the CIRA or the LAMPIT research groups by the end of July 2009.

1) Hourly rainfall depths in nine raingauge stations covering the watershed area, located both in the Toscana and in the Regione Emilia Romagna. Five stations are inside the basin or on its border (i.e. less than 100 m from the border) and the remaining four are at a distance from the border ranging from 800 m to 3 km. The rainfall data for the watershed area are available for every hour from 1 January to 31 December 2003.

2) River stages every 30 minutes at the Pracchia cross-section, along with the rating curve needed for the computation of the semi-hourly streamflow values.

3) Hourly rainfall depths measured in a set of 220 raingauges covering all the area of both Toscana (70 raingauges) and Emilia-Romagna (150 raingauges) Regions, for the 120 hourly time step of the 5 days from 0.00, 6 November 2003 to 23.00, 10 November 2003.

4) Hourly air temperature data collected in 125 surface weather stations scattered over all the Regione Emilia Romagna from 0.00, 6 November 2003 to 23.00, 10 November 2003.

5) Hourly relative humidity data collected in 34 surface weather stations in the Regione Emilia Romagna from 0.00, 6 November 2003 to 23.00, 10 November 2003.

6) Hourly wind direction data collected in 19 surface weather stations in the Regione Emilia Romagna from 0.00, 6 November 2003 to 23.00, 10 November 2003.

7) Hourly wind speed data collected in 15 surface weather stations in the the Regione Emilia Romagna from 0.00, 6 November 2003 to 23.00, 10 November 2003.

8) Hourly pressure data collected in 13 surface weather stations in the Regione Emilia Romagna from 0.00, 6 November 2003 to 23.00, 10 November 2003.

9) Hourly rainfall depths fields estimated from the radar data of two C-band dual-polarimetric weather radars located in the Regione Emilia Romagna, for the hours of the event in which rainfall

occurred, that is from 0.00, 7 November 2003 to 6.00, 9 November 2003, on a wide spatial area of around 5°(E-W) x 2.5°(S-N) lat-long degrees.

In addition to the collection and processing of the above data, the DISTART group performed the research activities needed for issuing the following products (delivered to the LAMPIT research group on the 30th September 2009):

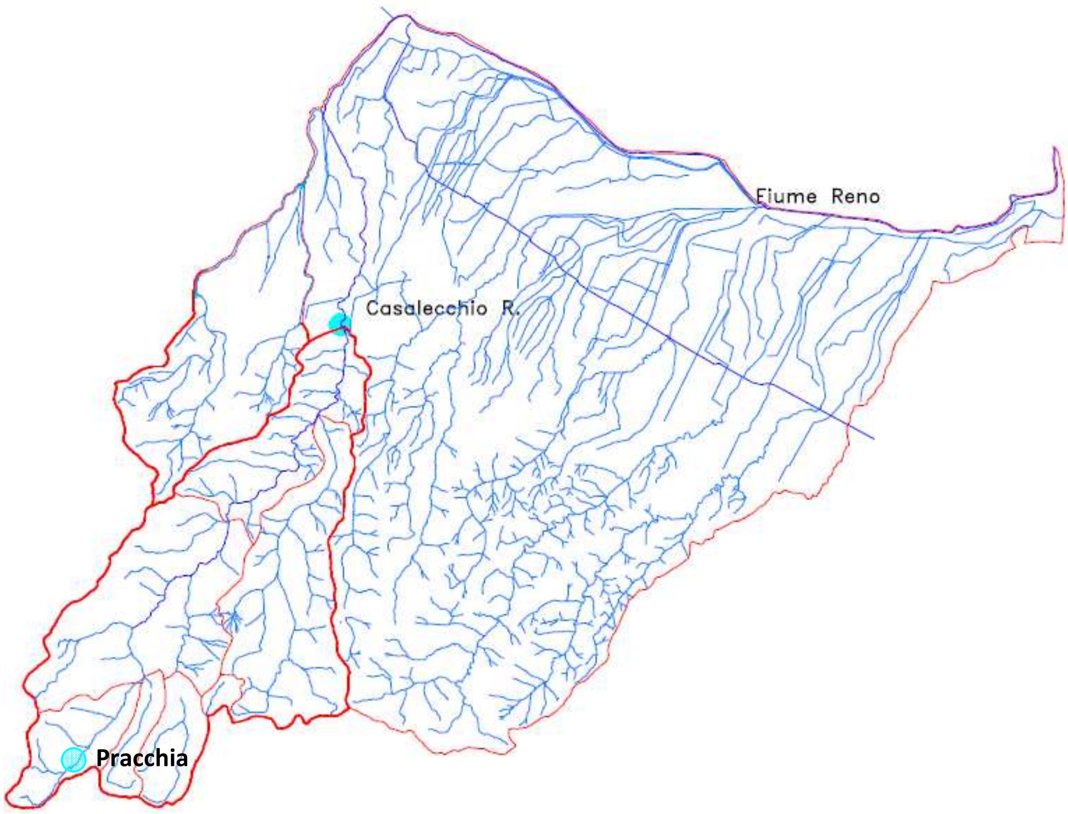
iii) the spatially distributed hourly rainfall fields on the basis of the ground raingauge data, for each hour from 0.00, 7 November 2003 to 23.00, 9 November 2003, that is the total (or gross) hourly rainfall fields (in a matrix form, following the standards required by the LAMPIT research group, that is for cells of 20 m x 20 m) over the watershed area (actually over an area slightly larger than the watershed area, in order to have a buffer zone just beyond the watershed border);

iv) an estimate of the spatio-temporal distribution of the net rainfall, that is of the part of the gross rainfall that actually becomes surface runoff (or overland flow). Net rainfall is obtained is subtracting from the gross rainfall the water losses ascribed to: interception by the vegetation, depression storage (or surface retention) and infiltration. A net rainfall map, over the watershed (plus buffer) area, was computed for each hour from 0.00, 7 November 2003 to 23.00, 9 November 2003. In order to implement an analysis of the infiltration/depression/infiltration losses to be subtracted by the gross rainfall fields, digital maps characterising the pedological characteristics and the land use over the watershed were collected and processed.

THE UPPER RENO WATERSHED

The analysed watershed is the most upstream part of Reno river basin, located in the Tuscan Apennines Mountains in North-Central Italy.

The drainage area of this part of the watershed, closed at the river cross-section of Pracchia (around 197 km far from the sea outlet of the Reno River), is almost 40 km^2 and the mean annual discharge is 2 m^3/s.



Watershed of the River Reno, at the sea outlet and at the closure of the mountain part (Casalecchio) and location of the water level gage of Pracchia (closure of the study watershed)

The average elevation is of 913 *m* above sea level, the highest peak and the outlet being at an altitude of 1634 and 610 *m* above sea level respectively. The hillslopes are significantly steep, with 47% of the area having slopes over 20°.

The basin is mountainous and covered primarily by soils and rocks of sedimentary origin (mainly sandy soil texture) The vegetation cover is constituted primarily by broad-leaved (77%) and mixed/coniferous (15%) forests.

Almost 94% of the watershed topsoil has from moderate to high vertical permeability and a good rainfall acceptance capacity; less than 5% of the surface, in the western part of the watershed, has low permeability and poor rainfall acceptance capacity and in the remaining 1%, around the closure section of Pracchia, the topsoil has a moderate rainfall acceptance capacity.

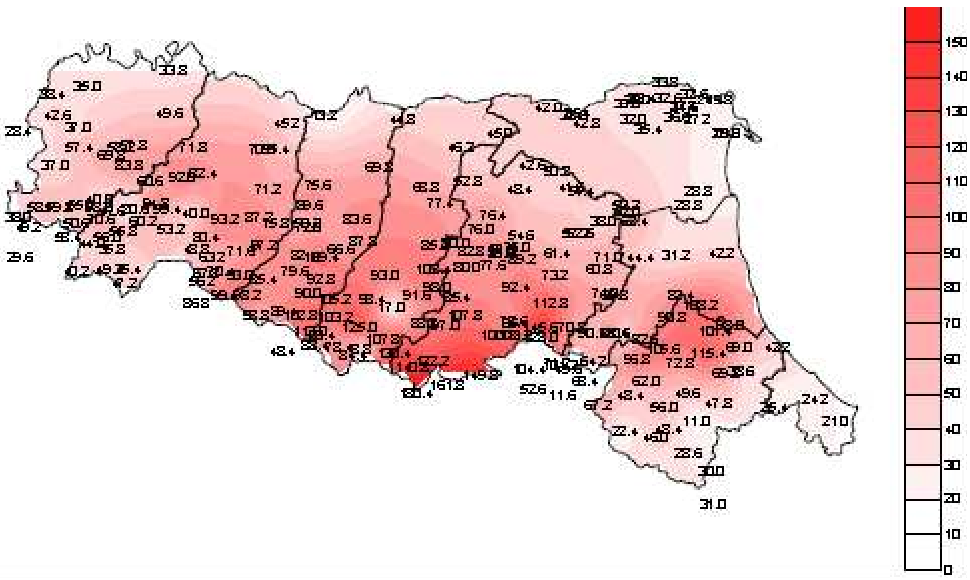
Since the majority of the land surface is forested and the majority of the topsoil has a good rainfall acceptance capacity, the retention capacity, despite the high slopes, is not negligible.

THE FLOOD EVENT

In the Reno basin, like in all the Northern Apennine watersheds, the majority of precipitation events occurs from October to April, November being the wettest month and the runoff regime follows closely the precipitation trend.

The second part of October 2003 was characterised by several, succeeding rainfall spells, as it is typical in this climatic area, and in particular, a two-peak rainfall event occurred in the days immediately preceding the case study event, that is from October 28th to November 1st, thus determining conditions of soil saturation over the watershed surface (the evapo-transpiration process is negligible in this season).

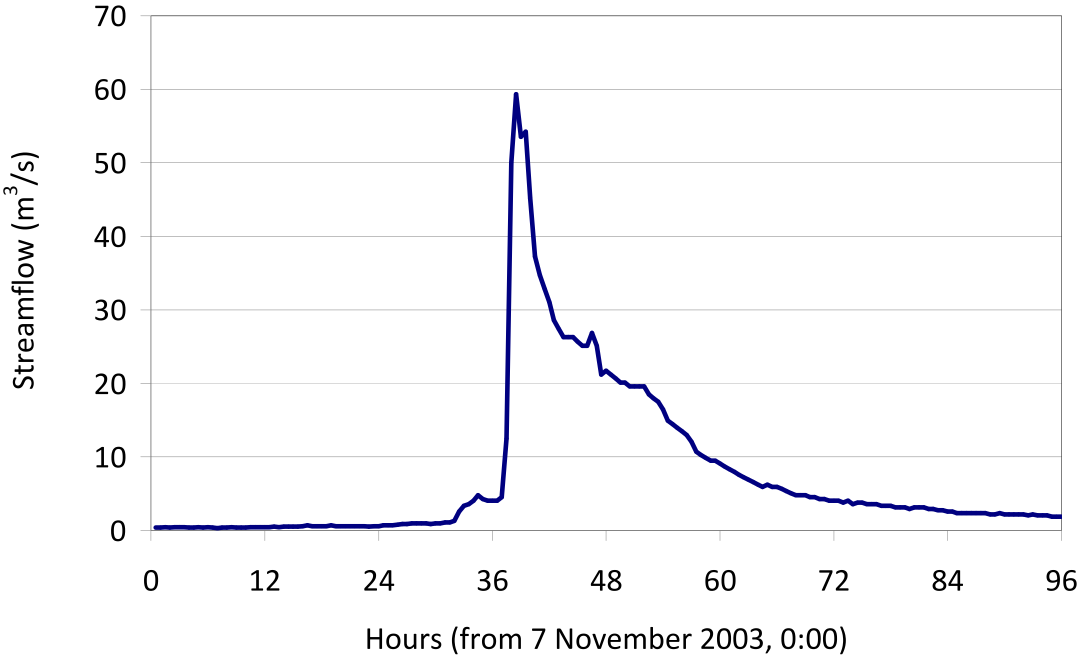
The main event occurred from the 7 to the 9 November 2003 and it was characterised by high rainfall intensities over the entire Northern Apennine chain (see Figure below, as far as the Regione Emilia Romagna is concerned).



Cumulated rainfall (mm) from 0.00, 7 November to 24.00, 9 November 2003, over the Emilia-Romagna-Region (courtesy of ARPA-SIMC Emilia-Romagna).

In the upper Reno area, in particular, the rain was distributed over the entire watershed for the hours from 3.00, 7th Nov to 3.00, 9th Nov: the cumulated rainfall depths in the raingauges inside or close to the watershed ranged from 94 to 178 mm in 48 hours. The maximum hourly rainfall intensity registered in the gauging stations ranges from 13.2 to 29.4 mm/h.

Following the increase of the rainfall intensities of the first hours of November, 8th , the streamflow values at the river section of Pracchia underwent a first increase around 8.00 and a steep rise from 13.00 to 15.00 of the 8th November, reaching a peak flow of almost 60 m^3/s, as shown in the hydrograph below.



SURFACE HYDRO-METEOROLOGICAL DATA

The surface weather and hydrometric data are managed respectively by the Hydro-Meteorological and Climate Service, ARPA-SIMC (Servizio Idro-Meteo-Clima di ARPA Emilia-Romagna, Area Centro Funzionale e Reti di Monitoraggio IdroMeteo), for the Regione Emilia Romagna, and by the Hydrologic Regional Service (Servizio Idrologico Regionale), for the Regione Toscana.

The two Services own and maintain a dense network of surface hydro-meteorological stations distributed over the whole regional areas, collecting the majority of recent data at fine temporal scales (generally 1 hour). Few of the weather stations are recording data from the early 1950, usually those located in the main cities or in strategic points like the mountain border facing other regions. The majority of the stations started their activity after the 1980's and several stations were installed at the beginning of the 2000's decade.

RAINGAUGES IN THE WATERSHED AREA

Raingauges belonging to both the Emilia-Romagna (Case Bezzi, Orsigna, Pracchia, Maresca and Piastre) and the Toscana (Monte Oppio, S. Marcello, Prunetta and Cireglio) networks were considered for estimating the hourly rainfall spatial fields over the watershed.

	Station	***Municipality***	***Prov***	***Gauss-Boaga Coord.***		***Elevation***	***Network***
				X (m)	***Y (m)***	***(m, a.s.l.)***	
1	CIREGLIO	Pistoia	PT	1648662	4872865	630	Toscana
2	MONTE OPPIO	San Marcello Pistoiese	PT	1647114	4878050	816	Toscana
3	PRUNETTA	Piteglio	PT	1644662	4874076	951	Toscana
4	S. MARCELLO	San Marcello Pistoiese	PT	1643295	4877534	1019	Toscana
5	PIASTRE	Pistoia	PT	1646926	4873697	741	Emilia Romagna
6	CASE BEZZI	Sambuca Pistoiese	PT	1655998	4881067	860	Emilia Romagna
7	MARESCA	San Marcello Pistoiese	PT	1648114	4880329	1043	Emilia Romagna
8	ORSIGNA	Pistoia	PT	1650973	4881814	806	Emilia Romagna
9	PRACCHIA	Pistoia	PT	1652663	4879939	627	Emilia Romagna

Operative raingauges inside and outside the watershed

The cumulative rainfall depths registered at each gauge at the end of the hour form a continuous record of hourly depths for each raingauge, to be subsequently used for estimating the rainfall fields over the watershed area. The rainfall data for the stations of the watershed area are available for every hour from 1st January to 31st December 2003, but only the hours belonging to the identified event will be analysed in the following.

SELECTED RAINGAUGES AT REGIONAL SCALE

A selection of 220 raingauges, of which 150 in Emilia-Romagna and 70 in Toscana, covering the entire areas of both Regions, was identified among the stations that were operating during the event (the list of the selected stations is reported in the Appendixes A1-A2). Hourly rainfall depths were collected for the 120 hourly time steps of the 5 days from 0.00, 6 November 2003 to 23.00, 10 November 2003.

SELECTED WEATHER STATIONS AT REGIONAL SCALE

Other hourly weather data were collected in the operating weather stations scattered over all the Regione Emilia Romagna from 0.00, 6 November 2003 to 23.00, 10 November 2003:

i) Hourly air temperature data (℃) collected in 125 surface weather stations.
ii) Hourly relative humidity (%) collected in 34 surface weather stations.
iii) Hourly wind direction data (*degrees*) collected in 19 surface weather stations.

iv) Hourly wind speed data (*m/s*) collected in 15 surface weather stations.

v) Hourly pressure data (*hPa*) collected in 13 surface weather stations.

The list of the selected stations is reported in Appendixes A3-A5.

RIVER STAGE AND RATING CURVE

The water levels recorded at 30 minutes time intervals in the cross-section of Pracchia, at the closure of the watershed, were collected for the whole 2003.

Such river section is located in correspondence of a bridge ("Ponte Appennino") and, for this reason, it may be considered sufficiently invariant in time. The River Reno Authority, on the basis of velocity field campaigns carried out in 2007, set up a rating curve for this section that, given the stability of the section, may be used also in correspondence of the November 2003 flood event, in order to convert the water levels in discharge values.

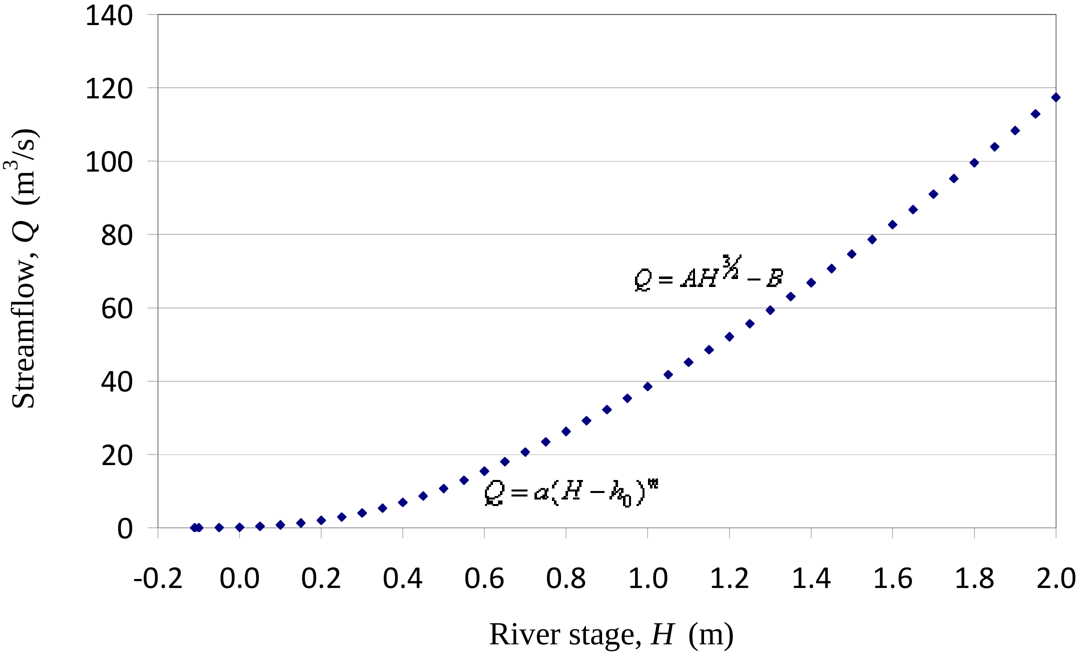
The rating curve is formed by two equations: the first one being:

$Q = a(H - h_0)^m$,

where Q is the streamflow, H is water level, h_0 is gauge level of the "zero flow", equal to -0.11 in the present case, A and m are constants, here equal to 2.45 and 36 respectively. This equation holds for H < 0.56 m, while the second one:

$Q = AH^{3/2} - B$,

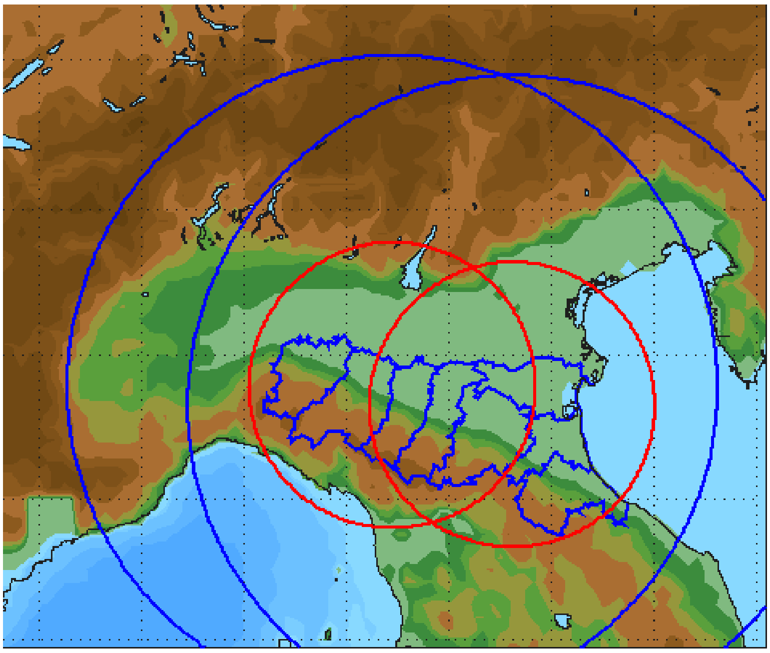
with A and B equal to 43.13 and 4.58 in the present case, is valid for the higher levels.



Rating curve for the Pracchia water level gage

RADAR DATA

Ground-based radars provide rainfall fields estimates covering large areas. Although the radar system is superior to rain gauge networks in capturing the space-time distribution of heavy rainfall system, many problems need to be resolved in rain rate estimation from these radars, and effective weather warning requires the integration of information from many sources, including, for example, input from ground weather stations and/or from multiple radars, as the two radars of the Regione Emilia Romagna radar network.



Regione Emilia Romagna radar network. Range of S. Pietro Capofiume (BO) and Gattatico (RE) radars: the red circles represent the area where quantitative rainfall fields may be estimated (short range), the blue circles (long range) the area where meteorological monitoring is active.

The radar data here collected are those of the two C-band Doppler polarimetric multiparametric radars managed by ARPA Emilia Romagna (Unità Radarmeteorologia Radarpluviometria Nowcasting e Reti Non Convenzionali, coordinated by Dr. P. Alberoni), both located in the Po valley and about 90 km apart: San Pietro Capofiume (BO) and Gattatico (RE). The rainfall fields are obtained combining the information of the two sensors, in order to improve the spatial coverage.

Radar data are acquired with a prescribed scanning strategy during operational activity, consisting of 15 elevations with an angular spacing of 1°. Radial spatial resolution is set to 250 m for short ranges (i.e., 125 km) and to 1500 m for long range (i.e., 250 km) scans, the latter being carried out only twice per hour. Time sampling of radar volume data is such that there are 4 short-range acquisitions per hour (i.e., every 15min), but the quantitative rainfall fields are made available after a temporal averaging, that is with hourly time-step.

Raw polar radar data are processed in order to obtain reliable rainfall estimates taking into account propagation effects, interaction with the orography, anomalous propagation (Alberoni et al., 2001; Montopoli et al., 2006). The table below displays the system specifications.

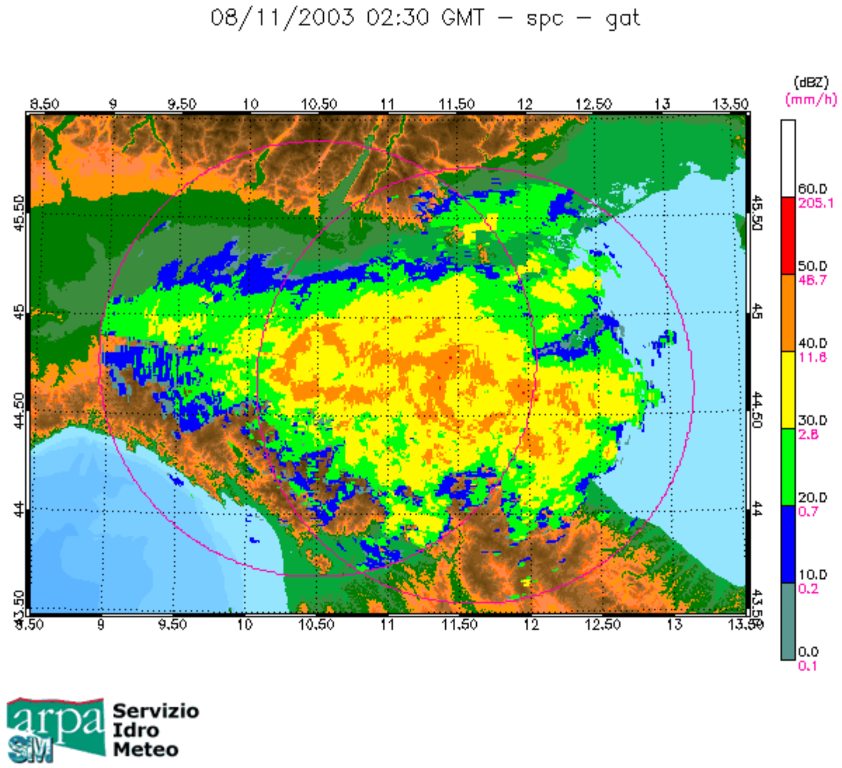
Main technical data of the radar system

Radar type	GPM 500C
Wavelength (cm)	5.5
Polarization type	linear H or V
Antenna type	dual offset
Antenna diameter (m)	5
Beam width	0.9 deg
Maximum sidelobe level	-30 dB
Maximum cross polar discrimination	-27 dB
Antenna gain	46 dB
Transmitter type	Klystron
Frequency (MHz)	5430–5640
Nominal peak power (kW)	500
PRF (Hz)	300–1200
Pulse length (ms)	0.5, 1.5, 3.0

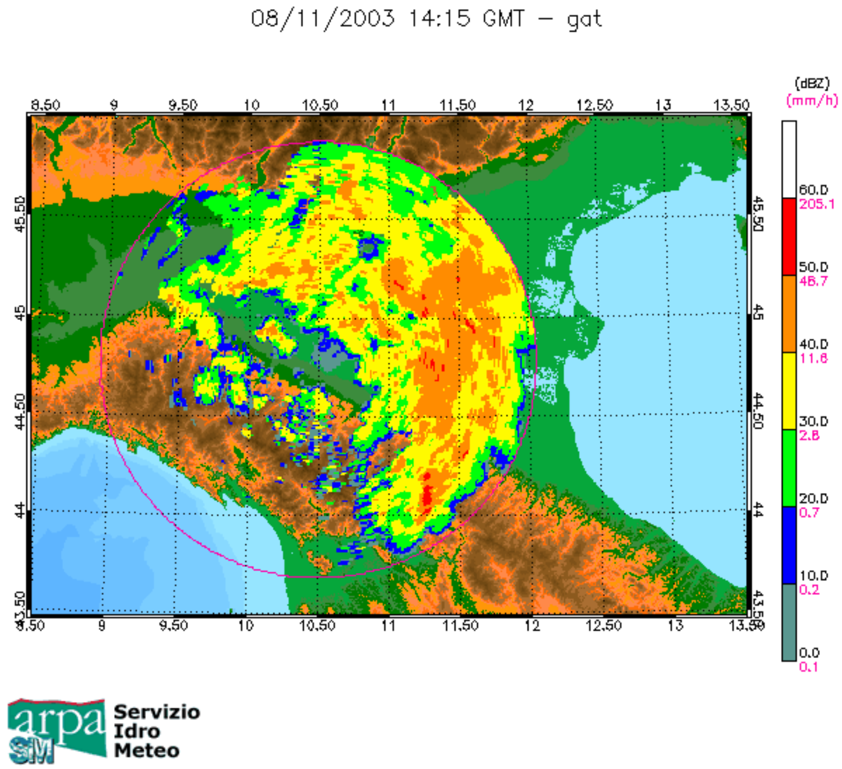
Polarimetric scan parameters for ‘‘Bad weather’’ mode

Variables: reflectivity ZH, differential reflectivity ZDR, mean Doppler velocity V and the width of the velocity spectrum σV
15 elevations, from 0.5 to 18 deg
H-H-V transmitting mode
Pulse width: 0.5 ms, PRF: 1200 Hz
Range resolution: 250 m, maximum range: 125 km
Repetition time: 15’ (at the 04’, 19’, 34’ and 49’ of every hour)

The rainfall intensity fields estimated from the radar data of both radars (but in some of the hours only one of radar was operating, like in the example in Figure below), were collected for the part of the event in which rainfall occurred, that is from 0.00, 7 November 2003 to 6.00, 9 November 2003, on a wide spatial area of around 5°(E-W) x 2.5°(S-N) lat-long degrees.



a)



b)

Examples of the radar maps obtained by both radars (a) or when only one radar, in this case the Gattatico one, were operating.

SOIL USE MAPS

The spatially-distributed description of the soil use on the watershed comes from the CORINE Land Cover database. From 1985 to 1990, the European Commission implemented the CORINE Programme (Co-ordination of Information on the Environment). During this period, an information system on the state of the European environment was created (the CORINE system) and nomenclatures and methodologies were developed and agreed at EU level. CORINE Land Cover 1990 (CLC90) is the largest of CORINE databases, providing information on the physical characteristics of the earth surface: images acquired by earth observation satellites were used to derive land cover information.

The Image and Corine Land Cover 2000 project, a joint initiative of EU Commission and EU Environment Agency (EEA), involved 26 countries in updating at year 2000 environmental parameters and information (Varanou et al., 2000). The CORINE Land Cover 2000 is a full available database now including orthorectified Landsat 7 ETM satellite images of the Italian and European territory, Land Cover and Changes definition maps.

The basic aim of the CLC project was to provide an inventory of the Earth surface features for managing the environment (Heymann et al., 1994). Only features that are relatively stable in time are mapped: CLC is not interested in diurnal changes (tide), seasonal changes (e.g. vegetation cycle) or short-term changes (e.g. flooding).

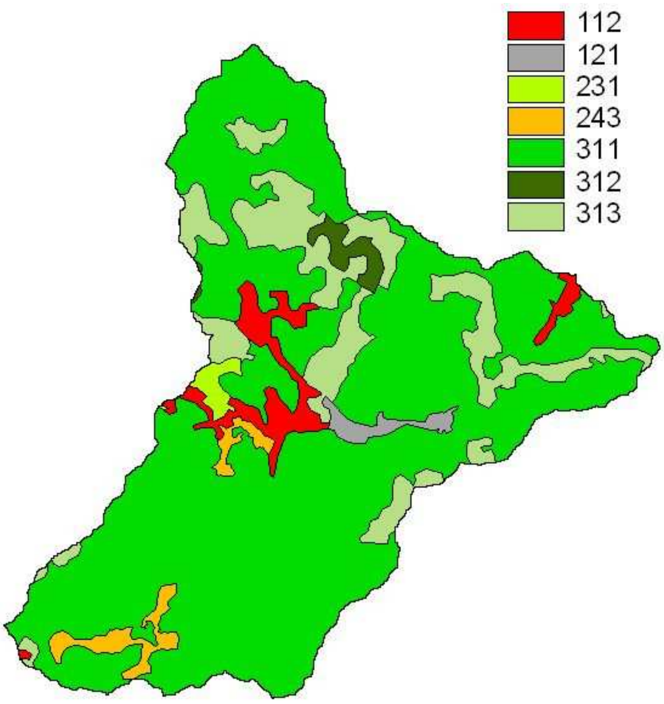
The choice of scale (1:100.000), minimum mapping unit (MMU) to be mapped (25 hectares) and minimum width of linear elements (100 metres) represents a trade-off between cost and detail of land cover information. These basic parameters are the same for CLC90 and CLC2000, even if in CLC90 some of the countries have not maintained the 25 ha limit.

The standard CLC nomenclature includes 44 land cover classes, grouped in a three level hierarchy. The five level-one categories are: 1) artificial surfaces, 2) agricultural areas 3) forests and semi-natural areas, 4) wetlands, 5) water bodies. All national teams had to adapt the nomenclature according to their landscape conditions.

The Italian National Authority managing the project and the diffusion of the products is the Institute for Environmental Protection and Research, ISPRA (Istituto superiore per la protezione e la ricerca ambientale), former APAT (Italian Environment Protection and Technical Services Agency), from whose website we acquired the digital information map over the entire Regione Toscana, that we then customised and geo-referenced for the watershed of the Reno River at Pracchia.

The following CORINE land cover classes are present on the watershed:

CLC class ID	CLC 3rd level class	% of the watershed surface
112	Discontinuous urban fabric	4.1
121	Industrial or commercial units	1.1
231	Pastures	0.9
243	Land principally occupied by agriculture, with significant areas of natural vegetation	2.3
311	Broad-leaved forest	76.5
312	Coniferous forest	1.3
313	Mixed forest	13.9



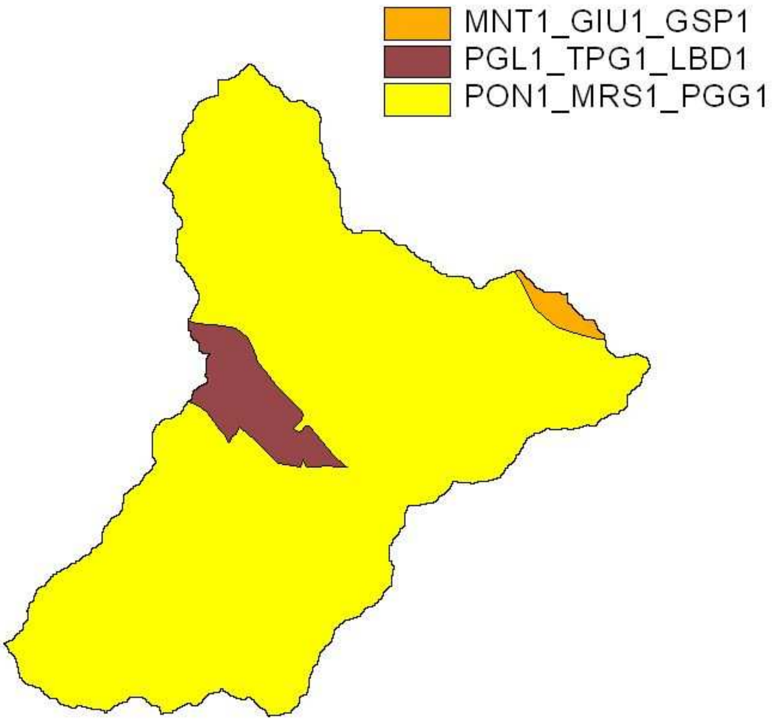
The vegetation cover is constituted primarily by broad-leaved (almost 77%) and mixed/coniferous (15%) forests. In the middle part of the basin, in the valleys where the torrents Maresca and Bardalone join the Reno River, close to the hamlets of Campo Tizzoro and Pontepetri - and also, to a lesser extent, in the valley area of the closure section, Pracchia - there are urbanised (4%) and industrial areas (1%) and pastures (1%). A small part of the basin (2%), near to Campo Tizzoro and near to Piastre (southern border of the watershed) is cultivated.

SOIL TYPE MAPS

As far as the pedological information is concerned, the soil type map comes from the Project "Carta dei Suoli della Regione Toscana" (Map of the Soils of Regione Toscana, Gardin and Vinci, 2001), developed within the national project "Carta dei Suoli d'Italia a scala 1:250.000", funded by the Ministero per le Politiche Agricole in the Interregional Program "*Agricoltura e Qualità" Misura 5*.

The project includes a digital map at scale 1:250.000 and an extensive database of detailed information on soil texture, relative permeability and organic content, provided by the local administration Settore Foreste e Patrimonio Agro-forestale of Regione Toscana.

The pedological cartographic units are formed by polygons characterised by similar pedological and landscape content.



The more common soils of the watershed (93.6%) are "sandy flysch" and they belong to the PON1_MRS1_PGG1 unit, whose lithology is quartzo-feldespatic sandstone, sometimes turbiditic, with intercalations of marls and argillites. The topsoil has from moderate to high vertical permeability and a good rainfall acceptance capacity.

In the western part of the watershed, there are some soils (5.5% of the total area) belonging to the PGL1_TPG1_LBD1 unit (Lithology: a chaotic argillaceous structure of marly limestone, ofiolitic gravels, calcarenites and limestone), mainly composed by facies of argillites where we can observe strong erosive processes, and secondly, glaciation processes. Such clay-based soils have low permeability and poor rainfall acceptance capacity

About 1% of the watershed, around the closure section of Pracchia, is part of the MNT1_GIU1_GSP1 unit (Lithology: siltic schist, marls, argillites and sandstone, usually turbiditic), that includes the facies developed on Mugello rocks. In this unit, we find either erosive processes with different intensity or humidification and illuviation processes. The topsoils are characterised by moderate rainfall acceptance capacity.

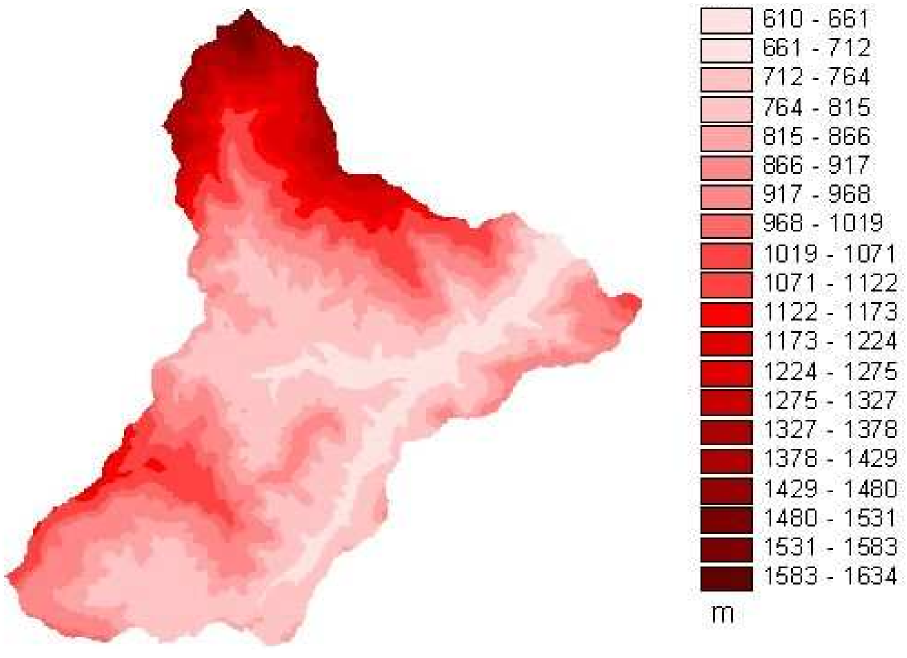
The main physic and chemical characteristics of the soils in the above cartographic units are reported in the following table.

Cartographic Unit	**% Sand**	**% Clay**	**% Silt**	**% Organic Substance**	**USDA Texture class**
MNT1_GIU1_GSP1	29.9	21.3	30	2.57	F
PGL1_TPG1_LBD1	18.9	38	50	2.57	FLA
PON1_MRS1_PGG1	56.4	13.8	20	2.9	FS

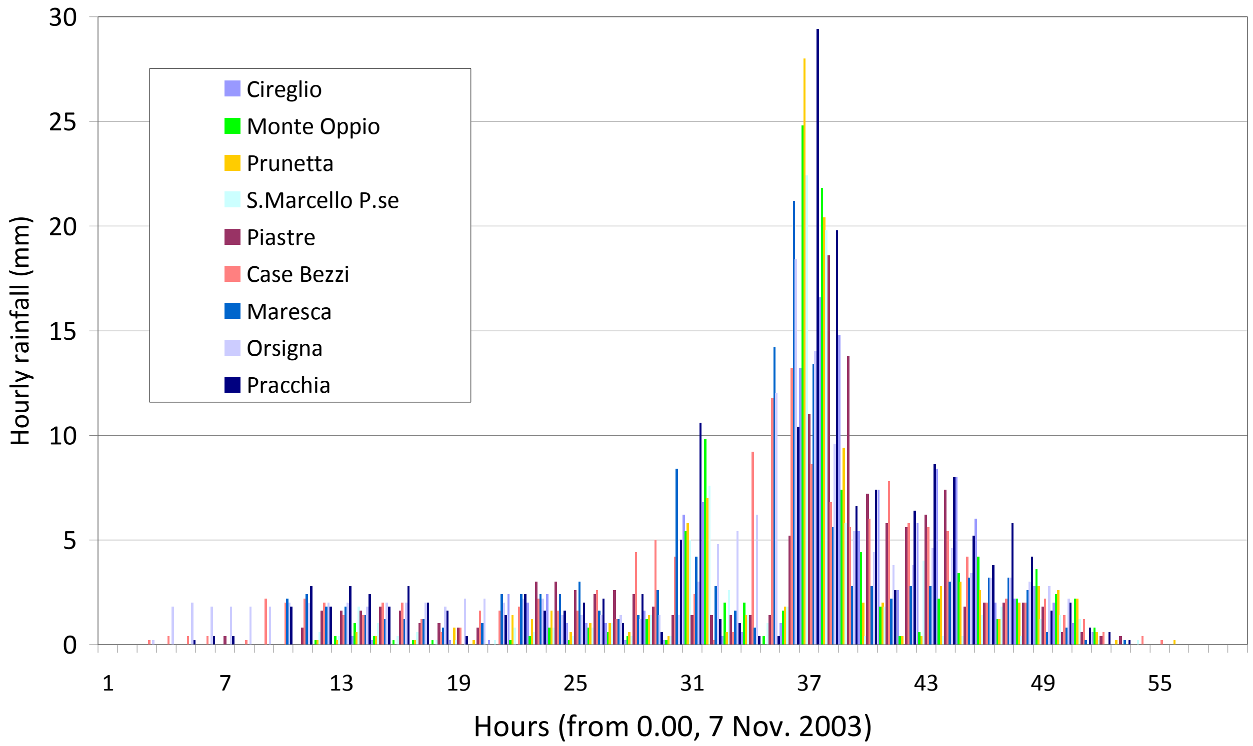
GROSS RAINFALL FIELDS

In order to exploit fully the advantages of the spatially variable representation of the rainfall-runoff transformation processes, it is necessary a reliable assessment of the spatial distribution of both the total (gross) rainfall fields and of the part that actually becomes surface runoff (net rainfall).

The model discretises the basin in 99302 square cells coinciding with the pixels of the DEM (Digital Elevation Model) with resolution 20 x 20 *m* that was estimated, on the base of the contour lines, by the LAMPIT research group. The grid based DEM is given in raster format by means of a rectangular matrix, placed in an ASCII text file. Each element of the matrix represents the mean elevation of the corresponding DEM cell, whereas cells located outside of the catchment are assigned a “No data” value.



Ground precipitation data are available in the form of the observed hourly rainfall depths that were measured in each one of the nine raingauges located within or close to the catchment: the hyetographs of the hourly rainfall in the 9 gauges during the event is shown below:



On the basis of such point data, for each hour, a rainfall field, spatially-distributed over the entire watershed area was estimated.

At each hourly time step of the event, the rainfall in correspondence of each 20 m x 20 m cell is estimated with an inverse squared distance weighting of the raingauges observations, that is, the interpolated estimate *P[t,(i,j)]* of rainfall over the cell of coordinates *(i, j)* for hour *t* is given by the weighted sum of the rainfall depths *P[t,k]*, *k*=1,…, N_G, measured at each one of the N_G raingauges (in the present case, N_G =9).

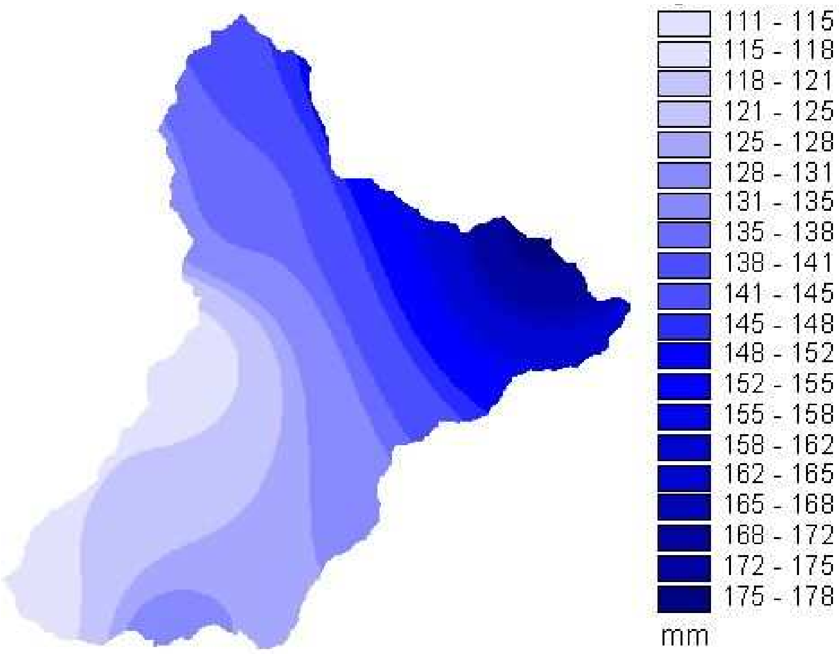
$$P[t,(i,j)] = \sum_{k=1}^{N_G} \lambda_k(i,j) \cdot P[t,k],$$

where the weights are given by

$$\lambda_k(i,j) = \frac{1/d_k^2(i,j)}{\sum_{m=1}^{N_G} 1/d_m^2(i,j)^2}$$

and $d_k(i,j)$ is the distance between the *(i,j)* cell and the *k-th* raingauge.

The cumulated rainfall depths (*mm*) over the entire event (72 hours from 1.00, 7 Nov. 2003 to 24.00, 9 Nov. 2003) for each 20 x 20 *m* cell, are shown in the rainfall field depicted in the figure below:



The Mean Areal Precipitation (MAP) over the watershed is computed as:

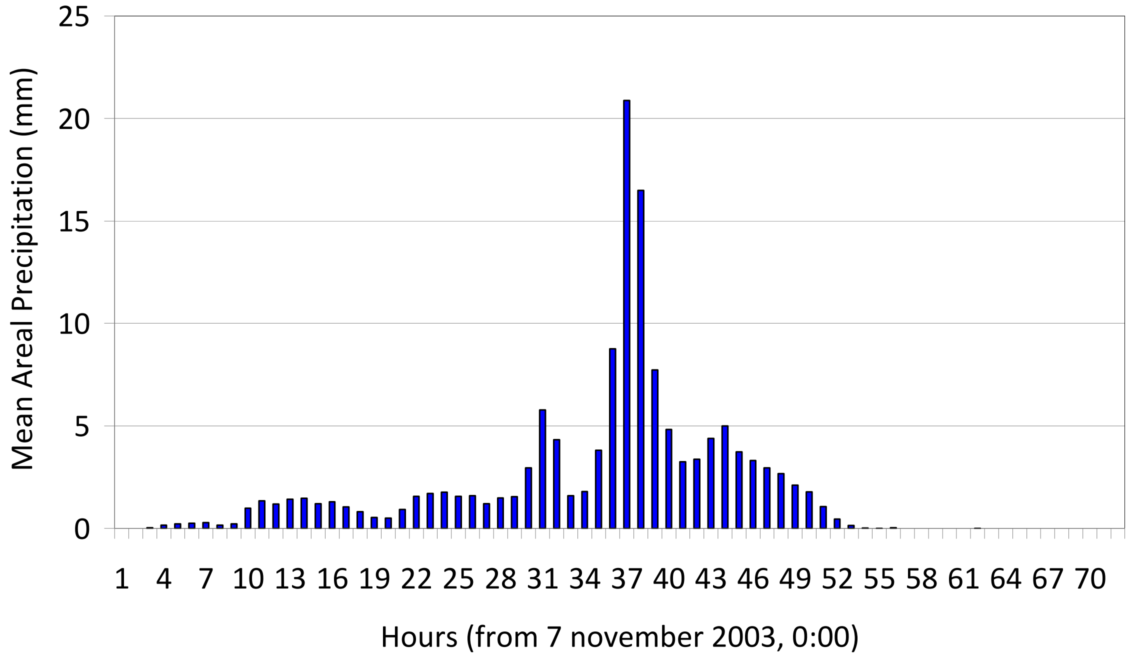
$$MAP(t) = \sum_{k=1}^{N_G} \overline{\lambda}_k P[t,k],$$

where:

$$\overline{\lambda}_k = \frac{\sum_{j=1}^{N_C} \lambda_k(i, j)}{N_C}$$

with N_C is the total number of cells, (= 99302 in the present case).

The MAP accumulated over each hour of the event is depicted in the gross MAP hyetograph below.



The cumulated MAP during the entire event is 139.85 mm, for a corresponding total volume over the watershed is 5556055 m^3.

NET RAINFALL ESTIMATION

SURFACE RUNOFF PRODUCTION MECHANISM

In a surface runoff model, the catchment hydrologic response is determined by the composition of the two processes of hillslope surface runoff formation and channel propagation along the river network. Surface runoff, or overland flow, is conceptualized as the thin sheet flow on the hillslopes that takes places before the runoff concentrates in recognized channels.
The most important variable in determining the surface runoff production mechanism is the ratio of the rainfall rate to the potential infiltration rate of soils in the watershed. Whenever this ratio exceeds 1, in the absence of a near-surface water table, runoff is produced by the Hortonian or “infiltration excess” production mechanism. Non-hortonian, or “saturation-excess” overland flow occurs instead due to rising water tables, and consists of direct runoff from rain falling on saturated areas and return flow contributed by groundwater exfiltration. Actually, since Hortonian runoff production depends on both the rainfall intensity and the watersheds characteristics, it may not be strictly appropriate to refer to watersheds as being either Hortonian or non-Hortonian, as the particular event and recent climatic conditions may ultimately decide what the dominant runoff production mechanism will be: there are watersheds that produce runoff primarily by the saturation-excess mechanism under ordinary rainfall conditions, but can also produce widescale Hortonian runoff under the action of extreme rainfall when the ratio of rainfall rate to soil potential infiltration rate exceeds 1.0 (Downer et al., 2000).

In the upper Reno watershed, as in many Apennine regions, rainfall rates during extreme precipitation events may be very high, up to tens of mm/h, whereas infiltration capacities are generally much less than this rate. As far as the flood event of 7-9 November 2003 is concerned, the maximum hourly rainfall intensity reaches almost 30 mm/h (29.4 mm/h at Pracchia and 28 mm/h at Prunetta at 13.00, 8th of Nov. 2003).

Secondly, as it is typical in watersheds in which Hortonian flow is likely to occur, the Reno river closed at Pracchia have high relief and deep water tables.

Thirdly, the event hydrograph, as in typical upland Hortonian events, is characterised by a rapid rise and a relatively fast recession, with little base flow.

For the above reasons, we believe that the flood event may be appropriately modelled by an approach that is primarily driven by a Hortonian (infiltration excess) surface runoff generation mechanism.

COMPUTATION OF THE LOCAL SURFACE RUNOFF PRODUCTION

Hydrological practice estimates the net (or excess or effective) precipitation, that is the part of the gross rainfall that becomes surface runoff, on the basis of the soil-water balance. Although the soil-water balance is a physically based approach, it might be a complicated process, that should account for a large number of parameters, that is sensitive to the available data, and that produces results that have to be interpreted with caution. A reliable, objective estimation of the excess precipitation is in fact still far from being achieved (Olivera and Maidment, 1999).

In the present study a rather classical, simplified approach that represents the spatial distribution of excess precipitation with a single parameter, the runoff coefficient, was applied.

Following the approach proposed in the WetSpa distributed rainfall-runoff model (Wang et al., 1996; De Smedt et al., 2002), the surface runoff or rainfall excess for each raster cell is calculated using a moisture-related modified rational method in relation with a potential runoff coefficient, C:

$$S(t) = C \cdot P(t) \cdot \frac{\theta(t)}{\theta_s}$$

where,
S =excess rainfall or surface runoff (mm)
C = potential runoff coefficient (-)
P = precipitation (mm)
θ = soil moisture content (m^3 m^{-3})
θ_s = saturated soil moisture (m^3 m^{-3})

The potential runoff coefficient, C is strongly related to runoff production, where high values (close to one) correspond to relatively impermeable surfaces that generate much runoff, and low values (close to zero) to permeable areas that generate little or no runoff at all. The actual runoff coefficient represents the fraction of the gross rainfall that is not subject to surface retention and infiltration but is made available for the generation of surface runoff.

INITIAL SOIL MOISTURE CONDITIONS

When implementing event-based models, it raises the problem of the determination of the initial saturation conditions of the watershed.
In fact, whereas continuous-type rainfall-runoff models automatically update the water content in the different parts of the watershed by continuously accounting for the water budget (and the system is permanently ready to respond to a sudden rain event), event-based models require an initialisation of the water content, that is an estimate of the saturation condition of the soil (soil moisture content) to be implemented at the beginning of each flood event.

In the present case, given the high amount of rainfall that has fallen on the watershed area during the second half of October and in particular during the event occurred from October 28th to the 1st of November (cumulated rainfall ranging from 166 to 223 mm in 110 hours), that immediately preceded the 7-10 November event, it is likely that, during all the simulation period, since its very beginning, the soils are staying completely saturated. We assume, therefore, that the soil moisture content of the topsoils of the watershed may be represented by fully saturated conditions during all the event, that is:

$$\theta(t) = \theta_s, \forall t$$

where θ = soil moisture content ($m^3\ m^{-3}$) and θ_s = saturated soil moisture ($m^3\ m^{-3}$), for every cell of the watershed.

It follows that equation:

$$S(t) = C \cdot P(t) \cdot \frac{\theta(t)}{\theta_s}$$

becomes:

$$S(t) = C \cdot P(t)$$

where,
S =excess rainfall or surface runoff (mm)
C = potential runoff coefficient (-)
P = precipitation (mm)

FIRST ESTIMATE OF THE SPATIAL DISTRIBUTION OF THE POTENTIAL RUNOFF COEFFICIENT

Modeling the formation of excess precipitation, with any surface runoff generation approach, requires the estimation of infiltration parameters from the soil properties, that must be known at local scale over the entire watershed when implementing of a spatially-distributed rainfall-runoff model.

In typical applications of distributed models, few, if any, actual measured values of spatially distributed parameters are available and detailed in situ surveys are not economically convenient over large spatial extent: it follows that deriving net rainfall parameters from the soil type and soil use maps, as will be described in the following, is the only feasible alternative (Vieux, 2001).

The maps of land use and soil type described before are here used to infer a first estimate of the values of the only one spatially-varied parameter, that is the potential runoff coefficient. The two maps are used to develop a combined land use/soil type map, each combination having a unique set of parameters. The choice of the runoff coefficient as the only parameter characterising the net precipitation distribution parameter is extremely convenient because a first estimate of the runoff coefficient can be derived, on the basis of soil type and land use information, from studies available in the literature (e.g. NRCS, 1972; Chow et al., 1988; Browne, 1990; Schwab et al., 1993).

Such studies provide a relation between the runoff coefficient and the hydrologic soils groups identified by the Soil Conservation Service of the United States Department of Agriculture (USDA, 1986). The SCS (Soil Conservation Service) has classified more than 4000 soils into four hydrologic soil groups (HSG) according to their minimum infiltration rate obtained for bare soil after prolonged wetting.

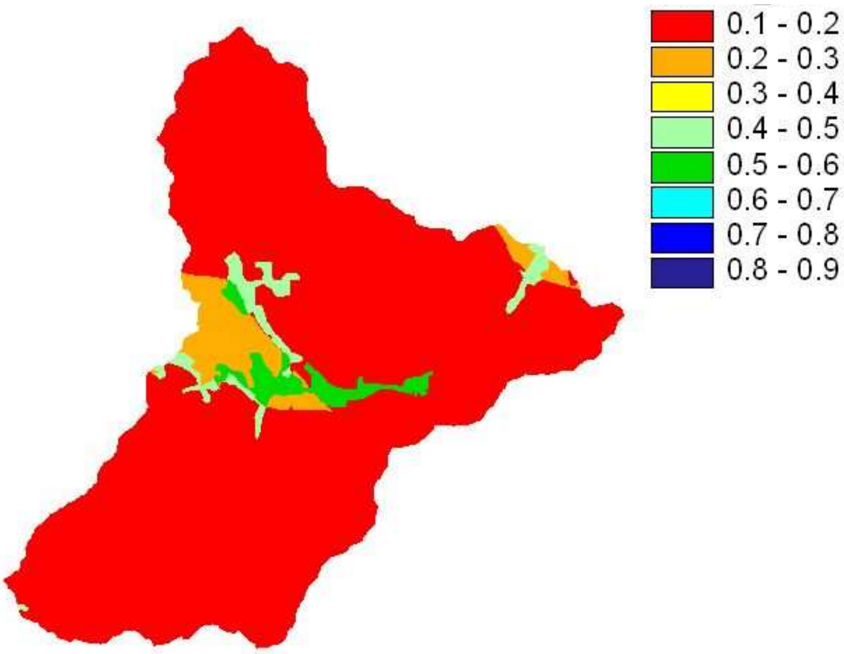
Soil Group	***Description***
A	*Lowest runoff potential*. Includes deep sands with very little silt and clay, also deep, rapidly permeable loess.
B	*Moderately low runoff potential*. Mostly sandy soils less deep than A, and loess less deep or less aggregated than A, but the group as a whole has above-average infiltration after thorough wetting
C	*Moderately high runoff potential*. Comprises shallow soils and soils containing considerable clay and colloids, though less than those of group D. The group has below-average infiltration after presaturation.
D	*Highest runoff potential*. Includes mostly clays of high swelling percent, but the group also includes some shallow soils with nearly impermeable subhorizons near the surface.

On the basis of the pedological characteristics of the topsoils identified in the cartographic units of the “Carta dei Suoli della regione Toscana”, the PON1_MRS1_PGG1 unit is assumed to belong to soil group B (above average rainfall acceptance capacity), the PGL1_TPG1_LBD1 unit (poor rainfall acceptance capacity) to group D and the MNT1_GIU1_GSP1 unit to the intermediate group

C.

The runoff coefficients depend not only on the hydrological soil group but also on the land use and the topographical slope (that is almost everywhere extremely high in the present watershed): the potential runoff coefficients for each cell of the watershed were estimated from literature values and, in particular, following the values reported in McCuen, (2004, see Appendix B), according to the combination of soil types and land use.

The values of the potential runoff coefficients, C, are shown in the map below:



Given the large majority of broad-leaved woods on a topsoil (unit PON1_MRS1_PGG1) that is characterised by relatively high rainfall acceptance capacity, the resulting runoff coefficient, even in saturated soil moisture conditions, is rather low, with an average value over the entire watershed of around 0.215.

CALIBRATION OF THE CORRECTION FACTOR OF THE POTENTIAL RUNOFF COEFFICIENT

Literature values of infiltration parameters typically are typically characterised by a great deal of uncertainty. Literature values for a single parameter, from a single reference, for a single land use may have a range of values of soil parameters. In fact, the runoff coefficient parameter has a conceptual nature and, even in the cases in which detailed surveys are available, it cannot be directly assessed on a physical basis, nor it can easily be derived on the basis of the values obtained for different case studies.

Therefore, in order to set up an appropriate net precipitation model it is necessary to fine tune, or calibrate, the parameter to our set of observed data.

The spatial variation of the parameters describing the potential runoff coefficient has been obtained from the combined maps of soil type and land use. In distributed models, it is convenient to define spatial patterns of parameter values, so that a given cell parameter mainly reflects the significant and systematic variation for a certain process, relatively to the parameter values in the other cells, thus reducing significantly the number of free parameters that need to be adjusted subsequently. If we know the spatial pattern of a parameter, we can adjust its magnitude while preserving its relative variation in space. This calibration procedure can be performed manually by applying scalar multipliers or additive constants to parameter maps until the desired match between simulated and observed is obtained (Vieux, 2001). In the present study, this approach is adopted: having already fixed the spatial pattern of the variation of the model parameter (on the basis of literature values depending on soil type and land use information), we multiply each cell value by a unique correction, calibration factor.

The value of such correction factor is derived from the observed hydrograph, or better from its separation in surface and base flows: in fact, in correspondence of a flood event, the total volume of the net rainfall over the watershed area should correspond to the total volume of surface runoff at the outlet river section.
For determining such surface runoff volume, the flow record undergoes a base flow separation, producing time series of surface runoff and base flow.

Hydrograph separation

Before a rain event, the flow is composed of the baseflow part only. When the rainfall starts, in case of unsaturated soil conditions, a period of time elapses before the flow begins to rise (period when the rainfall is intercepted by the vegetation, fills the soil surface cavities and makes up the soil-moisture deficits). Once the surfaces and soils are saturated, the effective rainfall starts to contribute to flow as surface runoff: this part of the hydrograph is called the rising limb, up to the peak. After the peak, the slope of the curve flattens over time from its initial steepness as the quickflow component passes and baseflow becomes dominant. Typically, the inflection point is considered as the start of the main, baseflow recession.

The flood hydrograph may be separated into two main components: the area under the hump, representing surface runoff, and the lower part near the time axis, representing the baseflow, i.e.

the part of the flow contributed from interflow and groundwater.

Unfortunately, there is no satisfactory, objective technique for extracting the surface runoff hydrograph from the total hydrograph (Beven, 2001, Bedient et al, 1992). The common separation methods are either graphical, which tend to focus on defining the points where baseflow intersects the rising and falling limbs of the quickflow response, or involve a filtering procedure, where data processing of the entire stream hydrograph derives a baseflow hydrograph (see e.g. Linsley et al, 1958; Hall, 1968; Hino and Hasebe, 1984; Chapman, 1989). However, the methods are arbitrary and different hydrologists using the same graphical hydrograph-separation method may produce different base-flow estimates (Nash, 1960).

Considering the lack of a unique reference separation technique, consistency (see Nathan and McMahon, 1990) was privileged in this study and a graphical method was chosen.

In graphical separation methods, the shape of the hydrograph recession curve is used to decipher the timing and magnitude of surface and subsurface runoff.

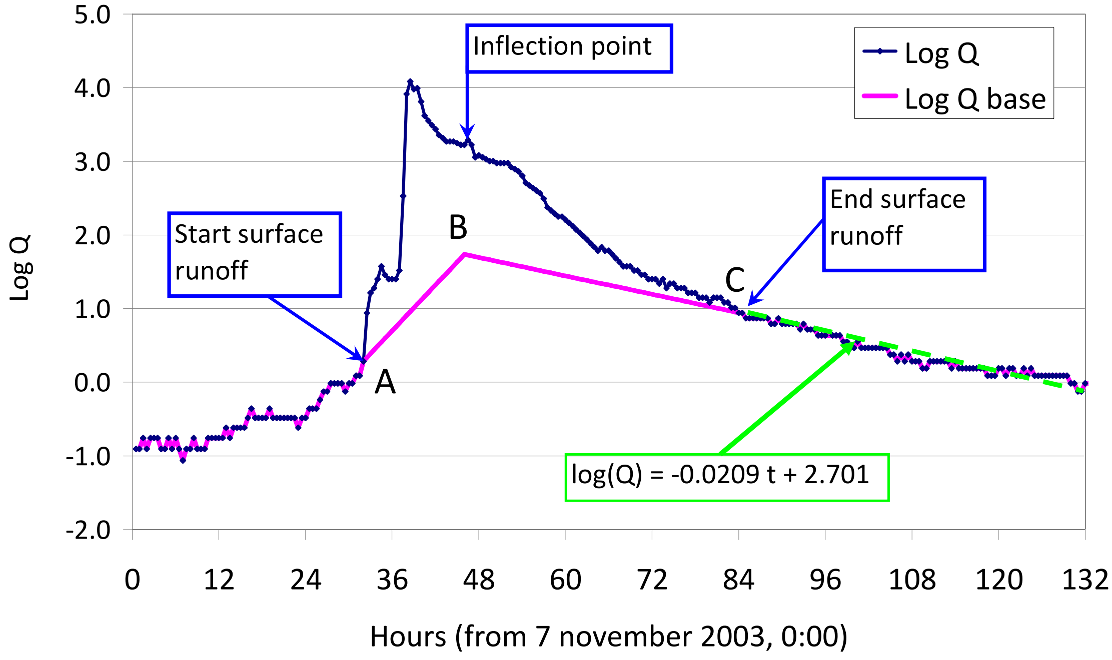
An exponential form, resulting from the assumption that the recession is a linear process, is traditionally used to describe the hydrograph recession behaviour (e.g. Hall, 1968) and it can be written in the following form (e.g. Hino and Hasebe, 1984; Nathan and McMahon, 1990; Tallaksen, 1995):

$$Q(t) = Q_o \cdot e^{Kt}$$

where Q(t) is the discharge at time t, Q_0 is the initial discharge, K is a negative constant (the recession coefficient).

The exponential function of the hydrograph recession implies that the recession will plot as a straight line on a semi-logarithmic axis, with discharge on the logarithmic scale against time on the linear (natural) scale: the slope of this line is equal to the recession parameter K and the intercept identifies the position of the curve on the hydrograph.

For the study event, such exponential function is computed in the semi-logarithmic graph, detecting the part of the log(Q) curve that shows a linear behaviour.



The equation in the semi-log graph that reproduces the linear recession results to be:

$$\log[Q(t)] = -0.0209\,t + 2.701 \;.$$

On the recession limb, we single out a point (C) that may be considered the end of the surface runoff. Such point is graphically identified as the point where the total runoff curve, going backward, parts from the straight line above described. We pinpoint such time instant as the 84th hour (from 0.00 of 7th Nov).

The choice of such time is substantially in line with the indication given by the so-called "area-method", introduced by Linsley et al.(1958), who proposed an empirical equation to define the temporal interval *N* from the peak time to such instant:

$$N = A^{0.2},$$

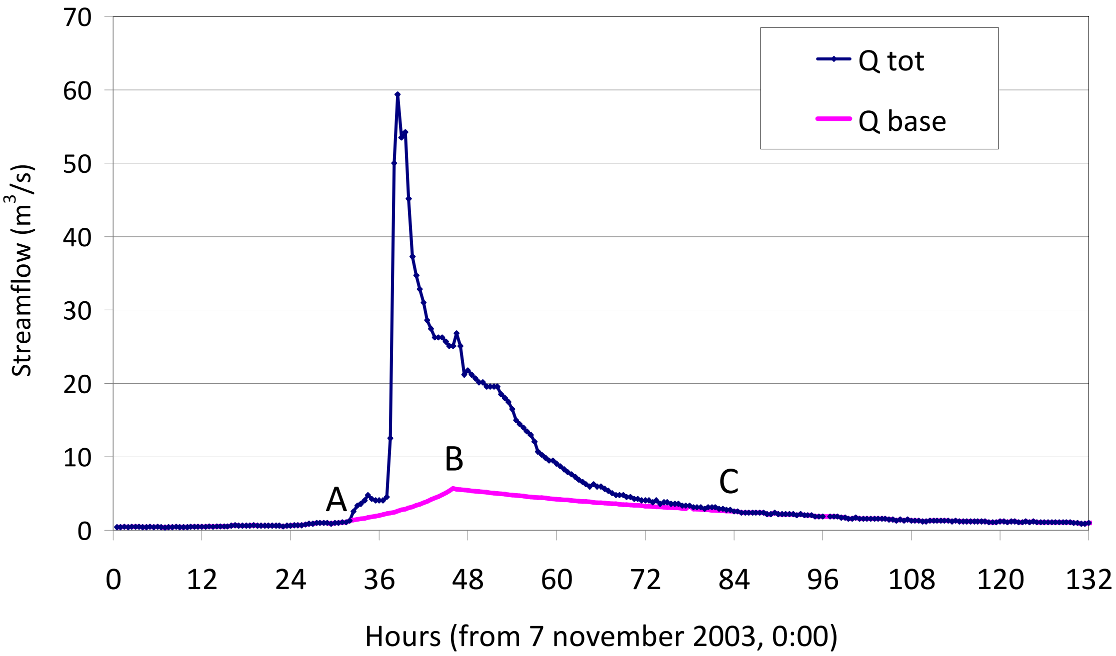
where *A* is the drainage area in square miles and *N* is measured in days.
In fact, for the Reno River at Pracchia, *N* results to be around 42 hours and, for the present hydrograph, the peak occurs between hours 38 and 40, thus obtaining an estimate of around 80 hours (from 0.00 of 7th Nov), for the time when the surface runoff ends.

The identification of the beginning of the surface runoff (point A) is more straightforward, being coincident with the start of the rising limb, occurring at t = h 32: such rise, as it generally happens, is pretty sudden and well-identifiable in the natural scale axes (see figure below). Its timing, in a watershed that is already saturated, follows closely the hyetograph behaviour, which, in the present case, shows a sudden rainfall increase at hours 30-32.

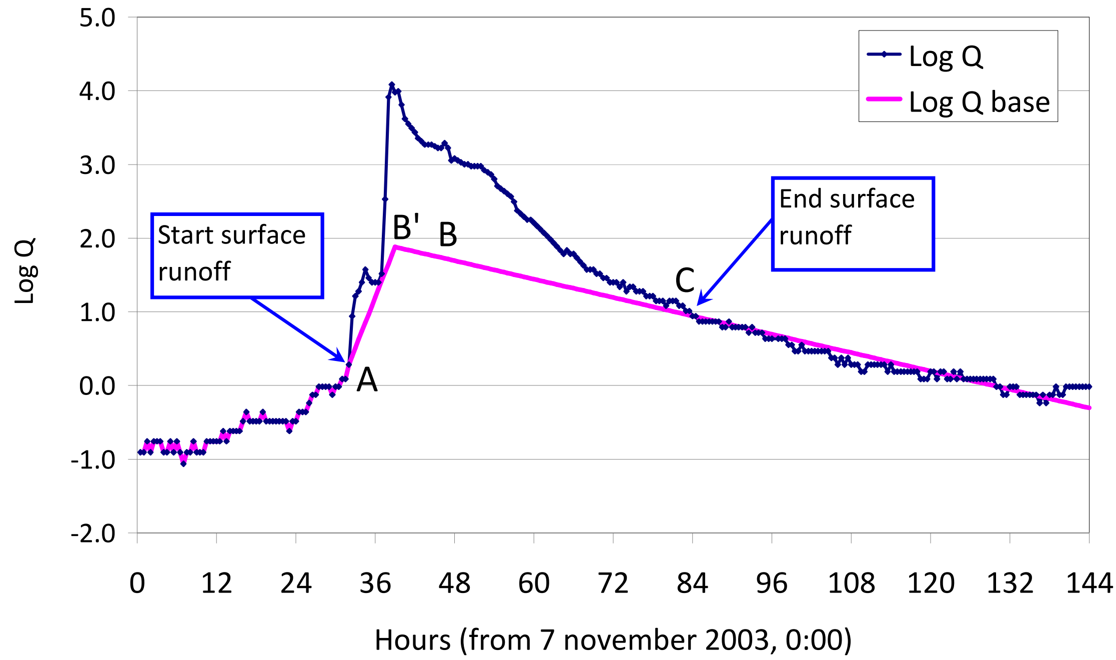
As far as the form of the curve separating baseflow and surface runoff between A and C, we follow the method described by Subramanya (1994): the exponential depletion function is propagated backward drawing on the semi-log hydrograph the corresponding line on the recession limb from point C up to the time instant of the inflection point of the recession curve (point B, t = h 46). As above said, such point is considered as the start of the main recession, represented by an exponential depletion function.

In the next, last step, point B is connected back to the beginning of the surface runoff event (point A), as depicted in the figure above.

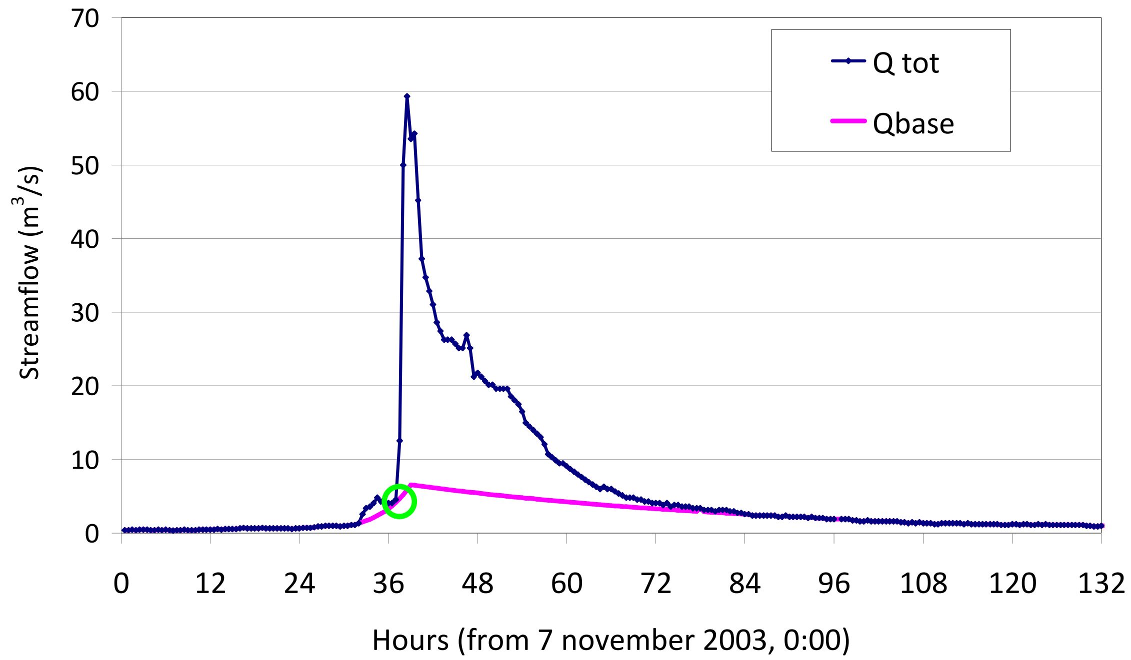
In natural scale axes, the baseflow hydrograph is thus identified, as depicted in the figure below:



An alternative method would be (Gray, 1973) to extend the straight line backward from point B to a point (B') beneath the crest of hydrograph (rather than interrupting beneath the inflection point, in B), as shown below:.

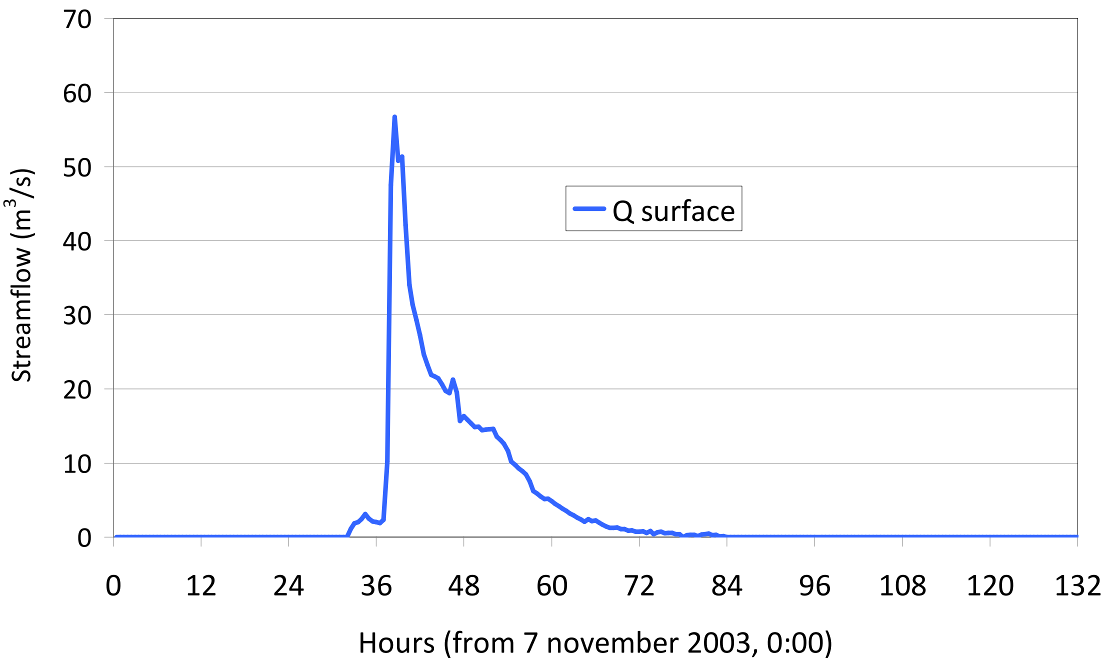


But this second method is not physically consistent with our hydrograph, that has a two-peak shape: the AB’C baseflow curve would in fact intersect the total runoff curve (therefore annulling the surface flow) after the first peak of the surface runoff (generated by the first rainfall spell, hours 30-32), as shown also in the natural axes in the figure below).



It follows that the alternative method (based on Gray, 1973) is not adequate for the present case study.

With the hydrograph separation obtained following the first graphical method described above (that is interrupting the exponential recession flow at the inflection point B, as in Subramanya, 1994), the surface runoff hydrograph results from the difference between total streamflow and baseflow and it is depicted in the figure below.



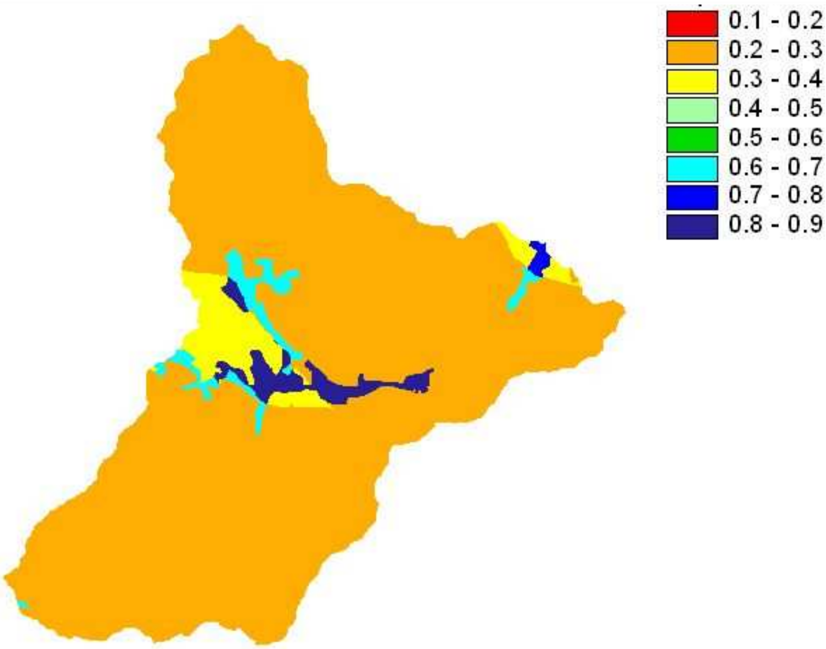
The area under this hydrograph is equal to the total surface runoff volume, that is 1720319 m^3.

Calibrated net rainfall maps

The ratio between the total surface volume (1720319 m^3) and the total gross rainfall volume (5556055 m^3) is the mean runoff coefficient corresponding to the considered event and we must, therefore, calibrate the local runoff coefficient so that the total net rainfall volume equals the total surface volume.

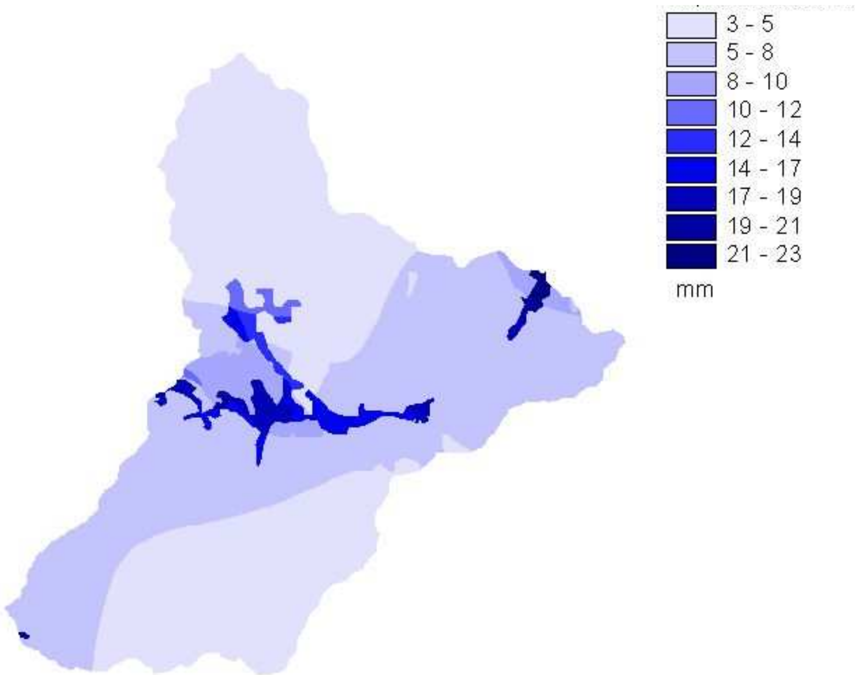
The average value over the entire watershed of the runoff coefficient obtained on the basis of literature values in the first estimate of the corresponding map (as described in the previous section) was in fact equal to 0.215; such value should become, after the calibration procedure, equal to 0.310.

The calibration procedure is therefore completed by applying a constant scalar multiplier to the value of each cell of the parameter map: such multiplier is given by the ratio between the calibrated and the first-estimate mean runoff coefficient, that is 0.310/0.215=1.44. The calibrated values of the local runoff coefficients are depicted in the map below:



The final net rainfall fields, for each time step of the rainfall event, are obtained by multiplying, in each cell, the corresponding gross rainfall depth by the local runoff coefficient.

We show below, as an example, the net rainfall map obtained for h. 13.00 of 8 November 2003:



The matrixes representing the cell values (one matrix for each hourly time step *t*) are the data that are provided as input to the spatially-distributed rainfall-runoff model (by the LAMPIT research group), for the propagation of the surface runoff over the hillslopes and in the channels.

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APPENDIX A1

Raingauges - Toscana Network					
	GAUGE [code]	Municipality and Province	Elevation (m a.s.l.)	EAST Gauss-Boaga (m)	NORTH Gauss-Boaga (m)
1	Vara [25]	Carrara (MS)	440	1590400	4881820
2	Gallena [78]	Stazzema (LU)	350.9	1600467	4871743
3	Retignano [79]	Stazzema (LU)	440	1602127	4873290
4	Cervaiole [81]	Seravezza (LU)	1009.25	1600001	4876921
5	Azzano [83]	Seravezza (LU)	428.19	1598539	4874893
6	Cerreta S.Nicola [85]	Seravezza (LU)	155.26	1597508	4871227
7	Pedona [106]	Camaiore (LU)	339.55	1604150	4863396
8	Vallelunga [108]	Camaiore (LU)	715.62	1607247	4869378
9	Villacollemandina [203]	Villa Collemandina (LU)	524.38	1610793	4890457
10	Casone Profecchia [221]	Castiglione di Garfagnana (LU)	1336.33	1615421	4896432
11	Lucca [512]	Lucca (LU)	20.29	1621548	4855277
12	Chiatri [515]	Lucca (LU)	250.01	1610815	4858608
13	Vorno [519]	Capannori (LU)	87	1621857	4849570
14	Capezzine [701]	Montepulciano (SI)	327	1738412	4783395
15	Arezzo [771]	Arezzo (AR)	296	1733932	4816995
16	Laterina [799]	Laterina (AR)	191	1719297	4820680
17	Badia Agnano [811]	Bucine (AR)	230	1714317	4812705
18	Vallombrosa [901]	Reggello (FI)	955	1705947	4845270
19	Cavallina [911]	Barberino di Mugello (FI)	270	1678957	4872710
20	Monte di Fo' [916]	Barberino di Mugello (FI)	764	1682647	4882970
21	Marcoiano [925]	Scarperia (FI)	537.51	1684567	4880320
22	Le Croci (Barberino) [926]	Barberino di Mugello (FI)	384.15	1682068	4875278
23	Ponte a Olmo [931]	Scarperia (FI)	444	1684657	4879845
24	Villore [1011]	Vicchio (FI)	418	1704207	4871150
25	Dicomano [1029]	Dicomano (FI)	180	1702987	4862870
26	Consuma [1041]	Rufina (FI)	950	1708072	4851215
27	Caldine [1103]	Fiesole (FI)	460.16	1688086	4857219
28	Lamole [1115]	Greve iChianti (FI)	557.45	1690340	4824254
29	Ferrone [1129]	Greve iChianti (FI)	149	1682187	4835900
30	Ugolino [1136]	Impruneta (FI)	201.59	1685100	4840820
31	Antella [1141]	Bagno a Ripoli (FI)	170	1687597	4844355
32	Colombano [1147]	Scandicci (FI)	33.38	1671503	4849463
33	Vaiano [1181]	Prato (PO)	106.24	1670737	4865312
34	Le Croci Calenzano [1189]	Calenzano (FI)	440	1677647	4868135
35	Baggio [1263]	Pistoia (PT)	434.52	1657445	4872516
36	La Ferruccia [1269]	Agliana (PT)	45	1660487	4860540
37	Fattoria Iavello [1273]	Montemurlo (PO)	551	1666127	4869670
38	Radda iChianti [1284]	Radda iChianti (SI)	576.28	1690685	4816879
39	S.Donato iPoggio [1291]	Tavarnelle Val di Pesa (FI)	401.67	1680947	4822820
40	Casole d'Elsa [1391]	Casole d'Elsa (SI)	418	1665622	4800790

41	S.Gimignano [1419]	SaGimignano (SI)	374	1665137	4815110
42	Poggio Aglione [1445]	Gambassi Terme (FI)	453.04	1655263	4821499
43	S.Miniato (Cimitero) [1491]	SaMiniato (PI)	124	1647687	4838450
44	Montecatini Terme [1601]	Montecatini Terme (PT)	60	1642422	4861760
45	Castelmartini [1629]	Larciano (PT)	23	1647317	4853830
46	S.Baronto [1634]	Quarrata (PT)	435.94	1655841	4855210
47	Casciana Terme [1781]	Casciana Terme (PI)	114	1630732	4820385
48	Monte Serra [1801]	Calci (PI)	918	1625137	4845300
49	Coltano [1831]	Pisa (PI)	1	1612167	4832605
50	Segromigno Monte [1849]	Capannori (LU)	65	1628007	4861360
51	Monterotondo [2371]	Monterotondo Marittimo (GR)	530	1651067	4778993
52	Monteverdi [2376]	Monteverdi Marittimo (PI)	364	1639329	4781644
53	Madonna a Brolio [2643]	Castelnuovo Berardenga (SI)	409.02	1703707	4809762
54	Monteroni d'Arbia [2689]	Monteroni d'Arbia (SI)	229.39	1696787	4792265
55	Montalcino [2701]	Montalcino (SI)	605.22	1702888	4769286
56	Montalcinello [2733]	Chiusdino (SI)	380	1668560	4784096
57	Sovicille [2761]	Sovicille (SI)	226.81	1681180	4793178
58	S.Lorenzo a Merse [2766]	Monticiano (SI)	195.25	1684939	4779890
59	Torniella [2781]	Roccastrada (GR)	470	1674995	4770984
60	Pari [2789]	Civitella Paganico (GR)	280.14	1689261	4770748
61	Monte Antico [2801]	Civitella Paganico (GR)	74.62	1692236	4761569
62	Spineta [2819]	Sarteano (SI)	505.59	1731092	4759064
63	Roccalbegna [3019]	Roccalbegna (GR)	520	1705372	4740215
64	Capanne [3041]	Manciano (GR)	364.22	1708352	4728865
65	Usi [3053]	Roccalbegna (GR)	371.42	1701637	4732930
66	Torricelle [3063]	Scansano (GR)	169.7	1698789	4723757
67	Scansano [3071]	Scansano (GR)	438	1691786	4728831
68	Manciano [3079]	Manciano (GR)	443	1708887	4717660
69	Marsiliana [3089]	Manciano (GR)	21.35	1692742	4712997
70	S.Donato [3099]	Orbetello (GR)	19	1682617	4711055

APPENDIX A2

Raingauges - Emilia-Romagna Network						
	GAUGE	Municipality	Province	Elevation (m a.s.l.)	EAST LONG degrees	NORTH LAT degrees
1	Albareto	Modena	Modena	28	10.956695	44.702143
2	Castelfranco Emilia	Castelfranco Emilia	Modena	33	11.02745	44.630086
3	Sant'Agata Sul Santerno	Sant'Agata Sul Santerno	Ravenna	10	11.866664	44.448528
4	San Clemente	San Clemente	Rimini	63	12.659322	43.927652
5	San Salvatore	Rimini	Rimini	35	12.580159	43.994317
6	Casola Canina	Imola	Bologna	32	11.754078	44.419531
7	Sant'Agata Bolognese	Sant'Agata Bolognese	Bologna	18	11.144922	44.695
8	Copparo	Copparo	Ferrara	1	11.8213	44.916303
9	Sala Bolognese	Sala Bolognese	Bologna	25	11.249569	44.589602
10	Correggio	Correggio	Reggio Emilia	33	10.772919	44.743253
11	Cavriago	Cavriago	Reggio Emilia	95	10.510614	44.689528
12	Carpineta	Cesena	Forli-Cesena	113	12.274586	44.08903
13	Lavezzola	Argenta	Ferrara	5	11.844027	44.563498
14	Camposanto	Camposanto	Modena	17	11.118178	44.79683
15	Campremoldo Di Sopra	Gragnano Trebbiense	Piacenza	92	9.52925	45.004046
16	Gainago	Torrile	Parma	28	10.380697	44.885471
17	Brisighella	Brisighella	Ravenna	185	11.755445	44.219774
18	Camse	Argenta	Ferrara	-1	12.077371	44.60016
19	Finale Emilia	Finale Emilia	Modena	12	11.284019	44.839059
20	Malborghetto Di Boara	Ferrara	Ferrara	4	11.66134	44.857987
21	Martorano	Cesena	Forli-Cesena	25	12.267972	44.166139
22	San Pietro Capofiume	Molinella	Bologna	11	11.622633	44.653775
23	Loiano	Loiano	Bologna	741	11.326454	44.260931
24	Vignola	Vignola	Modena	100	11.004133	44.504049
25	Panocchia	Langhirano	Parma	169	10.295833	44.683696
26	Imola Mario Neri	Imola	Bologna	68	11.749529	44.333198
27	Fiorenzuola	Fiorenzuola D'Arda	Piacenza	82	9.89456	44.92895
28	Monticelli	Castelvetro Piacentino	Piacenza	37	9.970864	45.080495
29	Vicobarone	Ziano Piacentino	Piacenza	263	9.378718	44.991537
30	San Pancrazio	Parma	Parma	59	10.272447	44.808057
31	Sasso Marconi	Sasso Marconi	Bologna	275	11.241247	44.439667
32	Volano	Codigoro	Ferrara	1	12.250363	44.812866
33	Rolo	Rolo	Reggio Emilia	20	10.873997	44.884811
34	Ravenna Le Bassette	Ravenna	Ravenna	2	12.205548	44.465348
35	Bagnacavallo Villa Prati	Bagnacavallo	Ravenna	4	12.019918	44.45256
36	Loiano	Loiano	Bologna	675	11.34154	44.263522
37	Ca' Bortolani	Savigno	Bologna	691	11.084543	44.346802
38	Invaso	San Benedetto V.Sambro	Bologna	460	11.221895	44.227354
39	Casalecchio Canonica1	Casalecchio Di Reno	Bologna	54	11.288114	44.487873
40	Madonna Dei Fornelli	San Benedetto V. Sambro	Bologna	900	11.256794	44.215704
41	Bologna Meteo	Bologna	Bologna	80	11.328197	44.501223
42	Monteacuto Nelle Alpi	Lizzano In Belvedere	Bologna	900	10.887403	44.136372
43	Sasso Marconi	Sasso Marconi	Bologna	105	11.247815	44.381542
44	Bazzano	Bazzano	Bologna	80	11.084006	44.508435

45	Pianoro	Pianoro	Bologna	174	11.33999	44.371047
46	Casalecchio Tiro A Volo	Casalecchio Di Reno	Bologna	54	11.282044	44.480252
47	Vergato	Vergato	Bologna	193	11.11312	44.287794
48	Casalecchio Canale	Casalecchio Di Reno	Bologna	63	11.281162	44.475679
49	Porretta Terme	Porretta Terme	Bologna	352	10.977288	44.154037
50	Imola	Imola	Bologna	42	11.712658	44.34581
51	Anzola Dell'Emilia	Anzola Dell'Emilia	Bologna	39	11.196517	44.552077
52	Monteombraro	Zocca	Modena	700	11.008748	44.376321
53	Cottede	Castiglione Dei Pepoli	Bologna	794	11.169299	44.109614
54	Casoni Di Romagna	Monterenzio	Bologna	708	11.425349	44.253597
55	Ponte Verucchio	Torriana	Rimini	117	12.405809	43.981045
56	Le Taverne	Fontanelice	Bologna	486	11.587496	44.249227
57	Riola Di Labante	Castel D'Aiano	Bologna	623	11.035359	44.261172
58	San Clemente	Castel San Pietro Terme	Bologna	166	11.490651	44.319154
59	Monte Albano	Casola Valsenio	Ravenna	480	11.673944	44.225754
60	Monghidoro	Monghidoro	Bologna	825	11.321292	44.219578
61	San Ruffillo Savena	Bologna	Bologna	92	11.365187	44.453775
62	Monte San Pietro	Monte San Pietro	Bologna	291	11.138369	44.440299
63	Sestola	Sestola	Modena	985	10.768713	44.232114
64	Pievepelago	Pievepelago	Modena	1083	10.577223	44.19428
65	Pavullo	Pavullo Nel Frignano	Modena	678	10.82825	44.319567
66	Ferriere Pluvio	Ferriere	Piacenza	656	9.495954	44.644469
67	Bardi	Bardi	Parma	597	9.732825	44.633786
68	Bedonia	Bedonia	Parma	521	9.626736	44.507445
69	Castelnovo Ne' Monti	Castelnovo Ne' Monti	Reggio Emilia	729	10.3947	44.434863
70	Frassinoro	Frassinoro	Modena	1091	10.575654	44.295744
71	Succiso	Ramiseto	Reggio Emilia	998	10.192523	44.363422
72	Isola Di Palanzano	Palanzano	Parma	597	10.162157	44.428357
73	Lagdei	Corniglio	Parma	1252	10.008529	44.412282
74	Marra	Corniglio	Parma	618	10.047452	44.47342
75	Parma T.P.	Parma	Parma	54	10.330313	44.808064
76	Langhirano	Langhirano	Parma	297	10.26108	44.604133
77	Calestano	Calestano	Parma	381	10.124506	44.60591
78	Mangiarosto	Farini	Piacenza	761	9.598131	44.661346
79	Boretto	Boretto	Reggio Emilia	25	10.540667	44.905993
80	Borgotaro	Borgo Val Di Taro	Parma	348	9.842044	44.514182
81	Farini	Farini	Piacenza	423	9.569934	44.71194
82	Bobbio	Bobbio	Piacenza	270	9.384121	44.754893
83	Sassostorno	Lama Mocogno	Modena	971	10.674074	44.259396
84	Nociveglia	Bedonia	Parma	855	9.610026	44.547102
85	Doccia Di Fiumalbo	Fiumalbo	Modena	1371	10.673097	44.190124
86	Pontelagoscuro	Ferrara	Ferrara	8	11.608257	44.888758
87	Lago Ballano	Monchio Delle Corti	Parma	1339	10.102065	44.369482
88	Ligonchio	Ligonchio	Reggio Emilia	900	10.344929	44.316986
89	Neviano Arduini	Neviano Degli Arduini	Parma	513	10.313753	44.583373
90	Montegroppo	Albareto	Parma	656	9.686388	44.418777
91	Pianello Val Tidone	Pianello Val Tidone	Piacenza	410	9.431035	44.937114
92	Bosco Di Corniglio	Corniglio	Parma	902	10.033517	44.439004
93	Salsomaggiore	Salsomaggiore Terme	Parma	146	9.991247	44.819008
94	Santa Maria Di Taro	Tornolo	Parma	853	9.480696	44.437509
95	La Stella	Casina	Reggio Emilia	729	10.49071	44.529901
96	Febbio	Villa Minozzo	Reggio Emilia	1148	10.427491	44.297916

97	Farneta	Montefiorino	Modena	703	10.57013	44.349862
98	Collagna	Collagna	Reggio Emilia	832	10.271194	44.344748
99	Montese	Montese	Modena	920	10.942046	44.276914
100	Ponte Samone	Guiglia	Modena	224	10.922762	44.356672
101	Trebbia Valsigiara	Ottone	Piacenza	490	9.330275	44.640162
102	Ponte Cavola	Carpineti	Reggio Emilia	367	10.522779	44.409369
103	Berceto	Berceto	Parma	758	9.982996	44.510473
104	Villa Minozzo	Villa Minozzo	Reggio Emilia	704	10.460034	44.362511
105	Serramazzoni	Serramazzoni	Modena	826	10.787069	44.428854
106	Carpineti	Carpineti	Reggio Emilia	594	10.495343	44.467873
107	San Valentino	Castellarano	Reggio Emilia	302	10.699195	44.523714
108	Ramiseto	Ramiseto	Reggio Emilia	798	10.275604	44.411434
109	Predolo	Castelnovo Ne' Monti	Reggio Emilia	751	10.446758	44.484416
110	Musiara Superiore	Tizzano Val Parma	Parma	982	10.178341	44.498531
111	Campora Di Sasso	Neviano Degli Arduini	Parma	649	10.275539	44.521218
112	Grammatica	Corniglio	Parma	980	10.092877	44.438252
113	Casaselvatica	Berceto	Parma	834	10.035629	44.54781
114	Bettola	Bettola	Piacenza	600	9.633621	44.795508
115	Selva Ferriere	Ferriere	Piacenza	1109	9.482435	44.586766
116	Cassimoreno	Ferriere	Piacenza	881	9.579336	44.636163
117	San Michele	Morfasso	Piacenza	662	9.702302	44.762733
118	Tarsogno	Tornolo	Parma	852	9.61802	44.44668
119	Varano Marchesi	Medesano	Parma	434	10.023625	44.733397
120	Salsominore	Cerignale	Piacenza	379	9.405107	44.632818
121	Piandelagotti	Frassinoro	Modena	1219	10.516331	44.237129
122	Lago Pratignano	Fanano	Modena	1319	10.817791	44.177396
123	Civago	Villa Minozzo	Reggio Emilia	1051	10.465789	44.24716
124	Ospitaletto	Ligonchio	Reggio Emilia	1150	10.316667	44.296952
125	Canossa	Canossa	Reggio Emilia	516	10.465811	44.565884
126	Quattro Castella	Quattro Castella	Reggio Emilia	173	10.474252	44.633269
127	Cerreto Laghi	Collagna	Reggio Emilia	1336	10.238571	44.298726
128	Bobbiano	Travo	Piacenza	552	9.490199	44.877595
129	Riglio	Bettola	Piacenza	419	9.675593	44.81916
130	Case Bonini	Vernasca	Piacenza	347	9.775812	44.752031
131	Noveglia	Bardi	Parma	541	9.766827	44.592691
132	Pellegrino	Pellegrino Parmense	Parma	434	9.934678	44.727183
133	Pessola	Varsi	Parma	803	9.866968	44.629481
134	Pione	Bardi	Parma	689	9.633987	44.619461
135	Roncovetro	Canossa	Reggio Emilia	571	10.381345	44.517691
136	Polinago	Polinago	Modena	754	10.729767	44.343643
137	Perino	Coli	Piacenza	240	9.497075	44.81869
138	Casalporino	Bedonia	Parma	925	9.547373	44.52711
139	Mormorola	Valmozzola	Parma	556	9.886517	44.568797
140	Bore	Bore	Parma	800	9.788295	44.714216
141	Albareto Parma	Albareto	Parma	495	9.698466	44.446855
142	Farfanaro	Compiano	Parma	787	9.679518	44.566678
143	Varsi	Varsi	Parma	451	9.821047	44.649418
144	Valdena	Borgo Val Di Taro	Parma	762	9.784202	44.444138
145	Rifugio Bargetana	Ligonchio	Reggio Emilia	1517	10.398283	44.261016
146	Frassineto	Bardi	Parma	824	9.585066	44.581569
147	Guiglia	Guiglia	Modena	456	10.992428	44.432487
148	Baiso	Baiso	Reggio Emilia	550	10.605699	44.499066

149	Gropparello	Gropparello	Piacenza	341	9.7255	44.825101
150	Ca' De' Caroli	Scandiano	Reggio Emilia	98	10.676524	44.595484

APPENDIX A3

Temperature gages						
	GAUGE	Municipality	Province	Elevation (m a.s.l.)	EAST LONG degrees	NORTH LAT degrees
1	Camse	Argenta	Ferrara	-1	12.077371	44.60016
2	Finale Emilia	Finale Emilia	Modena	12	11.284019	44.839059
3	Malborghetto Di Boara	Ferrara	Ferrara	4	11.66134	44.857987
4	Martorano	Cesena	Forli-Cesena	25	12.267972	44.166139
5	San Pietro Capofiume	Molinella	Bologna	11	11.622633	44.653775
6	Loiano	Loiano	Bologna	741	11.326454	44.260931
7	Vignola	Vignola	Modena	100	11.004133	44.504049
8	Panocchia	Langhirano	Parma	169	10.295833	44.683696
9	Imola Mario Neri	Imola	Bologna	68	11.749529	44.333198
10	San Pancrazio	Parma	Parma	59	10.272447	44.808057
11	Albareto	Modena	Modena	28	10.956695	44.702143
12	Castelfranco Emilia	Castelfranco Emilia	Modena	33	11.02745	44.630086
13	Sasso Marconi	Sasso Marconi	Bologna	275	11.241247	44.439667
14	San Clemente	San Clemente	Rimini	63	12.659322	43.927652
15	San Salvatore	Rimini	Rimini	35	12.580159	43.994317
16	Casola Canina	Imola	Bologna	32	11.754078	44.419531
17	Sant'Agata Bolognese	Sant'Agata Bolognese	Bologna	18	11.144922	44.695
18	Copparo	Copparo	Ferrara	1	11.8213	44.916303
19	Sala Bolognese	Sala Bolognese	Bologna	25	11.249569	44.589602
20	Correggio	Correggio	Reggio Emilia	33	10.772919	44.743253
21	Cavriago	Cavriago	Reggio Emilia	95	10.510614	44.689528
22	Carpineta	Cesena	Forli-Cesena	113	12.274586	44.08903
23	Lavezzola	Argenta	Ferrara	5	11.844027	44.563498
24	Camposanto	Camposanto	Modena	17	11.118178	44.79683
25	Campremoldo Di Sopra	Gragnano Trebbiense	Piacenza	92	9.52925	45.004046
26	Volano	Codigoro	Ferrara	1	12.250363	44.812866
27	Rolo	Rolo	Reggio Emilia	20	10.873997	44.884811
28	Invaso	San Benedetto V. Sambro	Bologna	460	11.221895	44.227354
29	Sestola	Sestola	Modena	985	10.768713	44.232114
30	Pavullo	Pavullo Nel Frignano	Modena	678	10.82825	44.319567
31	Bardi	Bardi	Parma	597	9.732825	44.633786
32	Bedonia	Bedonia	Parma	521	9.626736	44.507445
33	Castelnovo Ne' Monti	Castelnovo Ne' Monti	Reggio Emilia	729	10.3947	44.434863
34	Frassinoro	Frassinoro	Modena	1091	10.575654	44.295744
35	Isola Di Palanzano	Palanzano	Parma	597	10.162157	44.428357
36	Lagdei	Corniglio	Parma	1252	10.008529	44.412282
37	Marra	Corniglio	Parma	618	10.047452	44.47342
38	Parma T.P.	Parma	Parma	54	10.330313	44.808064
39	Langhirano	Langhirano	Parma	297	10.26108	44.604133
40	Calestano	Calestano	Parma	381	10.124506	44.60591
41	Monte Grosso	Rocca San Casciano	Forli-Cesena	670	11.871813	44.071534
42	Rontana	Brisighella	Ravenna	370	11.73784	44.226985
43	Corsicchie	Bagno Di Romagna	Forli-Cesena	1200	12.035707	43.845971
44	Civitella	Civitella Di Romagna	Forli-Cesena	460	11.9453	43.993487
45	Lodolone	Brisighella	Ravenna	250	11.874879	44.197579

46	Monte Romano	Brisighella	Ravenna	705	11.652922	44.134865
47	Voltre	Civitella Di Romagna	Forli-Cesena	270	12.043257	44.032475
48	Trebbio	Modigliana	Forli-Cesena	570	11.837038	44.136568
49	Monte Iottone	Mercato Saraceno	Forli-Cesena	365	12.168656	43.996905
50	Roversano	Cesena	Forli-Cesena	175	12.20682	44.085705
51	Corniolo	Santa Sofia	Forli-Cesena	735	11.7933	43.924257
52	Montriolo	Santa Sofia	Forli-Cesena	685	11.957652	43.922638
53	Madonna Dei Fornelli	San Benedetto V. Sambro	Bologna	900	11.256794	44.215704
54	Bologna Meteo	Bologna	Bologna	80	11.328197	44.501223
55	Monteacuto Nelle Alpi	Lizzano In Belvedere	Bologna	900	10.887403	44.136372
56	Casalecchio Tiro A Volo	Casalecchio Di Reno	Bologna	54	11.282044	44.480252
57	Gallo	Malalbergo	Bologna	21	11.545375	44.724096
58	Borgotaro	Borgo Val Di Taro	Parma	348	9.842044	44.514182
59	Quarto	Sarsina	Forli-Cesena	247	12.095174	43.892145
60	Santa Sofia	Santa Sofia	Forli-Cesena	258	11.905141	43.941326
61	Santa Zaccaria	Ravenna	Ravenna	10	12.214062	44.257283
62	Teodorano	Meldola	Forli-Cesena	79	12.084919	44.091478
63	Bobbio	Bobbio	Piacenza	270	9.384121	44.754893
64	Monteombraro	Zocca	Modena	700	11.008748	44.376321
65	Cottede	Castiglione Dei Pepoli	Bologna	794	11.169299	44.109614
66	Casoni Di Romagna	Monterenzio	Bologna	708	11.425349	44.253597
67	Sassostorno	Lama Mocogno	Modena	971	10.674074	44.259396
68	Nociveglia	Bedonia	Parma	855	9.610026	44.547102
69	Doccia Di Fiumalbo	Fiumalbo	Modena	1371	10.673097	44.190124
70	Pontelagoscuro	Ferrara	Ferrara	8	11.608257	44.888758
71	Lago Ballano	Monchio Delle Corti	Parma	1339	10.102065	44.369482
72	Ligonchio	Ligonchio	Reggio Emilia	900	10.344929	44.316986
73	Neviano Arduini	Neviano Degli Arduini	Parma	513	10.313753	44.583373
74	Montegroppo	Albareto	Parma	656	9.686388	44.418777
75	Pianello Val Tidone	Pianello Val Tidone	Piacenza	410	9.431035	44.937114
76	Bosco Di Corniglio	Corniglio	Parma	902	10.033517	44.439004
77	Salsomaggiore	Salsomaggiore Terme	Parma	146	9.991247	44.819008
78	Santa Maria Di Taro	Tornolo	Parma	853	9.480696	44.437509
79	La Stella	Casina	Reggio Emilia	729	10.49071	44.529901
80	Febbio	Villa Minozzo	Reggio Emilia	1148	10.427491	44.297916
81	Farneta	Montefiorino	Modena	703	10.57013	44.349862
82	Collagna	Collagna	Reggio Emilia	832	10.271194	44.344748
83	Montese	Montese	Modena	920	10.942046	44.276914
84	Trebbia Valsigiara	Ottone	Piacenza	490	9.330275	44.640162
85	Ponte Cavola	Carpineti	Reggio Emilia	367	10.522779	44.409369
86	Berceto	Berceto	Parma	758	9.982996	44.510473
87	Villa Minozzo	Villa Minozzo	Reggio Emilia	704	10.460034	44.362511
88	San Carlo	Cesena	Forli-Cesena	54	12.199836	44.090979
89	Serramazzoni	Serramazzoni	Modena	826	10.787069	44.428854
90	Carpineti	Carpineti	Reggio Emilia	594	10.495343	44.467873
91	San Valentino	Castellarano	Reggio Emilia	302	10.699195	44.523714
92	Ramiseto	Ramiseto	Reggio Emilia	798	10.275604	44.411434
93	Predolo	Castelnovo Ne' Monti	Reggio Emilia	751	10.446758	44.484416
94	Musiara Superiore	Tizzano Val Parma	Parma	982	10.178341	44.498531
95	Campora Di Sasso	Neviano Degli Arduini	Parma	649	10.275539	44.521218
96	Grammatica	Corniglio	Parma	980	10.092877	44.438252
97	Casaselvatica	Berceto	Parma	834	10.035629	44.54781

98	Bettola	Bettola	Piacenza	600	9.633621	44.795508
99	Selva Ferriere	Ferriere	Piacenza	1109	9.482435	44.586766
100	Cassimoreno	Ferriere	Piacenza	881	9.579336	44.636163
101	San Michele	Morfasso	Piacenza	662	9.702302	44.762733
102	Tarsogno	Tornolo	Parma	852	9.61802	44.44668
103	Varano Marchesi	Medesano	Parma	434	10.023625	44.733397
104	Salsominore	Cerignale	Piacenza	379	9.405107	44.632818
105	Piandelagotti	Frassinoro	Modena	1219	10.516331	44.237129
106	Lago Pratignano	Fanano	Modena	1319	10.817791	44.177396
107	Civago	Villa Minozzo	Reggio Emilia	1051	10.465789	44.24716
108	Ospitaletto	Ligonchio	Reggio Emilia	1150	10.316667	44.296952
109	Canossa	Canossa	Reggio Emilia	516	10.465811	44.565884
110	Cerreto Laghi	Collagna	Reggio Emilia	1336	10.238571	44.298726
111	Roncovetro	Canossa	Reggio Emilia	571	10.381345	44.517691
112	Polinago	Polinago	Modena	754	10.729767	44.343643
113	Teruzzi	Morfasso	Piacenza	1077	9.685236	44.69503
114	Casalporino	Bedonia	Parma	925	9.547373	44.52711
115	Mormorola	Valmozzola	Parma	556	9.886517	44.568797
116	Albareto Parma	Albareto	Parma	495	9.698466	44.446855
117	Farfanaro	Compiano	Parma	787	9.679518	44.566678
118	Varsi	Varsi	Parma	451	9.821047	44.649418
119	Valdena	Borgo Val Di Taro	Parma	762	9.784202	44.444138
120	Rifugio Bargetana	Ligonchio	Reggio Emilia	1517	10.398283	44.261016
121	Frassineto	Bardi	Parma	824	9.585066	44.581569
122	Guiglia	Guiglia	Modena	456	10.992428	44.432487
123	Baiso	Baiso	Reggio Emilia	550	10.605699	44.499066
124	Gainago	Torrile	Parma	28	10.380697	44.885471
125	Brisighella	Brisighella	Ravenna	185	11.755445	44.219774

APPENDIX A4

Weather stations: HUMIDITY						
	GAUGE	Municipality	Province	Elevation (m a.s.l.)	EAST LONG degrees	NORTH LAT degrees
1	Camse	Argenta	Ferrara	-1	12.077371	44.60016
2	Finale Emilia	Finale Emilia	Modena	12	11.284019	44.839059
3	Malborghetto Di Boara	Ferrara	Ferrara	4	11.66134	44.857987
4	Martorano	Cesena	Forli-Cesena	25	12.267972	44.166139
5	San Pietro Capofiume	Molinella	Bologna	11	11.622633	44.653775
6	Loiano	Loiano	Bologna	741	11.326454	44.260931
7	Vignola	Vignola	Modena	100	11.004133	44.504049
8	Panocchia	Langhirano	Parma	169	10.295833	44.683696
9	Imola Mario Neri	Imola	Bologna	68	11.749529	44.333198
10	San Pancrazio	Parma	Parma	59	10.272447	44.808057
11	Albareto	Modena	Modena	28	10.956695	44.702143
12	Castelfranco Emilia	Castelfranco Emilia	Modena	33	11.02745	44.630086
13	Sasso Marconi	Sasso Marconi	Bologna	275	11.241247	44.439667
14	San Clemente	San Clemente	Rimini	63	12.659322	43.927652
15	San Salvatore	Rimini	Rimini	35	12.580159	43.994317
16	Casola Canina	Imola	Bologna	32	11.754078	44.419531
17	Sant'Agata Bolognese	Sant'Agata Bolognese	Bologna	18	11.144922	44.695
18	Copparo	Copparo	Ferrara	1	11.8213	44.916303
19	Sala Bolognese	Sala Bolognese	Bologna	25	11.249569	44.589602
20	Correggio	Correggio	Reggio Emilia	33	10.772919	44.743253
21	Cavriago	Cavriago	Reggio Emilia	95	10.510614	44.689528
22	Carpineta	Cesena	Forli-Cesena	113	12.274586	44.08903
23	Lavezzola	Argenta	Ferrara	5	11.844027	44.563498
24	Camposanto	Camposanto	Modena	17	11.118178	44.79683
25	Campremoldo Di Sopra	Gragnano Trebbiense	Piacenza	92	9.52925	45.004046
26	Volano	Codigoro	Ferrara	1	12.250363	44.812866
27	Rolo	Rolo	Reggio Emilia	20	10.873997	44.884811
28	Invaso	San Benedetto V. Sambro	Bologna	460	11.221895	44.227354
29	Madonna Dei Fornelli	San Benedetto V. Sambro	Bologna	900	11.256794	44.215704
30	Bologna Meteo	Bologna	Bologna	80	11.328197	44.501223
31	Febbio	Villa Minozzo	Reggio Emilia	1148	10.427491	44.297916
32	Teruzzi	Morfasso	Piacenza	1077	9.685236	44.69503
33	Gainago	Torrile	Parma	28	10.380697	44.885471
34	Brisighella	Brisighella	Ravenna	185	11.755445	44.219774

APPENDIX A5

Weather stations: WIND SPEED, WIND DIRECTION, PRESSURE

	GAUGE	Municipality	Province	Elevation (m a.s.l.)	EAST LONG degrees	NORTH LAT degrees
1	Camse	Argenta	Ferrara	-1	12.077371	44.60016
2	Finale Emilia	Finale Emilia	Modena	12	11.284019	44.839059
3	Malborghetto Di Boara	Ferrara	Ferrara	4	11.66134	44.857987
4	Martorano	Cesena	Forli-Cesena	25	12.267972	44.166139
5	San Pietro Capofiume	Molinella	Bologna	11	11.622633	44.653775
6	Loiano	Loiano	Bologna	741	11.326454	44.260931
7	Vignola	Vignola	Modena	100	11.004133	44.504049
8	Panocchia	Langhirano	Parma	169	10.295833	44.683696
9	Imola Mario Neri	Imola	Bologna	68	11.749529	44.333198
10	Volano	Codigoro	Ferrara	1	12.250363	44.812866
11	Rolo	Rolo	Reggio Emilia	20	10.873997	44.884811
12	Madonna Dei Fornelli	San Benedetto V. Sambro	Bologna	900	11.256794	44.215704
13	Bologna Meteo	Bologna	Bologna	80	11.328197	44.501223
14	Febbio	Villa Minozzo	Reggio Emilia	1148	10.427491	44.297916
15	Cesenatico Porto	Cesenatico	Forli-Cesena	1	12.403483	44.201826
16	Teruzzi	Morfasso	Piacenza	1077	9.685236	44.69503
17	Varsi	Varsi	Parma	451	9.821047	44.649418
18	Fiorenzuola	Fiorenzuola D'Arda	Piacenza	82	9.89456	44.92895
19	Vicobarone	Ziano Piacentino	Piacenza	263	9.378718	44.991537

GAUGE	Wind speed	Wind direction	Pressure
Camse			N.O.
Finale Emilia	N.O.		
Malborghetto Di Boara			
Martorano			
San Pietro Capofiume			
Loiano	N.O.		
Vignola			
Panocchia			
Imola Mario Neri			
Volano			
Rolo			
Madonna Dei Fornelli			
Bologna Meteo			N.O.
Febbio			
Cesenatico Porto			N.O.
Teruzzi			
Varsi			N.O.
Fiorenzuola	N.O.		N.O.
Vicobarone	N.O.		N.O.

N.O.: Not Operative gauges during the event

APPENDIX B

Runoff Coefficients for the Rational Formula for Hydrological Soil Groups (A, B, C, D) and Slope Ranges, Source: McCuen, 2004.

TABLE 7–9 Runoff Coefficients for the Rational Formula versus Hydrologic Soil Group (A, B, C, D) and Slope Range

	A			B			C			D		
Land Use	0–2%	2–6%	6%+	0–2%	2–6%	6%+	0–2%	2–6%	6%+	0–2%	2–6%	6%+
Cultivated land	0.08[a]	0.13	0.16	0.11	0.15	0.21	0.14	0.19	0.26	0.18	0.23	0.31
	0.14[b]	0.18	0.22	0.16	0.21	0.28	0.20	0.25	0.34	0.24	0.29	0.41
Pasture	0.12	0.20	0.30	0.18	0.28	0.37	0.24	0.34	0.44	0.30	0.40	0.50
	0.15	0.25	0.37	0.23	0.34	0.45	0.30	0.42	0.52	0.37	0.50	0.62
Meadow	0.10	0.16	0.25	0.14	0.22	0.30	0.20	0.28	0.36	0.24	0.30	0.40
	0.14	0.22	0.30	0.20	0.28	0.37	0.26	0.35	0.44	0.30	0.40	0.50
Forest	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.20	0.25
Residential lot size 1/8 acre	0.25	0.28	0.31	0.27	0.30	0.35	0.30	0.33	0.38	0.33	0.36	0.42
	0.33	0.37	0.40	0.35	0.39	0.44	0.38	0.42	0.49	0.41	0.45	0.54
Residential lot size 1/4 acre	0.22	0.26	0.29	0.24	0.29	0.33	0.27	0.31	0.36	0.30	0.34	0.40
	0.30	0.34	0.37	0.33	0.37	0.42	0.36	0.40	0.47	0.38	0.42	0.52
Residential lot size 1/3 acre	0.19	0.23	0.26	0.22	0.26	0.30	0.25	0.29	0.34	0.28	0.32	0.39
	0.28	0.32	0.35	0.30	0.35	0.39	0.33	0.38	0.45	0.36	0.40	0.50
Residential lot size 1/2 acre	0.16	0.20	0.24	0.19	0.23	0.28	0.22	0.27	0.32	0.26	0.30	0.37
	0.25	0.29	0.32	0.28	0.32	0.36	0.31	0.35	0.42	0.34	0.38	0.48
Residential lot size 1 acre	0.14	0.19	0.22	0.17	0.21	0.26	0.20	0.25	0.31	0.24	0.29	0.35
	0.22	0.26	0.29	0.24	0.28	0.34	0.28	0.32	0.40	0.31	0.35	0.46
Industrial	0.67	0.68	0.68	0.68	0.68	0.69	0.68	0.69	0.69	0.69	0.69	0.70
	0.85	0.85	0.86	0.85	0.86	0.86	0.86	0.86	0.87	0.86	0.86	0.88
Commercial	0.71	0.71	0.72	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
	0.88	0.88	0.89	0.89	0.89	0.89	0.89	0.89	0.90	0.89	0.89	0.90
Streets	0.70	0.71	0.72	0.71	0.72	0.74	0.72	0.73	0.76	0.73	0.75	0.78
	0.76	0.77	0.79	0.80	0.82	0.84	0.84	0.85	0.89	0.89	0.91	0.95
Open space	0.05	0.10	0.14	0.08	0.13	0.19	0.12	0.17	0.24	0.16	0.21	0.28
	0.11	0.16	0.20	0.14	0.19	0.26	0.18	0.23	0.32	0.22	0.27	0.39
Parking	0.85	0.86	0.87	0.85	0.86	0.87	0.85	0.86	0.87	0.85	0.86	0.87
	0.95	0.96	0.97	0.95	0.96	0.97	0.95	0.96	0.97	0.95	0.96	0.97

[a] Runoff coefficients for storm recurrence intervals less than 25 years.

[b] Runoff coefficients for storm recurrence intervals of 25 years or longer.