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THE ROLE OF TERRAIN CHARACTERISTICS IN FLOOD MANAGEMENT, ATTICA, GREECE

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The purpose of this study is to investigate the role of terrain characteristics in flood management studies in Attica, Greece. Special emphasis is given to the peak storm runoff of the drainage basins in normal and wet conditions related to catastrophic events. Values computed by using the empirical and the Soil Conservation Service methods, refer to extreme values of the maximum probable peak storm runoff that might ever occur with a 50-yr recurrence period. The maximum 24-hr rainfall historical data according to Gumbel were used for the calculation. Terrain characteristics such as topography, land use, condition of soil, and permeability are considered. To illustrate the role of permeability, an example is presented for two basins in Attica, Greece. The study showed that there is a significant change of the curve number values (up to 33 percent) depending on the permeability of the basin. Peak storm runoff showed a 26 percent difference between normal and wet conditions.

INTRODUCTION

Severe urban flooding is a frequent phenomenon in Attica, Greece. In 1997, for example, approximately 12 inches of rain fell on the city, resulting in 15 fatalities and the evacuation of 20,000 residents. High intensity of rains, coupled with easy erodibility of terrain, constitute the main natural causes of flooding. In certain cases, anthropogenic factors like man's interventions in the stream system, including arbitrary construction of buildings and houses, have caused unprecedented flood hazards. Deforestation in the hilly areas of the region is also one of the causes of flooding. Floods of the Attica drainage basins, characterized by their large magnitude, need better understanding to improve flood management. The need for a more sophisticated technique than the empirical methods used to date has resulted in the introduction of the U.S. Soil Conservation Service (SCS) method (Soil Conservation Service, 1972) to:

1. represent terrain characteristics such as land use, and condition of soil,
2. study peak storm runoff as a function of terrain permeability, and
3. study scenarios such as normal and wet conditions.

The purpose of this paper is to assess terrain characteristics and their impacts on flood management as used for environmental studies (calculation of curve numbers and peak storm runoff). In the first part of the methodology, the empirical and SCS method are used. Then the study areas, consisting of two characteristic drainage basins are described. The results are given in terms of curve numbers and peak storm runoff in normal and wet conditions. Finally, from the comparison of the results, the study conclusions are presented.

METHODOLOGY

The Empirical Method

The well known empirical method, first introduced by Monterey in 1949, is recommended by the legislative Law 696/74 in Greece for the calculation of peak runoff discharge. For the metric system, the peak storm runoff is given by the following equation:

$$Q_p = 0.278\phi\rho Ai \qquad (1)$$

where

A = area of the drainage basin in km

i = maximum height of rainfall in a period equal to the total basin concentration time, T_c, in *mm/hr*

Q_p = peak storm runoff in m^3/s

ϕ = an empirical coefficient depending on the terrain topography, cover and geological character

ρ = the rainfall uniformity coefficient $(\rho = A^{\frac{1}{2}})$

The Soil Conservation Service (SCS) Method

The Soil Conservation Service Method is used for the calculation of the peak runoff discharge in this study. For the metric system the peak storm runoff is given by the following equation:

$$Q_p = 0.278 CN \rho A i \quad (2)$$

where

CN = the runoff curve number or specific runoff coefficient in various humidity conditions, in decimal values.

CN Determination

The equation used for the rainfall-runoff relation is:

$$Q / P = (P - Q) / S \quad (3)$$

where:

P = rainfall height

Q = basin discharge

S = maximum storage

hence

$$Q = P^2 / (P + S) \quad (4)$$

If the initial losses (I_a) (Hawkins, 1978; Hjelmfelt, 1980a; Hjelmfelt, 1980b; Hjelmfelt, 1991) are considered:

$$Q = \left(P - 1_a\right)^2 / \left(P + S - I_a\right) \quad (5)$$

and with the assumption $I_a = 0.2\ S$ (Cheng-Lung, 1982) basin discharge is given by:

$$Q = (P - 0.2S)^2 / (P + 0.8S) \quad (6)$$

S can be used in the curve nunber equation:

$$CN = 1000 / \left[10 + (S / 25.4)\right] \quad (7)$$

We can separate soil into three categories of antecedent moisture conditions according to wet or dry conditions as shown in Table 1:

Table 1. Antecedent Moisture Condition (AMC) Values

Condition of soil	**Winter period (October – April)**	**Rest periods (May-September)**
AMC I	<12.7	<35.6
AMC II	12.7 – 27.9	35.6-53.3
AMC III	>27.9	>53.3

For different land use and hydrolithological categories the CN values are presented in Table 2.

Table 2. CN Values According to SCS, 1972

	Hydrolithological Classification				
	Land use	**Highly Permeable**	**Moderately Permeable**	**Marginally Permeable**	**Permeable**
1	Municipal Land Size	84	92	94	95
2	500 m2	77	85	90	92
3	1.000 m2	61	75	83	87
4	2.000 m2	54	70	80	86
5	4.000 m2	51	68	79	85
6	Industrial	81	88	91	93
7	Not covered	77	86	91	94
8	Bushes	35	56	70	77
9	Forest	30	55	70	77
10	Crops	51	67	76	80
11	Fields	49	69	79	84
12	Vineyards	62	71	78	81
13	Cultivated trees	57	73	82	86

The following relationships are used for CN's corresponding to AMC I,II, III according to Chow (1964) and Hawkins (1985).

$$CNI = CNII / (2.281 - 0.01281 CNII) \tag{8}$$

$$CNIII = CNII / (0.427 - 0.00573 CNII)$$

Intensity (I) Determination

The maximum 24-hr rainfall according to Gumbel was used for various recurrence periods to calculate the rainfall height-rainfall duration and rainfall intensity-rainfall duration curves. The Montana height-duration curve equation was adopted for this application:

$$H = at^b \tag{9}$$

where

H = height of a rainfall duration in time t

b = a constant usually ranging from 0.33 to 0.50 (here b=0.33)

The intensity is then calculated as a function of duration:

$$I = H / t = H_{hour} t^{b-1} \tag{10}$$

Curves (1) and (2) are straight lines on a logarithmic scale.

According to this methodology, the intensity (I) of the rainfall is calculated at a duration, t, equal to the total basin concentration time, T_c:

$$T_c = \frac{\left(\sqrt{A} + 1.5L\right) / 0.80}{0.80\sqrt{\left(Y_m - Y_0\right)}} \tag{11}$$

where:

T_c = concentration time of drainage basin (hrs)

A = drainage basin area (km^2)

L = length of drainage basin (km)

Y_m = mean altitude of drainage basin (m)

Y_0 = min altitude of drainage basin (m)

THE STUDY AREA

The drainage basins of the Avlon and Spata streams lie in northern and central Attica. They belong geotectonically to the Subpelagonic zone. The drainage basin of the Avlon lies in northern Attica and consists of highly permeable schists. The basin is surrounded by the Koryfi, Agia Trias, Armenias, Drompala, Myti and Vounalaki mountains. The city of Avlon lies 2700 m downstream of the basin area. The drainage basins of the Spata lie in central Attica. They are surrounded by small hills, and the drainage basin consists of impermeable clay and silt. The city of Spata lies 1200 m downstream of the basin areas.

Table 3 shows the characteristics of the drainage networks of the Avlon (B1) and Spata (B2)drainage basins.

Table 3. Drainage Basin Characteristics

Basin	Area (m^2)	Slope (%)	Highest Altitude (m)	Lower Altitude (m)	Length (km)
B1	1869162	28	847	759	1.62
B2	784897	25	123	100	1.14

RESULTS

The peak storm runoffs (Q_p) were calculated at the exits of the drainage basins using the empirical method. Topography cover resulted in almost similar coefficients, i.e. 0.60 and 0.55 for the Avlon and Spata respectively. The mean annual height of precipitation is 374.5 mm based on observations of the meteorological station of Marathon for the observation time period 1958-1998. Based on the maximum 24-hr rainfalls we estimated, according to the Gumbel analysis, the expected rainfall height for a recurrence period of 5, 10, 25, and 50 yrs is shown in Table 4:

Table 4. Gumbel Analysis for 5, 10, 25, and 50 Years

61.1	$< X_5 <$	104.5
72.9	$< X_{10} <$	133.2
87.3	$< X_{25} <$	170.1
104.1	$< X_{50} <$	216.9

The rainfall uniformity coefficients are shown in Table 5.

Table 5. Rainfall Uniformity Coefficients

Basin	**Rainfall Uniformity Coefficient**
B1	0.949
B2	0.951

The peak storm runoff for the Avlon and Spata drainage basins is calculated using the SCS method geometry, basin concentration time, and the uniformity coefficient.

To calculate the runoff curve number, or the specific runoff coefficient for every elementary homogeneous soil area of the two basins, the following analysis was carried out:

- A land use/cover map was drawn using available data. The map was completed by field observation. The following categories can be distinguished: (1) forest, (2) annual cultivation, (3) bushy areas, (4) vineyards, and (5) uncultivated areas and urban areas.
- A hydrolithologic classification map was drawn. The lithological formations were classified in four categories according to permeability coefficients: (1) permeable formations, (2) moderately permeable formations, (3) low permeable formations, and (4) impermeable formations.
- The runoff curve number (CN) was calculated. This determination is a derivative of the land use/cover diagram and the hydrolithological classification diagram. Data from air photos and satellite photos of the study areas were used.

The diagram has five categories of runoff curve numbers. For each category a single mean runoff number was used. The runoff curve number (CN) for every drainage basin that resulted from the integration of every combination of land use and hydrolithologic classification was calculated by the SCS method.

The runoff curves of wet and dry periods were calculated by the SCS equations (Table 6).

Table 6. CN for the Drainage Areas in Normal and Wet Conditions

Basin	**CN normal**	**CN wet**
B1	0.47	0.64
B2	0.36	0.58

In order to estimate the maximum peak storm runoff for the two drainage basins, it is necessary to know the correlation between rainfall height and intensity (Table 7) and mean rainfall intensity (I) of duration equal to the total basin concentration time, T_c, of each basin which is defined as the maximum rainfall height that occurs at time T_c in the basin, with recurrence period of 5, 10, 25, and 50 yrs.

The rainfall height-rainfall duration and rainfall intensity-rainfall duration curves according to the 24-hr rainfall from the Gumbel method for rainfalls that took place in the area with recurrence period of 50 yrs and the rainfall height-rainfall duration curve, $H = H_{hour} t^{0.333}$, are given in Table 7. The basin concentration time and rainfall intensity are given in Table 8.

The runoff curves of wet and dry periods were calculated the SCS method. The maximum 24-hr runoffs (Q) calculated for the two drainage basins are presented in Table 9.

Table 7. Correlation of Height and Intensity of Rainfall and the Duration of Rainfall

Rainfall duration (hours)	**Rainfall duration** (mm)	**Rainfall height** (mm)	**Rainfall intensity** (mm/hour)
0.1	6	22.440	224.403
0.15	9	25.684	171.228
0.2	12	28.266	141.332
0.25	15	30.447	121.788
0.3	18	32.353	107.842
0.4	24	35.605	89.013
0.5	30	38.352	76.704
0.6	36	40.752	67.921
0.7	42	42.889	61.284
0.8	48	44.850	56.062
0.9	54	46.644	51.826
1	60	48.309	48.309
1.5	90	55.293	36.862
2	120	60.852	30.426
2.5	150	65.546	26.218
3	180	69.648	23.216
4	240	76.650	19.163
5	300	82.563	16.513
6	360	87.731	14.622
7	420	92.352	13.193
8	480	96.651	12.069
9	540	100.413	11.157
10	600	103.999	10.400
12	720	110.509	9.209
15	900	119.033	7.936
20	1200	131.000	6.550
24	1440	139.200	5.800
30	1800	149.938	4.998
40	2400	165.012	4.125

Table 8. Concentration Time and Rainfall Intensity

Drainage Basin	**Basin concentration time (T_c) in min**	**Rainfall intensity (I) with a duration equal to the basin concentration time in mm/hr**
B1	37	103.9
B2	34	109.9

Table 9. Maximum Probable 24 Hour Runoff

Drainage Basin	**Maximum probable 24-hr runoff (Q) in mm**	
	Empirical	**Normal/wet conditions**
B1	67.46	57.12/77.78
B2	36.48	27.72/44.46

Comparing the curve numbers for the two case studies, one can see that there is a significant difference of 23 percent between permeable and non permeable basins, and comparing normal and wet conditions there is also a significant difference of 26 and 27 percent respectively. A comparison between the empirical method and the SCS method resulted in a difference of 17.5 and 33 percent for the two cases examined that may be attributed only to the size of the area.

CONCLUSION

The study was based on SCS methods and empirical models, and on the experience of consultants derived from studies in nearby basins. The values of storm runoff refer to extreme values of the maximum probable peak storm runoff that might ever happen in the study area with a 50-yr recurrence period. The empirical method cannot adequately describe the characteristics of the drainage basins, especially the effect of permeability.

There is significant change of the CN values for the non permeable and permeable cases. The corresponding peak storm runoff showed a difference of up to 23 percent. Also the significant change in the peak storm runoff resulted in a change of up to 33 percent in terms of the discharge.

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