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Hydrology and Earth System Sciences

Technical Note: Determination of the SCS initial abstraction ratio in an experimental watershed in Greece

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Abstract. The present study was conducted in an experimental watershed in Attica, Greece, using observed rainfall/runoff events. The objective of the study was the determination of the initial abstraction ratio of the watershed. The average ratio (*Ia/S*) of the entire watershed was equal to 0.014. The corresponding ratio at a subwatershed was 0.037. The difference was attributed to the different spatial distribution of landuses and geological formations at the extent of the watershed. Both of the determined ratios are close to the ratio value of 0.05 that has been suggested from many studies for the improvement of the SCS-CN method.

1 Introduction

SCS-CN method constitutes a popular empirical approach for the estimation of direct runoff for a given rainfall event from small agricultural, forest, and urban watersheds and is capable of incorporating several watershed runoff producing characteristics; soil type, land cover and practice, hydrologic condition, and (AMC) antecedent moisture condition (Mishra and Singh, 2003; Mishra et al., 2004, 2005; Jain et al., 2006). It was developed by the U.S. Department of Agriculture (SCS, 1956) Soil Conservation Service (SCS), now called Natural Resources Conservation Service (NRCS). Due to its low input data requirements and its implementation within GIS, it has been incorporated in many widely used hydrological models.

The initial abstraction ratio (*Ia/S*); (initial abstraction Ia-potential maximum retention S) plays an important role in the calculated runoff depth, the hydrograph peak and the time distribution of runoff. It largely depends on climatic conditions (Ponce and Hawkins, 1996) and is the most ambiguous assumption and requires considerable refinement. Therefore, it has been investigated in many studies (Jiang, 2001; Hawkins et al., 2002; Mishra and Singh, 2004; Mishra et al., 2004, 2005, 2006). This ratio was assumed in its original development to be equal to 0.2. Mishra et al. (2006), employing a large dataset of 84 small watersheds (0.17 to 71.99 ha) in USA, investigated a number of Ia-S-relations incorporating antecedent moisture (M) as a function of antecedent precipitation. Hawkins et al. (2002) using data sets that covered a plethora of rainfall/runoff events in USA, suggested changing the coefficient from 0.2 to 0.05 for use in runoff calculations. Mishra and Singh (2004) examined the applicability of a versatile SCS-CN model to long-term hydrological modeling and found that the model efficiency is maximum when the ratio is in the order of 0.01.

The objective of this study is the determination of the initial abstraction ratio (*Ia/S*), in a 15.18 km^2 experimental watershed in Greece, by analyzing measured rainfall/runoff events. Eighteen storm events of various rainfall depths were used for that purpose. Moreover, the initial abstraction ratio was determined in a subwatershed with different landuses and geological formations, based on common, but fewer storm events and conclusions were drawn regarding the change in ratio value.

2 Study area

The experimental watershed (Fig. 1) is located on the eastern side of Penteli Mountain, in the prefecture of Attica, Greece. The vegetation type consists mainly of pasture areas. A small percentage of inhabited area (Drafi) is included in the southern part of the watershed. The landuses and the corresponding percentages are shown in Table 1. The total area of the watershed is 15.18 km^2, its geometric figure is oblong in the North-South direction and the mean, minimum and maximum altitudes are 430, 146 and 950 m, respectively.

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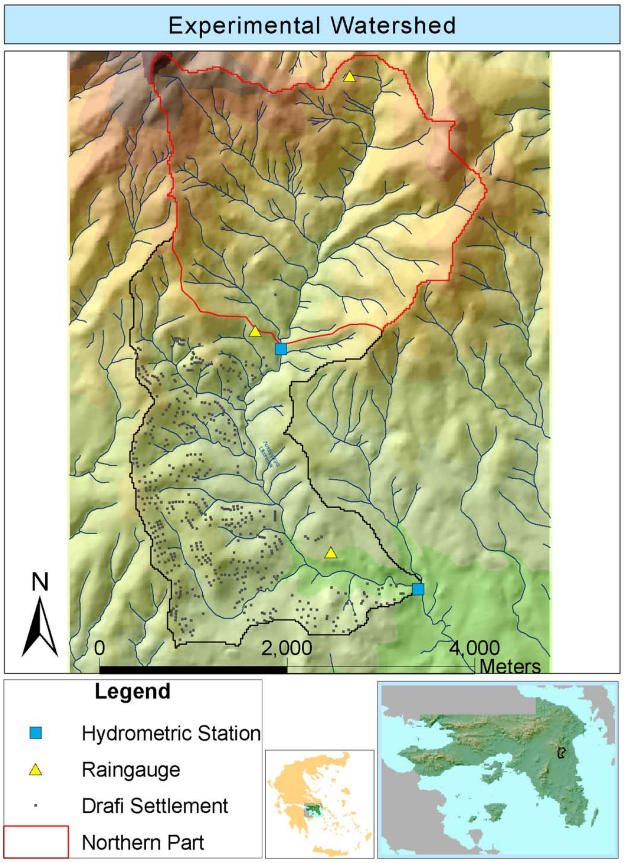

Fig. 1. The study area.

The steep slopes constitute another characteristic. The mean slope is equal to 21%.

The watershed is divided into north and south part, from the geological point of view. It consists approximately of 60% schists, 23% conglomerates, 9% marls and 8% marbles. The geologic formations that prevail in the northern part, which constitutes about 51% of the extent of the entire watershed, are schists with marble intercalations. Schists are not impervious. They are tectonically intensely fractured and their upper layer is eroded. A karstic aquifer contributes significantly to the baseflow of the watershed, which is constant throughout the year. In the southern part of the watershed, there are cohesive conglomeratic formations with varying participation of clay and sand and thus varying infiltration capacity. Additionally, there is a low percentage of impervious marly formations. The installed equipment consists of two hydrometric stations and a dense raingauge network that has been operating since October 2003. The raingauge network consists of three gauges that are properly installed at sites of different altitude; 203, 383 and 680 m, correspondingly. The gauges' records have a ten-minute time step. The first hydrometric station has been operating since January 2003 and is located at the watershed's outlet, where stage-discharge

Table 1. The landuses of the experimental watershed.

Landuse	Area (m^2)	Percentage %
Pasture	10 541 581	70.2
Wood	113 247	0.75
Inhabited area (Drafi)		
1.Residencies	1 118 250	7.37
2.Roads (impervious) surface)	502 394	3.3
3.Pasture among residencies	2 791 013	18.38
SUM	15 182 800	100

measurements are regularly made. The second hydrometric station (a spillway construction) is installed at the outlet of the northern subwatershed and has been operating since January 2005.

3 Methodology

3.1 Selection of storm events

Eighteen storm events were selected (Table 2). The analysis time step was thirty minutes. A storm event was considered to be over when there was at least a six-hour period without rainfall. The surface rainfall for each event was estimated by the use of the Thiessen Polygon method (Wride et al. 2004; NRCS, 1993). The selection criteria were the following:

- Uniform spatial distribution of rainfall at the extent of the watershed.
- Continuous rainfall. Storm events with discontinuous rainfall were excluded.
- The winter events at which snowmelt contributed to runoff were excluded.

The peak flow rate of the hydrograph should be higher than 0.2 m^3/s. A lower peak value in a watershed area of approximately 15 km^2indicates an insignificant event for analysis.

The antecedent runoff condition (ARC) of the watershed should be average or high, ARC II or III, correspondingly.

According to Hjelmfelt (1980), the SCS method performs better if the amount of water retained during runoff is a small fraction of rainfall. ARC II or III implies that the retained water will be comparatively a smaller fraction of rainfall. Therefore, the selected events were predominantly winter and spring events. ARC depends on antecedent soil moisture condition, which is closely associated with antecedent precipitation. The 5-day and the 10-day antecedent precipitation were determined for each event. The 5-day antecedent precipitation ranged approximately from 20 to 100 mm in ten out of the eighteen storm events, while in the remaining eight, it was lower than 3 mm. However, the 10-day antecedent precipitation ranged from 15 to 60 mm in five out of these eight events and only in the remaining three events it was insignificant.

Regarding the northern subwatershed, five storm events, common to those of the entire watershed, were selected based on the same criteria as above, plus the criterion that the rainfall depth P for each storm event should be higher than 20 mm, since lower rainfall produces insignificant hydrograph at the outlet of the northern subwatershed.

3.2 Determination of the SCS initial abstraction ratio

The basic rainfall-runoff relationship with the initial abstraction taken into account is the following (SCS, 1972):

$$Pe = \frac{(P-Ia)^2}{(P-Ia)+S} \quad \text{for} \quad P > Ia$$
$$Pe = 0 \quad \text{for} \quad P < Ia \qquad (1)$$

Where:

- P is the depth of rainfall (mm)
- Pe is the depth of runoff or excess rainfall (mm)
- Ia is the initial abstraction (mm)
- S is the maximum potential retention after runoff begins (mm)

The initial abstraction (Ia) represents losses due to interception, infiltration and surface storage, all of which occur before runoff begins. Predominantly, retention S consists of the infiltration occurring after runoff begins (SCS, 1972). The empirical initial abstraction ratio that relates the initial abstraction Ia with the retention S is used in many studies. That is:

$$Ia = 0.2S \qquad (2)$$

Substituting Ia from Eq. (2) in Eq. (1), results in the following widely used Equation:

$$Pe = \frac{(P-0.2S)^2}{P+0.8S} \quad \text{for} \quad P > 0.2S$$
$$Pe = 0 \quad \text{for} \quad P < 0.2S \qquad (3)$$

The procedure for the determination of the initial abstraction ratio (*Ia/S*) for each event was the following; firstly, the total excess rainfall Pe in mm was calculated by dividing the total direct runoff volume of the event by the total area of the watershed. The separation of each observed hydrograph into direct runoff and baseflow was based on the hygrograph's points of inflection. These points indicated the starting and the ending point of direct runoff on the rising and recession limb of each hydrograph, correspondingly. Then, followed the initial abstraction Ia, which is equal to the accumulated rainfall from the beginning of the storm to the time when direct runoff started. The total rainfall depth P for each storm event was known. The only unknown parameter, which was the retention S, was calculated by using Eq. (1). Finally, after dividing Ia by S, a unique initial abstraction ratio was determined for each event.

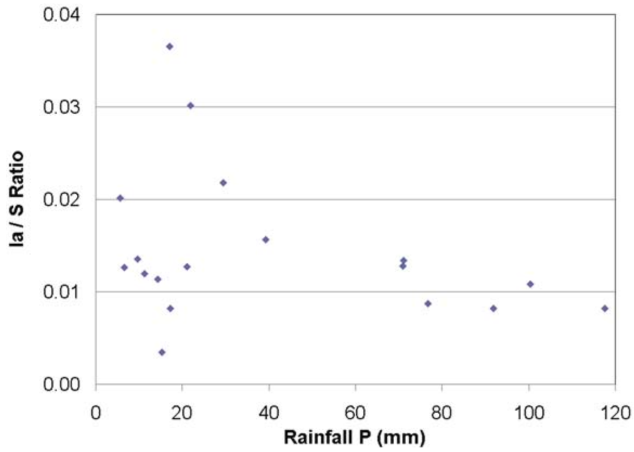

Fig. 2. Initial abstraction ratio *Ia/S* versus rainfall depth P, for each event.

Additionally, for comparison reasons, the (*Ia/S*) ratio was determined in the northern subwatershed. In this part there are no impervious residential areas, as well as no impervious geological formations, in contrary to the southern part of the watershed.

4 Results and discussion

Eighteen storm events were examined and it was found that the average initial abstraction (*Ia/S*) ratio of the watershed is equal to 0.014. The maximum value was 0.037 and the minimum 0.004 (Table 2). Figure 2 shows that the (*Ia/S*) ratio is predominantly around 0.01 and is not related to rainfall depth P.

Similar results, concerning the low ratio value, have resulted from other studies. Mishra and Singh (2004), evaluating the impact of the initial abstraction ratio on the efficiency of a versatile SCS-CN model, found that as the ratio increases the efficiency decreases. The maximum efficiency was obtained when the ratio was in the order of 0.01. Based on recent investigations, Jiang R. (2001)and Hawkins et al. (2002) suggest changing the coefficient from 0.2 to 0.05 for use in runoff calculations. Hawkins et al. (2002) determined the coefficient by using rainfall/runoff data from 307 watersheds or plots and a total of 28 301 events in USA. The results showed that the ratio is not a constant from storm to storm, or watershed to watershed, and that the assumption of 0.2 is unusually high. According to the event analysis, the median *Ia/S* ratio was 0.0476. More than 90 percent of *Ia/S* ratios were less than 0.2.

Regarding the initial abstraction ratio in the northern subwatershed, the ratio values (Table 3) varied from 0.014 to 0.054 and the average value was 0.037. Despite the fact that

Table 2. Storm events.

A/A	Storm Event	Rainfall P (mm)	Excess Rainfall Pe (mm)	Peak Flow Rate (m^3/s)	Initial Abstr. Ia (mm)	Retention S (mm)	Ratio Ia/S
1	6/3/2005	5.60	0.17	0.25	1.7	84.0	0.020
2	24/1/2005	6.53	0.23	0.53	1.4	110.3	0.013
3	26/2/2005	9.59	0.30	0.34	2.3	170.7	0.014
4	29/1/2004	11.22	0.54	0.79	1.8	154.5	0.012
5	1/1/2004	14.26	0.33	0.36	3.7	325.4	0.011
6	15/2/2005	15.23	0.74	1.00	0.9	261.7	0.004
7	23/2/2005	17.05	0.50	1.39	7.0	191.9	0.037
8	8/11/2004	17.26	0.21	0.60	5.4	652.7	0.008
9	17/2/2007	21.09	0.27	0.49	7.9	622.0	0.013
10	25/12/2003	21.92	0.82	0.87	7.4	243.7	0.030
11	29/12/2004	29.44	1.38	1.97	7.3	334.3	0.022
12	11/2/2007	39.20	1.11	2.36	10.9	693.1	0.016
13	22/3/2007	70.93	4.34	5.10	10.1	791.1	0.013
14	10/10/2006	71.11	3.67	7.26	12.0	892.9	0.013
15	23/11/2005	76.66	6.46	15.09	6.1	699.0	0.009
16	11/1/2004	91.84	7.47	3.06	7.2	874.9	0.008
17	25/11/2005	100.37	18.67	11.02	4.3	398.0	0.011
18	31/10/2006	117.58	13.41	5.85	6.6	807.5	0.008

Table 3. Initial abstraction ratio in the northern subwatershed.

Storm Event	Rainfall P (mm)	Excess Rainfall Pe (mm)	Peak Flow Rate (m^3/s)	Initial Abstr. Ia (mm)	Retention S (mm)	Ratio Ia/S
22/3/2007	73.5	2.23	1.45	31.3	759.7	0.041
10/10/2006	78.4	1.12	2.05	46.7	867.6	0.054
23/11/2005	92.2	3.93	4.05	26.7	1025.3	0.026
25/11/2005	99.8	10.63	2.28	9.2	681.5	0.014
31/10/2006	111.1	5.42	1.00	42.4	801.2	0.053

more events are necessary for the analysis in this part, the calculated values clearly indicate a higher ratio value. Under approximately the same antecedent runoff condition in the entire watershed, the average ratio of the entire watershed (0.014) is lower than that of the northern subwatershed (0.037). This is attributed to their differences in the landuses and the geology; the greater percentage of impervious areas (roads, residencies) and impervious geological formations (marls) in the southern part, in combination to the fact that these are located near the outlet of the watershed, leads to the conclusion that runoff from these areas reaches the outlet in a short period of time, at the early stages of the storm. Thus, the initial abstraction of the entire watershed is lower than that of the subwatershed and consequently, this leads to the lower initial abstraction ratio of the entire watershed.

The antecedent runoff condition (ARC) of the watershed in all events is classified as ARC II (average) or III (high) and contributed to the low amount of initial abstraction. Initial abstraction is proportional to retention. When the retention increases, the initial abstraction also increases. This indicates that the initial abstraction of the entire watershed is not only affected by the impervious areas, either those of the residential area or those of the impervious marls. It also depends on ARC, which among others (NRCS, 2004) depends on the antecedent soil moisture condition of the geological formations.

Another characteristic of the watershed is that the retention increases with rainfall. This is mainly attributed to the special geological characteristics, plus the fact that the geological formations of the entire area are tectonically intensely fractured and folded, thus making easier their fast erosion into deeper layers and increasing their storage capacity. Additionally, the landcover that is dominated by densely vegetated pasture areas plays an important role in the interception of rainfall, as well as in the retention of water due to the decrease in overland flow velocity.

5 Conclusions

The determined values of the initial abstraction ratio are close to the suggested ratio of 0.05 (Hawkins et al., 2002). The average ratio was equal to 0.037 and 0.014 for the northern subwatershed and the entire watershed respectively. Similar low ratio values have been reported from other studies (Hawkins et al., 2002; Mishra and Singh, 2004; Jiang, 2001). Under approximately the same hydrologic conditions in the entire area, the ratio values for the northern and the entire watershed are different. The human intervention, in the form of urban development and the impervious geological formations found in the southern part, contribute to the decrease in the initial abstraction ratio of the watershed. Runoff from these impervious areas reaches the outlet at the early stages of the storm and thus leads to low initial abstraction. On the contrary, the initial abstraction is higher in the northern subwatershed due to the lack of impervious areas.

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