Abstract

The effect of antecedent precipitation index of Soil Conservation Service-Curve Number (SCS-CN) method (SCS, 1956) on the precipitation-runoff relationship was examined. Using long-term measured rainfall data from Istanbul-Catalca Damlica Creek Watershed (ICDCW) located in a semi-arid region, calculated runoff values under both taking 5-day antecedent precipitation amount into account and not taking it into account conditions were compared. There were not any statistically significant differences between the calculated runoff values under both conditions. However, when the calculated runoff values under both conditions were compared with the directly measured runoff values, calculated values were found to be significantly larger, up to 7 folds, than the directly measured ones. Therefore, SCS-CN method was criticised in terms of over-sizing hydraulic structures and increasing the cost.

Keywords: Antecedent precipitation index, curve number method, hydrologic modelling, rainfall-runoff, Thrace, Turkey

Introduction

Precise determination of the depth of surface runoff is crucial in designing dam’s spillways, flood control and water diversity structures and drainage studies. Rainfall-runoff relationship is determined by the depth and intensity of the rainfall varying with time and location, and the watershed...
characteristics, namely, soil type, topography, land use and cover, farming system, soil moisture status and soil conservation techniques. Soil Conservation Service (SCS) Curve Number (SCS-CN) Method (SCS, 1956 and 1971) developed for the conditions prevailing in the United States is an empirical method using all these parameters. Since the method was developed, it has been adapted to conditions in other parts of the world. Although some regional research centres have developed additional criteria, the basic concept is still widely used all over the world (Boonstra, 1994).

Precise determination of surface runoff Curve Number (CN) plays key role in the prediction of the water yield of a watershed accurately. However, unevenly distributed rainfall and complex watershed characteristics make this difficult. The antecedent precipitation index is one of these parameters. The 5-day is used as an antecedent precipitation index in the original CN method. In the literature, other periods have also been reported to be more representative under different conditions. Hope and Schulze (1982), for example, used a 15-day antecedent period in an application of the SCS procedure in the humid east of South Africa, and Schulze (1982) found a 30-day antecedent period to yield better simulation of direct runoff in humid areas of the USA, but a 5-day period to be applicable in arid zones. In the CN method, the soil moisture condition is classified in 3 Antecedent Moisture Conditions (AMC): AMC I: the soils in the watershed are practically dry (i.e. the soil moisture content is at wilting point). AMC II: average conditions. AMC III: the soils in the watershed are practically saturated from antecedent rainfalls (i.e. the soil moisture content is at field capacity). These classes are based on the 5-day antecedent rainfall.

Aside the antecedent period (5, 15 and 30 days); the use of AMC classes in 5-day period is also under discussion: Some researchers claimed that AMC classes should be considered (Boonstra, 1994) while the rest reported that it had no effect. In this case AMC II should be used.

In this research, water yield of Istanbul Damlica Creek watershed was calculated by SCS-CN method for 5-day period when taking the AMC into account or not to determine its effect on the predicted water yield. The agreement between the computed and long-term directly measured water yield values was the criteria to evaluate its effect.

Material and Methods

The research watershed, Damlica Creek Watershed (DCW) covering 8.26 km² area is located in Catalca far 51 km from Istanbul in the Thrace (European) part of Turkey. The watershed outlet is situated at 41°06′ North Latitude, 28°25′ East Longitude and 110 m altitude.

The Mediterranean climate prevails in the watershed with cool and rainy winters and hot and dry summers. Almost all part of the precipitation falls as rain and the number of snowy days does not exceed 8 days a year. According to the long years records, annual, average temperature, total average precipitation, average relative humidity, total average evaporation and wind speed are 13.7 °C, 637.2 mm year⁻¹, 76 %, 575.4 mm year⁻¹ and 3.5 m s⁻¹, respectively (Anonymous, 1984 and 2003).

The soil of the watershed is entirely in Vertisol great soil group with AC profile. The soil of the watershed is clayey and swells after wetting and shrinks while dry-
ing. The watershed is moderately sloppy, 6-12 %. Dry farming system without following is practised with sunflower-wheat rotation in the entire watershed (Anonymous, 1987).

Three raingauges are located at 110 m (outlet), 195 m and 285 m altitude to record the daily depth of precipitation at different part of watershed during the study and one stage recording gauge is placed at the outlet to measure the daily amount of the direct runoff from the watershed.

The calculated depth of the runoff is determined using SCS-CN method (SCS, 1956) which relates the rainfall to the surface runoff empirically as:

\[
\frac{F}{S} = \frac{Q}{P - I_a} \tag{1}
\]

Where \( F \) is the actual retention (mm), \( S \) is the potential maximum retention (mm), \( Q \) is the accumulated runoff depth (mm), \( P \) is the accumulated rainfall depth (mm) and \( I_a \) is the initial abstraction (mm).

And from the continuity principle:

\[
P = Q + I_a + F \tag{2}
\]

May be written. When initial abstraction is assumed:

\[
I_a = 0.2 \ S \tag{3}
\]

And solving Equation (1) and (2) together, \( Q \) is calculated for the condition \( P > I_a \) as:

\[
Q = \frac{(P - I_a)^2}{P - I_a + S} \tag{4}
\]

The potential maximum retention, \( S \) is calculated using the soil hydrologic curve number (CN):

\[
S = \frac{2540}{CN} - 25.4 \tag{5}
\]

CN is a value ranging from 0 to 100 and concerns watershed characteristics, namely, soil, topography, land use and cover, farming practices and soil conservation techniques. 100 represents water surface and other soil surfaces are smaller. For an average conditions (i.e. AMC II) when 5-day period is applied the CN obtain CN value depending on the above conditions is used. However, for the conditions AMC I and AMC III the following equations are used to calculate CN I and CN III. It should be noted that when antecedent water content is not considered, the AMC II condition is used. In terms of rainfall depth, if the precipitation during this 5-day period is between 23 and 40 mm, CN II is applied. When the rainfall depth is below and over this range CN I and CN III, respectively, is used (Boonstra, 1994).

\[
CN I = \frac{4.2 \ CN II}{10 - 0.058 \ CN II} \tag{6}
\]

\[
CN III = \frac{23 \ CN II}{10 + 0.13 \ CN II} \tag{7}
\]

The computed runoff values when 5-day antecedent precipitation index is used and not used were compared to the directly measured runoff depths at the outlet of the watershed. Both measured and calculated values were also compared with the watershed infiltration index \( f \) (Linsley et al., 1988) and evapotranspiration (Doorenboss and Pruitt, 1977).
Results and Discussion

Calculated from the daily precipitation and runoff records of 10 years in Istanbul-Catalca-Damlyca Creek Watershed located in a semi-arid climate belt, monthly and annual average precipitation, evapotranspiration, directly measured runoff values, computed runoff rates for both unchanged CN conditions (i.e. AMC II) and 5-day antecedent precipitation index conditions (i.e. AMC, I, II and III) were presented in Table 1.

Using daily precipitation data, monthly computed runoff rates under unchanged CN conditions (AMC II) were found to be quite different from those under 5-day antecedent precipitation index conditions (AMC, I, II and III) when the monthly changes were considered in any chosen year. This means that 5-day antecedent moisture condition influences the surface runoff rates remarkably. However its influence was not regular: it sometimes decreased the surface runoff and vice-versa. This was determined by the distribution of precipitation, an independent variable, within the particular month. The distributed precipitations which were smaller than the upper limit of 5-day precipitation index, namely precipitations less than 23 mm in magnitude, caused no surface runoff while exceeding precipitation amounts did.

Unlike monthly calculated runoff rates for any particular year, there were not any differences between the averages of long years monthly and annual calculated runoff rates under unchanged CN conditions.

Table 1
Monthly and annual average precipitation, evapotranspiration, directly measured runoff values, computed runoff rates for both unchanged CN conditions (i.e. AMC II) and 5-day antecedent precipitation index conditions (i.e. AMC, I, II and III)

<table>
<thead>
<tr>
<th>Months</th>
<th>P</th>
<th>ET</th>
<th>Directly Measured Q</th>
<th>Calculated Q using SCS-CN Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>unchanged CN (AMC II)</td>
</tr>
<tr>
<td>January</td>
<td>94.4</td>
<td>23.6</td>
<td>5.87</td>
<td>23.6</td>
</tr>
<tr>
<td>February</td>
<td>47.9</td>
<td>42.1</td>
<td>4.53</td>
<td>9.8</td>
</tr>
<tr>
<td>March</td>
<td>69.4</td>
<td>76.3</td>
<td>6.39</td>
<td>28.9</td>
</tr>
<tr>
<td>April</td>
<td>55.2</td>
<td>113.4</td>
<td>3.75</td>
<td>17.2</td>
</tr>
<tr>
<td>May</td>
<td>30.8</td>
<td>180.1</td>
<td>1.02</td>
<td>6.9</td>
</tr>
<tr>
<td>June</td>
<td>42.3</td>
<td>210.3</td>
<td>0.18</td>
<td>9.9</td>
</tr>
<tr>
<td>July</td>
<td>29.4</td>
<td>211.4</td>
<td>0.04</td>
<td>10.0</td>
</tr>
<tr>
<td>August</td>
<td>22.6</td>
<td>176.4</td>
<td>0.05</td>
<td>6.1</td>
</tr>
<tr>
<td>September</td>
<td>18.9</td>
<td>114.0</td>
<td>0.02</td>
<td>3.4</td>
</tr>
<tr>
<td>October</td>
<td>60.9</td>
<td>67.0</td>
<td>0.14</td>
<td>21.2</td>
</tr>
<tr>
<td>November</td>
<td>101.6</td>
<td>31.8</td>
<td>1.10</td>
<td>44.2</td>
</tr>
<tr>
<td>December</td>
<td>112.5</td>
<td>17.1</td>
<td>8.97</td>
<td>45.1</td>
</tr>
<tr>
<td>Annual</td>
<td>685.9</td>
<td>1263.5</td>
<td>32.06</td>
<td>226.3</td>
</tr>
</tbody>
</table>

P: precipitation, mm, ET: evapotranspiration, mm and Q: runoff rates, mm
(AMC II) and 5-day antecedent moisture conditions (AMC, I, II and III) (after the statistical analysis, $R^2=96**$, last two columns of Table 1).

The annual calculated runoff rates using monthly unchanged CN conditions (AMC II) and 5-day antecedent moisture conditions (AMC, I, II and III) were fitted linear curves and compared to each other and to the long term directly measured values in Figure 1. While the two curves representing the calculated values are quite similar, they are significantly different from the curve representing directly measured values. This clearly shows that the reliability of SCS-CN method, either using unchanged CN conditions (AMC II) or 5-day antecedent moisture conditions (AMC, I, II and III) is questionable.

The calculated runoff depth for both conditions, with and without 5-day antecedent period, using the SCS-CN method were also compared to the long-term directly measured depths recorded at the outlet of the watershed in Figure 2. The comparisons were done on the rainfall hydrograph with $f$ index, which separate the surface runoff and infiltration part of a rainfall. The $f$ index with and without 5-day antecedent period may roughly be considered the same, 46.3 and 48.8 mm month$^{-1}$, respectively. This also proves that the effect of 5-day antecedent period on soil moisture condition, and therefore on the runoff depths, may be neglected on a yearly basis.

The $f$ index using the directly measured runoff depths was 94.3 mm month$^{-1}$, which was considerably greater than the calculated $f$ index. This under predicted $f$ index, or similarly runoff depths, has long been criticised by hydrologists, water resources planners, agriculturists, foresters and practitioners McCuen (1982), Chen (1982), Hjelmfelt (1991), Hawkins (1993), Ponce and Howkins (1996), Bonta (1997),

![Fig. 1. Rainfall-runoff relations of Istanbul-Catalca-Damlıca Creek watershed for SCS-CN method under unchanged CN (AMC II and 5-day precipitation index (AMC I, II and III) conditions and for directly measured values](image-url)
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Fig. 2. Monthly precipitation-$\phi$ index for of Istanbul-Catalca-Damlcica Creek watershed

Fig. 3. Monthly evaporation-loss index for Damlica Creek of Catalca in Istanbul
Effects of Antecedent Precipitation Index on the Rainfall-Runoff Relationship


To make this situation more clear a similar procedure was given in Figure 3. In this Figure, precipitation and evapotranspiration of the watershed (Doorenbos and Pruitt, 1977) were compared. Loss index (Shaw, 1994) was determined as 58.2 mm month$^{-1}$ to explain the changes in the soil moisture status (Linsley et al., 1988). The loss index fell between the two $\phi$ indexes calculated for measured and calculated runoff values using the SCS-CN method.

The loss index was markedly higher than the $f$ index for the calculated runoff no matter with or without 5-day antecedent moisture content conditions were considered.

This implies that the design capacity of hydraulic structures according to the calculated runoff depths by the investing organisations, State Hydraulic Works and Turkish Rural Affairs, is significantly larger than it should be and thus this increases the cost.

**Conclusions**

The 5-day antecedent moisture condition has an effect on monthly runoff depth however on yearly basis, the calculated runoff depths with or without 5-day antecedent moisture conditions has no effect. Therefore no need to consider 5-day antecedent period to calculate runoff depth from the watershed showing similar characteristic to the research watershed.

When the calculated runoff depths, with and without 5-day antecedent period, were compared with the long-term directly measured runoff values, the calculated values far greater than the measured values. In this case, the design capacity of reservoirs and hydraulic structures on the downstream is oversized and costs increase. This clearly shows that the reliability of SCS-CN method, either using unchanged CN conditions (AMC II) or 5-day antecedent moisture conditions (AMC, I, II and III) is questionable.

**References**


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