# Stormwater Detention - More Accurante Models Using Modified Rational and SCS Method

An Online Continuing Education Course for Engineers

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# Stormwater Detention - More Accurate Models Using Modified Rational & SCS Method

Designing stormwater detention facilities is one of the most common tasks for today's practicing engineers. Detention facilities are necessary to attenuate flows to prevent downstream flooding/damage and thus are required by many governing agencies. Many engineering firms have “adopted” a particular design method based on ease of use or accepted popularity but may still question the accuracy of the model results. Also, engineers may not have a thorough understanding of the applicability of particular design methods to particular conditions. This paper addresses two common methods for designing detention facilities, the Modified Rational Method and the SCS Method. Through the discussion of this paper, the student will gain an understanding of the inputs and limitations to increase accuracy for each method and will compare the design results for both runoff and detention design methods to actual measured results.

While there are many different models for stormwater runoff and detention design, this paper will look at two common design methods used for typical development projects. The Rational and SCS Methods are more simplified compared to many more complex methods available, but these methods will be evaluated because of their popularity. Their ease of use has made them common procedures for the design of construction projects. This discussion will be aimed toward using computer programs that will use either of these two methods for design.

There are two steps to designing detention ponds. The first is quantifying the amount of rainfall runoff to the pond, and the second is designing the detention pond to attenuate the flow out of the pond to the desired amount. Therefore, to accurately design detention ponds, a discussion of accurate rainfall determination is required. We will begin by looking at the Rational Method.

## Rational Method

The Rational Method was first presented in the United States by Emil Kuichling in 1851. The Rational equation we use today was developed in England by D.E. Lloyd-Davies in 1905 (Stephenson, 1981). Lloyd-Davies determined that storms with the highest runoff had durations which were equal to the amount of time for the furthest runoff to reach the end of the catchment, or the time of concentration (Escritt, 1964). He used this information to develop the Lloyd-Davies formula, which evolved into the balanced formula we use today. The rational method equation is □

$Q = c\ i\ A$, where $Q$ = flow rate (cubic feet per second, cfs)
$c$ = dimensionless runoff coefficient
$i$ = rainfall intensity (inches/hour, in/hr)
$A$ = catchment area (acres, ac)

## Area

The catchment area of a basin is most commonly determined by using topographic maps coupled with site investigation. The area that is determined to drain to the outfall of a catchment is then calculated. The analytical method is normally recommended for drainage areas less than 200 acres consisting of fairly homogenous land cover.

## Rainfall Intensity

The rainfall intensity rate is most commonly determined from Intensity-Duration-Frequency (IDF) Curves. IDF Curves are developed from historical rainfall records from many years and are available for most areas. IDF curves represent the highest intensities in the shortest time for storms of a particular frequency (AISI, 1995).

To determine the rainfall intensity, you must first determine the time of concentration, $T_c$. The time of concentration is the amount of time for rainfall at the furthest point of the drainage area to reach the outfall point. "Furthest" refers to the longest time, not necessarily the longest distance. The $T_c$ is only an estimate of the time during the storm in which rainfall intensity is the greatest, based on the Rational Method assumptions that the intensity is constant while the entire basin is contributing when the peak flow occurs (Rossmiller, 1982). In the analytical method, the $T_c$ does not necessarily begin as soon as rainfall begins. The $T_c$ can begin at any point within a storm.

There are many methods to determine the time of concentration. It is an important component of any drainage determination. Therefore, it is important to estimate the $T_c$ as accurately as possible. It is generally accepted that there may be different types of flow encountered as the flow traverses the drainage area. The flow may consist of overland or sheet flow, shallow concentrated flow, and open channel flow.

### Sheet Flow

Sheet flow is the runoff across a surface with a uniform depth. Although there are many available methods to compute sheet flow, the kinematic wave equation is widely accepted. It is more physically based than other methods; it also accounts for the rainfall intensity (AISI, 1995). The University of Maryland conducted a study in which the kinematic wave equation was found to be the most sound, practical method to compute sheet flow time of concentration (FHA, 1979). The kinematic wave equation is

$$T_c = \frac{k\,L^{0.6}\,n^{0.6}}{i^{0.4}\,s^{0.3}}$$

Where $T_c$ = time of concentration (min)
$k$ = 0.939
$L$ = Length of sheet flow (feet)
$n$ = Manning's roughness coefficient
$s$ = Average slope of sheet flow (ft/ft)
$i$ = rainfall intensity (in/hr)

For the input "i," an IDF curve for the basin location needs to be used in an iterative process with the above equation. First, assume a value for "i" and calculate $T_c$ from the equation. Then determine the intensity, i, for that $T_c$ from the IDF curve. Recalculate $T_c$ using the newest i value. Repeat this process until the intensity no longer changes, which will result in the sheet flow $T_c$.

Sheet flow typically occurs at the upstream point of a drainage basin and can remain sheet flow up to a generally accepted maximum of 300 feet. Because the sheet flow portion of the time of concentration can be long, the engineer should consider the actual length of sheet flow. Many studies have been done to determine the maximum length of sheet flow, and many propose an upper limit of 100 feet for unpaved areas. Others state there is no documented evidence to support the 100’ limit (McCuen & Spiess, 1995). All studies examined here state the need to use more criteria than maximum length alone to determine sheet flow travel time. Using a maximum length alone can result in an overestimation of travel time, especially if there is a high Manning's n value and flat slopes (Merkel, 2001). Many studies suggest using depth as an additional criterion. The maximum depth suggested before sheet flow transitions to shallow concentrated are 0.1 feet, with several studies suggesting 0.05 feet (Merkel, 2001). The depth can be found by estimating the flow at the end of the sheet flow section and calculating the depth based on Manning's equation with a one-foot width (Merkel, 2001). However, the most reliable verification of sheet flow length is to investigate in the field where the sheet flows path transitions to shallow concentrated flow by way of land depressions and swales.

Also considered in the calculation of the sheet flow component is the Manning’s n roughness coefficient. The roughness coefficient should reflect the cover conditions up to a height of 30 mm (1.2 in) as that is the portion of cover that will obstruct sheet flow (Brown et al., 1996). Soil Conservation Service (now NRCS) Technical Release 55 (TR-55) n values given are from a study by Engman in 1986. The n values derived from the study were based on 176 field plots at USDA stations in Indiana, Mississippi, and Arizona. The plots varied in length from 35’ - 70’ and in width from 5’ - 12’. The rainfall intensities applied to the plots varied from 2-4 in/hr. (Engman, 1986). The original table in Engman’s study lists the range of values for each cover condition encountered during the study. TR-55 uses a portion of Engman’s table, but only lists an average value, not a range. The TR-55 Table is shown below with applicable ranges from Engman’s study added.

| Surface description | n [1] | n value range [1] |
|---|---|---|

| | | |
|---|---|---|
| Smooth surfaces (concrete, asphalt, gravel or bare soil) .......................................... | 0.011 | 0.01 - 0.013 |
| Fallow (no residue) .................................................. | 0.05 | 0.006 - 0.16 |
| Cultivated soils: | | |
| Residue cover =20% ........................................ | 0.06 | |
| Residue cover >20% ........................................ | 0.17 | |
| Grass: | | |
| Short grass prairie ........................................... | 0.15 | 0.10 - 0.20 |
| Dense grasses [2] ................................................ | 0.24 | 0.17 - 0.30 |
| Bermudagrass . ................................................. | 0.41 | 0.30 - 0.48 |
| Range (natural) ........................................................ | 0.13 | 0.01 - 0.32 |
| Woods:[3] | | |
| Light underbrush ............................................. | 0.40 | |
| Dense underbrush ........................................... | 0.80 | |

[1] The n values are a composite of information compiled by Engman (1986).

[2] Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.

[3] When selecting n, consider the cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

Table 1. Roughness Coefficients for Sheet Flow (Table 3-1 from TR-55)

The engineer should choose an n value as close to the field conditions as possible, also considering the range of values, as a difference of 0.05 in n value can cause the sheet flow $T_c$ to vary in the range of 15%.

## Shallow Concentrated and Open Channel Flow

The second component of the time of concentration, shallow concentrated flow, can be estimated by determining the velocity from Figure 1 below and then computing the time of shallow concentrated flow based on the distance of the shallow concentrated flow.

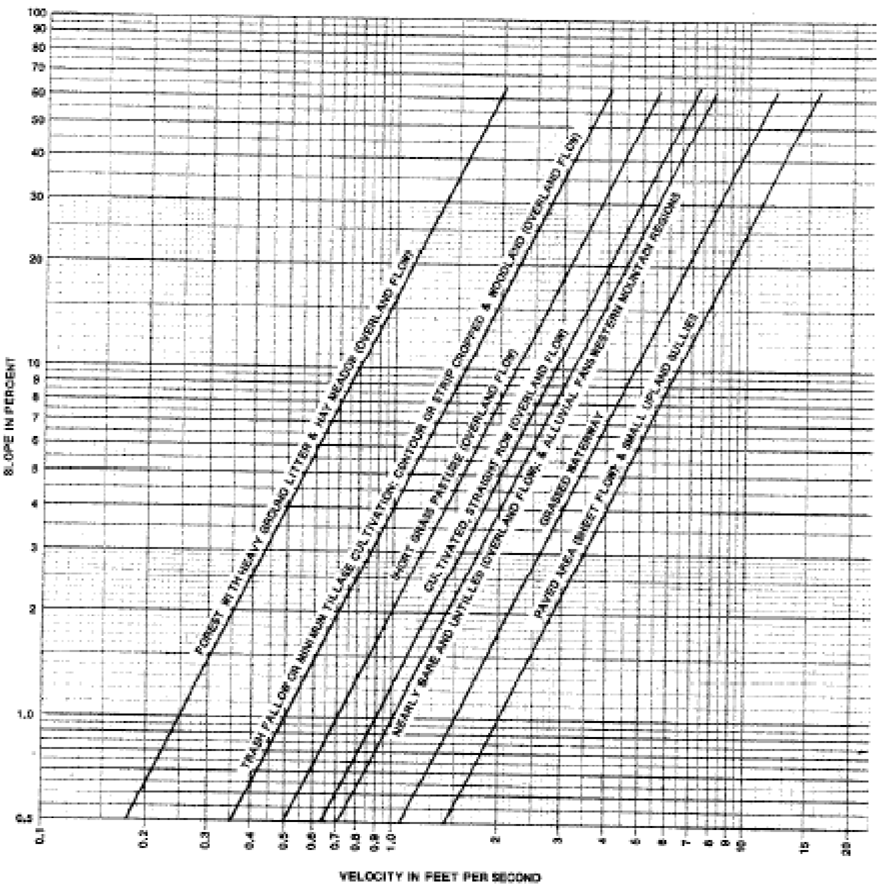

Figure 1. Velocity for Shallow Concentrated Flow Determination (reprinted from SCS TR-55, 1975 Ed.)

The open channel component of the time of concentration can be found by using Manning's equation to compute the velocity for the channel or pipe section and then computing the time of channel flow based on the length of channel flow.

After determining the total time of concentration by summing the individual sheet, shallow concentrated, and channel $T_c$, determine the rainfall intensity, i, from an IDF curve for the design area based on the total $T_c$.

## Rational c Value

The next input of the rational equation is the rational c value. Some may assume the c coefficient represents a percentage of impervious area, but the c value represents the ratio of peak runoff intensity to average rainfall rate assuming a hydraulic balance in the drainage catchment (Stephenson, 1981). Table 2 below contains typical c values.

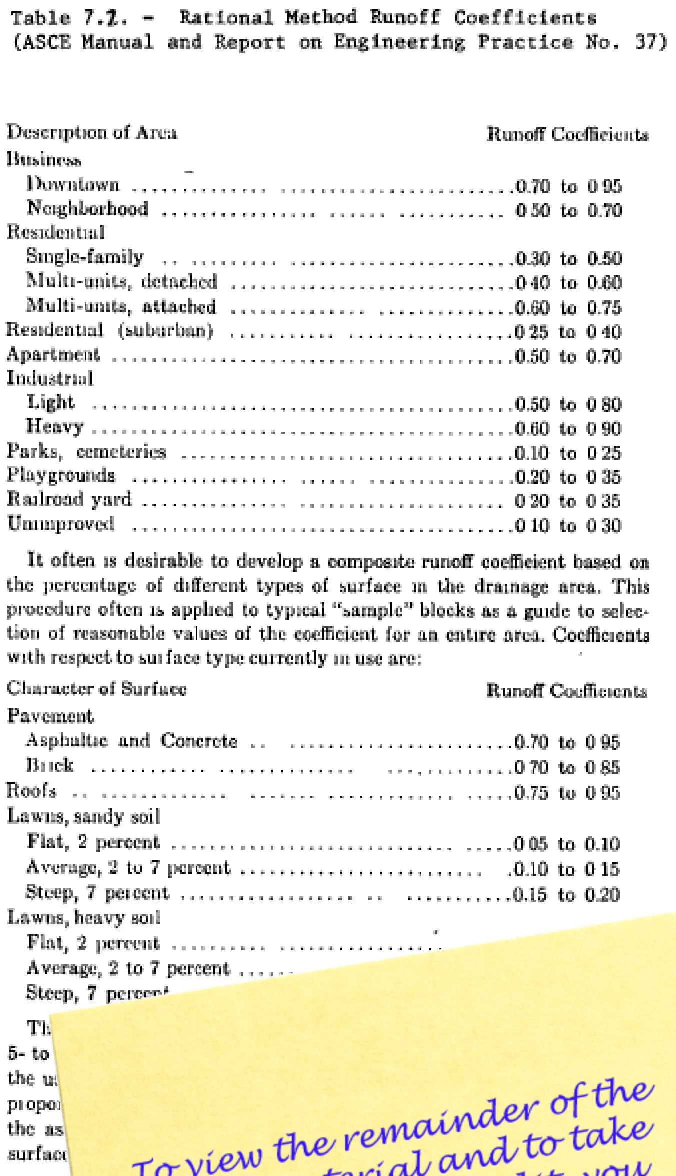
Table 7.2. - Rational Method Runoff Coefficients
(ASCE Manual and Report on Engineering Practice No. 37)

| Description of Area | Runoff Coefficients |
|---|---|
| Business | |
| Downtown | 0.70 to 0 95 |
| Neighborhood | 0 50 to 0.70 |
| Residential | |
| Single-family | 0.30 to 0.50 |
| Multi-units, detached | 0 40 to 0.60 |
| Multi-units, attached | 0.60 to 0.75 |
| Residential (suburban) | 0 25 to 0 40 |
| Apartment | 0.50 to 0.70 |
| Industrial | |
| Light | 0.50 to 0 80 |
| Heavy | 0.60 to 0 90 |
| Parks, cemeteries | 0.10 to 0 25 |
| Playgrounds | 0.20 to 0 35 |
| Railroad yard | 0 20 to 0 35 |
| Unimproved | 0 10 to 0 30 |

It often is desirable to develop a composite runoff coefficient based on the percentage of different types of surface in the drainage area. This procedure often is applied to typical "sample" blocks as a guide to selection of reasonable values of the coefficient for an entire area. Coefficients with respect to surface type currently in use are:

| Character of Surface | Runoff Coefficients |
|---|---|
| Pavement | |
| Asphaltic and Concrete | 0.70 to 0 95 |
| Brick | 0 70 to 0 85 |
| Roofs | 0.75 to 0 95 |
| Lawns, sandy soil | |
| Flat, 2 percent | 0 05 to 0.10 |
| Average, 2 to 7 percent | .0.10 to 0 15 |
| Steep, 7 percent | 0.15 to 0.20 |
| Lawns, heavy soil | |
| Flat, 2 percent | |
| Average, 2 to 7 percent | |
| Steep, 7 percent | |

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Table 2. Rational c … Highway Drainage, 1979)

The c value accour … osses that occur during the runoff process … inches on impervious surfaces, 0.10 inche … nd up to 0.3 inches in forest areas (Joint C … can range from 0.01 inches/hour in high … ervious sandy soils. Infiltration is also i … An interception by vegetation can norm … ry from 0.01 to 0.5 inches in forest area … nderstanding these factors that are inclu … e engineer to more accurately select an a … the range of c values given in a

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