The Rational Method[*]

David B. Thompson
Civil Engineering Deptartment
Texas Tech University

Draft: 20 September 2006

1. Introduction

For hydraulic designs on very small watersheds, a complete hydrograph of runoff is not always required. The maximum, or peak, of the hydrograph is sufficient for design of the structure in question. Therefore, a number of methods for estimating a design discharge, that is, the maximum value of the flood runoff hydrograph, have been developed.

The rational method is a simple technique for estimating a design discharge from a small watershed. It was developed by Kuichling (1889) for small drainage basins in urban areas.

The rational method is the basis for design of many small structures. In particular, the size of the drainage basin is limited to a few tens of acres.[1] The method is also described in most standard textbooks.[2]

---

[1] Texas Department of Transportation (TxDOT) experts suggest a maximum drainage area of 200 acres for rational method application. While many analysts consider this a "hard" limit, in actuality the limit really depends on watershed complexity. For a complex watershed (such as an urbanized watershed), this limit should probably be much less; for a rural watershed, the limit might be much larger. Therefore, it is the analyst's responsibility to determine whether the method is applicable or not and justify application of the rational method based on professional judgment.

[2] See, for example, Section 15.2 in Viessman, Jr., W. and Lewis, G. L., 1995, *Introduction to hydrology*, Fourth Edition, Harper Collins, pp 311ff.

2. Basics

Application of the rational method is based on a simple formula that relates runoff-producing potential of the watershed, the average intensity of rainfall for a particular length of time (the time of concentration), and the watershed drainage area. The formula is

$$Q = C_u C i A, \tag{1}$$

where:

$Q =$ design discharge (L^3/T),
$C_u =$ units conversion coefficient,
$C =$ runoff coefficient (dimensionless),
$i =$ design rainfall intensity (L/T), and
$A =$ watershed drainage area (L^2).

The units conversion coefficient,[3] C_u, is necessary because the iA product, while it has units of L^3/T, is not a standard unit in the traditional units system.

3. Runoff Coefficient

The runoff coefficient, C, is a dimensionless ratio intended to indicate the amount of runoff generated by a watershed given a average intensity of precipitation for a storm. While it is implied by the rational method, equation 1, that intensity of runoff is proportional to intensity of rainfall, calibration of the runoff coefficient has almost always depended on comparing the total depth of runoff with the total depth of precipitation,

$$C = \frac{R}{P}, \tag{2}$$

where:

$R =$ Total depth of runoff (L), and
$P =$ Total depth of precipitation (L).

The runoff coefficient represents the fraction of rainfall converted to runoff. Values are tabulated in table 1.

---

[3] The product of the dimensions of i, and A, is acre-inches per hour in traditional units. Dimensional analysis of this unit will show that this is equivalent to 1.00833 cubic feet per second. This is close enough to unity to be used as an equivalence for most cases.

Table 1: General runoff coefficients for the rational method.

Description	Runoff Coefficient
Business	
Downtown Areas	0.70–0.95
Neighborhood Areas	0.50–0.70
Residential	
Single-family	0.30–0.50
Multi-family detached	0.40–0.60
Multi-family attached	0.60–0.75
Residential suburban	0.25–0.40
Apartments	0.50–0.70
Parks, cemetaries	0.10–0.25
Playgrounds	0.20–0.35
Railroad yards	0.20–0.40
Unimproved areas	0.10–0.30
Drives and walks	0.75–0.85
Roofs	0.75–0.95
Streets	
Asphalt	0.70–0.95
Concrete	0.80–0.95
Brick	0.70–0.85
Lawns; sandy soils	
Flat, 2% slopes	0.05–0.10
Average, 2%–7% slopes	0.10–0.15
Steep, 7% slopes	0.15–0.20
Lawns; heavy soils	
Flat, 2% slopes	0.13–0.17
Average, 2%–7% slopes	0.18–0.22
Steep, 7% slopes	0.25–0.35

4. Storm Intensity

Storm intensity, i, is a function of geographic location and design exceedence frequency (or return interval). It is true that the longer the return interval (hence, the lower the exceedence frequency), the greater the precipitation intensity for a given storm duration. Furthermore, the longer the length of the storm, the lower the storm average precipitation intensity.

The relation between these three components, storm duration, storm intensity, and storm return interval, is represented by a family of curves called the *intensity-duration-frequency* curves, or IDF curves. The IDF curves can be determined by analysis of storms for a particular site or by the use of standard meteorological atlases, such as TP-40 (1963) and HYDRO-35 (1977).

For IDF curves, TxDOT[4] uses a formula for approximating the intensity-duration-frequency curve. The formula is

$$i = \frac{b}{(t_c + d)^e}, \tag{3}$$

---

[4] TxDOT Hydraulic Design Guidelines, `http://manuals.dot.state.tx.us/dynaweb/colbridg/hyd`

Table 2: IDF parameters for Lubbock County.

	Return Interval (years)					
Parameter	2	5	10	25	50	100
e	0.830	0.821	0.813	0.816	0.808	0.810
b	47	60	69	82	88	101
d	10.0	10.1	10.1	10.1	10.1	10.0

where:

i = design rainfall intensity (in/hr),
t_c = time of concentration (min), and
b, d, e = parameters.

For Lubbock County, the parameters are shown on table 2.

5. Time of Concentration

The time of concentration, t_c, of a watershed is often defined to be *the time required for a parcel of runoff to travel from the most hydraulically distant part of a watershed to the outlet.* It is not possible to point to a particular point on a watershed and say, “The time of concentration is measured from this point.” Neither is it possible to measure the time of concentration. Instead, the concept of t_c is useful for describing the time response of a watershed to a driving impulse, namely that of watershed runoff.

In the context of the rational method then, t_c represents the time at which all areas of the watershed that will contribute runoff are just contributing runoff to the outlet. That is, at t_c, the watershed is fully contributing. We choose to use this time to select the rainfall intensity for application of the rational method.

If the chosen storm duration is larger than t_c, then the rainfall intensity will be less than that at t_c. Therefore, the peak discharge estimated using the rational method will be less than the optimal value. If the chosen storm duration is less than t_c, then the watershed is not fully contributing runoff to the outlet for that storm length, and the optimal value will not be realized. Therefore, we choose the storm length to be equal to t_c for use in estimating peak discharges using the rational method.

5.1. Estimating Time of Concentration

There are many methods for estimating t_c. In fact, just about every hydrologist or engineer has a favorite method. All methods for estimating t_c are empirical, that is, each is based on the analysis of one or more datasets. The methods are not, in general, based on theoretical fluid mechanics.

For application of the rational method, TxDOT recommends that t_c be less than 300 minutes (5 hours) and greater than 10 minutes. Other agencies require that t_c be greater than 5 minutes. The concept is that estimates of i become unacceptably large for durations less than 5 or 10 minutes. For long durations (such as longer than 300 minutes), the assumption of a relatively steady rainfall rate is less valid.

5.2. Morgali and Linsley Method

For small urban areas with drainage areas less than ten or twenty acres, and for which the drainage is basically planar, the method developed by Morgali and Linsley (1965) is useful. It is expressed as

$$t_c = \frac{0.94(nL)^{0.6}}{i^{0.4}S^{0.3}}, \tag{4}$$

where:

t_c = time of concentration (min),
i = design rainfall intensity (in/hr),
n = Manning surface roughness (dimensionless),
L = length of flow (ft), and
S = slope of flow (dimensionless).

The Morgali and Linsley equation (equation 4) is implicit in that it cannot be solved for t_c without i. So, iteration is required. Such a solution can be achieved by combining equation 3 with equation 4 and solving using a numerical method (such as a calculator solver). The solution of the two equations yields both t_c and i.[5]

---

[5] Of course, the method of successive substitution can be used with a graph of the IDF curve to arrive at a solution as well.

5.3. Kirpich Method

For small drainage basins that are dominated by channel flow, the Kirpich (1940) equation can be used. The Kirpich equation is

$$t_c = 0.0078(L^3/h)^{0.385} \tag{5}$$

where:

$t_c =$ time of concentration (min),
$L =$ length of main channel (ft), and
$h =$ relief along main channel (ft).

Some authors use an adjustment factor for the Kirpich approach to correct for paved channels. The Kirpich method is limited to watershed with a drainage area of about 200 acres.

5.4. Kerby-Hatheway Method

For small watersheds where overland flow is an important component, but the assumptions inherent in the Morgali and Linsley approach are not appropriate, then the Kerby (1959) method can be used. The Kerby-Hatheway equation is

$$t_c = \left[\frac{0.67NL}{\sqrt{S}}\right]^{0.467} \tag{6}$$

where:

$t_c =$ time of concentration (min),
$N =$ Kerby roughness parameter (dimensionless), and
$S =$ overland flow slope (dimensionless).

Overland flow rarely occurs for distances exceeding 1200 feet. So, if the watershed length exceeds 1200 feet, then a combination of Kerby's equation and the Kirpich equation may be appropriate. Certainly, the combination of overland flow and channel t_c is an appropriate concept. Values for Kerby's roughness parameter, N, are presented on table 3.

6. Putting It Together

More here later...

Table 3: Kerby's roughness parameter.

Description	N
Pavement	0.02
Smooth, bare packed soil	0.10
Poor grass, cultivated row crops or moderately rough bare surfaces	0.20
Pasture, average grass	0.40
Deciduous forest	0.60
Dense grass, coniferous forest, or deciduous forest with deep litter	0.80

References

Kerby, W. S. (1959). Time of concentration for overland flow. *Civil Engineering 29*(3), 60. Kerby's work is based on Hatheway's (1945) data. (In PDF).

Kirpich, Z. P. (1940). Time of concentration of small agricultural watersheds. *Civil Engineering 10*(6), 362. The original source for the Kirpich equation. (In PDF).

Kuichling, E. (1889). The relation between the rainfall and the discharge of sewers in populous districts. *Transactions, American Society of Civil Engineers 20*, 1–56.

Morgali, J. R. and R. K. Linsley (1965, May). Computer analysis of overland flow. *Journal of the Hydraulics Division 91*(HY3), 81–101.

National Oceanic and Atmospheric Administration (1977, June). Five- to 60-minute precipitation frequency for the eastern and central united states. Hydro-35. (In PDF).

U. S. Weather Bureau (1963). Rainfall frequency atlas of the united states for durations of 30 minutes to 24 hours and return periods from 1 to 100 years. Technical Report 40, U. S. Weather Bureau.