A. Introduction

The Rational method is based upon the following formula:

Equation C3-S4-1

$$Q_T = Ci_T A$$

Where:
Q_T = estimate of the peak rate of runoff (cfs) for some recurrence interval, T
C = runoff coefficient; fraction of runoff, expressed as a dimensionless decimal fraction, that appears as surface runoff from the contributing drainage area.
i_T = average rainfall intensity (in/hr) for some recurrence interval, T during that period of time equal to T_c.
A= the contributing tributary drainage area to the point of design in acres which produces the maximum peak rate of runoff
T_c = rainfall intensity averaging time in minutes

Rainfall intensity averaging time is used as the definition of T_c in this instance because it more accurately describes the only use for this variable (i.e., to estimate a time during a storm in which the average rainfall intensity is at maximum. The time is defined as the time required for water to travel from the hydraulically most distant point in the contributing drainage area to the point of design.

B. Characteristics

1. When using the Rational formula, an assumption is made that maximum rate of flow is produced by a constant rainfall, which is maintained for a time equal to the period of concentration of flow at the point under consideration. Theoretically, this is the time of concentration, which is the time required for the surface runoff from the most remote part of the drainage basin to reach the point being considered. However, in practice, the concentration time is an empirical value that results in acceptable peak flow estimates. There are other assumptions used in the Rational method, and thus the designer or engineer should consider how exceptions or other unusual circumstances might affect those results:
   a. The recurrence interval of the peak flow rate is the same as that of the average rainfall intensity.
   b. The rainfall is uniform in space over the drainage area being considered.
   c. The rainfall intensity remains constant during the time period equal to the rainfall intensity averaging time.
   d. The storm duration associated with the peak flow rate is equal to the rainfall intensity during the rainfall intensity averaging time to that point.
   e. The runoff frequency curve is parallel to the rainfall frequency curve. This implies that the same value of the runoff coefficient is used for all recurrence intervals. In practice, the runoff coefficient is adjusted with a frequency coefficient (C_f) for the 25-year through 100-year recurrence intervals.
   f. The drainage area is the total area tributary to the point of design.
   g. The rainfall intensity averaging time is the time required for the runoff to flow from the hydraulically most distant point in the contributing drainage area to the point of design.

2. The following are additional factors that might not normally be considered, yet could prove important:
   a. The storm duration gives the length of time over which the average rainfall intensity (i_T) persists. Neither the storm duration nor i_T say anything about how the intensity varies during the storm, nor do they consider how much rain fell before the period in question.
   b. A 20% increase or decrease in the value of C has the same effect as changing a 5-year recurrence interval to a 15-year or a 2-year interval, respectively.
   c. The chance of all design assumptions being satisfied simultaneously is less than the chance that the rainfall rate used in the design will actually occur. This, in effect, creates a built-in factor of safety.
   d. Another built-in factor of safety is the usual design practice of having the hydraulic gradeline near the top of the pipe or box. Since the top of the storm sewer pipe is always a few feet lower than the street elevation, a rainfall intensity greater than the intensity for which the sewer is designed does not automatically mean

that flooding will occur.

e. A difference can exist between intense point rainfall (rainfall over a small area) and mean catchment area rainfall (average rainfall). For that reason, the Rational method should be applied to drainage areas less than 160 acres.

f. In an irregularly-shaped drainage area, a part of the area that has a short time of concentration (T_c) may cause a greater runoff rate (Q) at the intake or other design point) than the runoff rate calculated for the entire area. This is because parts of the area with long concentration times are far less susceptible to high-intensity rainfall. Thus, they skew the calculation.

g. A portion of a drainage area which has a value of C much higher than the rest of the area may produce a greater amount of runoff at a design point than that calculated for the entire area. This effect is similar to that described above. In the design of storm sewers for small subbasin areas such as a cul-de-sac in a subdivision, the designer should be aware that an extremely short time of concentration will result in a high estimate of the rainfall intensity and the peak rate of runoff. The time of concentration estimates should be checked to make sure they are reasonable.

h. In some cases, runoff from a portion of the drainage area that is highly-impervious may result in a greater peak discharge than would occur if the entire area was considered. In these cases, adjustments can be made to the drainage area by disregarding those areas where flow time is too slow to add to the peak discharge. Sometimes it is necessary to estimate several different times of concentration to determine the design flow that is critical for a particular application.

i. When designing a drainage system, the overland flow path is not necessarily the same before and after development and grading operations have been completed. Selecting overland flow paths in excess of 100 feet in urban areas and 300 feet in rural areas should be done only after careful consideration.

C. Limitations

The use of the rational formula is subject to several limitations and procedural issues in its use:

- The most important limitation is that the only output from the method is a peak discharge (the method provides only an estimate of a single point on the runoff hydrograph).
- The simplest application of the method permits and requires the wide latitude of subjective judgment by the user in its application. Therefore, the results are difficult to replicate.
- The average rainfall intensities used in the formula have no time sequence relation to the actual rainfall pattern during the storm.
- The computation of T_c should include the overland flow time, plus the time of flow in open and/or closed channels to the point of design.
- The runoff coefficient, C, is usually estimated from a table of values (Table C3-S4-1). The user must use good judgment when evaluating the land use in the drainage area under consideration. Note in Table C3-S4-1, that the value of C will vary with the return frequency.
- Many users assume the entire drainage area is the value to be entered in the Rational method equation. In some cases, the runoff from the only the interconnected impervious area yields the larger peak flow rate.

D. Use of the Rational method

1. **Runoff coefficient.** The runoff coefficient (C) represents the integrated effects of infiltration, evaporation, retention, flow routing, and interception; all of which affect the time distribution and peak rate of runoff. The runoff coefficient is the variable of the Rational method least-susceptible to precise determination and requires judgment and understanding on the part of the designer. While engineering judgment will always be required in the selection of runoff coefficients, a typical coefficient represents the integrated effects of many drainage basin parameters. The Engineer should realize that the C values shown in Table C3-S4-1 are typical values, and may have to be adjusted if the site deviates from typical conditions such as an increase or decrease in percent impervious.

   The values are presented for different surface characteristics, as well as for different aggregate land uses. The coefficient for various surface areas can be used to develop a composite value for a different land use. The runoff values for business, residential, industrial, schools, and railroad yard areas are an average of all surfaces typically found in the particular land use.

The hydrologic soil groups, as defined by NRCS soil scientists and used in Table C3-S4-1 are:

a. **Group A.** Soils having low runoff potential and a high infiltration rate, even when thoroughly wetted, consisting chiefly of deep, well- to excessively well-drained sands or gravels.

b. **Group B.** Soils having a moderate infiltration rate when thoroughly wetted, consisting chiefly of moderately-

c. deep to deep, moderately-well to well-drained soils, with moderately- fine to moderately-coarse texture.

d. **Group C.** Soils having a slow infiltration rate when thoroughly wetted, consisting chiefly of soils with a layer that impedes downward movement of water or soils with moderately-fine to fine texture.

e. **Group D.** Soils having high runoff potential and a very slow infiltration rate when thoroughly wetted, consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material.

Table C3-S4-1: Runoff coefficients for the Rational method

Hydrologic Soil Group	A			B			C			D		
Recurrence Interval	5	10	100	5	10	100	5	10	100	5	10	100
Land Use or Surface Characteristics Business:												
A. Commercial Area	.75	.80	.95	.80	.85	.95	.80	.85	.95	.85	.90	.95
B. Neighborhood Area	.50	.55	.65	.55	.60	.70	.60	.65	.75	.65	.70	.80
Residential:												
A. Single Family	.25	.25	.30	.30	.35	.40	.40	.45	.50	.45	.50	.55
B. Multi-Unit (Detached)	.35	.40	.45	.40	.45	.50	.45	.50	.55	.50	.55	.65
C. Multi-Unit (Attached)	.45	.50	.55	.50	.55	.65	.55	.60	.70	.60	.65	.75
D. ½ Lot or Larger	.20	.20	.25	.25	.25	.30	.35	.40	.45	.40	.45	.50
E. Apartments	.50	.55	.60	.55	.60	.70	.60	.65	.75	.65	.70	.80
Industrial												
A. Light Areas	.55	.60	.70	.60	.65	.75	.65	.70	.80	.70	.75	.90
B. Heavy Areas	.75	.80	.95	.80	.85	.95	.80	.85	.95	.80	.85	.95
Parks, Cemeteries Playgrounds	.10	.10	.15	.20	.20	.25	.30	.35	.40	.35	.40	.45
Schools	.30	.35	.40	.40	.45	.50	.45	.50	.55	.50	.55	.65
Railroad Yard Areas	.20	.20	.25	.30	.35	.40	.40	.45	.45	.45	.50	.55
Streets												
A. Paved	.85	.90	.95	.85	.90	.95	.85	.90	.95	.85	.90	.95
B. Gravel	.25	.25	.30	.35	.40	.45	.40	.45	.50	.40	.45	.50
Drives, Walks, & Roofs	.85	.90	.95	.85	.90	.95	.85	.90	.95	.85	.90	.95
Lawns												
A. 50%-75% Grass (Fair Condition)	.10	.10	.15	.20	.20	.25	.30	.35	.40	.30	.35	.40
B. 75% Or More Grass (Good Condition)	.05	.05	.10	.15	.15	.20	.25	.25	.30	.30	.35	.40
Undeveloped Surface[1] (By Slope)[2]												
A. Flat (0-1%)	0.04-0.09			0.07-0.12			0.11-0.16			0.15-0.20		
B. Average (2-6%)	0.09-0.14			0.12-0.17			0.16-0.21			0.20-0.25		
C. Steep	0.13-0.18			0.18-0.24			0.23-0.31			0.28-0.38		

[1]Undeveloped Surface Definition: Forest and agricultural land, open space.

[2]Source: Storm Drainage Design Manual, Erie and Niagara Counties Regional Planning Board.

2. **Composite runoff analysis.** Care should be taken not to average runoff coefficients for large segments that have multiple land uses of a wide variety (i.e., business to agriculture). However, within similar land uses, it is often desirable to develop a composite runoff coefficient based on the percentage of different types of surface in the drainage area. The composite procedure can be applied to an entire drainage area, or to typical sample blocks as a guide to selection of reasonable values of the coefficient for an entire area.
3. **Rainfall intensity.** The intensity (I) is the average rainfall rate in inches per hour for the period of maximum rainfall of a given frequency, with a duration equal to the time of concentration. The time of concentration is defined as the time required for a drop of water falling on the most remote point of a drainage basin to reach the outlet in question. The time of concentration is assumed to be the sum of two flow times. The first is the time required for the surface runoff to reach the first conveyance mechanism (swale, gutter, sewer, or channel). This is often called the inlet time. The second is the travel time in the conveyance system itself. Therefore $T_c = T_{travel} + T_{conveyance\ system} = T_t + T_{cs}$. To determine the time of concentration, see Chapter 3 - Section 3 Time of Concentration.

   After the T_c has been determined, the rainfall intensity should be obtained. For the Rational method, the design rainfall intensity averaging time (i_T) should be that which occurs for the design year storm whose duration equals the time of concentration. **Error! Reference source not found.** and **Error! Reference source not found.** provide the Iowa rainfall data from Bulletin 71 to allow determination of rainfall intensity based on duration equals time of concentration. **Error! Reference source not found.** provides the rainfall amounts for various storm frequencies and duration. The rainfall intensity is determined by dividing the total rainfall (**Error! Reference source not found.**) by the duration (time of concentration) in hours. **Error! Reference source not found.** provides the rainfall intensity directly from the table. The climate sectional codes for Iowa are shown in Figure C3-S3-1.

4. **Area.** The area (A) of the basin in acres. A map showing the limits of the drainage basin used in design should be provided with design data and will be superimposed on the grading plan showing subbasins. As mentioned earlier, the configuration of the contributing area with respect to pervious and impervious sub-areas and the flow path should be considered when deciding whether to use all or a portion of the total area.

5. **Adjustment of C values.** For larger storm events (less-frequent, higher-intensity storms), use multipliers in Table C3-S4-2 to adjust the 5-year C values.

Table C3-S4-2: Frequency factors for Rational formula

Recurrence Interval (years)	C_f
25	1.1
50	1.2
100	1.25

E. Design Example

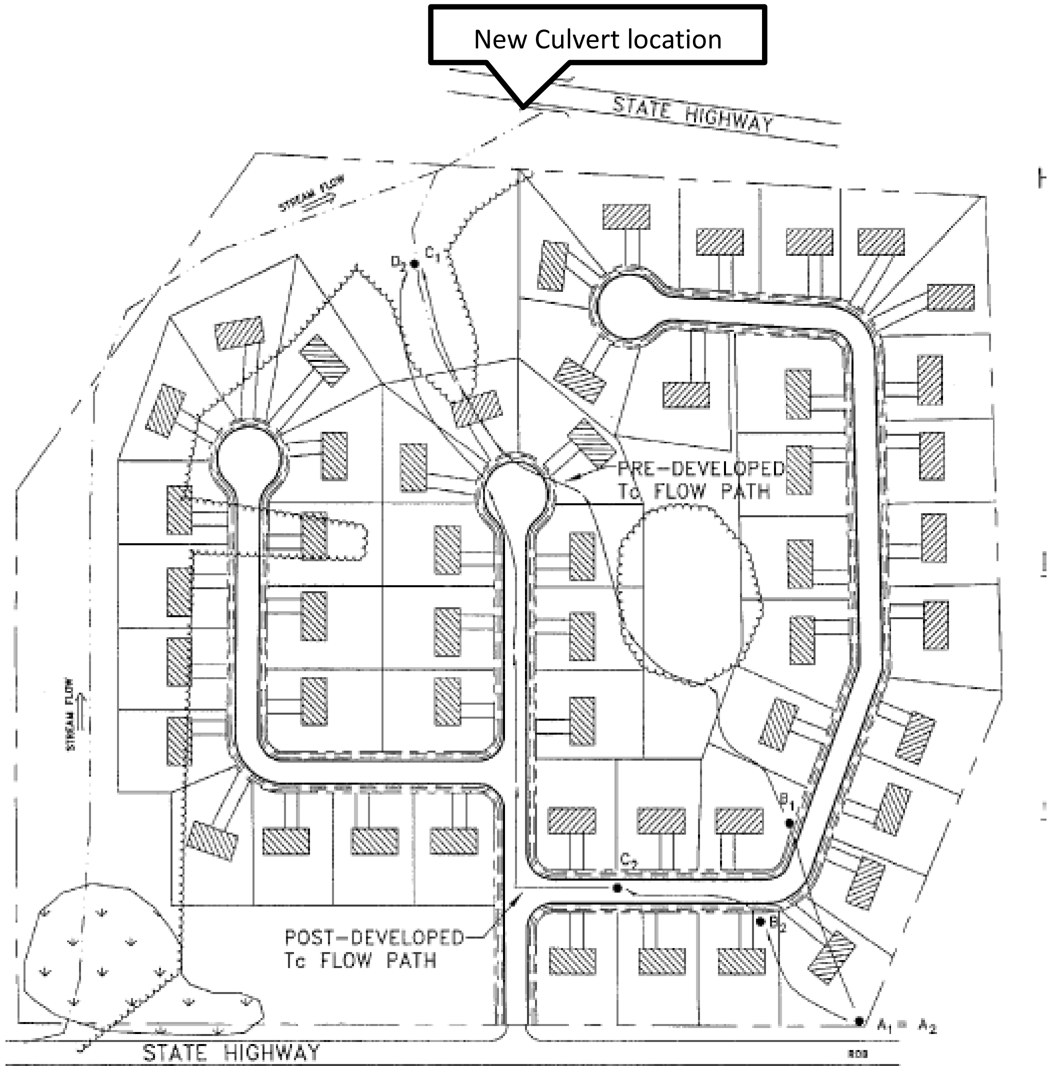
Rational method

Following is an example problem that illustrates the application of the Rational method to estimate peak discharges:

1. **Rate of runoff.** Estimates of the maximum rate of runoff are needed at the inlet to a proposed culvert for a 25-year return period. Design for 25-year peak runoff; check culvert design for 50-year event for road overtopping. HW_{max} for the culvert is 1 foot below the C/L elevation of road.
2. **Site data.** Using a topographic map of the City of Bucketsville, IA and a field survey, the area of the drainage basin upstream from the point in question is found to be 20 acres. In addition, the following data were measured:
   - Average overland slope = 2%
   - Length of overland flow = 80 ft
   - Length of main basin channel = 2,250 ft (open vegetated swale)
   - Slope of channel - 0.018 ft/ft = 1.8%

- Roughness coefficient (n) of channel was estimated to be 0.090

3. **Land use.** From existing land use maps, land use for the drainage basin was estimated to be:
   - Residential (single family) - 80%
   - Graded/grass common use area - silt loam soil sandy soil (HSG-C), 3% slope - 20%
   - From existing land use maps, the land use for the overland flow area at the head of the basin was estimated to be: lawn - silt-loam soil (HSG-C), 2% slope
4. **Overland flow.** A runoff coefficient (C) for the overland flow area is determined from Table C3-S4-1 to be 0.20.
5. **Time of concentration.** Compute from calculation data sheet. Computed T_c for the catchment is 0.102 hr or 6 minutes.



Flow path:		
Sheet flow across lawn:	A2 to B2	80 feet
Shallow concentrated flow (pavement):	B2 to C2 (inlet)	50 feet
Open channel flow in 18-inch RCP sewer:	C2 to D2	1000 feet
Open channel flow in vegetated swale:	D2 to culvert inlet	400 feet

Figure C3-S4-1: Sunset Ridge Development, Bucketsville, Iowa

Worksheet 1: Time of Concentration (T_c) or Travel Time (T_t)

Project: Sunset Road Culvert   By: SEJ   Date: ______

Location: Bucketsville IA   Checked: ______   Date: ______

Check one: ☒ Present ☐ Developed

Check one: ☒ T_c ☐ T_t through sub area

Notes: Space for as many as two segments per flow type can be used for each worksheet.
Include a map, schematic, or description of flow segments.

Sheet flow (Applicable to T_c only)	Units	Segment 1	Segment 2	Total
Segment ID		A2-B2		
1. Surface description (Table C3-S3- 2)		Dense grass		
2. Manning's roughness coefficients, n (Table C3-S3- 2)		0.24		
3. Flow Length, L (Total L less than or equal to 300')	ft	80		
4. Two-year 24-hour rainfall, P_2	in	2.91		
5. Land slope, s	ft/ft	0.02		
6. $T_t = \frac{0.007[(n)(L)]^{0.8}}{\sqrt{P_2} s^{0.4}}$ Compute T_t	hr	0.156	+	= 0.16

Shallow concentrated flow	Units	Segment 1	Segment 2	Total
Segment ID		B2-C2		
7. Surface description (paved or unpaved)		Paved		
8. Flow length, L	ft	50		
9. Watercourse slope, s	ft/ft	0.02		
10. Average velocity, V (Figure C3-S3- 1)	ft/s	2.9		
11. $T_t = \frac{L}{3600V}$ Compute T_t	hr	0.0048	+	= 0.005

Open channel flow	Units	Segment 1	Segment 2	Total
Segment ID		C2-D2	D2 to culvert inlet	
12. Cross sectional flow area, a	ft^2	1.32	6.4	
13. Wetted perimeter, P_w	ft	3.53	9.8	
14. Hydraulic radius, $r = \frac{a}{P_e}$ Compute r	ft	0.374	0.653	
15. Channel slope, s	ft/ft	0.018	0.016	
16. Manning's roughness coeff., n		0.013	0.06	
17. $V = \frac{1.49 r^{\frac{2}{3}} s^{\frac{1}{2}}}{n}$ Compute V	ft/s	7.94	2.35	
18. Flow length, L	ft	1000	400	
19. $T_t = \frac{L}{3600V}$ Compute T_t	hr	0.034	+ 0.047	= 0.081

Watershed or subarea T_c or T_t (add T_t in steps 6, 11, and 19)0.047 hr 0.102

6. **Determine rainfall intensity.** Use a rainfall duration of 6 minutes to calculate the rainfall intensity for the 25-year and 50-year return periods from **Error! Reference source not found.** or **Error! Reference source not found.**. Use rainfall depth for 5-minute duration.

	25-year	**50-year**
Rainfall depth	0.62 inches	0.70 inches
Intensity	6.2 in/hr	7.0 in/hr

7. **Determine peak discharge, Q:**

$$Q(cfs) = C_f \times C \times I \times A$$

From Table C3-S4-1, the runoff coefficient, C, for single-family residential and HSG-C soils for a 5-year RI is 0.40. Runoff coefficient for the vegetated common use area is 0.25.

Runoff coefficient:

Land use	% of total area	Runoff coefficient	Weighted runoff coefficient
Single family residential area	80	0.40	0.32
Grass common use area	20	0.25	0.05

Total weighted runoff coefficient = 0.37

8. **Peak runoff calculation:**

$$Q_{25}(cfs) = 1.1 \times 0.37 \times 6.2\, in/hr \times 20ac = 50.46cfs = \mathbf{50.5cfs}$$
$$Q_{50}(cfs) = 1.2 \times 0.37 \times 7.0\, in/hr \times 20ac = 62.16cfs = \mathbf{62.2cfs}$$