RATIONAL METHOD

\[ Q = CiA \]

Where:

- \( Q \) = Maximum Rate of Runoff (cfs)
- \( C \) = Runoff Coefficient
- \( i \) = Average Rainfall Intensity (in/hr)
- \( A \) = Drainage Area (in acres)
RATIONAL METHOD

Assumptions and Limitations:

• Watershed area < 200 acres
• The method is applicable if time of concentration ($t_c$) for the drainage area is less than the duration of peak rainfall intensity.
• The time of concentration ($t_c$) is the time required for water to travel from the hydraulically most remote point of the basin to the point of interest.

From Texas DOT Hydraulics Design Manual
**RATIONAL METHOD**

**Assumptions and Limitations:**
- The calculated runoff is directly proportional to the rainfall intensity.
- Rainfall intensity is uniform throughout the duration of the storm.
- The frequency of occurrence for the peak discharge is the same as the frequency of the rainfall producing that event.

From Texas DOT Hydraulics Design Manual
RATIONAL METHOD

Assumptions and Limitations:
- Rainfall is distributed uniformly over the drainage area.
- The minimum duration to be used for computation of rainfall intensity is 10 minutes.
RATIONAL METHOD

Assumptions and Limitations:

- The rational method does not account for storage in the drainage area. Available storage is assumed to be filled.
RATIONAL METHOD

\[ Q = CiA \]

Where:

- \( Q \) = Maximum Rate of Runoff (cfs)
- \( C \) = Runoff Coefficient
- \( i \) = Average Rainfall Intensity (in/hr)
- \( A \) = Drainage Area (in acres)
**Runoff Coefficient (C)**

**Definition:**
Dimensionless ratio intended to indicate the amount of runoff generated by a watershed given an average intensity of precipitation for a storm.

\[ C = \frac{R}{P} \]

**Where:**
- \( R \) = Total depth of runoff
- \( P \) = Total depth of precipitation

From Texas DOT Hydraulics Design Manual
## Runoff Coefficient (C)

### Table 1 Runoff Coefficients for the Rational Method

<table>
<thead>
<tr>
<th>Category</th>
<th>FLAT</th>
<th>ROLLING</th>
<th>HILLY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavement &amp; Roofs</td>
<td>0.90</td>
<td>0.90</td>
<td>0.90</td>
</tr>
<tr>
<td>Earth Shoulders</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Drives &amp; Walks</td>
<td>0.75</td>
<td>0.80</td>
<td>0.85</td>
</tr>
<tr>
<td>Gravel Pavement</td>
<td>0.85</td>
<td>0.85</td>
<td>0.85</td>
</tr>
<tr>
<td>City Business Areas</td>
<td>0.80</td>
<td>0.85</td>
<td>0.85</td>
</tr>
<tr>
<td>Apartment Dwelling Areas</td>
<td>0.50</td>
<td>0.60</td>
<td>0.70</td>
</tr>
<tr>
<td>Light Residential: 1 to 3 units/acre</td>
<td>0.35</td>
<td>0.40</td>
<td>0.45</td>
</tr>
<tr>
<td>Normal Residential: 3 to 6 units/acre</td>
<td>0.50</td>
<td>0.55</td>
<td>0.60</td>
</tr>
<tr>
<td>Dense Residential: 6 to 15 units/acre</td>
<td>0.70</td>
<td>0.75</td>
<td>0.80</td>
</tr>
<tr>
<td>Lawns</td>
<td>0.17</td>
<td>0.22</td>
<td>0.35</td>
</tr>
<tr>
<td>Grass Shoulders</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Side Slopes, Earth</td>
<td>0.60</td>
<td>0.60</td>
<td>0.60</td>
</tr>
<tr>
<td>Side Slopes, Turf</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Median Areas, Turf</td>
<td>0.25</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Cultivated Land, Clay &amp; Loam</td>
<td>0.50</td>
<td>0.55</td>
<td>0.60</td>
</tr>
<tr>
<td>Cultivated Land, Sand &amp; Gravel</td>
<td>0.25</td>
<td>0.30</td>
<td>0.35</td>
</tr>
<tr>
<td>Industrial Areas, Light</td>
<td>0.50</td>
<td>0.70</td>
<td>0.80</td>
</tr>
<tr>
<td>Industrial Areas, Heavy</td>
<td>0.60</td>
<td>0.80</td>
<td><strong>0.90</strong></td>
</tr>
<tr>
<td>Parks &amp; Cemeteries</td>
<td>0.10</td>
<td>0.15</td>
<td>0.25</td>
</tr>
<tr>
<td>Playgrounds</td>
<td>0.20</td>
<td>0.25</td>
<td>0.30</td>
</tr>
<tr>
<td>Woodland &amp; Forests</td>
<td>0.10</td>
<td>0.15</td>
<td>0.20</td>
</tr>
<tr>
<td>Meadows &amp; Pasture Land</td>
<td>0.25</td>
<td>0.30</td>
<td>0.35</td>
</tr>
<tr>
<td>Unimproved Areas</td>
<td>0.10</td>
<td>0.20</td>
<td>0.30</td>
</tr>
</tbody>
</table>

**Note:**
- **Impervious surfaces in bold**
- **Rolling** = ground slope between 2 percent to 10 percent
- **Hilly** = ground slope greater than 10 percent

From Ohio DOT Hydraulics Manual
Rainfall Intensity ($i$)

The determination of rainfall intensity ($i$) for use in the Rational Formula involves consideration of three factors:

- Average frequency of occurrence.
- Intensity-duration characteristics for a selected rainfall frequency.
- The time of concentration ($t_c$).
**TIME OF CONCENTRATION ($t_c$)**

**Definition:**
The time required for a parcel of runoff to travel from the most hydraulically distant part of a watershed to the outlet.

- $t_c$ represents the time at which all areas of the watershed that will contribute runoff are just contributing runoff to the outlet.

---

- **Area is less than 200 acres**
  - **Estimate time of concentration**
    - **Determine design rainfall intensity for duration for selected frequency**
      - **Configure rational equation model; estimate parameter**
        - **Compute design peak flow**
          - **Validate/verify**

*From Texas DOT Hydraulics Design Manual*
TIME OF CONCENTRATION ($t_c$)

- If the chosen storm duration > $t_c$, then the rainfall intensity will be less than that at $t_c$ (Peak discharge < optimal value).
- If the chosen storm duration < $t_c$, then the watershed is not fully contributing runoff to the outlet for that storm length (i.e. optimal value will not be realized).
- Therefore, choose storm duration = $t_c$ for peak discharge.
TIME OF CONCENTRATION ($t_c$)

Morgali and Linsley Method (1965)

\[ t_c = \frac{0.94(nL)^{0.6}}{i^{0.4}S^{0.3}} \]

$t_c = \text{time of concentration (min)},$

\( i = \text{design rainfall intensity (in/hr)}, \)

\( n = \text{Manning surface roughness (dimensionless)}, \)

\( L = \text{length of flow (ft)}, \) and

\( S = \text{slope of flow (dimensionless)}. \)

Assumptions and Limitations:

- For use with sheet flow (rarely more than 400 ft).
- Cannot be solved for $t_c$ without $i$. Therefore, iteration is required.
TIME OF CONCENTRATION \((t_c)\)

Morgali and Linsley Method (1965)

\[
t_c = \frac{0.94(\frac{nL}{i})^{0.6}}{i^{0.4}S^{0.3}}
\]

- \(t_c\) = 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).

Table 3-2. Manning’s Roughness Coefficient \((n)\) for Overland Sheet Flow

<table>
<thead>
<tr>
<th>Surface Description</th>
<th>(n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smooth asphalt</td>
<td>0.011</td>
</tr>
<tr>
<td>Smooth concrete</td>
<td>0.012</td>
</tr>
<tr>
<td>Ordinary concrete lining</td>
<td>0.013</td>
</tr>
<tr>
<td>Good wood</td>
<td>0.014</td>
</tr>
<tr>
<td>Brick with cement mortar</td>
<td>0.014</td>
</tr>
<tr>
<td>Vitrified clay</td>
<td>0.015</td>
</tr>
<tr>
<td>Cast iron</td>
<td>0.015</td>
</tr>
<tr>
<td>Corrugated metal pipe</td>
<td>0.024</td>
</tr>
<tr>
<td>Cement rubble surface</td>
<td>0.024</td>
</tr>
<tr>
<td>Fallow (no residue)</td>
<td>0.05</td>
</tr>
<tr>
<td>Cultivated soils</td>
<td></td>
</tr>
<tr>
<td>Residue cover ≤ 20%</td>
<td>0.06</td>
</tr>
<tr>
<td>Residue cover &gt; 20%</td>
<td>0.17</td>
</tr>
<tr>
<td>Range (natural)</td>
<td>0.13</td>
</tr>
<tr>
<td>Grass</td>
<td></td>
</tr>
<tr>
<td>Short grass prairie</td>
<td>0.15</td>
</tr>
<tr>
<td>Dense grasses</td>
<td>0.24</td>
</tr>
<tr>
<td>Bermuda grass</td>
<td>0.41</td>
</tr>
<tr>
<td>Woods*</td>
<td></td>
</tr>
<tr>
<td>Light underbrush</td>
<td>0.40</td>
</tr>
<tr>
<td>Dense underbrush</td>
<td>0.80</td>
</tr>
</tbody>
</table>

*When selecting \(n\), consider cover to a height of about 30 mm. This is only part of the plant cover that will obstruct sheet flow.

From FHWA-NHI-01-021
**Time of Concentration** \( (t_c) \)

Kirpich Method (1940)

\[
t_c = 0.0078 \left( \frac{L^3}{h} \right)^{0.385}
\]

\( t_c \) = time of concentration (min),

\( L \) = length of main channel (ft), and

\( h \) = relief along main channel (ft).

**Assumptions and Limitations:**

- For small drainage basins dominated by channel flow.
TIME OF CONCENTRATION \((t_c)\)

Kerby-Hatheway Method (1959)

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

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

Assumptions and Limitations:
- Primarily used for overland flow.

<table>
<thead>
<tr>
<th>Description</th>
<th>(N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavement</td>
<td>0.02</td>
</tr>
<tr>
<td>Smooth, bare packed soil</td>
<td>0.10</td>
</tr>
<tr>
<td>Poor grass, cultivated row crops or moderately rough bare surfaces</td>
<td>0.20</td>
</tr>
<tr>
<td>Pasture, average grass</td>
<td>0.40</td>
</tr>
<tr>
<td>Deciduous forest</td>
<td>0.60</td>
</tr>
<tr>
<td>Dense grass, coniferous forest, or deciduous forest with deep litter</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Table 3: Kerby’s roughness parameter.
**TIME OF CONCENTRATION** ($t_c$)

Shallow Concentrated Flow

\[ t_c = \frac{L}{V} \]

\[ V = 3.28k(s)^{1/2} \]

Where:
- $t_c =$ Time of Concentration
- $L =$ Length of Flow
- $V =$ Velocity (ft/s)
- $k =$ Intercept Coefficient
- $s =$ Slope (%)
**TIME OF CONCENTRATION ($t_c$)**

Open Channels and Pipe Flow

$$t_c = \frac{L}{V} \quad V = \frac{1.48}{n} r^{2/3} s^{1/2}$$

**Where:**

- $t_c$ = Time of Concentration
- $L$ = Length of Flow
- $V$ = Velocity (ft/s)
- $n$ = Roughness Coefficient
- $r$ = Hydraulic Radius (flow area/wetted perimeter) (ft)
- $s$ = Slope (ft/ft)

From FHWA-NHI-01-021
**TIME OF CONCENTRATION** \((t_c)\)

Numerous Flow Segments

\[
t_c = t_{t1} + t_{t2} + \ldots + t_{tn}
\]

**Where:**

- \(t_c\) = Time of Concentration
- \(t_{t1}\) = Travel time of Segment 1
- \(n\) = Number of segments
Rainfall Intensity ($i$)

Intensity-Duration-Frequency (IDF) Curves

From FHWA-NHI-01-021

IDF Curve for Boston, MA
(Hydrology Handbook for Conservation Commissioners, 2002)