SEES 503
SUSTAINABLE WATER RESOURCES

PRECIPITATION

Instructor

Assist. Prof. Dr. Bertuğ Akıntuğ

Civil Engineering Program
Middle East Technical University
Northern Cyprus Campus
2. PRECIPITATION

Overview

- **Introduction**
- **Measurement of Precipitation**
  - Non-recording Rain Gauges
  - Recording Rain Gauges
- **Analysis of Precipitation**
  - Converting the Recorded Diagram to the Hyetograph
  - Areal Mean Precipitation
  - Resultant Hyetograph
  - Depth-Area-Duration Curves
  - Intensity-Duration-Frequency Curves
- **Rational Method**
Introduction

- **Precipitation**: All forms of water coming from the atmosphere to the Earth
  - **Rain** → Drops > 0.5 mm in diameter, typically 1-2 mm diameter drops
    - Intensity < 2 mm/hr → Light Rain
    - Intensity > 7 mm/hr → Heavy Rain
  - **Snow** → Snow flakes and Snow grains
  - **Hail** → Roughly spherical lumps of ice, 5-50 mm or more in diameter.
  - **Drizzle** → Droplets < 0.5 mm in diameter
  - **Sleet (Ice Pellets)** → Partly melted snow or a mixture of rain and snow
Overview

- Introduction
- **Measurement of Precipitation**
  - Non-recording Rain Gauges
  - Recording Rain Gauges
- Analysis of Precipitation
  - Converting the Recorded Diagram to the Hyetograph
  - Areal Mean Precipitation
  - Resultant Hyetograph
  - Depth-Area-Duration Curves
  - Intensity-Duration-Frequency Curves
- Rational Method
Measurement of Precipitation

Non-recording Rain Gauges

- **US Weather Bureau Type Rain Gauge**
  - When snow is expected, the receiver and measuring tube are removed and snow is collected in the overflow can. Then snow is melted and poured into the measuring tube for measurement.
Measurement of Precipitation

**Non-recording Rain Gauges**

- Hellmann type:
  - Diameter = 16 cm
  - Cross-sectional area = 200 cm²
  - Height = 44 cm
  - A copper or brass receiver is fitted over the top
  - Below the rim there is a collecting vessel with a capacity of 70 mm (1.4 lt)
  - A glass measuring tube is used to measure the height of the precipitation
Measurement of Precipitation

Recording Rain Gauges

- Beside the total amount, it is often necessary to know the intensity of precipitation.
- The most commonly used recording rain gauges:
  - Weighing Gauges
  - Tipping Bucket Gauges
  - Float-type Gauges
- The weighing type is used most often in Turkey.
2. PRECIPITATION

Measurement of Precipitation

Recording Rain Gauges

- Weighing Gauge

The slope of this graph at any time with respect to the horizontal axis gives intensity of the rainfall at that time.
Measurement of Precipitation

Recording Rain Gauges

- Weighing Gauge

  - Usually a daily chart is used for the diagrams, but for locations where access is not easy, weekly charts can also be used.
Measurement of Precipitation

- **Recording Rain Gauges**
- **Tipping Bucket Gauges**
  - It has simple, durable, and reliable mechanism.

As rain fills up one side of the tipping bucket, the weight of the water causes the “seesaw” to tip over and dump. The magnet on the tipper passes the stationary magnet, sending a current to the transmitter below.
Measurement of Precipitation

- Recording Rain Gauges
- Tipping Bucket Gauges
  - During snowfall a supplementary device is necessary to melt snow.
  - In intense rains water loss may occur while the bucket is tipping.
Measurement of Precipitation

- **Recording Rain Gauges**
  - **Float-type Gauge**
    - The most important drawback of this type of gauges lies in their operation at temperatures below the freezing point.
2. PRECIPITATION

Measurement of Precipitation

Recording Rain Gauges

- Wireless Rain Gauge with Temperature Display

Features:
- Self-emptying cable free rain collector
- Indoor thermometer
- Long range capability allows the canister to be placed up to 300 feet from the main unit
- Calendar alarm clock
- Provides cumulative & daily precipitation totals for up to nine days
- Total rainfall display with registered date
- Rainfall alarm
- Rainfall display in inches or millimeters
- ºF/ºC switch
- Min/max temperature
- 12 or 24 hour clock format
- 4-line LCD display
- Wall or table mount features

http://www.generaltools.com
2. PRECIPITATION

Measurement of Precipitation

Storage or Totalizer Gauges

- Used in mountainous regions or remote areas, which are not accessible during winter or where observers are not available.
- Large tanks collecting precipitation during a whole season.
- It is measured at the end of the season.
- Usually equipped with windshields
- Antifreeze is added to melt the snow.
- The solution is covered by some low-viscosity oil, which prevents evaporation but allows the passage of precipitation.
Measurement of Precipitation

Weather Radar

- Determination of areal extent, orientation, and movement of rainstorms in time.
- Radars operate by emitting a regular succession of pulses of electromagnetic radiation in a narrow beam from the antenna of the system.
- The return signals are transformed into a visual display on the radar scope (echo).
- The brightness of the echo is an indication for the intensity of the precipitation.

Overview

- Introduction
- Measurement of Precipitation
  - Non-recording Rain Gauges
  - Recording Rain Gauges
- Analysis of Precipitation
  - Converting the Recorded Diagram to the Hyetograph
  - Areal Mean Precipitation
  - Resultant Hyetograph
  - Depth-Area-Duration Curves
  - Intensity-Duration-Frequency Curves
- Rational Method
Analysis of Precipitation

- Precipitation data consists of the following three categories:
  - Daily total precipitation depths, obtained from non-recording gauges.
  - Recorded diagrams of cumulative precipitation with respect to time, obtained from recording gauges.
  - Seasonal total depths or recorded diagrams obtained from storage gauges.
- These data are used to determine the time and the areal variation as well as the frequency of precipitation.
Analysis of Precipitation

Converting the Recorded Diagram to the Hyetograph

- Before hyrograph analysis, the diagrams obtained from recording gauges need to be converted into hyetograph.
- Hyetograph → (intensity vs time diagram)
- For this purpose:
  1. The recorded diagram is approximated by linear segments
Analysis of Precipitation

Converting the Recorded Diagram to the Hyetograph

For this purpose:

2. The slope of each segment found as shown in the table

Table: Determination of Hyetograph

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Σ Depth (mm)</th>
<th>Δt (min)</th>
<th>Δd (mm)</th>
<th>Intensity (mm/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_0$</td>
<td>$d_0$</td>
<td>$\Delta t_1=t_1-t_0$</td>
<td>$\Delta d_1=d_1-d_0$</td>
<td>$i_1=(\Delta d_1/\Delta t_1) \times 60$</td>
</tr>
<tr>
<td>$t_1$</td>
<td>$d_1$</td>
<td>$\Delta t_2=t_2-t_1$</td>
<td>$\Delta d_2=d_2-d_1$</td>
<td>$i_2=(\Delta d_2/\Delta t_2) \times 60$</td>
</tr>
<tr>
<td>$t_2$</td>
<td>$d_2$</td>
<td>$\Delta t_3=t_3-t_2$</td>
<td>$\Delta d_3=d_3-d_2$</td>
<td>$i_3=(\Delta d_3/\Delta t_3) \times 60$</td>
</tr>
<tr>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
</tr>
<tr>
<td>$t_{n-1}$</td>
<td>$d_{n-1}$</td>
<td>$\Delta t_n=t_n-t_{n-1}$</td>
<td>$\Delta d_n=d_n-d_{n-1}$</td>
<td>$i_n=(\Delta d_n/\Delta t_n) \times 60$</td>
</tr>
<tr>
<td>$t_n$</td>
<td>$d_n$</td>
<td>$\Delta t_{n+1}=t_{n+1}-t_n$</td>
<td>$\Delta d_{n+1}=d_{n+1}-d_n$</td>
<td>$i_{n+1}=(\Delta d_{n+1}/\Delta t_{n+1}) \times 60$</td>
</tr>
</tbody>
</table>
Analysis of Precipitation

Converting the Recorded Diagram to the Hyetograph

For this purpose:

3. Then intensities are plotted with respect to time as shown in the figure.
Analysis of Precipitation

Converting the Recorded Diagram to the Hyetograph

Example

The cumulative depth diagram of a storm obtained from a recording raingauge is given in the figure. Obtain the corresponding hyetograph for this storm.
Analysis of Precipitation

Converting the Recorded Diagram to the Hyetograph

Example - Solution

The cumulative depth diagram is approximated by straight line segments as shown in the figure with dotted lines.
2. PRECIPITATION

Analysis of Precipitation

Converting the Recorded Diagram to the Hyetograph

Example – Solution:
The slope of each segment gives the rainfall intensity for that period

<table>
<thead>
<tr>
<th>Time (hr)</th>
<th>Σ Depth (mm)</th>
<th>Δt (hr)</th>
<th>Δd (mm)</th>
<th>Intensity (mm/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>10</td>
<td>1</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>2</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>1</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>50</td>
<td>2</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>60</td>
<td>3</td>
<td>10</td>
<td>3.3</td>
</tr>
<tr>
<td>11</td>
<td>70</td>
<td>2</td>
<td>10</td>
<td>5</td>
</tr>
</tbody>
</table>
2. PRECIPITATION

Analysis of Precipitation

Areal Mean Precipitation

- Data gathered at precipitation gauges → Point Values
- Areal mean values are necessary in most hydrologic studies.
- To calculate the mean rainfall on an area (basin)
  - The Arithmetic Mean Method
  - The Theissen Polygons Method
  - The Isohyetal Map Method
Analysis of Precipitation

Areal Mean Precipitation

1. **The Arithmetic Mean Method**

\[
P_{\text{ave}} = \frac{\sum P_i}{n}
\]

where

- \(P_{\text{ave}}\): the areal mean precipitation,
- \(P_i\): rainfall observed at the \(i\)th station inside the basin,
- \(n\): the number of inside stations
Analysis of Precipitation

Areal Mean Precipitation

2. The Thiessen Polygons Method

Each point location in the watershed is assigned a precipitation equal to that of the closest gauge.

If $A_i$ is area assigned to station $i$, then areal precipitation can be estimated as

$$\overline{P}_{ave} = \sum_{i=1}^{m} \frac{A_i}{A} P_i$$

where

- $P_{ave}$: the areal mean precipitation,
- $P_i$: rainfall observed at the $i^{th}$ station inside or outside the basin,
- $A_i$: in-region portion of the area of the polygon surrounding the $i^{th}$ station,
- $m$: the number of area
Analysis of Precipitation

Areal Mean Precipitation

2. The Thiessen Polygons Method
Analysis of Precipitation

Areal Mean Precipitation

2. The Thiessen Polygons Method
2. PRECIPITATION

Analysis of Precipitation

Areal Mean Precipitation

2. The Thiessen Polygons Method

\[ \overline{P}_{ave} = \sum_{i=1}^{m} \frac{A_i}{A} P_i \]
2. PRECIPITATION

Analysis of Precipitation

Areal Mean Precipitation

3. The Isohyetal Map Method

Each point location in the watershed is assigned a precipitation equal to that of the closest gauge.

If \( A_i \) is area assigned to station \( i \), then areal precipitation can be estimated as

\[
\overline{P_{\text{ave}}} = \sum_{i=1}^{m} \frac{A_i}{A} P_i
\]

where

\( P_{\text{ave}} \): the areal mean precipitation,

\( P_i \): rainfall observed at the \( i^{\text{th}} \) station inside or outside the basin,

\( A_i \): in-region portion of the area of the polygon surrounding the \( i^{\text{th}} \) station,

\( m \): the number of area
Analysis of Precipitation

Areal Mean Precipitation

3. The Isohyetal Map Method
Analysis of Precipitation

Areal Mean Precipitation

3. The Isohyetal Map Method

\[
\overline{P}_{\text{ave}} = \sum_{i=1}^{m} \frac{P_i A_i}{A}
\]
Analysis of Precipitation

**Resultant Hyetograph**
- In hydrograph analysis, the variation of the areal mean precipitation over time is important.
- The mean hyetograph for a basin → resultant hyetograph.
- Resultant Hyetograph → by superposing the hyetographs in the stations and taking a suitable time interval such as minute, hour, or day.
- For superposition of hyetographs
  1. The Arithmetic Mean Method
  2. The Thiessen Polygon Method
Analysis of Precipitation

Resultant Hyetograph

1. The Arithmetic Mean Method
   - Only the inside stations are considered
   - The average intensity for each time interval is found by taking the arithmetic mean of the intensities observed in the stations for that time interval.

2. The Thiessen Polygons Method
   - All the stations inside and outside the basin are considered.
   - For any time interval, the observed intensities in that time interval are multiplied by the polygon areas of the corresponding stations and
   - the average intensity is found by dividing the sum of these products by the total area.
2. PRECIPITATION

Analysis of Precipitation

Resultant Hyetograph

Arithmetic mean method

\[ i_1 = \frac{(6.2 + 6.5 + 7.2 + 9.1)}{4} = 7.75 \text{ mm/hr} \]
\[ i_2 = \frac{(7.8 + 4.6 + 6.1 + 7.6)}{4} = 6.525 \text{ mm/hr} \]
\[ i_3 = \frac{(5.2 + 3.4 + 4.2 + 4.8)}{4} = 4.4 \text{ mm/hr} \]
Analysis of Precipitation

Resultant Hyetograph
Thiessen Polygons
Method
## Analysis of Precipitation

### Resultant Hyetograph

**Thiessen Polygons Method**

<table>
<thead>
<tr>
<th>Station</th>
<th>Area (km²)</th>
<th>Precipitation (mm)</th>
<th>Σa_i</th>
<th>p_i</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>486</td>
<td>6.1 4.9 3.7</td>
<td>2964.6</td>
<td>2381.4</td>
<td>1798.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>1890</td>
<td>8.2 7.8 5.2</td>
<td>15498.0</td>
<td>14742.0</td>
<td>9828.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>635</td>
<td>12.4 9.2 6.1</td>
<td>7874.0</td>
<td>5842.0</td>
<td>3873.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>158</td>
<td>8.4 6.3 4.3</td>
<td>1327.2</td>
<td>995.4</td>
<td>679.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>15</td>
<td>5.3 4.1 4.8</td>
<td>79.5</td>
<td>61.5</td>
<td>72.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>1680</td>
<td>6.5 4.6 3.4</td>
<td>10920.0</td>
<td>7728.0</td>
<td>5712.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>2901.5</td>
<td>7.2 6.1 4.2</td>
<td>20890.8</td>
<td>17699.2</td>
<td>12186.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>1815</td>
<td>9.1 7.6 4.8</td>
<td>16516.5</td>
<td>13794.0</td>
<td>8712.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>515.5</td>
<td>8.7 6.2 5.1</td>
<td>4484.9</td>
<td>3196.1</td>
<td>2629.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Σ</td>
<td>10096</td>
<td></td>
<td>80555.5</td>
<td>66439.6</td>
<td>45490.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Σa_i: Sum of areas

p_i: Precipitation at station i
Analysis of Precipitation

**Intensity-Duration-Frequency Curves**

- In general, the higher the intensity of the rainfall, the shorter the duration of it will be.
- The Intensity-Duration-Frequency curve is used in designing hydraulic structures.
Analysis of Precipitation

Intensity-Duration-Frequency Curves

- In Statistical distributions are used to find the relationship between the rainfall intensity and its duration and then the required frequency.
2. PRECIPITATION

Analysis of Precipitation

Intensity-Duration-Frequency Curves

- These curves are obtained by the statistical analysis of the maximum storm observed in the study area using long time series of rainfall data.
- They should be generated for all the areas or basins where small hydraulic structures are to be planned and constructed.
Analysis of Precipitation

Intensity-Duration-Frequency Curves

Intensity-Duration-Frequency curves for Ankara (on Semi-log scale)
Overview

- Introduction
- Measurement of Precipitation
  - Non-recording Rain Gauges
  - Recording Rain Gauges
- Analysis of Precipitation
  - Converting the Recorded Diagram to the Hyetograph
  - Areal Mean Precipitation
  - Resultant Hyetograph
  - Depth-Area-Duration Curves
  - Intensity-Duration-Frequency Curves
- Rational Method
Rational Method

- One of the oldest methods to relate rainfall on a basin to the corresponding runoff.
- It is mainly used to estimate the peak discharge from a basin or from a contributing area which is smaller than 100 km².
Rational Method

- Idea: If a rainfall of a certain intensity begins instantaneously and continues indefinitely, the rate of runoff will increase until the time of concentration, when the entire basin is contributing to flow at the outlet, then stays constant.

- The peak flow is

\[
Q_p = 0.278 \, C \, i \, A
\]

where

- \( Q_p \): the peak flow rate (m\(^3\)/s)
- \( C \): the runoff coefficient (dimensionless)
- \( i \): the average rainfall intensity (mm/hr), lasting for a critical period of time, \( t_c \).
- \( t_c \): the time of concentration (hr)
- \( A \): the drainage area (km\(^2\))
Rational Method

- The time of concentration, $t_c$, is defined as the time necessary for raindrops falling at the farthest point of the basin to flow to the outlet point.

- The intensity of rainfall, $i$, is assumed to be constant during concentration time, $t_c$, and the peak flow $Q_p$ occurs after the period $t_c$. 

![Diagram of a basin with runoff paths](image)
Rational Method

- The effect of rainfall duration, $t_d$, compared to the time of concentration $t_c$ is explained below.

**Case 1** ($t_d < t_c$)  **Case 2** ($t_d = t_c$)  **Case 3** ($t_d > t_c$)

$q_p$: max discharge  
$Q_p$: Basin max discharge

Peak discharges for different rainfall durations
## Rational Method

### Typical C Coefficients for Design with 5 to 10-yr Frequencies (ASCE, 1970)*

<table>
<thead>
<tr>
<th>Description of area</th>
<th>Runoff coefficient</th>
<th>Description of area</th>
<th>Runoff coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business</td>
<td></td>
<td>Streets</td>
<td></td>
</tr>
<tr>
<td>Downtown areas</td>
<td>0.70 – 0.95</td>
<td>Asphalt</td>
<td>0.70 – 0.95</td>
</tr>
<tr>
<td>Neighborhood areas</td>
<td>0.50 – 0.70</td>
<td>Concrete</td>
<td>0.80 – 0.95</td>
</tr>
<tr>
<td>Residential</td>
<td></td>
<td>Brick</td>
<td>0.70 – 0.85</td>
</tr>
<tr>
<td>Single-family areas</td>
<td>0.30 – 0.50</td>
<td>Drives and walks</td>
<td>0.75 – 0.85</td>
</tr>
<tr>
<td>Multiunits, detached</td>
<td>0.40 – 0.60</td>
<td>Roof</td>
<td>0.75 – 0.95</td>
</tr>
<tr>
<td>Multiunits, attached</td>
<td>0.60 – 0.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential (suburban)</td>
<td>0.25 – 0.40</td>
<td>Lawns; Sandy soil:</td>
<td></td>
</tr>
<tr>
<td>Apartment dwelling areas</td>
<td>0.50 – 0.70</td>
<td>Flat, 2%</td>
<td>0.05 – 0.10</td>
</tr>
<tr>
<td>Industrial</td>
<td></td>
<td>Average, 2-7%</td>
<td>0.10 – 0.15</td>
</tr>
<tr>
<td>Light areas</td>
<td>0.50 – 0.80</td>
<td>Steep, 7%</td>
<td>0.15 – 0.20</td>
</tr>
<tr>
<td>Heavy areas</td>
<td>0.60 – 0.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Railroad yard areas</td>
<td>0.20 – 0.40</td>
<td>Lawns; Heavy soil:</td>
<td></td>
</tr>
<tr>
<td>Parks and cemeteries</td>
<td>0.10 – 0.25</td>
<td>Flat, 2%</td>
<td>0.13 – 0.17</td>
</tr>
<tr>
<td>Playgrounds</td>
<td>0.20 – 0.35</td>
<td>Average, 2-7%</td>
<td>0.18 – 0.22</td>
</tr>
<tr>
<td>Unimproved areas</td>
<td>0.10 – 0.30</td>
<td>Steep, 7%</td>
<td>0.25 – 0.35</td>
</tr>
</tbody>
</table>

*For 25 and 100 year frequencies, multiply by 1.1 and 1.25 respectively (product cannot exceed 1.0)
Rational Method

- In urban areas, the drainage area usually consists of subareas or subbasins of different surface characteristics.
- If the area of subbasins are denoted by \( A_j \) and the runoff coefficients of each subbasin are denoted by \( C_j \) for \( j=1, 2, \ldots n \)
- The peak runoff is

\[
Q_p = 0.278 i \sum_{j=1}^{n} C_j A_j
\]
Rational Method

The following steps are utilized in the application of the Rational formula for the determination of peak flow.

1. Estimation of the time of concentration of the drainage area, \( t_c \).
2. Estimation of the runoff coefficient, \( C \).
3. Selection of the return period (frequency) \( T_r \), and finding the intensity of rain that will be equaled or exceeded on the average, once every \( T_r \) years. To produce equilibrium flows, this design storm must have a duration equal to \( t_c \) or longer. The desired intensity can be found from the Intensity-Duration-Frequency (IDF) curves of that region using a rainfall duration equal to the time of concentration.
4. Determination of the desired peak flow \( Q_p \).