Precipitation

Conditions:
1. A humid air mass must be cooled to the dew point temperature
2. Condensation or freezing nuclei must be present
3. Droplets must coalesce to form raindrops
4. Large enough raindrops
Measurement of Precipitation

U.S. Standard gage, 8”

**Manual** — read once daily
- wind effects
- should be placed close to earth in the open
- opening parallel to surface

**Automatic**
- → temporal distribution
- U.S. has 13,500 stations

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**Tipping bucket rain gauge**

- A funnel collects and channels precipitation into a small seesaw-like container.
- amount of precipitation is set
- After that amount falls, the lever tips, dumping the collected water and sending an electrical signal.
- Can incorporate weighing gauges.
- Exact rainfall can be read at any moment.
- When collector tips, the gauge is re-zeroed.
- Can sent signal to a remote location
Radars

Rain reflects part of radar beam
reflection intensity ~ rain intensity
Can be integrated

Missing data
Estimated value at point 2:

\[
P_2 = \frac{1}{3} \left[ \frac{N_2}{N_A} P_A + \frac{N_2}{N_B} P_B + \frac{N_2}{N_C} P_C \right]
\]

N = annual values
P_A, P_B, and P_C = actual (available) values
Effective depth of precipitation = Effective Uniform Depth (EDU)
“average” rainfall value over watershed
Needed for water budget

Estimating EUD
- Generally uniform rain density
  - EUD = arithmetic average
- Non uniform rain density
  1. Thiessen Method
     Based on a weighting factor for each gage
  2. Create contour map (lines of equal rainfall = Isohyets)
     Based on relative size of each isohyets area
     Need to be done for each analysis
     (both need to estimate sub areas, e.g., by using planimeters)
Arithmetic Mean Method

- Simplest method for determining areal average

\[ \bar{P} = \frac{1}{N} \sum_{i=1}^{N} P_i \]

\[ \bar{P} = \frac{10 + 20 + 30}{3} = 20 \text{ mm} \]

- Gages must be uniformly distributed
- Gage measurements should not vary greatly about the mean

Thiessen polygon method

- Steps
  1. Draw lines joining adjacent gages
  2. Draw perpendicular bisectors to the lines created in step 1
  3. Extend the lines created in step 2 in both directions to form representative areas for gages
  4. Compute representative area for each gage
  5. Compute the areal average using the following formula

\[ \bar{P} = \frac{1}{A} \sum_{i=1}^{N} A_i P_i \]

\[ \bar{P} = \frac{12 \times 10 + 15 \times 20 + 20 \times 30}{47} = 20.7 \text{ mm} \]

P1 = 10 mm, A1 = 12 km²
P2 = 20 mm, A2 = 15 km²
P3 = 30 mm, A3 = 20 km²
Isohyetal method

- Steps
  - Construct isohyets (rainfall contours)
  - Compute area between each pair of adjacent isohyets ($A_i$)
  - Compute average precipitation for each pair of adjacent isohyets ($p_i$)
  - Compute areal average using the following formula

$$\bar{P} = \frac{1}{N} \sum_{i=1}^{N} A_i p_i$$

$$\bar{P} = \frac{5 \times 5 + 18 \times 15 + 12 \times 25 + 12 \times 35}{47} = 21.6 \text{ mm}$$

Example

Drainage basin with seven stations in its boundaries. An additional six stations are located outside the drainage divide.
Arithmetic Mean Method

In the arithmetic mean method, only the gages inside the drainage basin boundary are considered.

Arithmetic mean

\[
= \frac{1.03 + 0.65 + 1.46 + 1.75 + 4.81 + 3.45 + 5.76}{7}
\]

\[
= 2.70 \text{ in.}
\]

**Thiessen polygon method**

A. The stations are connected with lines.

B. The perpendicular bisector of each line is found.

C. The bisectors are extended to form the polygons around each station.

**Figure 2.7** Thiessen polygons based on the rain-gage network of Figure 2.5. A. The stations are connected with lines. B. The perpendicular bisector of each line is found. C. The bisectors are extended to form the polygons around each station.
<table>
<thead>
<tr>
<th>A</th>
<th>Station Precipitation (in.)</th>
<th>B</th>
<th>Net Area (sq mi)</th>
<th>C</th>
<th>Percent of Total Area</th>
<th>D</th>
<th>Weighted Precipitation (in.) (A x C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.76</td>
<td>5.76</td>
<td>16.9</td>
<td>11.9</td>
<td>0.686</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.81</td>
<td>16.1</td>
<td>4.11</td>
<td>3.4</td>
<td>0.546</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.86</td>
<td>1.6</td>
<td>3.45</td>
<td>19.3</td>
<td>0.044</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.89</td>
<td>2.5</td>
<td>1.75</td>
<td>12.0</td>
<td>0.470</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.46</td>
<td>19.8</td>
<td>1.03</td>
<td>18.0</td>
<td>0.033</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.65</td>
<td>17.0</td>
<td>0.21</td>
<td>7.2</td>
<td>0.012</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.46</td>
<td>6.0</td>
<td>0.09</td>
<td>2.0</td>
<td>0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>141.8 sq mi</td>
<td>141.8 sq mi</td>
<td>2.47 in. NET EUD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Isohyetal method**

Isohyetal lines show contours of equal rainfall depth within a contour interval of 0.5 in. The contours are based on simple linear interpolation.
<table>
<thead>
<tr>
<th>Isohyet (in.)</th>
<th>B Estimated EUD</th>
<th>C Net Area (sq mi)</th>
<th>D Percent of Total Area</th>
<th>E Weighted Precipitation (in.) (B x D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.5+</td>
<td>5.6</td>
<td>1.1</td>
<td>0.8</td>
<td>0.045</td>
</tr>
<tr>
<td>5.0 – 5.5</td>
<td>5.25</td>
<td>5.6</td>
<td>7.6</td>
<td>0.078</td>
</tr>
<tr>
<td>4.5 – 5.0</td>
<td>4.75</td>
<td>10.6</td>
<td>7.4</td>
<td>0.352</td>
</tr>
<tr>
<td>4.0 – 4.5</td>
<td>4.25</td>
<td>9.5</td>
<td>6.7</td>
<td>0.285</td>
</tr>
<tr>
<td>3.5 – 4.0</td>
<td>3.75</td>
<td>8.6</td>
<td>6.0</td>
<td>0.225</td>
</tr>
<tr>
<td>3.0 – 3.5</td>
<td>3.25</td>
<td>8.3</td>
<td>5.8</td>
<td>0.189</td>
</tr>
<tr>
<td>2.5 – 3.0</td>
<td>2.75</td>
<td>10.7</td>
<td>7.5</td>
<td>0.206</td>
</tr>
<tr>
<td>2.0 – 2.5</td>
<td>2.25</td>
<td>12.3</td>
<td>8.6</td>
<td>0.194</td>
</tr>
<tr>
<td>1.5 – 2.0</td>
<td>1.75</td>
<td>15.1</td>
<td>10.6</td>
<td>0.186</td>
</tr>
<tr>
<td>1.0 – 1.5</td>
<td>1.25</td>
<td>23.8</td>
<td>16.7</td>
<td>0.209</td>
</tr>
<tr>
<td>0.5 – 1.0</td>
<td>0.75</td>
<td>31.2</td>
<td>21.8</td>
<td>0.164</td>
</tr>
<tr>
<td>&lt;0.5</td>
<td>0.3</td>
<td>4.0</td>
<td>2.8</td>
<td>0.008</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>142.8 sq mi</td>
<td></td>
<td>2.34 in. NET EUD</td>
</tr>
</tbody>
</table>

Mean Annual Rainfall
Island of O‘ahu

2011 Rainfall Atlas of Hawai‘i
Department of Geography
University of Hawai‘i at Mānoa

Annual Rainfall O‘ahu

- 0-250 mm
- 251-500 mm
- 501-750 mm
- 751-1000 mm
- 1001-1250 mm
- 1251-1500 mm
- 1501-1750 mm
- 1751-2000 mm
- 2001-2250 mm
- 2251-2500 mm
- 2501-2750 mm
- 2751-3000 mm
- 3001-3250 mm
- 3251-3500 mm
- 3501-3750 mm
- 3751-4000 mm
- 4001-4250 mm
- 4251-4500 mm
- 4501-4750 mm
- 4751-5000 mm
- 5001-5250 mm
- 5251-5500 mm
- 5501-5750 mm
- 5751-6000 mm

Mean Annual Precipitation (mm)
Rainfall patterns in the US

Global precipitation pattern
Incremental Rainfall

Rainfall Hyetograph

Runoff & Streamflow

Events during precipitation
(1) Interception  8-35%
(2) Stem Flow
(3) Infiltration
Infiltration capacity ≡
capacity to absorb water
\( f_c \) ≡ equilibrium capacity
\( f_p = f_p(t) \)
\( f_o \) = initial capacity

\[ f_p = f_c e^{kt} \]
Relationship of infiltration capacity and precipitation rate:

A. Precipitation rate less than equilibrium infiltration capacity.

B. Precipitation rate greater than equilibrium infiltration capacity but less than initial infiltration capacity.

C. Precipitation rate greater than initial infiltration capacity.
(4) Depression storage
(puddles)

(5) Overland flow
If rainfall exceeds infiltration capacity

Storm (stream) flow hydrograph

• Hypothetical storm hydrograph for a period of evenly distributed precipitation, separated into Horton overland flow, direct precipitation, and interflow.
Hydrograph Separation
Baseflow recession
\[ Q = Q_0 e^{-at} \]
Effect of flood state on the ground-water regime adjacent to the river. As the flood peak passes, the normal direction of ground-water flow into the stream is reversed.

Induced streambed infiltration caused by a pumping well.
River duration curve

Rank values
Rank m: from greatest to lowest

\[ P = \frac{m}{n+1} \times 100 \]

Probability that certain value will be exceeded.

Measurement of Streamflow

\[ Q = VA \]

\[ V = \text{average velocity} \]
\[ A = \text{cross sectional area} \]
\[ V \equiv \text{measured by a current meter} \]
Current-meter discharge measurements are made by determining the discharge in each subsection of a channel cross section and summing the subsection discharges to obtain a total discharge.

Stream rating curve
**Weirs**

$$Q = \frac{10}{3} (L - 0.2H)H^{3/2}$$

$$Q = 2.5H^{5/2}$$

ft – sec units

**Manning equation: Average stream velocity**

$$V = \frac{1.49R^{2/3}S^{1/2}}{n}$$

ft – sec units

$$R = \frac{\text{Area}}{\text{wetted perimeter}}$$

$R = \text{hydraulic radius}$

$S = \text{slope of water surface}$

$n = \text{manning roughness coefficient}$

$\approx 0.012 \quad \rightarrow \quad 0.05$

smooth concrete \quad mountain streams