Engineering Hydrology

Week-2

Lecture-2 Hydrology and its Measurement

Sisay Demeku Derib (PhD, PE)
Sisay.demeku@aastu.edu.et
Addis Ababa Science and Technology University (AASTU),
Department of Civil Engineering
February, 2025

Lecture contents of the last week (Week-1)

- Course outline
- Pre-requisite courses
- Basic concepts on Engineering Hydrology
- Hydrologic Cycle
- The Hydrology of Ethiopia

Home assignment:

Try to do on your exercise book and to internalize by self study:

1. Define the word “Hydrology” and “Engineering Hydrology”
2. Sketch the systematic representation of hydrologic or water balance, label the components and describe what water balance mean for your sketch.
3. Consider the **case around** (Ethiopia) and identify hydrology based on:
   a) **Elevation**
   b) **Drainage basin**
   c) Surface **water** and **irrigable land distribution**
   d) **High and low annual rainfall area**
   e) Water distribution with respect to **inland and transboundary** drainage basin
   f) **Water development** and water **diplomacy**

Lecture contents of the week (Week-2)

CHAPTER 1: Hydrology and its Measurement

1.1 Hydrologic balance and the water cycle

1.2. Meteorological data

1.3 Principle of data analysis

1.4 Hydrological data

1.5 Filling missing data

Lecture Learning Outcomes

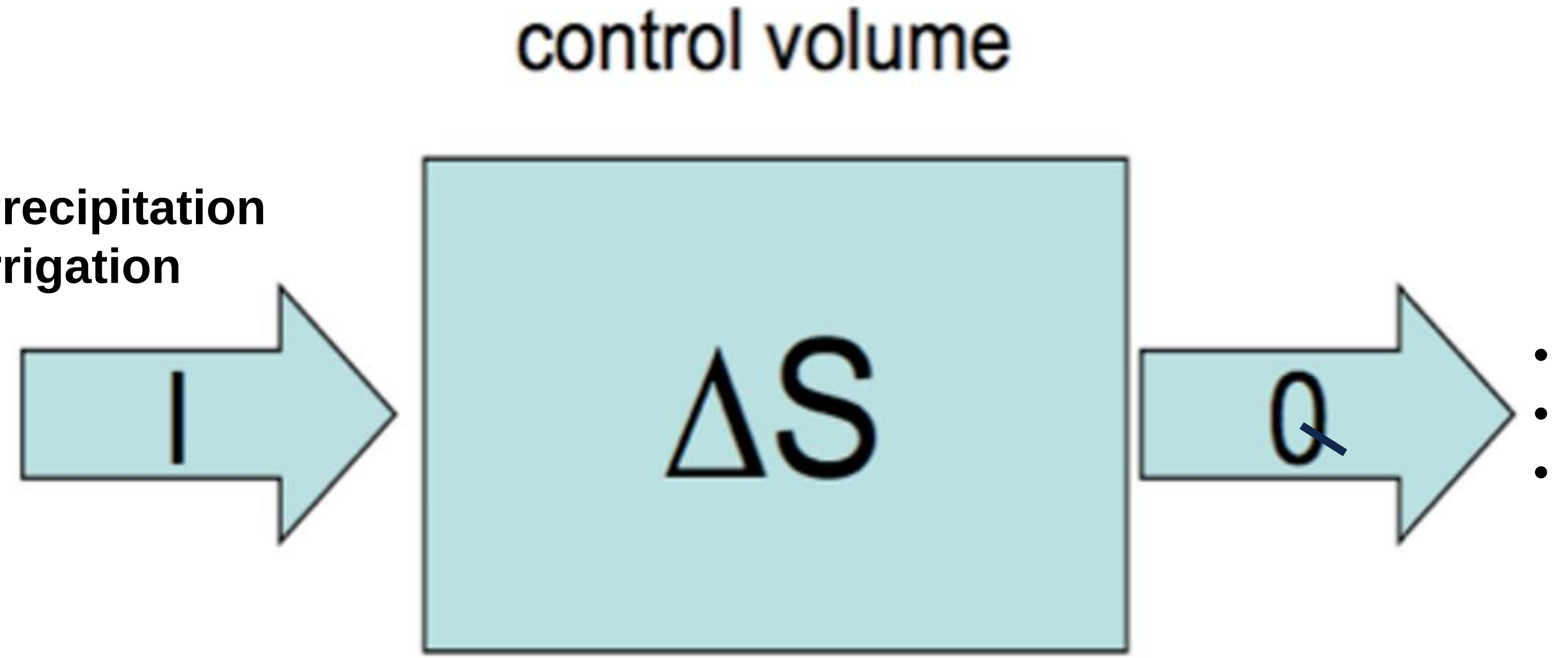
Course Learning Outcomes: After completion of this lecture, you will be able to:

CLO-1: Apply measurement techniques of the components of the hydrologic cycle, water balance and filling of missed data;

- Identify components of the hydrologic balance
- Describe types and measurements of meteorological and hydrological data
- Analyze hydrological data and
- Fill missing data

CLO-2: Examine rainfall-runoff relationship and hydrograph;
CLO-3: Examine the probability of occurrence;
CLO-4: Analyze the water movement in to, over, and through the soil surface;
CLO-5: Design capacity of reservoir;
CLO-6: Design runoff volume and time of distribution of the runoff hydrograph from urbanization effect.

Water Balance



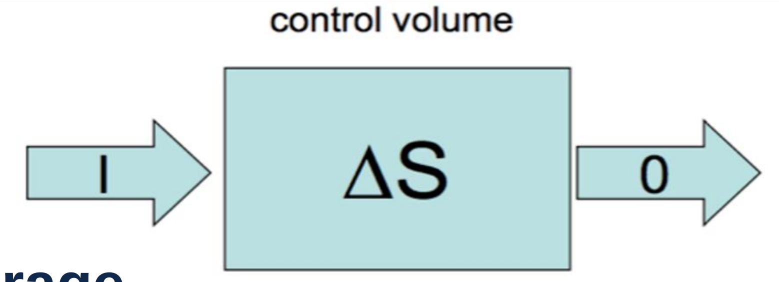
- Precipitation
- Irrigation

- Evaporation
- Transpiration
- Infiltration

- Storages
- Canal segment
- Stream/river reach

Water Balance

- **Mathematically,** $I - Q = \Delta S/\Delta t$
- **or** $I - Q = \frac{dS}{dt}$



***where*, I = inflow**

Q = outflow

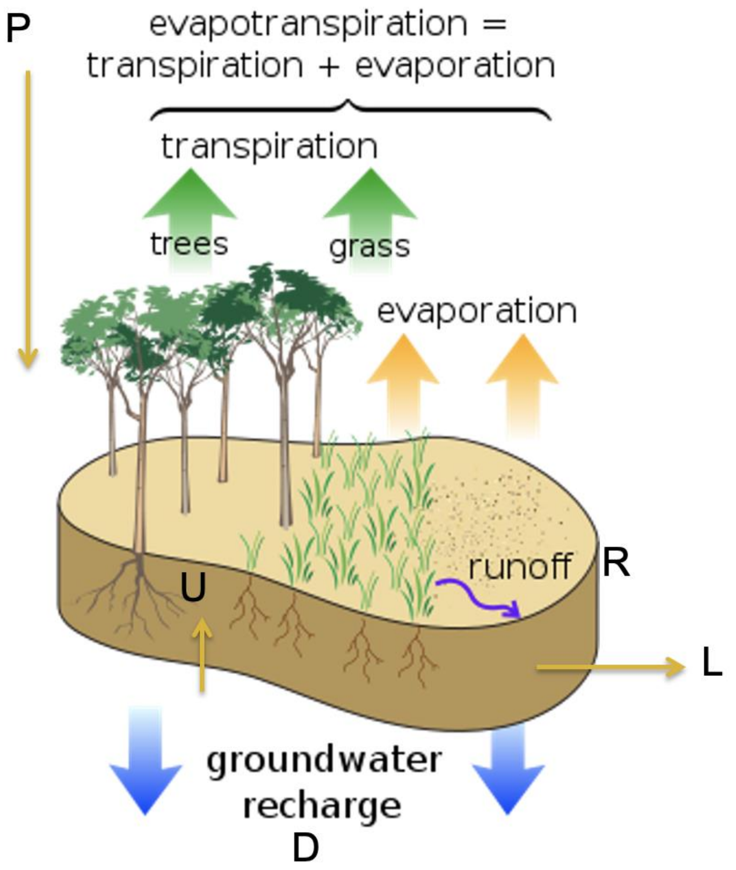
$\frac{dS}{dt}$ **= change in storage**

- The first two parameters depends on the control volume within the time scale selected**.**
  - **Eg. P, I, ET, surface and subsurface flows, groundwater flows**
- The storage parameter may be storages like **reservoir, soil, canal, atmosphere**
- The time scale may be **hourly, daily, monthly or annual.**

Different possible control volumes:

1. Soil/ land/ irrigation field
2. Lake or reservoir
3. River segment
4. Catchment or basin or watershed

Water Balance: Soil/ land/ irrigation field



P = precipitation

I = Irrigation inputs (*optional*)

U = Upward capillary flow

E = Evaporation

T = Transpiration

R = Runoff

D = Drainage to groundwater

L = Lateral groundwater flow

S = Storage (at any given time)

One can formulate the water balance equation, over a time increment, as:

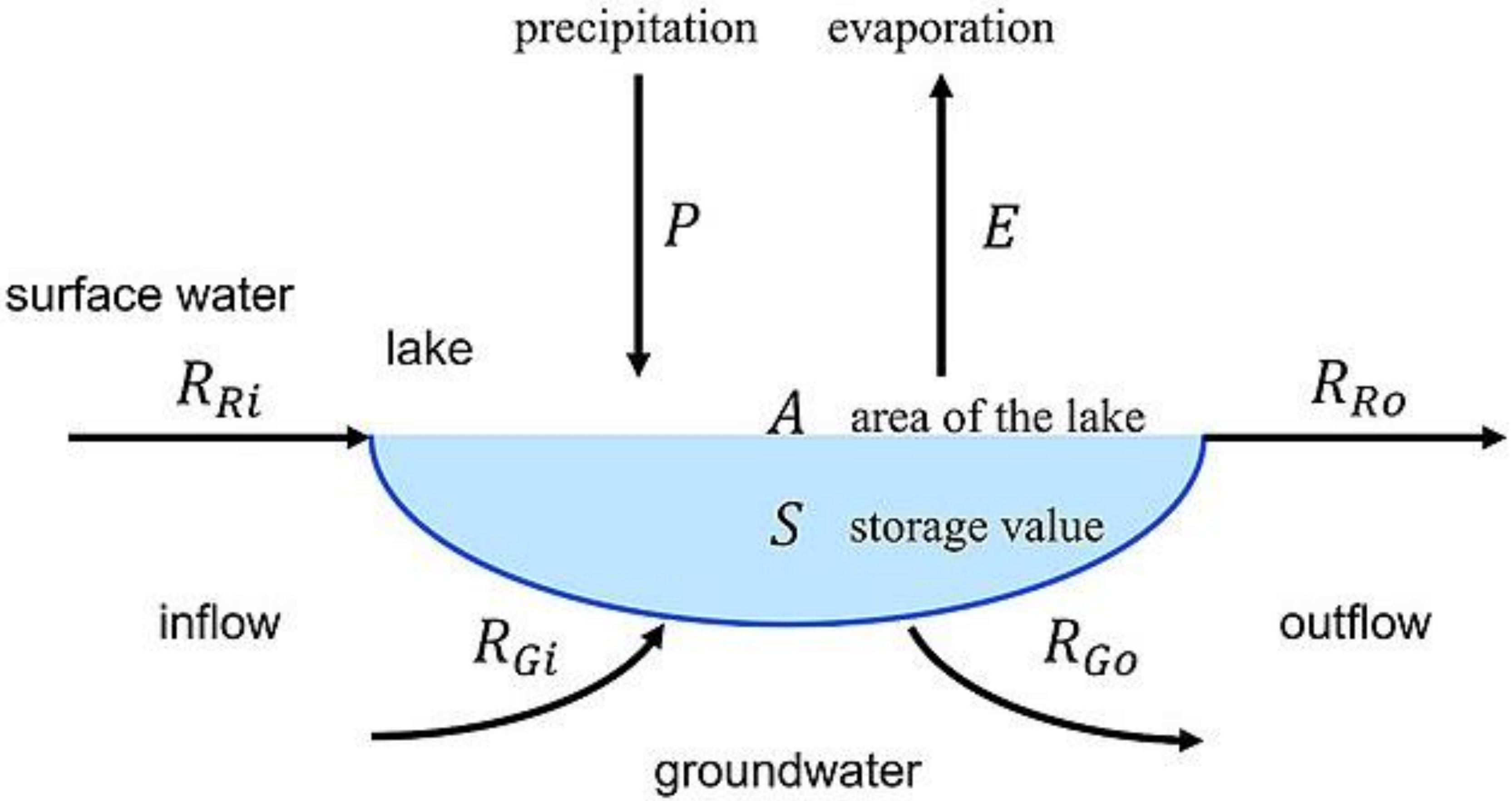
$$(\boldsymbol{P} + \boldsymbol{I} + \boldsymbol{U}) - (\boldsymbol{ET} + \boldsymbol{R} + \boldsymbol{D} + \boldsymbol{L}) = \boldsymbol{\Delta S}$$

where:

- ET = evapotranspiration
- ΔS = change in soil water storage

[1] Web-based "workbook": https://aquaticecodynamics.github.io/hydrology-workbook/

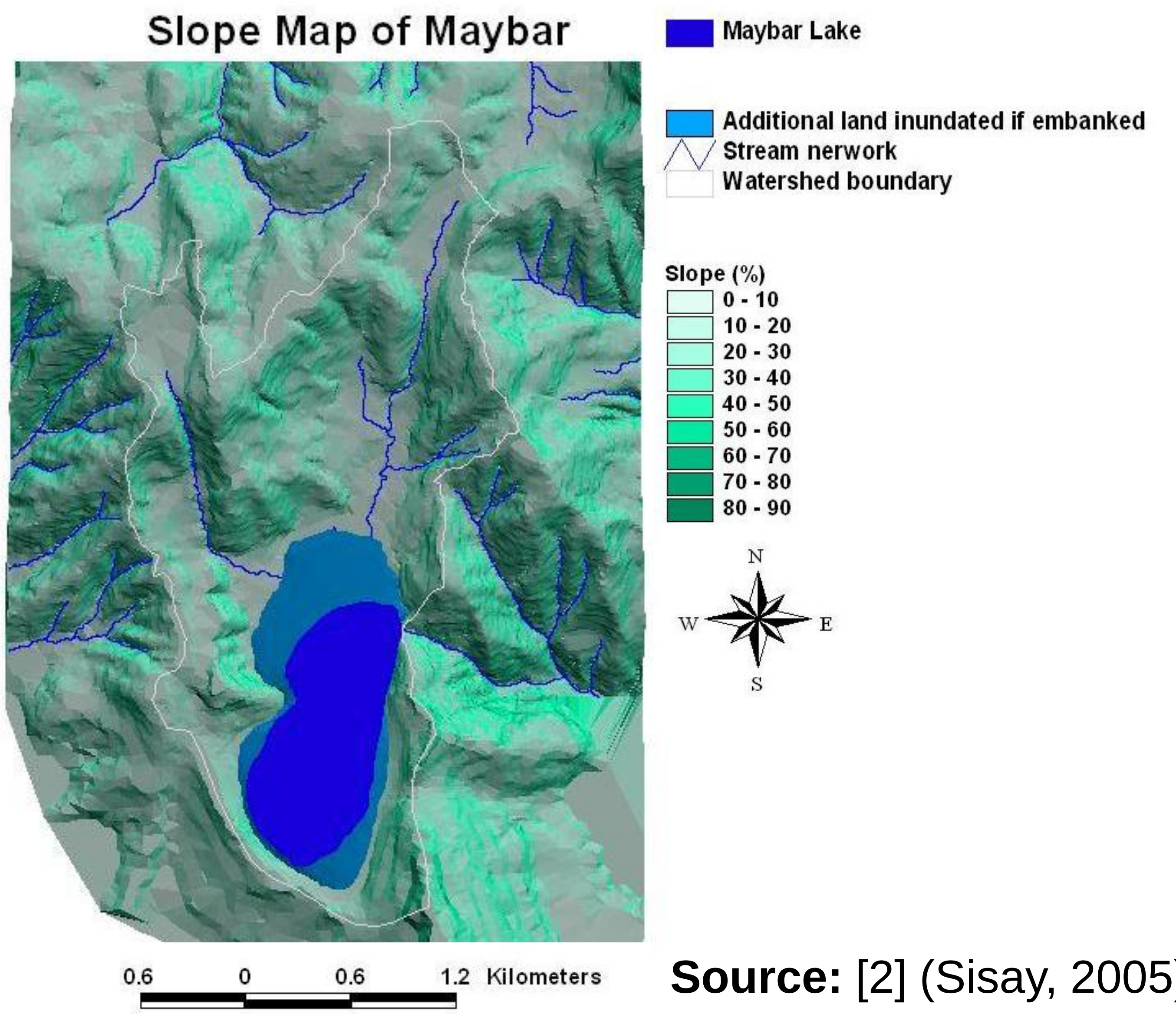
Water Balance : Lake/reservoir



$$\frac{dS}{dt} = (P - E)A + (R_{Ri} - R_{Ro}) + (R_{Gi} - R_{Go})$$

https://commons.wikimedia.org/wiki/File:Water_balance_lake.jpg

Water Balance : Lake/reservoir



Source: [2] (Sisay, 2005)

Example-1: Lake Mybar, 20 km away Dessie Town, had a water surface elevation of **2465 m** above a datum at the beginning of July. The lake received an average inflow of **6 m³/s** from surface runoff, and released **6.5 m³/s** out to *Borkena* River. It received **145 mm** rainfall and released evaporation loss of **0.2 cm/day** from lake surface within the same month. The net groundwater contribution for the lake is **+2 m³/hr**. The average lake surface area of the lake was **58ha** within the month.

1. Write water budget equation for the lake,
2. Calculate the water surface elevation of the lake at the end of the month.

Water Balance

Given:

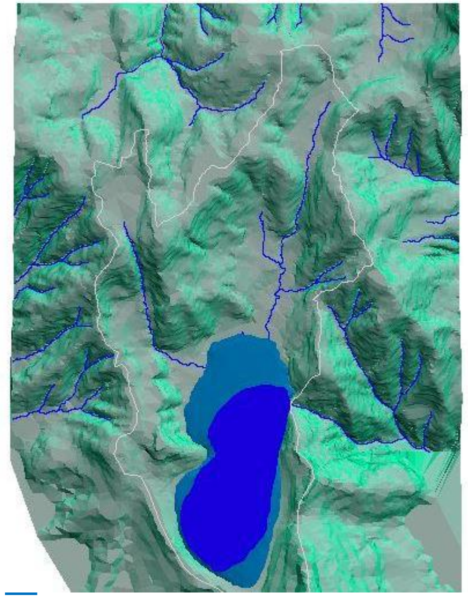
Control volume: Lake Mybar, Δt=1 month, 30 days,

A_L=58 ha $= 58\ ha * \frac{10{,}000\ m^2}{1ha}$ =**580,000 m^2**

- E_i=2465 m asl

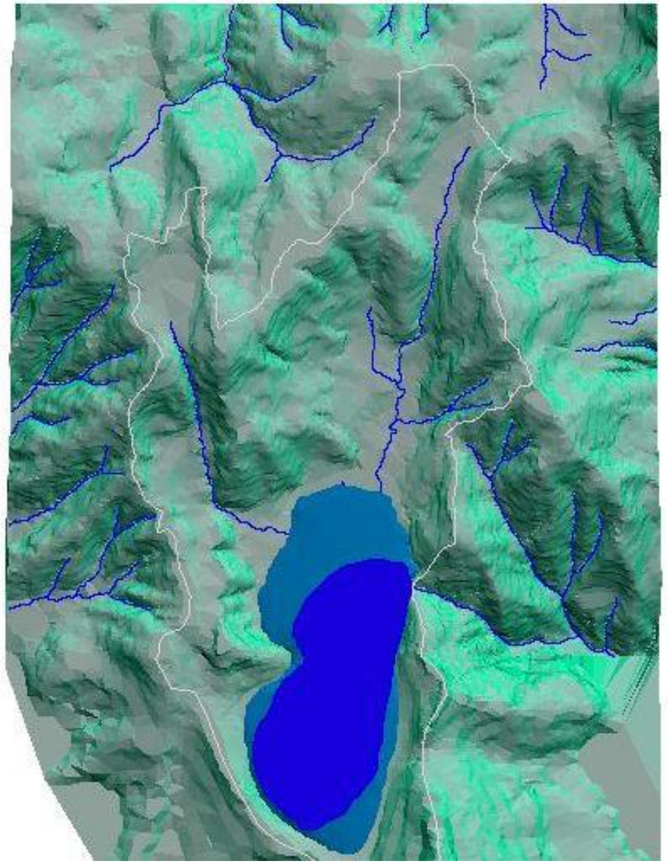
- **Water in**: I_T
  - **Q_i**= 6 m^3/s, , $Q_i = \frac{6\ m^3/s}{580{,}000\ m^2} * \frac{60s}{1min} * \frac{60min}{1hr} * \frac{24hr}{1day} * \frac{30days}{1month}$ = **26.8 m/month -#**
  - RF=145 mm/month, $\boldsymbol{RF = 145mm/month * \frac{1m}{1000mm}/month =}$ **0.145 m/month --- #**
  - **G_W**=+ 2 m^3/hr, $G_W = \frac{2\ m^3/hr}{580{,}000\ m^2} * \frac{24hr}{1day} * \frac{30days}{1month}$ = 0.0025 **m/month ----#**

Slope Map of Maybar



NB: Changing units of all water balance components to m/month is crucial.

Water Balance



Given:

Water out: Q_T

Q_o=6.5 m^3/s,

$$Q_o = \frac{6.5\ m^3/s}{580{,}000\ m^2} * \frac{60s}{1min} * \frac{60min}{1hr} * \frac{24hr}{1day} * \frac{30days}{1month} = \textbf{29 m/month ---- \#}$$

E=0.2 cm/day,

$$E = 0.2\frac{cm}{day} * \frac{1m}{100cm} * \frac{30days}{1month} = \mathbf{0.06\ m/month\ ---\ \#}$$

Required:

1. Water budget equation
2. $\boldsymbol{\Delta S}$ (in elevation of the surface level (m) above sea level)

Water Balance

Solution:

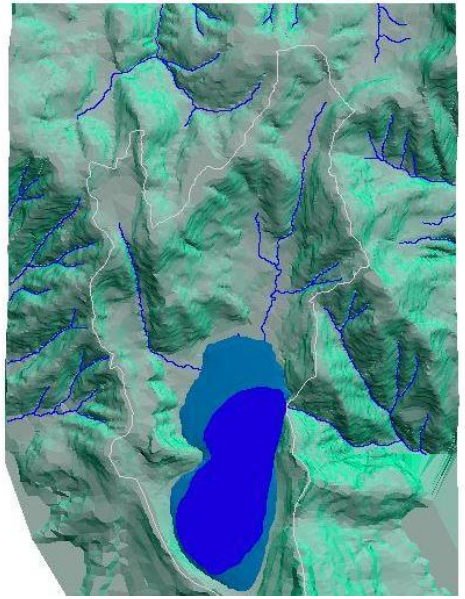
1. I(m/month) – Q(m/month) = ΔS/month, $(Q_i+RF+G_W)-(Q_0+E)=\Delta S$/month

   - ΔS=[(26.8+ 0.145 + 0.0025) –(29 + 0.06) m/month
   - ΔS=[26.9475-29.06] m/month
   - **ΔS=-2.1125 m/month ---#**

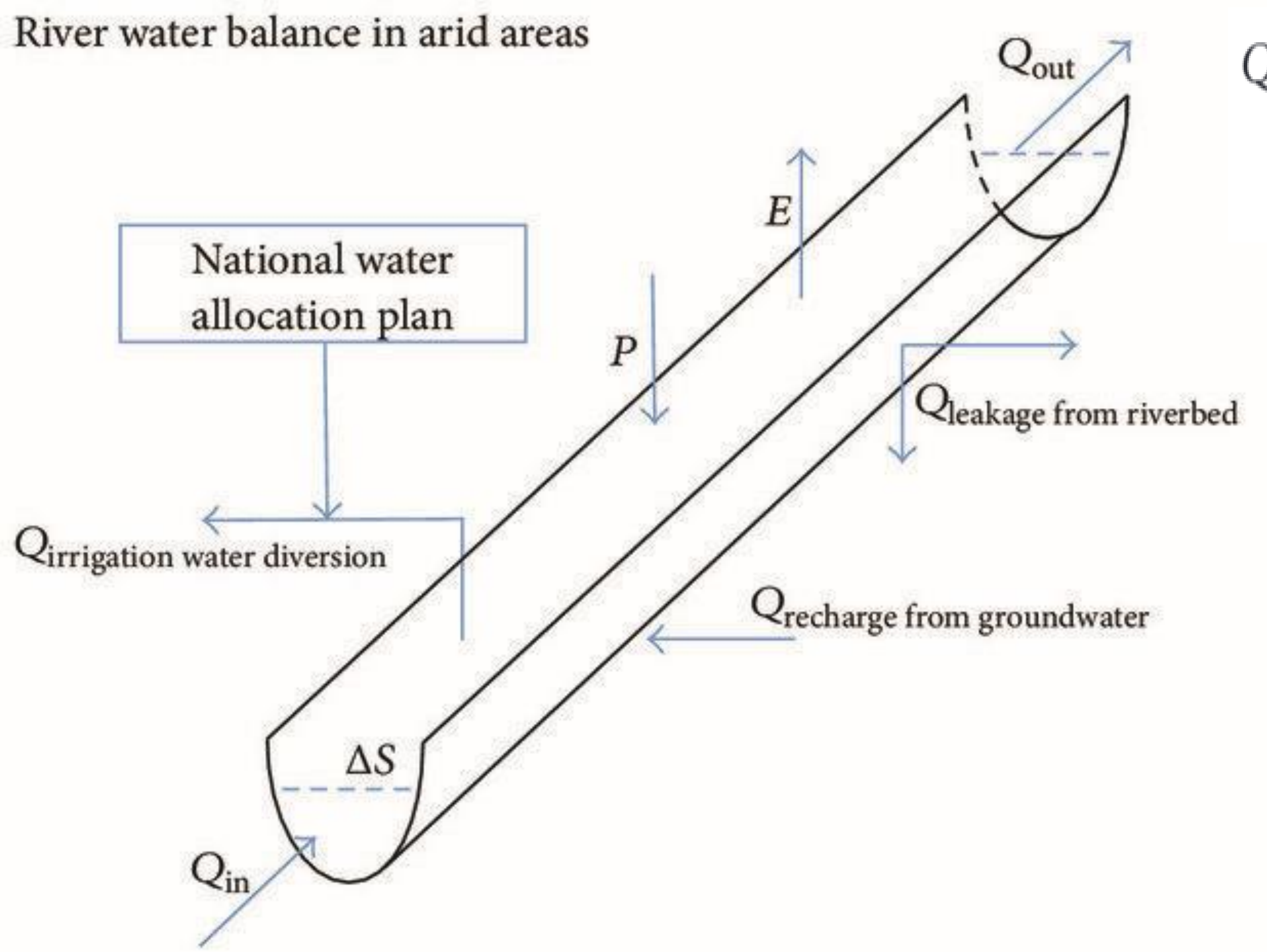
2. $E_f = E_i + \Delta S$=(2465-2.1125)=**2462.8875 m asl---#**

❖ **The surface level of the lake is decreased by 2.1125 m**

Slope Map of Maybar



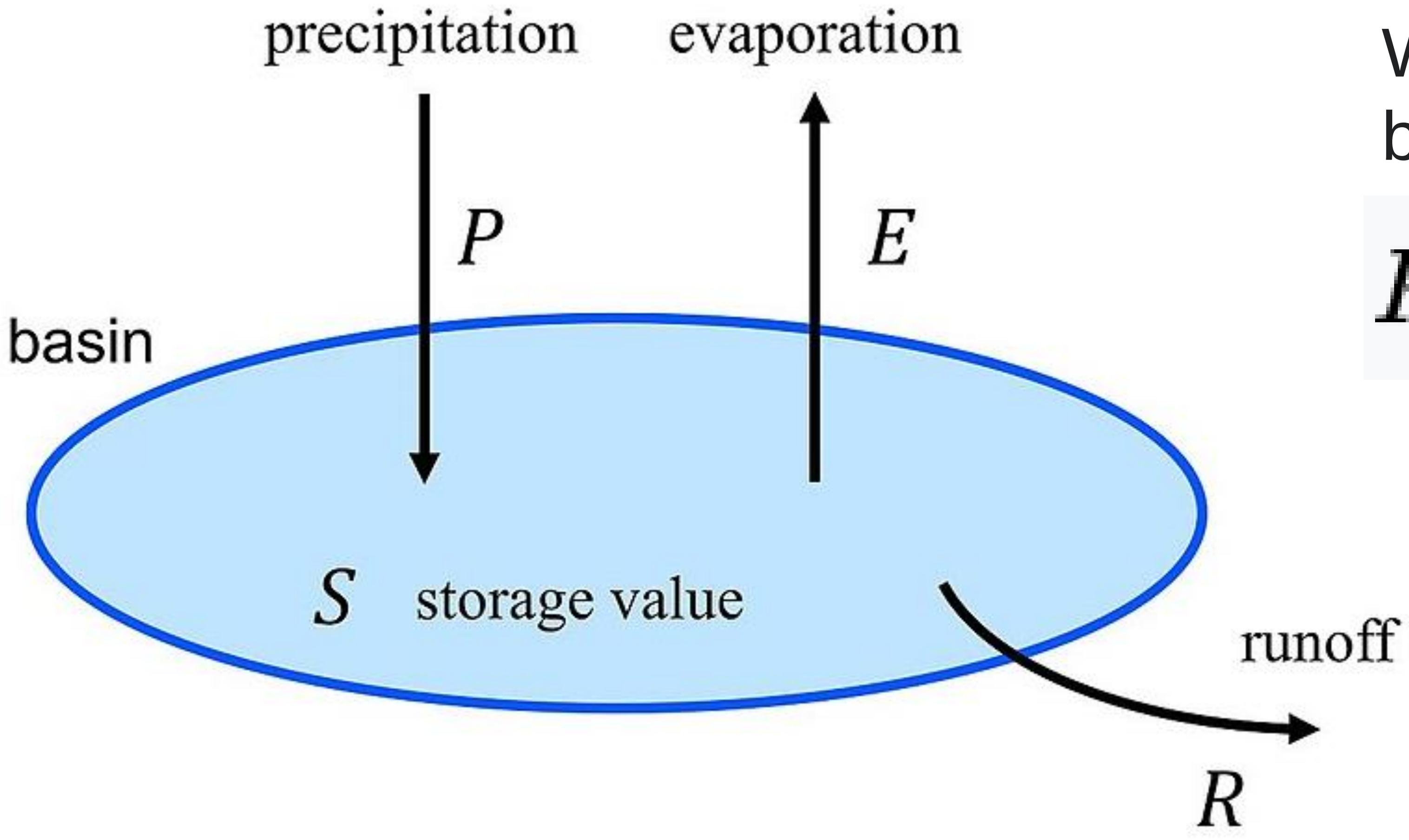
Water Balance : River/canal segment



$$Q_{\text{out,month}} = P_{\text{month}} + Q_{\text{in,month}} - Q_{\text{use,month}} - E_{\text{in-out}} - Q_{\text{in,month}} \times D_{\text{in-out}} \times \delta_{\text{in-out}} + \Delta S_{\text{in-out}}.$$

Source: [3] (Shuang Liu et al, 2016)

Water Balance : Catchment/watershed



Water balance in a basin/catchment/watershed:

$$P - E - R = \Delta S$$

Source: https://commons.wikimedia.org/wiki/File:Water_balance_basin.jpg

Break:-
for rehearsal on:

Measurements, data and data sources

Important data needed to understand and apply the water balance:

- Rainfall, **RF**, (mm)
- Runoff, **Q**, (m^3/s, mm), Subsurface flow (m^3/s, mm)
- Evaporation, **E**, Potential and Actual evapotranspiration, PET/AET, (mm)
- Infiltration, $\boldsymbol{f_c}$, (mm/hr)
- Soil water moisture (mm)
- Groundwater (capillary rise) (mm)

Measurements, data and data sources

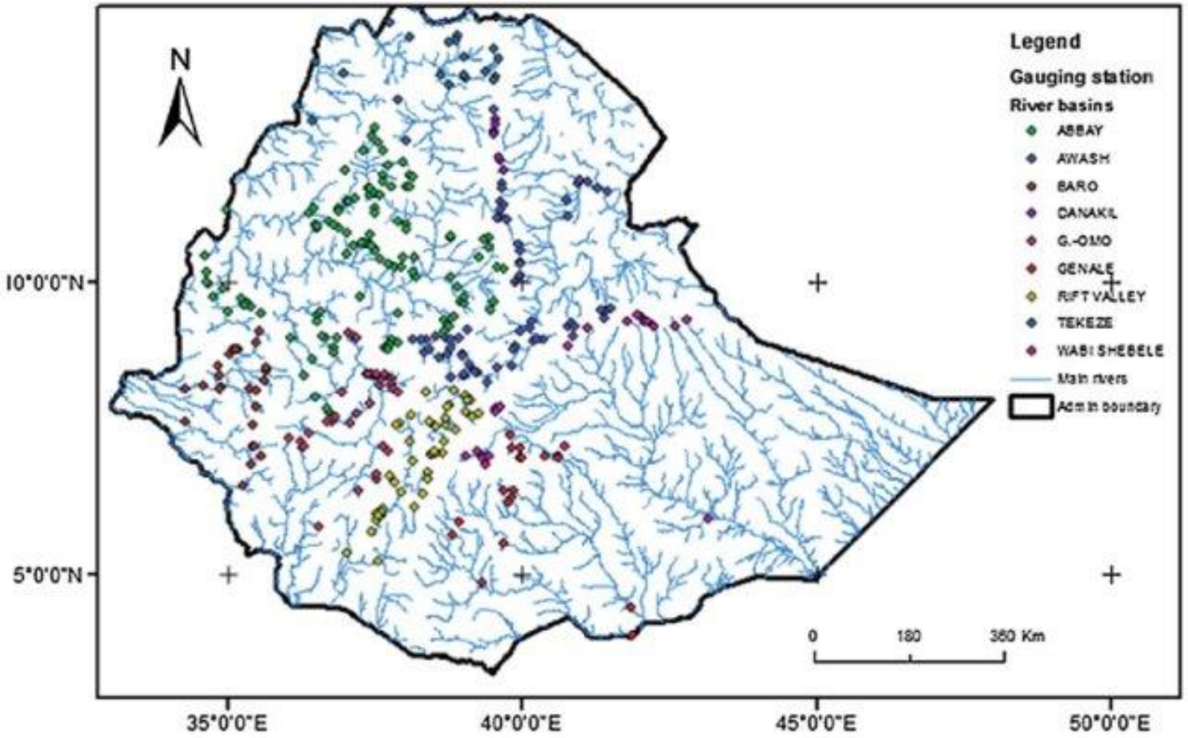
Recordings as a data sources:

- Weather records or meteorological data:-
  - Precipitation, temperature, relative humidity, evaporation and wind speed,
- Stream-flow records for hydrological data.
- Infiltration and transpiration data,
- Groundwater characteristics
- Physical and geological characteristics of the area under consideration:
  - area, land use land cover, area, soil, slope,…

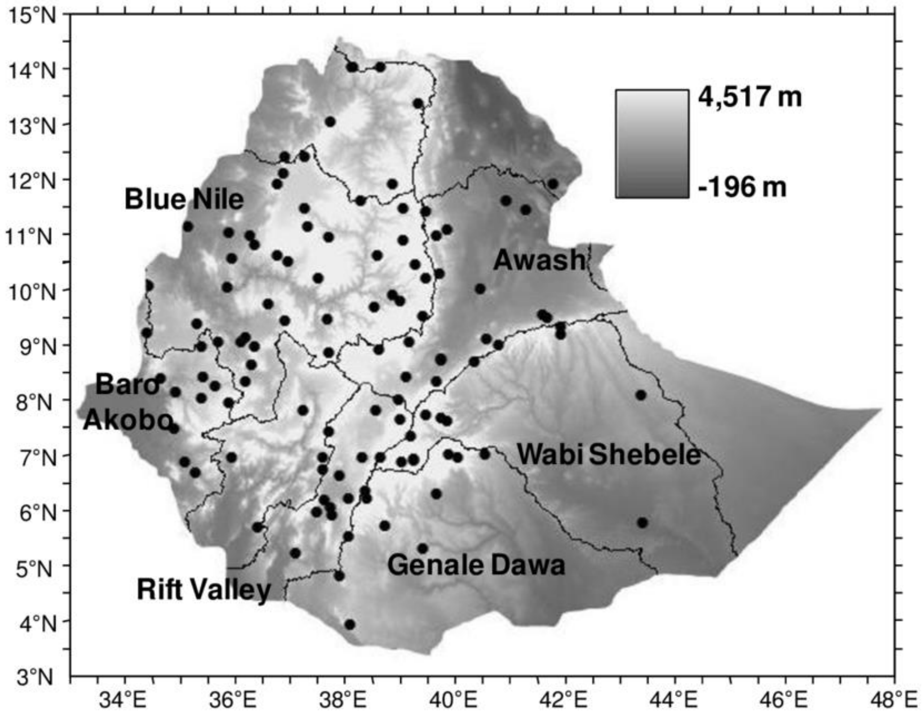
Refer: Source: [4]
https://www.ethiomet.gov.et/documents/68/june2023_hydromet_monthly_bulletin.pdf

Measurements, data and data sources

Data sources in Ethiopia:



River gauging stations, Ethiopian Ministry of Water Resources (MoWR database); (n = 409)
[5] (Nigussie et al, 2015)
https://www.researchgate.net/publication/288073318



River basins of Ethiopia with associated **rain gauges stations,** (Romilly & Gebremichael, 2010)

Precipitation and rainfall

Precipitation: is the fall of water in various **forms** on the earth from the clouds.

Short video on forms of precipitation

Source: [6] https://youtu.be/9knozomoMUU?si=V8wjIVQ36Zd12NxO (1.42 min.)

Precipitation and rainfall

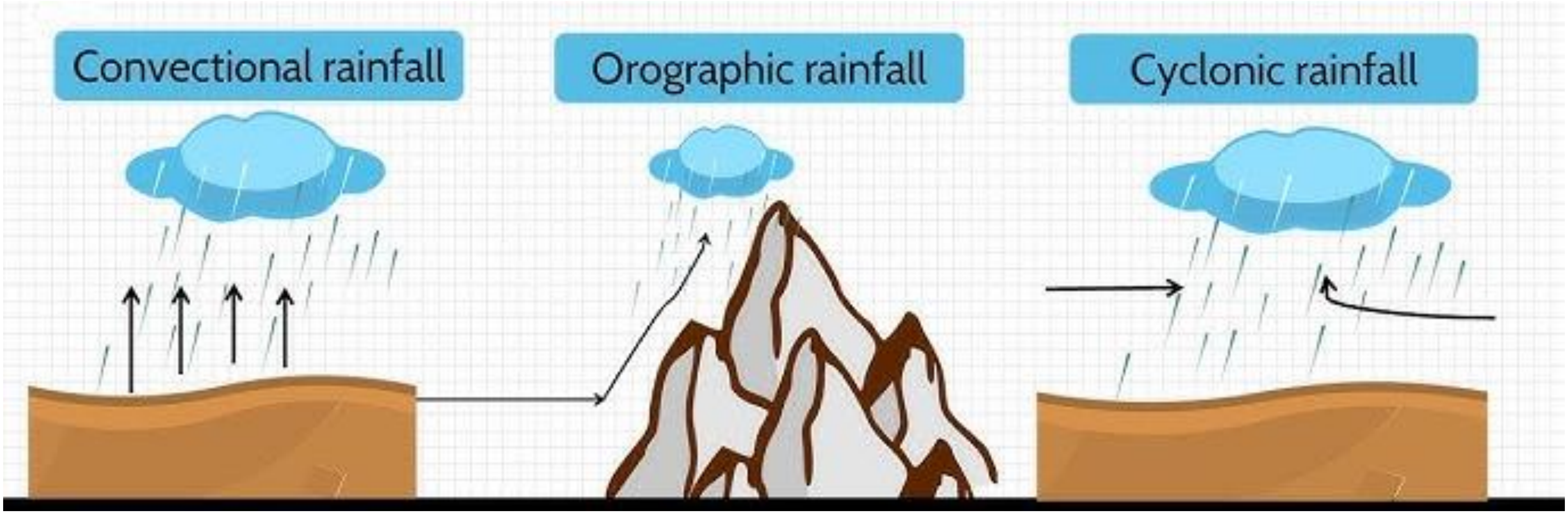
Precipitation: is the fall of water in various forms on the earth from the clouds.

Types of precipitation

- **Rainfall:** Rain is the liquid form of precipitation. Raindrops can be up to 6 mm in diameter, but anything less than 0.5 mm in diameter is classed as drizzle.
- **Snow:** Snow is formed by tiny ice crystals that stick together to become a snowflake. Once heavy enough, and if it doesn't melt below the cloud, it falls to the ground as snow.
- **Sleet or ice pellets**: refers to a mixture of snow and rain or snow that partially melts as it falls below the cloud.
- **Hail**: Hailstones are pieces of ice that form in vigorous convective clouds.

Precipitation and rainfall

Types of Precipitation:



Source: [7] https://iasgoogle.com/news/types-of-rainfall

Precipitation and rainfall

Types of Precipitation:

- **Orographic Precipitation** occurs due to lifting of moist air over mountains, i.e., it results from mechanical lifting over mountain barriers. It results in cooling, condensation and precipitation.
- **Convective precipitation** occurs due to heating of air. The rising of warmer, lighter air in cold, denser surroundings causes convective rainfall.
- **Cyclonic Precipitation** results from the lifting of air converging into a low-pressure area, or cyclone. A cyclone is a large zone of low pressure, which is surrounded by circular wind motion.

A short video on types of precipitation

Source:[8]Tupo3D**,** https://www.youtube.com/watch?v=nL48-LiYVmY

Weather or meteorological station

Standard station settings:

1. Put in an open area, away from buildings, trees, or any obstructions.
2. Empty the rain gauge completely after each rainfall event.
3. Clean the gauge regularly to remove debris.
4. Use multiple rain gauges positioned at various locations.
5. Regularly calibrate rain gauges.
6. Shelter from high winds
7. Avoid installing on the top or the side of the hill
8. Protect the station with a fence.
9. The gauge must always be mounted firmly

Source: (Adonay M, from group 6 of the students, Mar. 6, 2025)

Instruments in meteorological station

1. **A rain gauge** measures the **precipitation** that has fallen in a given time interval.
2. **A thermometer** measures temperature or temperature gradient.
3. **An anemometer** measures **wind speed and direction**.
4. **A barometer** is used to measure **air pressure**.
5. **Hygrometer** measures relative **humidity**.
6. **Sunshine recorder** records the amount of **sunshine in hours**.
7. **A cloud altimeter** measures the **height and thickness of clouds.**
8. **Radiometer** measures the **intensity of solar radiation**.

Rainfall measurements

- All forms of precipitation are expressed in terms of **the vertical depth of water** that would accumulate on a level surface if all the precipitation were collected on it.
- Two kinds of rain gauges:

1. Non – recording type.
   - do not record the rain but only collect the rain. Then, the rainfall is calculated as:
   - $$\boldsymbol{RF\ (cm) = \frac{RF\ collected\ (cm^3)}{Area\ of\ the\ aperture\ of\ the\ gauge\ (cm^2)}}$$

Source: https://www.weather.gov/images/iwx/webpages/coop/srg3.jpg

Rainfall measurements

2. Recording type rain gauges: produces a record of cumulative rain Vs time in the form of a graph, called <u>mass curve:</u>

- Mass curve allows us to estimate rainfall intensity.
- Better for eliminating human errors,
- Used to calculate intensity,
- High initial investment cost
- Subjected to electrical, power, mechanical errors.

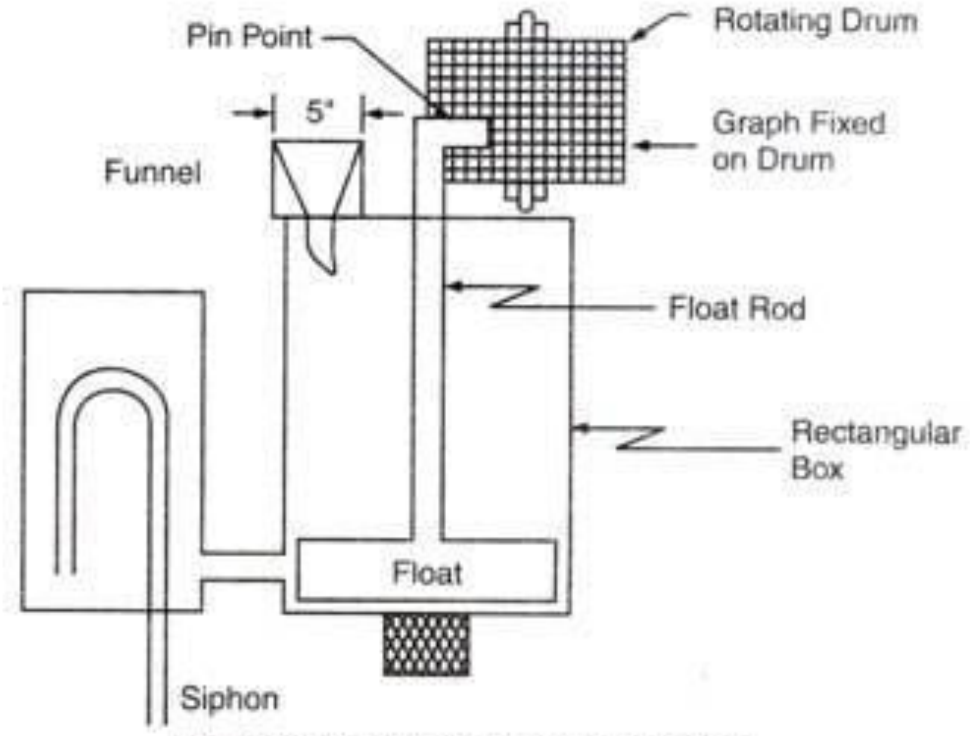


Fig. 2.5. Recording type rain-gauge

[natural-syphone-type-rain-gauges-details.jpg (331×278)]

Source: [11] https://theconstructor.org/wp-content/uploads/2016/08/natural-syphone-type-rain-gauges-details.jpg

Rainfall measurements

Floating rain gauge, Mybar, Ethiopia. Photo credited to (Sisay, 2005)

- There are three types of recording gauges in common use.

1. Floating or natural syphon gauge,
2. Tipping bucket gauge, and
3. Weighing bucket gauge.

Read more on them and come up with notes to differentiate the briefly.

Designing Rain Gauge Network

- Based up on the statistical principle, the optimum number of rain gauges (N) can be obtained by:

$$N = \left(\frac{C_V}{\in}\right)^2$$

where N = optimal number of stations

ε = allowable degree of (percentage) error in the estimate of the mean rainfall (10%) and

CV = coefficient of variation of the rainfall values at the existing m stations (%)

C_v is calculated from average precipitation, $\bar{P}$, and standard deviation, σ_{n-1}, as:

$$\bar{P} = \frac{\sum P_i}{n}$$

$$\sigma_{n-1} = \sqrt{\frac{1}{(n-1)}\sum (P_i - P_{av})^2}$$

$$C_V = \frac{100 \ x \ \sigma_{n-1}}{\bar{P}}$$

Designing Rain Gauge Network

Example 2:

There are four existing raingauge stations in a catchment. The average annual rainfall of these stations are 800, 620, 400 and 540 mm.

Determine:

1. The optimum number of raingauges to limit measurement error to 10%.
2. The number of additional raingauge to be installed.

Given:

- RF of 4 stations (mm/y)
- $\in = 10\%$

Required:

1. N (-)
2. Additional n (-)

Solutions:

1. $$N = \left(\frac{C_V}{\in}\right)^2$$ where, $$\sigma_{n-1} = \sqrt{\frac{1}{(n-1)}\sum (P_i - P_{av})^2}$$ $$C_V = \frac{100 \; x \; \sigma_{n-1}}{\overline{P}}$$
2. Additional No. (-) = N-4

Designing Rain Gauge Network

Station	Precipitation	Value (mm/y)	$p-p_{avg}$	$(p-p_{avg})^2$
1	p_1	800	210	44100
2	p_2	620	30	900
3	p_3	400	-190	36100
4	p_4	540	-50	2500
n=4	total	**2360**		**83600**
	average	**590**		

$$\sigma_{n-1} = \sqrt{\frac{1}{(n-1)}\sum (P_i - P_{av})^2}$$

$$= \sqrt{\frac{1}{(4-1)}(83600)} = 166.933$$

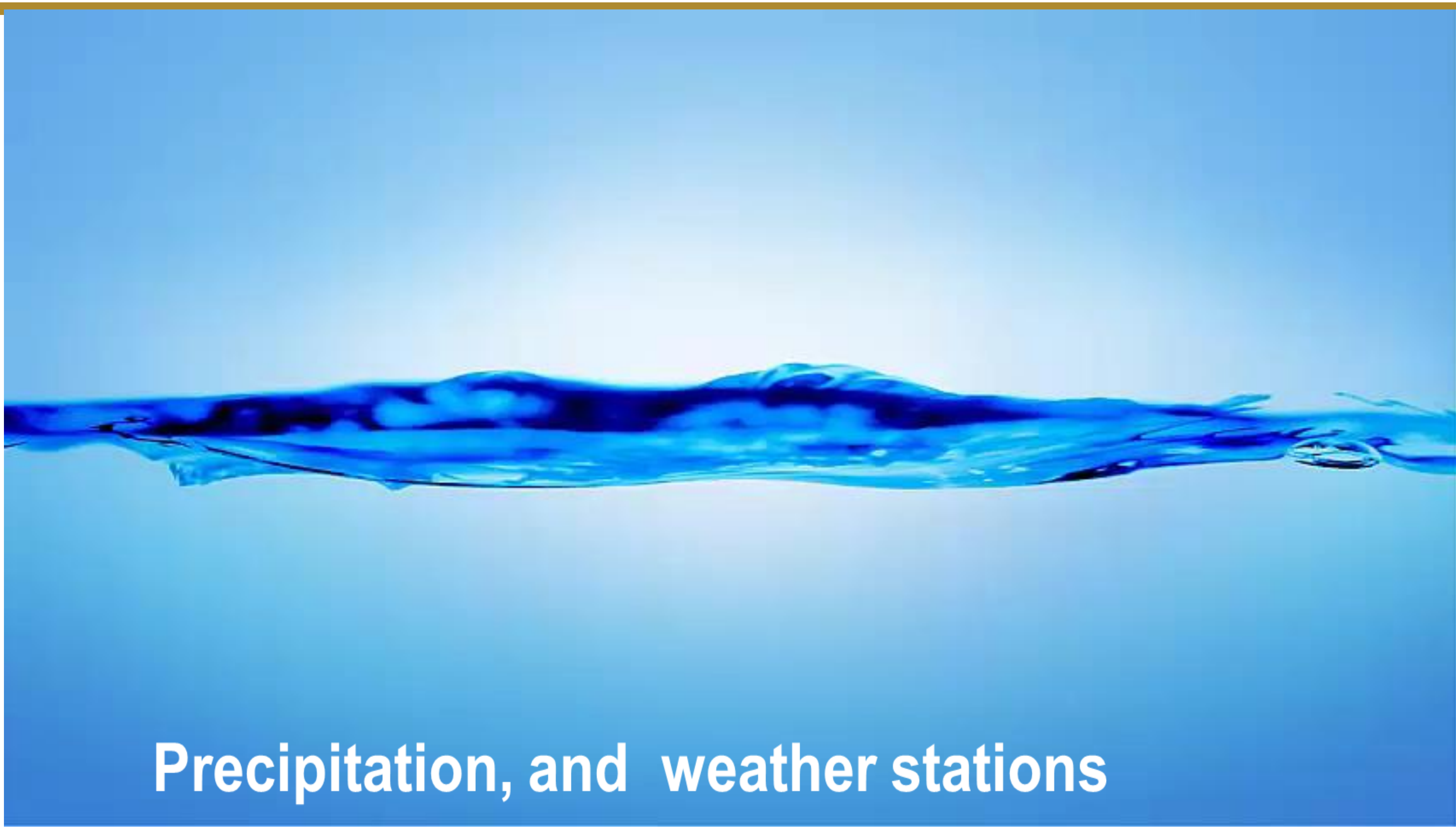
$$C_V = \frac{100 \; x \; \sigma_{n-1}}{\overline{P}} = \frac{100 \; x \; 166.933}{590}$$

$$= 28.294$$

1) $N = \left(\frac{C_v}{\epsilon}\right)^2 = \left(\frac{28.29}{10}\right)^2 = 8.004 \cong 8$

2) Additional stations needed to have accurate rainfall over the area = N-4=8-4= **4 rain gauge stations ----#**

Break:-
for rehearsal
on:



Measurement of Surface Water Flow

Streamflow or **discharge:** is the most common measurement of the quantity is flow per unit time by a **stream gaging station**.

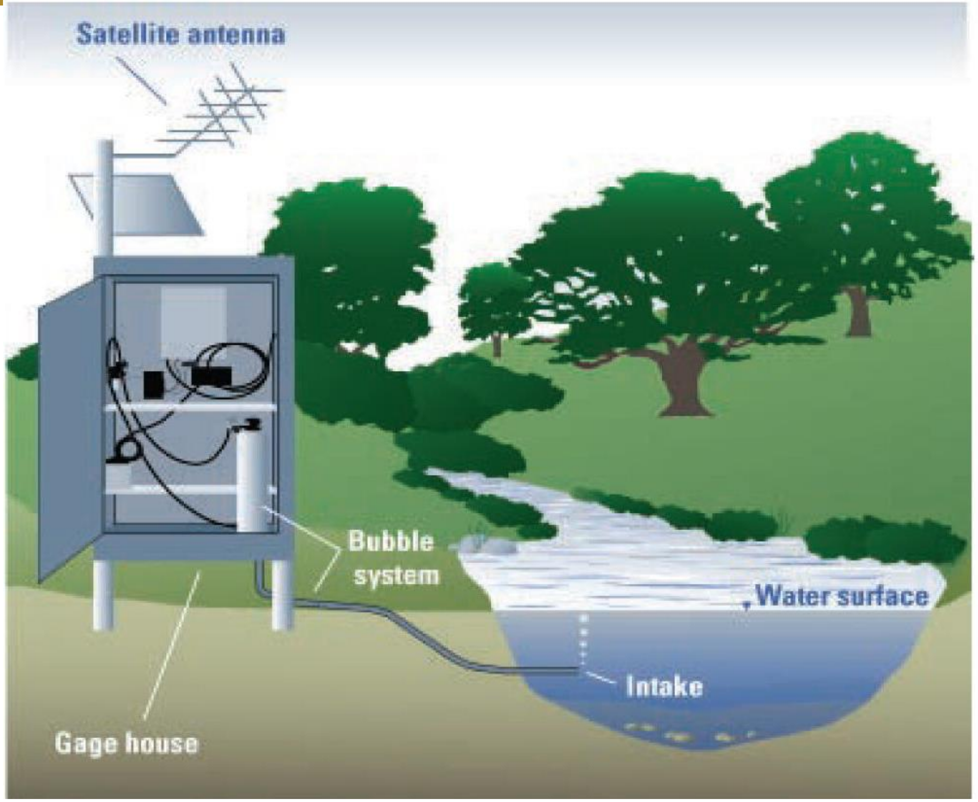
- **Permanent measurements**: is designed for continuous data collected.
- **Storage or level gauge measurements**: used for lake and other surface reservoirs.

I. Measurement of streamflow

A. **Direct** measurement or stream gaging

B. Measurement through **hydraulic devices**

C. **Indirect** measurement of peak flows



Source: [12] Streamgaging Basics (USGS)

Direct measurement or stream gaging

Stream gaging or **hydrometry** is a procedure for measuring the water **stage (level)** continuously.

- Optional recording of any other hydrologic parameter, such as **sediment load**.
- The measurement of **discharge computational** steps are:
  1. Measuring water level (stage) on a continuous basis
  2. Measuring discharge from time to time (eg. Using **current meter**)
  3. Establishing a relation between stage and discharge (called **rating curve**)
  4. Converting the measured **continuous stage into discharge** using the relation of step 3
  5. Disseminating the streamflow information to users, including water managers, engineers, scientists, and the general public.

Auto stage station, Mybar, Ethiopia. Photo credited to (Sisay, 2005)

Direct measurement or stream gaging

Flow velocity measurement

Methods for measuring surface water flows are:

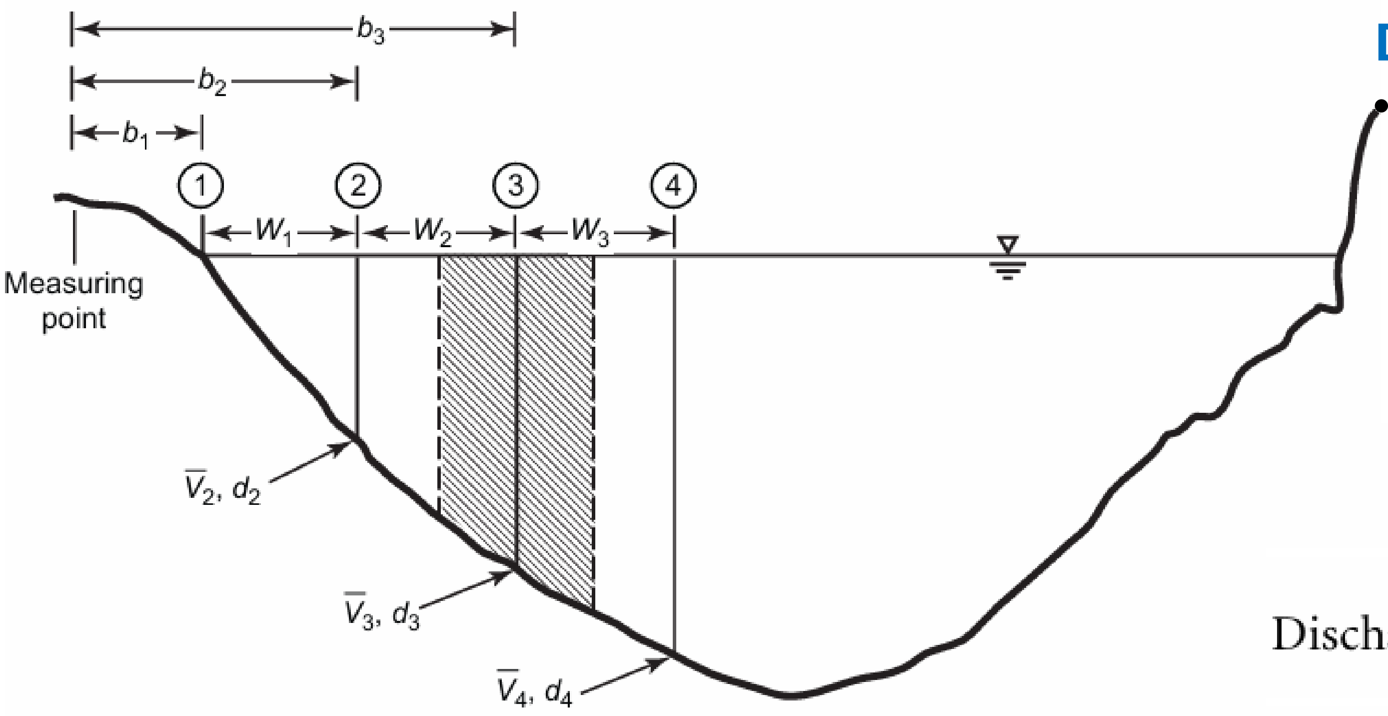
1. **Current meter** method
2. Hydroacoustic method
3. Ultrasonic method
4. Electromagnetic method

A current meter measures the velocity of flowing water at a single point.

Video on current meter application

Source: [13] https://youtu.be/TWr5feW-SFQ?si=7Ftm-Z1vfQwsQxim

Direct measurement or stream gaging



Discharge measurements and calculation

- the velocity at each vertical represents a mean velocity for a section that extends half the distance into the preceding and following segments.

$$\text{Area for subsection } 3 = \frac{W_2 + W_3}{2} d_3$$

$$\text{Discharge through subsection } 3 = \bar{V}_3 \frac{W_2 + W_3}{2} d_3$$

$$\text{Discharge through subsection } x = \bar{V}_x \frac{W_{x-1} + W_x}{2} d_x \quad [L^3 T^{-1}]$$

Source: [13] (Subramanya, 2008)

Direct measurement or stream gaging

Discharge rating

- Is the relation between stage and discharge for a gaging station.
- is established by performing periodic field measurements of discharge and stage.

The following **conditions are important** for developing rating curves:

1. covering the range of low to high flows, and
2. periodic measurements to check the validity of the relation.
3. Certain physical characteristics called station controls, stabilize the stage and discharge relation.

For a simple stage-discharge relation, the curve has a general form, given by:

There are **three types of rating** curves:

1. **Simple stage-discharge**, or two-parameter discharge relation
2. **Slope-stage-discharge**, or three-parameter discharge relation with slope
3. **Velocity index-stage-discharge**, or three-parameter discharge relation with velocity.

$$Q = A(h \pm a)^n \quad [L^3T^{-1}]$$

where

Q = discharge

h = gage height

a = stage reading at zero flow (datum correction)

A, n = constants

Direct measurement or stream gaging

Examples-3:

The data pertaining to a stream-gauging operation at a gauging site are given below.
The rating equation of the current meter is v = 0.51 Ns + 0.03 m/s where Ns = revolutions per second.
Calculate the discharge in the stream.

Distance from left water edge (m)	0	1.0	3.0	5.0	7.0	9.0	11.0	12.0
Depth (m)	0	1.1	2.0	2.5	2.0	1.7	1.0	0
Revolutions of a current meter kept at 0.6 depth	0	39	58	112	90	45	30	0
Duration of observation (s)	0	100	100	150	150	100	100	0

Source: [13] (Subramanya, 2008)

Direct measurement or stream gaging

Solution:

For the first and last sections,

$$\overline{W} = \frac{\left(1+\frac{2}{2}\right)^2}{2\times 1} = 2.0 \text{ m}$$

$$\overline{W} = \left(\frac{2}{2}+\frac{2}{2}\right) = 2.0 \text{ m}$$

- For the rest of the segments,

Distance from left water edge (m)	Average width $\overline{W}$ (m)	Depth y (m)	N_s = Rev./second	Velocity $\overline{v}$ (m/s)	Segmental discharge ΔQ_i (m^3/s)
0	0	0			0.0000
1	2	1.10	0.390	0.2289	0.5036
3	2	2.00	0.580	0.3258	1.3032
5	2	2.50	0.747	0.4110	2..0549
7	2	2.00	0.600	0.3360	1.3440
9	2	1.70	0.450	0.2595	0.8823
11	2	1.00	0.300	0.1830	0.3660
12	0	0.00			0.0000
				Sum =	**6.45393**

Discharge in the stream = 6.454 m^3/s

- The calculation of discharge by the mid-section method is shown in tabular form below:

Source: [13] (Subramanya, 2008)

Measurement Evaporation

Evaporation:

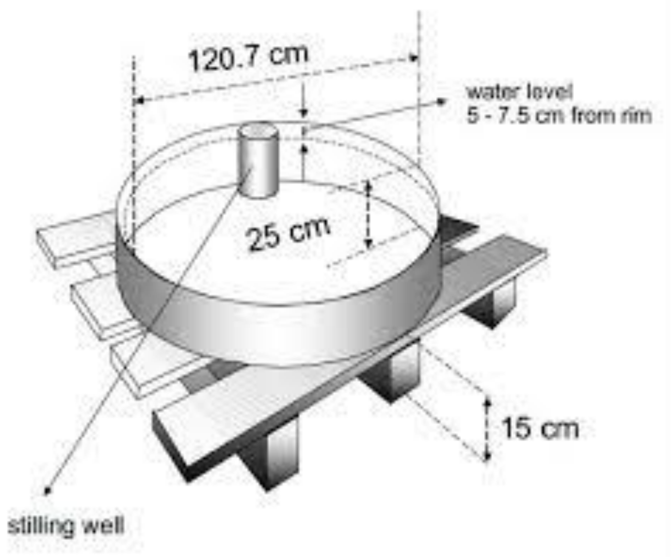
Precipitation that does not ultimately become available as surface or subsurface runoff is called water loss.

- It consists of **evaporation** and **transpiration**.
- **Evaporation** is the amount of water vaporized into the atmosphere from free water surface and land areas.
- **Transpiration** is the water absorbed by plants and crops and eventually discharged into the atmosphere.

Evaporation from free-water bodies depends on:

(1) Solar radiation,
(2) Air temperature,
(3) Atmospheric pressure,
(4) Relative humidity,
(5) Water temperature,
(6) Wind speed,
(7) Quality of water, and
(8) Geometry of the evaporating surface.

Measurement Evaporation



Estimation of evaporation:

The methods of estimating evaporation include:

(1) comparative methods, such as pan evaporation and atmometers;
(2) aerodynamic methods, such as eddy correlation, gradient, and mass transfer;
(3) balance methods, such as water budget and energy budget; and
(4) combination methods such as the Penman method

Evaporation using pans: Class A pan (dimensions and levels shown on the figure) is widely used.

- Evaporation occurs more rapidly from a pan than from larger water bodies.

$$E_W = C_p E_p \quad [L]$$

Where,
E_W = evaporation from a water body,
E_p = evaporation from the pan, and
C_p= pan coefficient (ranged from 0.6 to 0.8)

Source: [14] (Ahaya et al., , 2018)
https://www.hec.usace.army.mil/confluence/hmsdocs/hmstrm/evaporation-and-transpiration/monthly-average-method

Measurement Infiltration

Infiltration:

Infiltration is the process by which water on the ground surface enters the soil surface.

- If not evaporated, infiltrated water **may percolate** further down to the groundwater table.
- Soil water is the water that is found between the soil surface and the groundwater table.
  - This is called the **soil water zone** or the **unsaturated zone** or **vadose zone.**
- The infiltration capacity is defined as the maximum rate of infiltration.
- The infiltration capacity decreases as the soil moisture content of soils surface layers increases.
- Infiltrometers are all devices that can be used to measure infiltration rates.

Factors affecting infiltration rates are:

- Soil characteristics,
- Soil moisture content,
- Organic materials in soils,
- Land cover,
- Slope

Measurement Infiltration

https://en.wikipedia.org/wiki/Infiltrometer#/media/File:Single_ring.JPG

Infiltration can be measured:

- Flooding type infiltrometer,
- Rainfall simulator,
- Hydrograph analysis,

- Commonly used infiltrometers are **single-ring** and **double-ring infiltrometers**
- Analysis of infiltration capacity using Horton infiltration equation:

$$f(t) = f_c + (f_o - f_c)e^{-kt}$$

where, f_o = infiltration capacity at $t = 0$ (dry soil conditions; mm/hr)

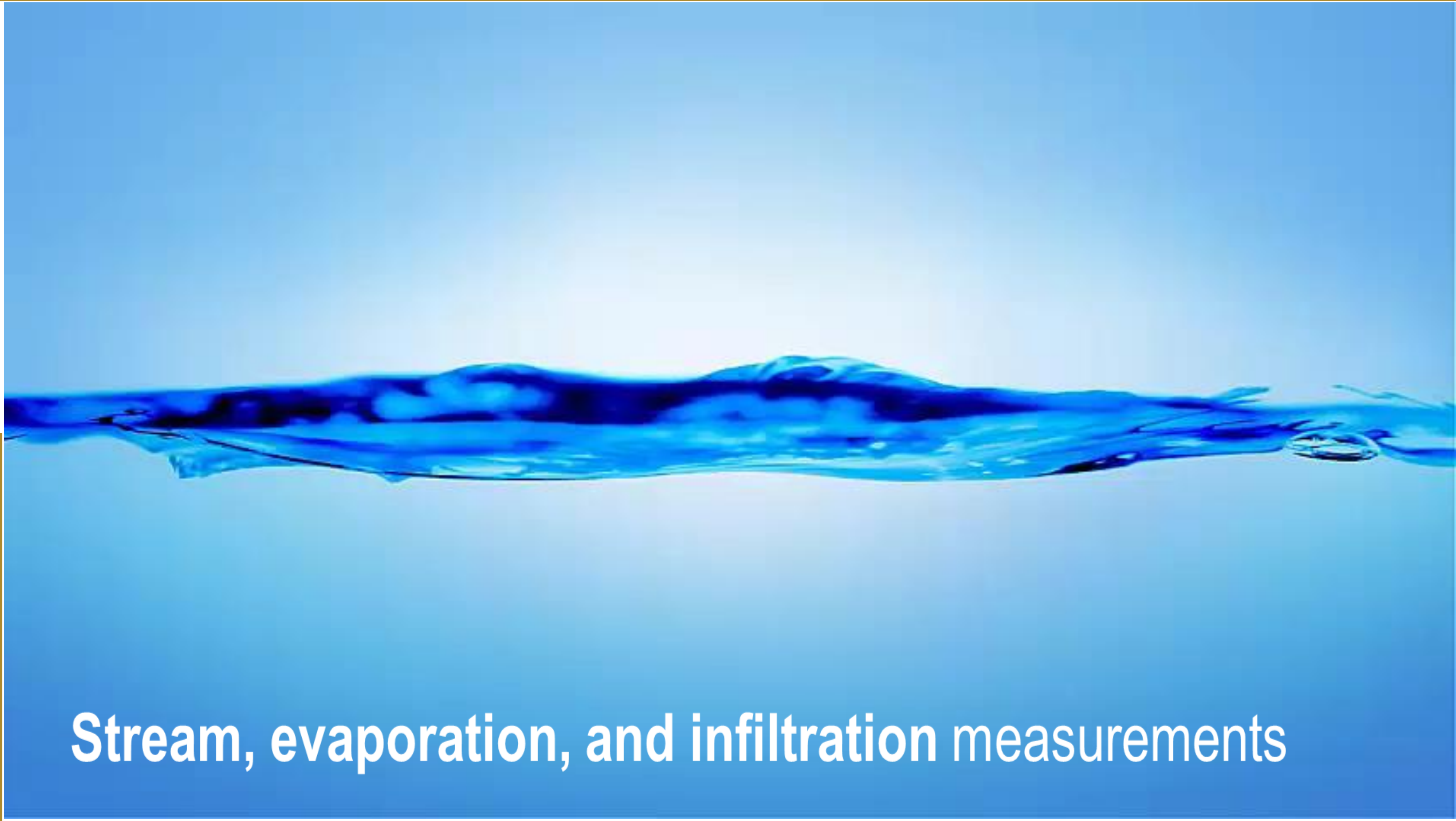
f_c = final infiltration capacity (mm/hr)

k = constant determining how quickly the infiltration capacity decreases (hr^{-1})

t = time (hr)

Source: Sisay, 2005

Break:
for rehearsal on:



Estimating Missing Rainfall Data

There are 4 adopted methods to fill these missing data:

1. Weightage transmission
2. Simple arithmetic average
3. Normal ratio method
4. Inverse Distance Method

$$P_{xi} = \frac{\sum_{i=1}^{n} a_i P_i}{\sum_{i=1}^{n} a_i}$$

1. Weightage transmission

Where P_{xi} is the data required to be filled up.

P_i is the normal rainfall of i^{th} surrounding station

- The weight coefficient a_i for the i^{th} station is given as;

$$a_i = \sum \frac{N_x}{nN_i}$$

N-annual rainfalls.

Estimating Missing Rainfall Data

There are 4 adopted methods to fill these missing data:

1. Weightage transmission
2. Simple arithmetic average
3. Normal ratio method
4. Inverse Distance Method

Simple arithmetic average is applied if the average annual rainfalls stations 1,2, & 3 differ **with in 10%** of the average annual rainfall of station X

Using a formulae:

$$P_x = \frac{P_1 + P_2 + P_3}{3} \qquad OR, \qquad P_x = \frac{\sum_i^n P_i}{N}$$

where $\boldsymbol{P_x}$ is the data required to be filled up.

$\boldsymbol{P_i}$ is the normal rainfall of i^{th} surrounding station

N is the total number of surrounding stations that have measured data.

Estimating Missing Rainfall Data

There are 4 adopted methods to fill these missing data:

1. Weightage transmission
2. Simple arithmetic average
3. Normal ratio method
4. Inverse Distance Method

$$P_x = \frac{1}{3}\left[P_1 \frac{N_x}{N_1} + P_2 \frac{N_x}{N_2} + P_3 \frac{N_x}{N_3}\right]$$

Normal Ratio (NR) Method is used if the normal annual precipitation of any surrounding gauges **exceeds 10%** of the gauge that is under consideration. Using a formula give at the left side.

$$OR, \qquad P_x = \frac{1}{N}\sum_{1}^{N} \frac{N_x}{N_i} P_i$$

where $\boldsymbol{P_x}$ is the data required to be filled up for station x.

$\boldsymbol{P_i}$ is the normal rainfall of i^{th} surrounding station

N_x and N_i are the mean annual precipitation value of the station x and the i^{th} adjacent station respectively, while N is a number of adjacent stations.

Estimating Missing Rainfall Data

There are 4 adopted methods to fill these missing data:

1. Weightage transmission
2. Simple arithmetic average
3. Normal ratio method

4. Inverse Distance Method

Inverse Distance Method is the most acceptable method for flat area. It is an interpolation method that weights the gage data based on the gage locations.

$$P_x = \frac{\sum_{i=1}^{n} W_i P_i}{\sum_{i=1}^{n} W_i}$$

$$OR, \qquad P_x = \frac{\sum_1^N \frac{1}{D^2} P_i}{\sum_1^N \frac{1}{D^2}}$$

Where: $D^2 = (\Delta x^2 - \Delta y^2)$ D is the distance of the station I in X and Y coordinates.

$$where, the\ weighing\ factor, W_i = \frac{1}{D^2}$$

Estimating Missing Rainfall Data

Examples-4:

One of the four meteorological stations, x, was not functional for a month while there were measurements for stations A, B, and C as 107, 89, and 122 mm, respectively.

The normal annual precipitation of X, A, B, and C are 978, 1120, 935, and 1200 mm.

Estimate the precipitation of station X for the missed month.

Given:

- P_A =107 mm, P_B =89 mm, & P_C =122 mm
- P_x =978 mm/y, P_A =1120mm/y, & P_B =935 m/y & P_C =1200mm/y

Required:

1. P_x in mm

Solutions: Check 10% error to select ether simple arithmetic average or normal ratio method:

- N_x=978 mm and 10% of N_x =97.8 mm
- The maximum of N_x within 10% error is 978mm + 97.8 mm = 1075.8 mm which is less than the two stations measurements, 1120 mm and 1200 mm.

Estimating Missing Rainfall Data

Solutions: …

- This indicates that the error in between is greater than 10%.
- The weighted mean method should be applied.

Given:

- P_A =107mm, P_B =89mm, & P_C =122mm
- P_x =978mm/y, P_A =1120mm/y, & P_B =935mm/y & P_C =1200mm/y
- N=3

$$P_x = \frac{1}{N}\sum_1^N \frac{N_x}{N_i} P_i = \frac{1}{3}[(\frac{978}{1120}107) + \frac{978}{935}89 + \frac{978}{1200}122] = 95.3 \text{ mm}$$

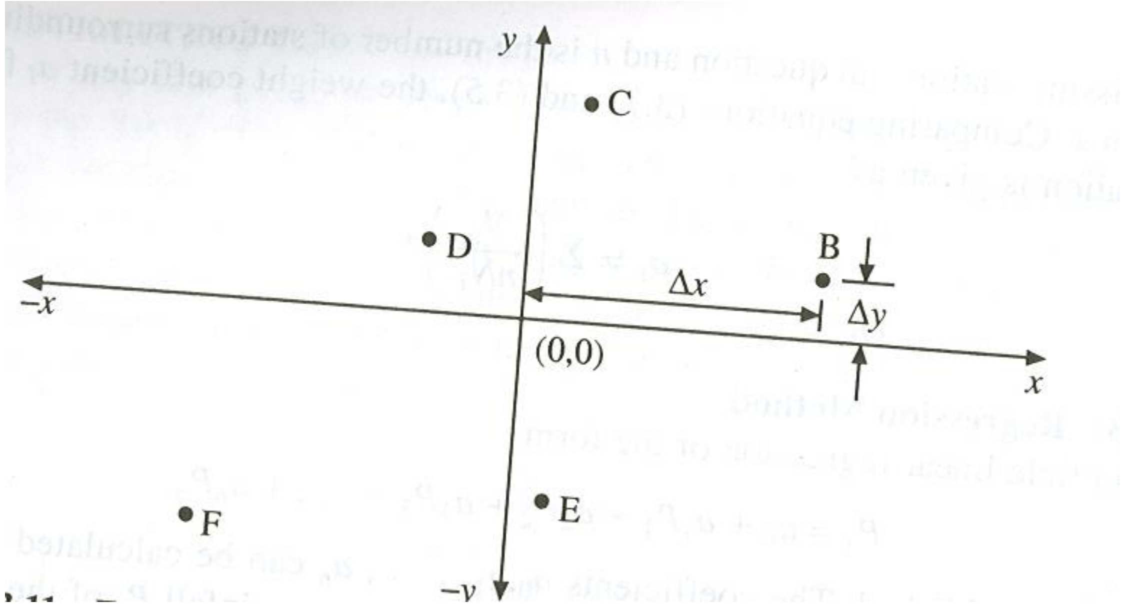
❖ The missed precipitation monthly data missed is 95.3 mm

Estimating Missing Rainfall Data

Examples 5: In a river basin, a station A was **not functioning** during a storm, while stations B, C and D surrounding A were functional, registering 12.3, 14.8 and 11.9 cm of precipitation. Mean annual precipitation at the four stations A, B, C and D are 1290, 1510, 1680 and 1375 mm respectively.

Estimate the missing storm precipitation of station A.

The coordinates of B, C and D are (6, -4), (8, -6) and (-4, 4), respectively, (x,y), where as the coordinate of A is (0, 0) as shown in Fig above



Required: P_A (cm)

Given:

- P_B =12.3 cm, P_C =14.8 cm, & P_D =11.9 cm
- P_A =1290 mm/y, P_B =1510 mm/y, & P_C =1680 m/y & P_D =1375 mm/y
- Coordinates of stations as (x_i, y_j)

Estimating Missing Rainfall Data

Examples-5: **Solutions:** Inverse distance method should applied to estimate the missing data.

$$P_x = \frac{\sum_1^N \frac{1}{D^2} P_i}{\sum_1^N \frac{1}{D^2}}$$

where, distance between coordinates of the stations are calculated using: $D = \sqrt{(x_1 - x_2)^2 - (y_1 - y_2)^2}$

Station	Monthly RF (cm)	Annual RF (cm)	Coord-inates	D^2	W_i	W_iP_i
A	?	1290	(0, 0)			
B	12.3	1510	(6, -4)	52	0.019231	0.236538
C	14.8	1680	(8, -6)	100	0.01	0.148
D	11.9	1375	(-4, -4)	32	0.13125	0.371875
				$\sum W_i$ and $\sum W_i P_i$	**0.060481**	**0.756413**

$$P_x = \frac{\sum_1^N \frac{1}{D^2} P_i}{\sum_1^N \frac{1}{D^2}} = \frac{0.756413}{0.060481}$$

$$= \mathbf{12.507\ cm}$$

The missed rainfall data for station A is estimated as **12.507 cm.**

Consistency of Records

Data consistency is the data quality being **uniform**, **accuracy, completeness**, **coherence**, and **correctness** of data stored in a database across time.

- Inconsistent data can lead to **incorrect** analysis, decision-making, and outcomes**.**

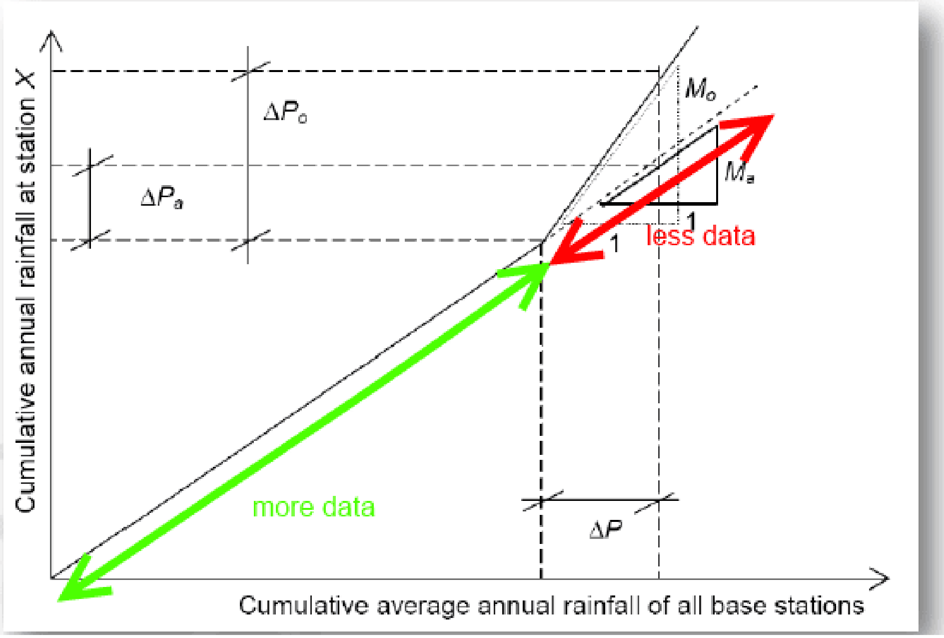
The common causes of inconsistency of record can be summarized as follow.

- Shifting of a rain gauge station to a new station,
- The neighbor hood of the station under going a marked change,
- Change in the ecosystem due to disasters such as forest fires, land slides and
- Occurrence of observational error from a certain data.
- Inconsistent data entry
- Duplicated data
- Inaccurate data

Therefore, inconsistence, if any, has to be detected and corrected before any further analysis.

Consistency of Records

Double Mass Curve



$$P_a = P_o \frac{M_a}{M_o}$$

where

$$M_o = \frac{\Delta P_o}{\Delta P}$$

$$M_a = \frac{\Delta P_a}{\Delta P}$$

P_a – adjusted ppt of station x
P_o – original ppt of station x
M_a – the slope adjusted graph
M_o – the slope of original graph

Source: Watch

- [15] https://youtu.be/GlRb3JydBtg?si=OZF5dxbn0GtY3cwZ
- [16] https://youtu.be/vcn823VIwDA?si=tHR2PBKFzTXEvFVG.

Consistency check:

- is performing a systematic process **to identify and rectify** inconsistencies within datasets.
- is the process of comparing **local entries** with entries in the **remote database** to ensure database integrity.

The double- mass curve:

- is used to check the consistency of many kinds of hydrologic data by
  - comparing date for a **single station** with that of a pattern composed of the data from several **other stations** in the area.

Areal rainfall determination

There are three methods that are used to get the mean rainfall over an area.
They are:

1. **Arithmetical** mean method
2. **Thiessen's** polygon method
3. **Isohyetal** method

1. **Arithmetical Mean Method:** recommended when the gage stations are **evenly distributed** over the area.
   - It assigns equal weight to all stations **irrespective of their relative spacings** and other factors.

$$\bar{P} = \frac{P_1 + P_2 + \cdots P_i + \cdots P_n}{N} = \frac{1}{N}\sum_{1}^{N} P_i$$

2) **Thiessen's Polygon Method**: recommended for gage stations are not evenly distributed over the area. Weight is assigned with representative area defined by a polygon.

These polygons are formed as follows:

1. Plot rainfall stations over the area/basin
2. Connect every raingauge using a straight line
3. Draw perpendicular bisectors of each line drawn at step 2,
4. Calculate the area of polygons drawn around each station by the bisectors and
5. the boundary of the area
6. Apply the ratio of each area by the area of the area/basin as weighing factor to
7. calculate an areal rainfall of the basin

Areal rainfall determination

3) Isohyetal method:

- can be applied when the rainfall is **not evenly distributed** over the area.
- is the most accurate of the three methods.
- The procedure is as follows:

1. The stations and rainfall values are **plotted on a map** to a suitable scale.
2. The contours of equal precipitation, called **isohyets**, are drawn.
3. The area between successive isohyets is computed and multiplied by the numerical average of the two contour (isohyets) values.
4. The sum of item under step 3 divided by the total drainage area provides the weighted average precipitation.

Polygon and isohyets maps can be done by:

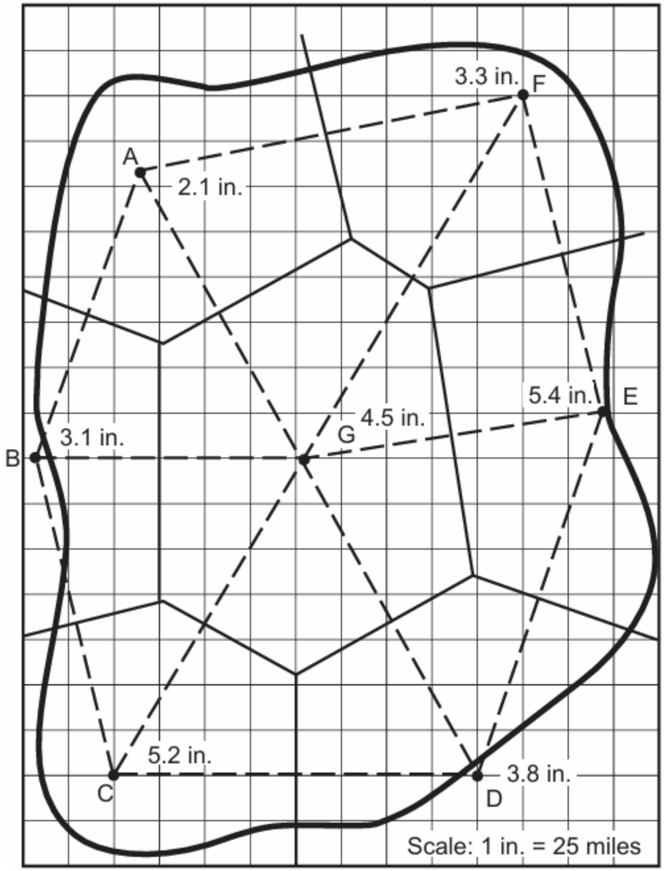
- a graphic tool like AutoCAD or a planimeter,
- drawing the figure to a scale on graph paper,

Areal rainfall determination

Example -7:
The rain gages located in and around a drainage area are shown in the Figure along with the rainfall recorded.

- Determine the **average precipitation** for the **drainage area** by:

(a) the arithmetic average method,
(b) the Thiessen polygon method, and
(c) the isohyetal method.



Given: Rainfall of 7 stations(in), map of area on **a scale square paper**

Required: areal rainfall (in) using AA, TP, I methods

Solution:

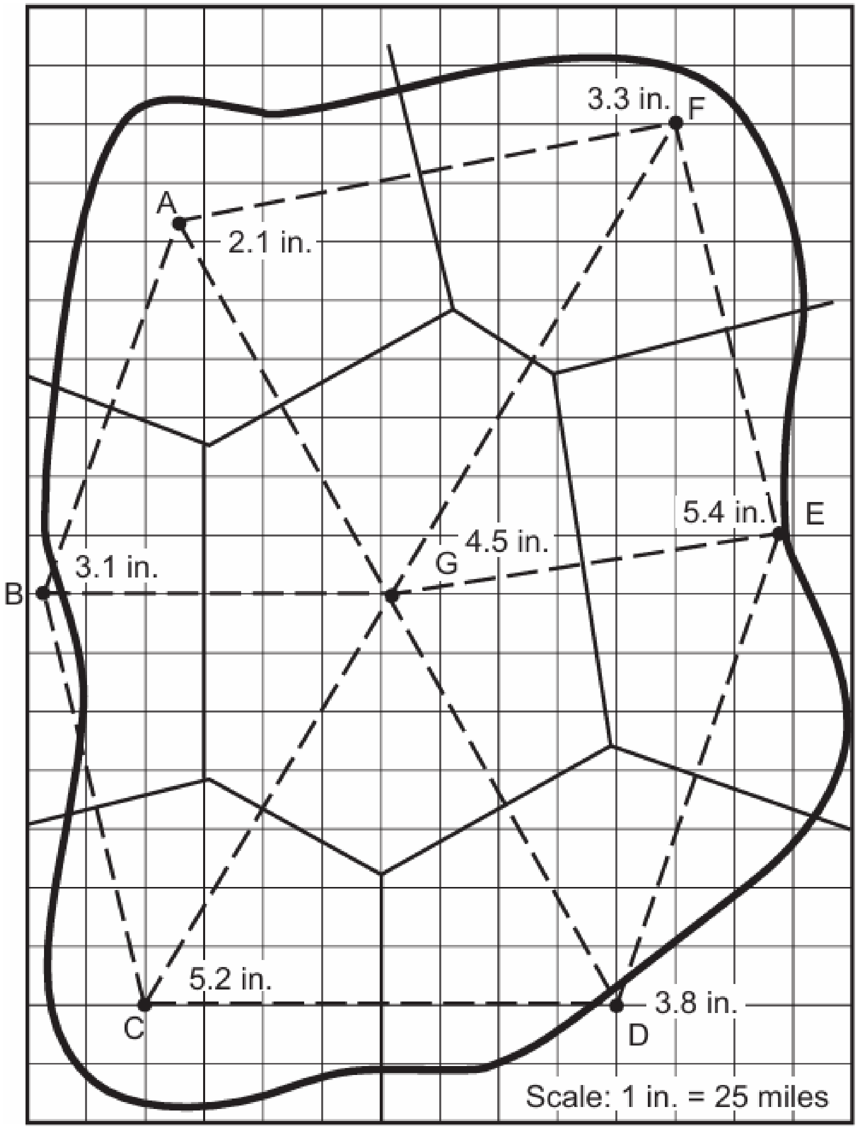
(a) Arithmetic method:

$$\overline{\boldsymbol{P}} = \frac{1}{N}\sum_{1}^{N} P_i = \frac{\boldsymbol{P_1} + \boldsymbol{P_2} + \cdots \boldsymbol{P_i} + \cdots \boldsymbol{P_n}}{\boldsymbol{N}} = \frac{2.1 + 3.1 + 5.2 + 3.8 + 5.4 + 3.5 + 4.5}{7}$$

$\overline{\boldsymbol{P}}$ =**3.91 in**. ……..#

Areal rainfall determination

Example -7: **Solution**: **(b) Thiessen polygon method:**



(1) Observed Precipitation (in.)	(2) Area of Polygon (mi^2)	(3) Precipitation × area (col. 1 × col. 2)
2.1	735	1,543.5
3.1	475	1,472.5
5.2	640	3,328.0
3.8	620	2,356.0
5.4	740	3,996.0
3.3	685	2,260.5
4.5	1,210	5,445.0
Total	5,105	20,401.5

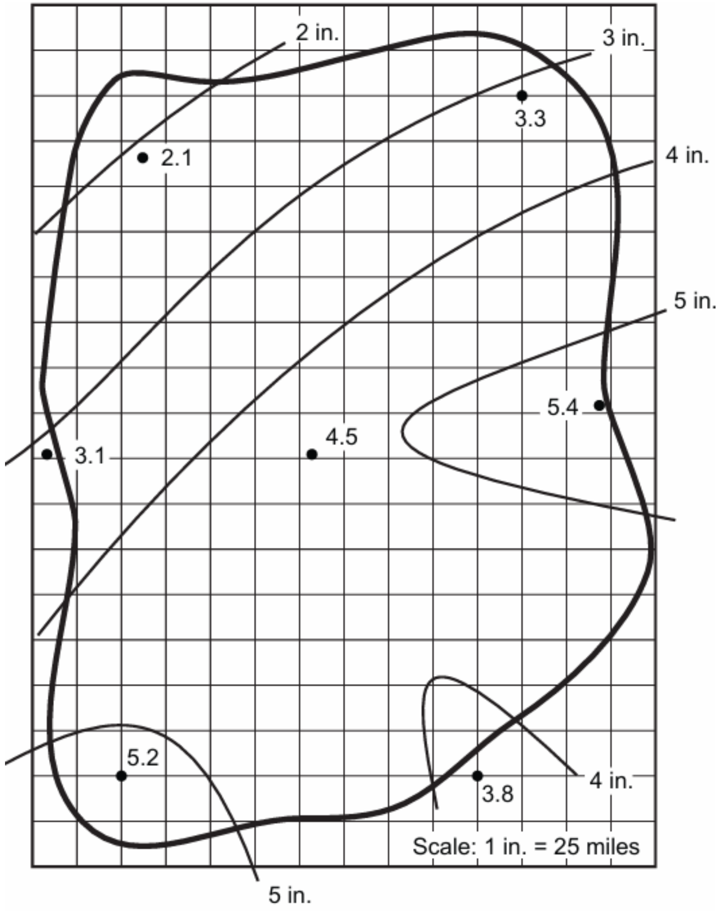
$$\overline{P} = \frac{20{,}401.5}{5{,}105} = 4.0\ in.\ .\ ....\#$$

Areal rainfall determination

Example -7: **Solution**: **(C) Isohyetal method:**

(1) Isohyet (in.)	(2) Area Covered by the Isohyet (mi^2)	(3) Area between Two Isohyets (mi^2)	(4) Average of Two Isohyets (in.)	(5) Precipitation × Area (col. 3 × col. 4)
<2	0			
		125	1.8 (est)	225
2	125			
		820	2.5	2,050
3	945			
		1,100	3.5	3,850
4	2,045			
		2,555	4.5	11,498
5	4,600			
		500	5.2	260
>5	5,100			
Total		5,100		20,233

$$\bar{P} = \frac{20,233}{5,100} = 3.96\ in.\ .\ \ ....\#$$



Home assignment:

Questions raised in class by the instructor and students

1. Lake Haromaya has dried for some years. Now it is going to be recovered. What can we take a lesson from these processes as engineering hydrologist (Gabisa)?
2. What possible control volumes can be considered for understanding water balance or water budget?
3. What important procedures can we follow to understand and analyze water balance for given potential control volume?
4. A lake has an area of 15 km^2. Observation of hydrological variables during representative years with constant water levels has shown that:

   Precipitation, $\boldsymbol{P}$ = 700 mm/year

   Average inflow, $\boldsymbol{Q_{in}}$ = 1.4 m^3/s

   Average outflow, $\boldsymbol{Q_{out}}$ = 1.6 m^3/s

   Assume that there is no net water exchange between the lake and the groundwater.

   - Sketch representative control volume and label the components.
   - Determine the evaporation during this year.

Home assignment:

5. The evaporation from a lake is to be calculated by the water balance method.

- Inflow to the lake occurs through three small rivers A, B, and C.
- The outflow occurs through river D.
- The water level was at +571.04 m on May 1 and +571.10 m on August 31.
- The lake surface area is 100 km^2.
- The precipitation P during the period was 100 mm.
- Average inflows and outflow are given below.
  - ❖ Calculate **the evaporation** from the lake surface during summer (May-August)

River	*Catchment (km^2)*	*Q, average (m^3/s)*
A	150	15.0
B	120	20.0
C	130	17.0
D	—	45.0

References

Derib, S.D. 2005. Rainfall-Runoff Processes at a Hillslope Watershed: Case of Simple Models Evaluation at Kori Sheleko Catchment of Ethiopia. MSc Thesis, Wageningen University, The Netherlands.

Shuang, L.Z., X. Zhenghui, Y. Zeng, and Y. Zeng. 2016. Discharge Estimation for an Ungauged Inland River in an Arid Area Related to Anthropogenic Activities: A Case Study of Heihe River Basin, Northwestern China, Advances in Meteorology (2):1-11

Subramanya, K. 2008. Engineering Hydrology, Tata McGraw-Hill Publishing Company Limited, New Delhi

Olotu Yahaya, Bello Smart, Omoakhalen AI and Ehibor OG 2018.Development and Calibration of Automated Class A Evaporimeter, Hydrology: https://www.researchgate.net/publication/328090650_2157-7587-9-304

Hende, C.V., Bert V,Schaeybroeck, J. Nyssen, Sander V. V., Michiel V.G., and Piet T. 2021. Analysis of rain-shadows in the Ethiopian Mountains using climatological model data, Climate Dynamics, 56:1663–1679

Thank you very much for your active attendance!!

Prepared By: Sisay Demeku Derib (PhD, Practicing Hydraulics Engineer, Assistant Prof.)
Affiliated to: Addis Ababa Science and Technology University –AASTU, Department of Civil Engineering
----
Scopus WOS ORCID ResearchGate Google Scholar LinkedIn YouTube