FIRST EDITION

Introduction to Hydrology

NOR AFZAN BINTI ARIFFIN
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CONTENT

PREFACE

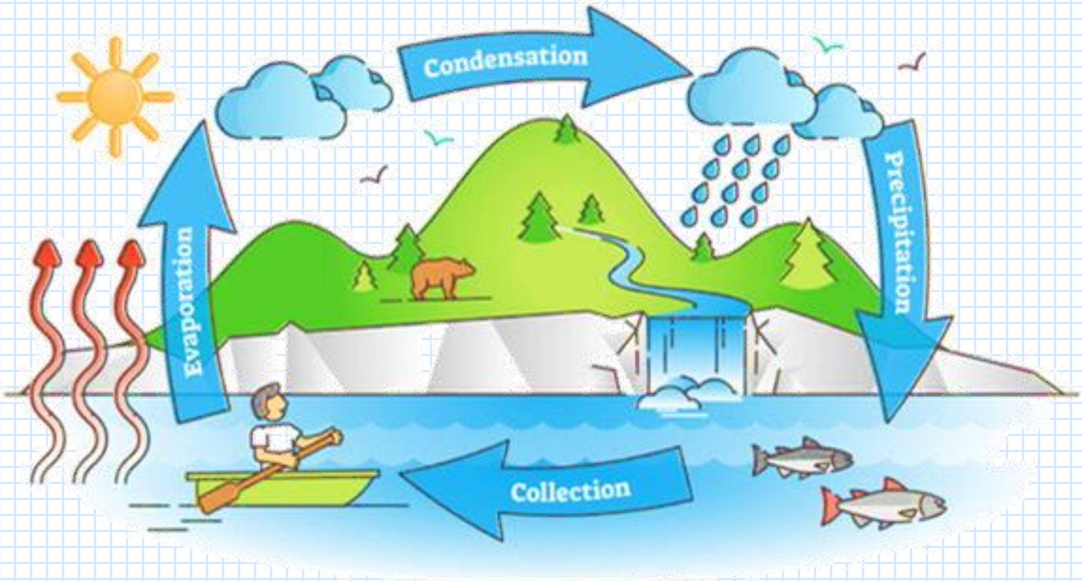
Introduction to Hydrology is designed to help students understand key hydrological concepts crucial to civil and environmental engineering. This book introduces the river basin and catchment area, the hydrological cycle, climate change impacts, and water balance calculations. Emphasizing both theory and real-world application, it aims to build a solid foundation for students to analyze and manage water systems effectively. It is a practical guide to strengthen comprehension and prepare students for hydrological challenges in their academic and professional journey.

01 The concept of river basin and catchment area

What is the Hydrology?

- It is the science of the water of the earth and its atmosphere.

- It deals with occurrence, circulation, distribution and movements of these waters above the globe and their interaction with the physical and biological environments.



Need for the Hydrologic Studies

- The need of the hydrologic studies arises from the following problems:

  i. Uncertainty of precipitation and its seasonal occurrence.

  ii. Seasonal flow of rivers.

  iii. Population growth and rising standards of living.

Engineering Hydrology

- Engineering hydrology is the branch of hydrology which deals with estimation of water resources and related hydrologic quantities.

- It also investigates hydrologic problems such as floods and droughts and develops strategies to mitigate them.

Importance of Hydrology in Civil Engineering

- Hydrology has an important role in the design and operation of water resources engineering projects like irrigation, flood control, water supply schemes, hydropower projects and navigation.

- Many important civil engineering projects have failed because of improper assessment of hydrologic aspects of the projects.

- Hydraulic structures which are very important civil engineering projects and cost millions of ringgit may fail due to improper hydrologic design.

Major Aspects of Hydrology

- The main jobs of a hydrologist are collection and analysis of data and making predictions out of this analysis.

- Collection of data (the hydrologic data) comprises:
  i. Rainfall Data
  ii. Snowfall and Snowmelt Data
  iii. Runoff Data (Catchment Runoff and Stream Flows), and
  iv. Groundwater Data

- Analysis of Data: Analysis of hydrologic data includes checking it for consistency and homogeneity as well as finding its various statistical parameters.

- Prediction: Prediction means finding design values and maximum possible floods and droughts. Various approaches for prediction of hydrologic values are:
  i. Statistical Approach
  ii. Physical Approach
  iii. Deterministic Approach

Major Hydrologic Project

- Engineering Hydrology provides hydrologic data essentially required for a variety of projects, such as:
  i. Hydraulic Structures like Dams, Bridges, Head-works, Spillways and Culverts etc.
  ii. Hydroelectric Power Generation
  iii. Flood Control Projects
  iv. Irrigation Projects
  v. Environmental Pollution Control, and
  vi. Planning and Execution of Water Resources Development Projects

Catchment Area

CATCHMENT AREA

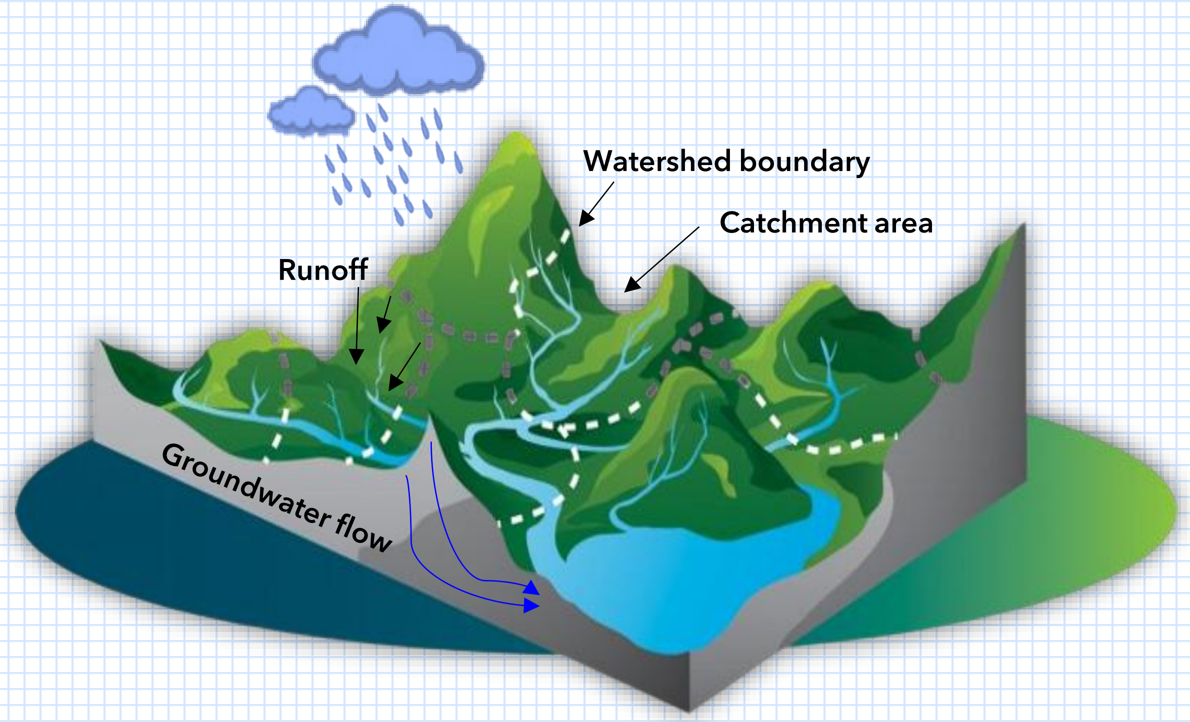
- A catchment is an area of land, usually bounded by mountains, over which water flows and is collected by the natural landscape.

- In a catchment, all rain and run-off water eventually flows into a creek, river, lake, lagoon or the ocean.

- In some places small catchment areas join up to form a larger catchment. These small catchments are sometimes called sub-catchments.

- Adjoining catchments are separated by higher points, usually a ridge or mountain, these boundaries are called watersheds.

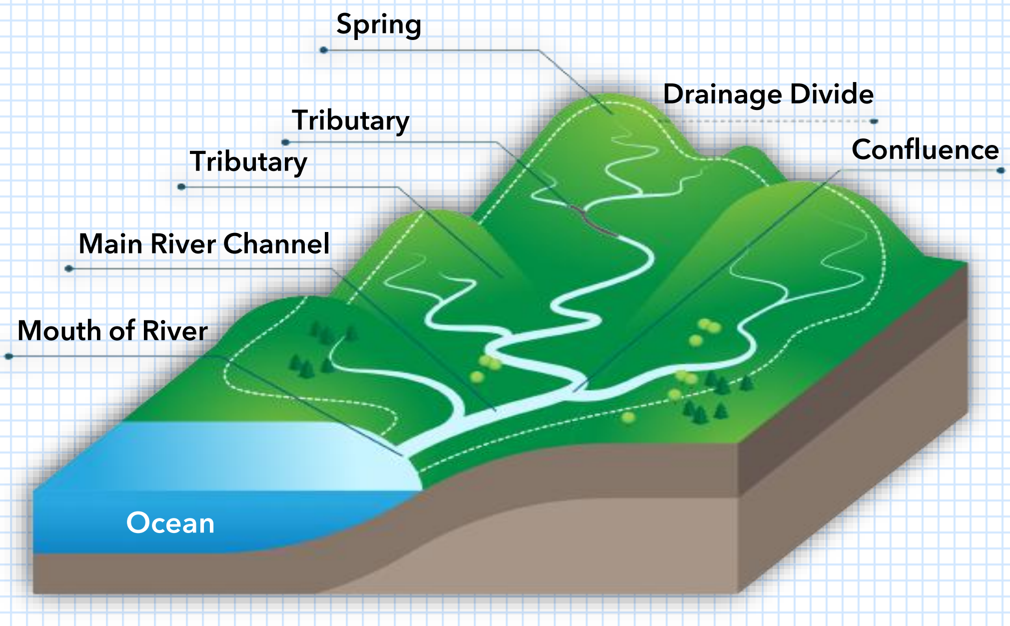
Catchment Area



- The watershed which is a boundary that separates one catchment and its flows from the neighboring catchment.
- The headwaters which are generally the more elevated parts of a catchment (usually hills or mountains and with most runoff collecting into many small but often steep sided channels that collect together and form a rapid flow quickly after rain).

Catchment Area

- Tributary is a smaller river or stream flowing into a larger river.
- A confluence is a river joins another river.
- The mid reaches of a catchment, where the stream begins to slow down and widen.
- The lower reach of a catchment which is usually the delta where a stream enters an estuary or the sea (ocean).



River Basin

RIVER BASIN

- A river basin is the land that water flows through or under on its ways to a river.
- Just as a bathtub catches all the water that falls within its sides, a river basin sends all the water falling within it to a central river and out to an estuary or to the ocean.

What is the difference between a River Basin and a Watershed?

- Both river basins and watersheds are areas of land that drain to a particular water body, such as a lake, stream, river or estuary.

- In a river basin, all the water drains to a large river.

- The term watershed is used to describe a smaller area of land that drains to a smaller stream, lake or wetland.

- There are many smaller watersheds within a river basin.

02 Hydrology Cycle

Hydrology Cycle

- A continuous process of water movement in various forms, phases and places between the atmosphere, the land, and the oceans.

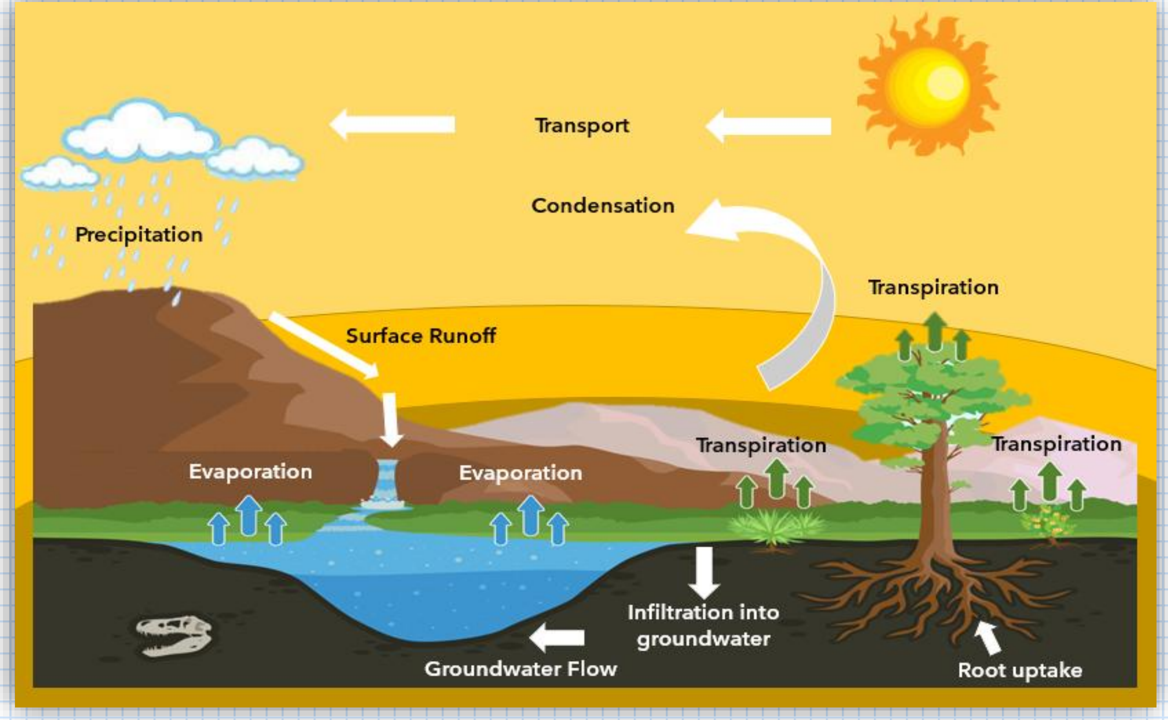
- The actual process is very complex, containing many sub-cycles without any beginning or ending.

- In this respect, we may consider the oceans as the major sources of water, the atmosphere as the conveyer of water, and the land as the user of water.

The Process Involved In Hydrologic Cycle

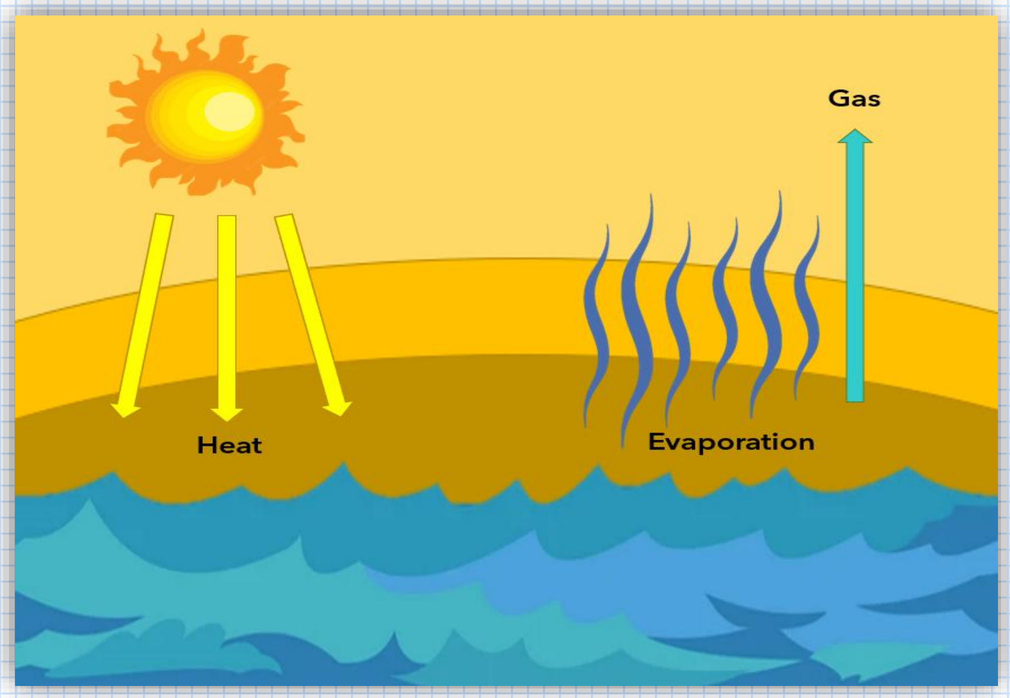
9 PROCESSES INVOLVED IN HYDROLOGIC CYCLE

1. Evaporation
2. Condensation
3. Precipitation
4. Surface Runoff
5. Infiltration
6. Underground water
7. Interception
8. Transpiration
9. Evapotranspiration



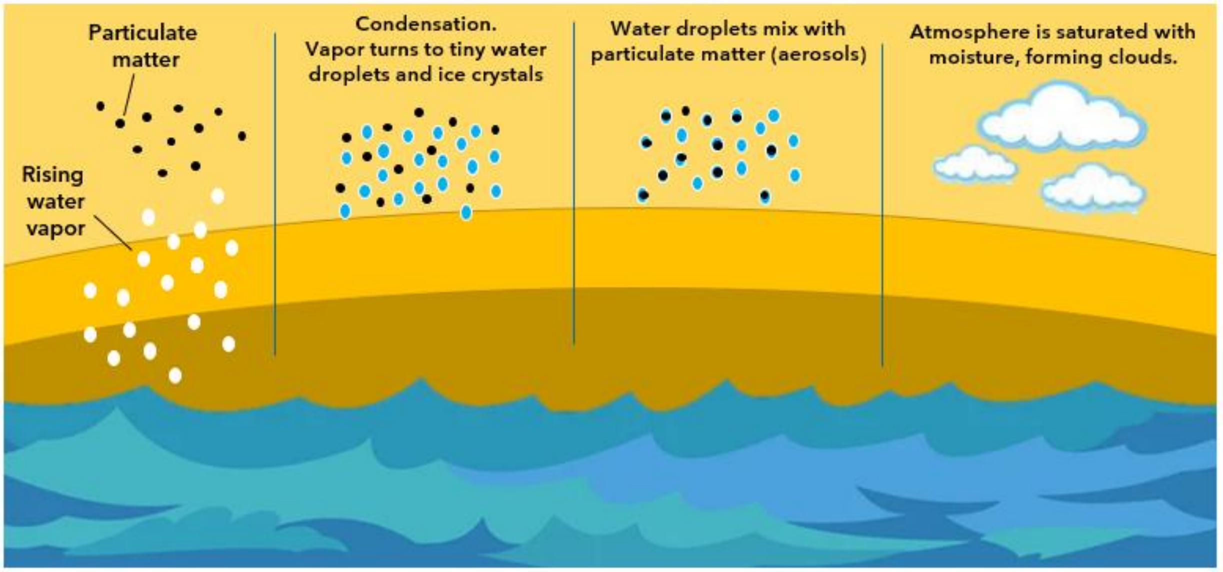
Evaporation

- Evaporation is the process by which water changes from a liquid to a gas or vapor.
- Evaporation into a gas finishes when the gas reaches saturation.



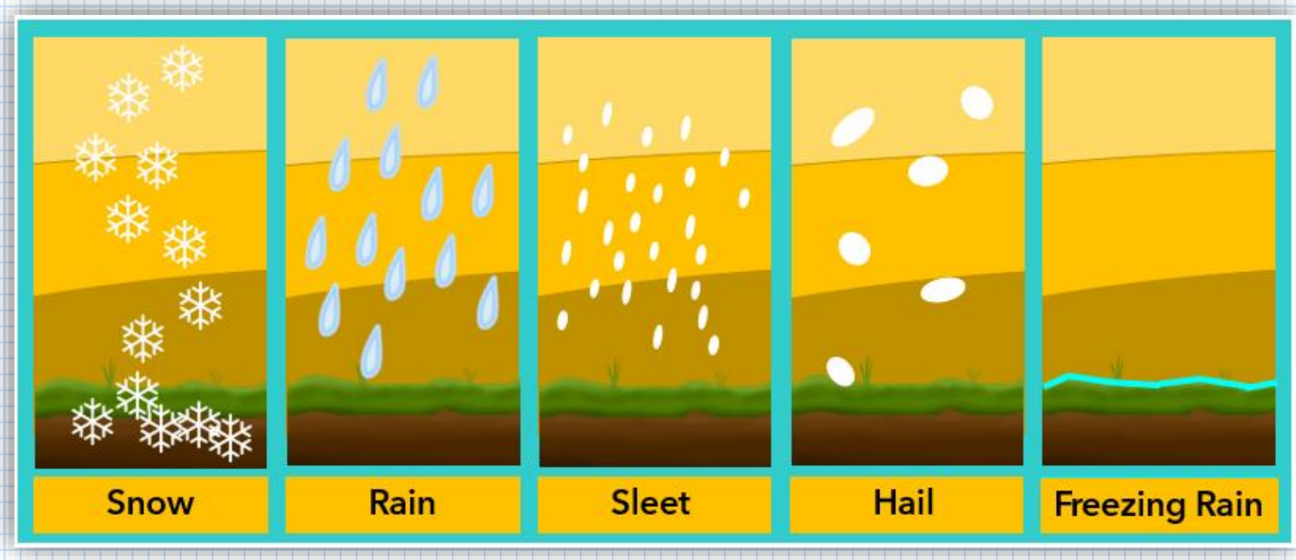
Condensation

- Condensation is the process by which water vapor in the air is changed into liquid water, creating clouds and fog.
- Condensation can happen high in the atmosphere or at ground level.
- Clouds form as water vapor condenses or becomes more concentrated (dense).



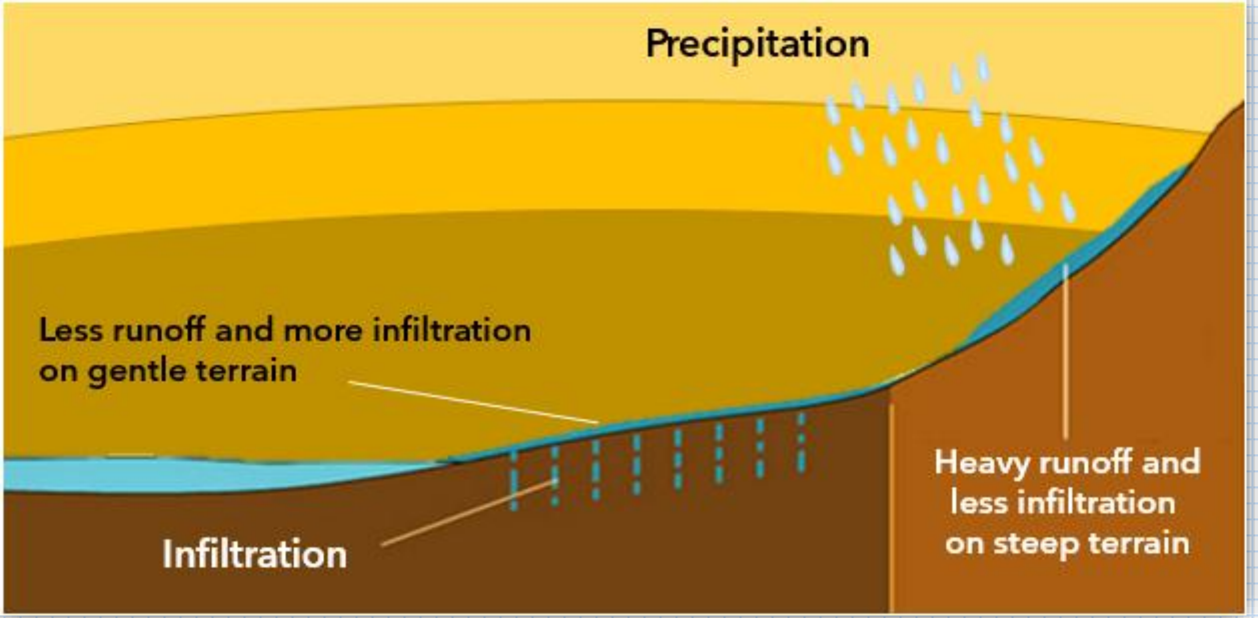
Precipitation

- Precipitation is defined as the condensed water vapor that falls to the earth surface in any physical form.



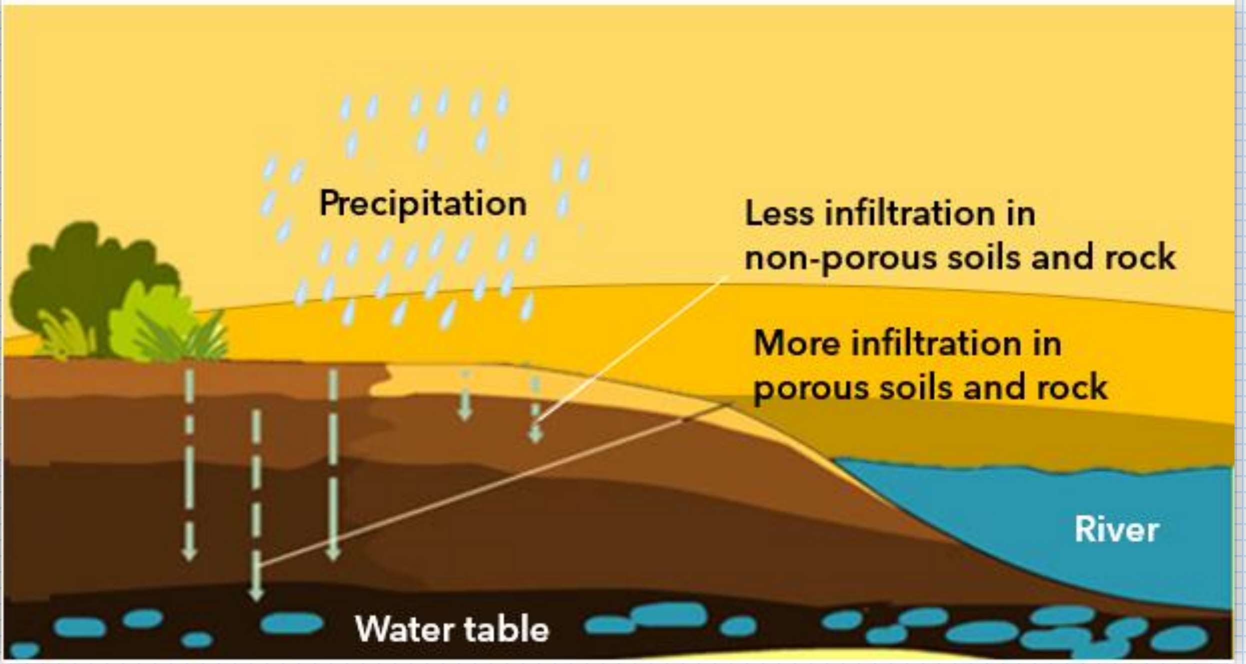
Surface Runoff

- The portion of the precipitation which by a variety of paths above and below the surface of the earth reaches the stream channel is called runoff.
- The draining or flowing off precipitation from a catchment area through a surface channel.



Infiltration

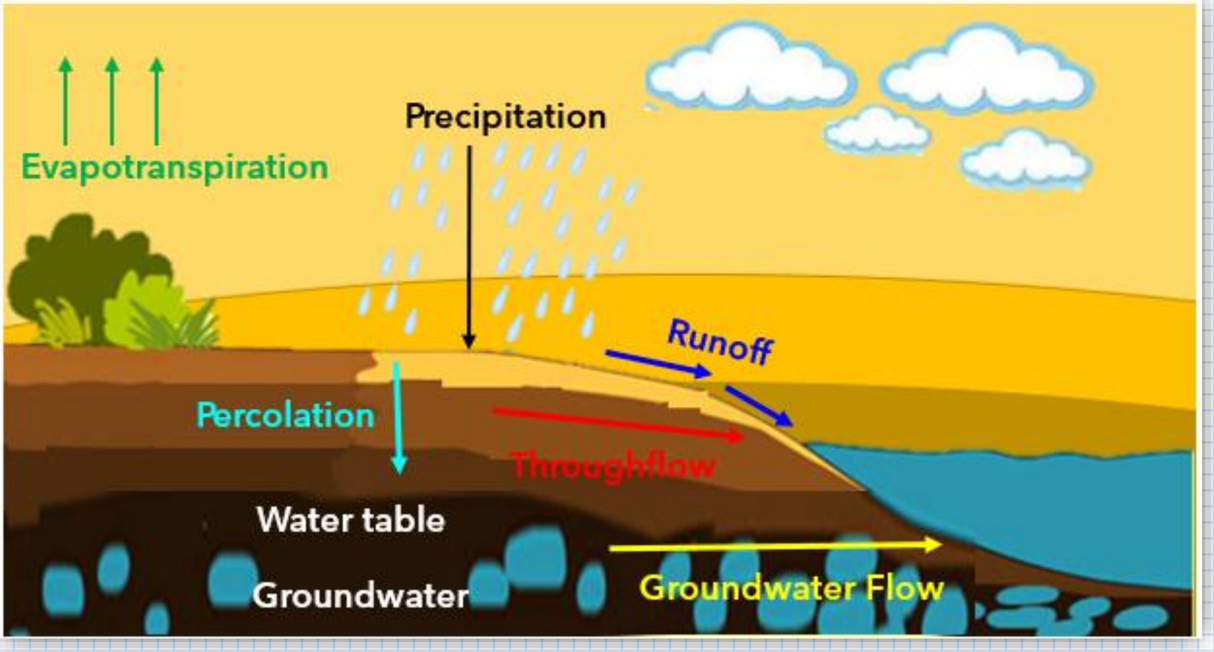
- Infiltration is the process by which water on the ground surface enters the soil.



Underground water

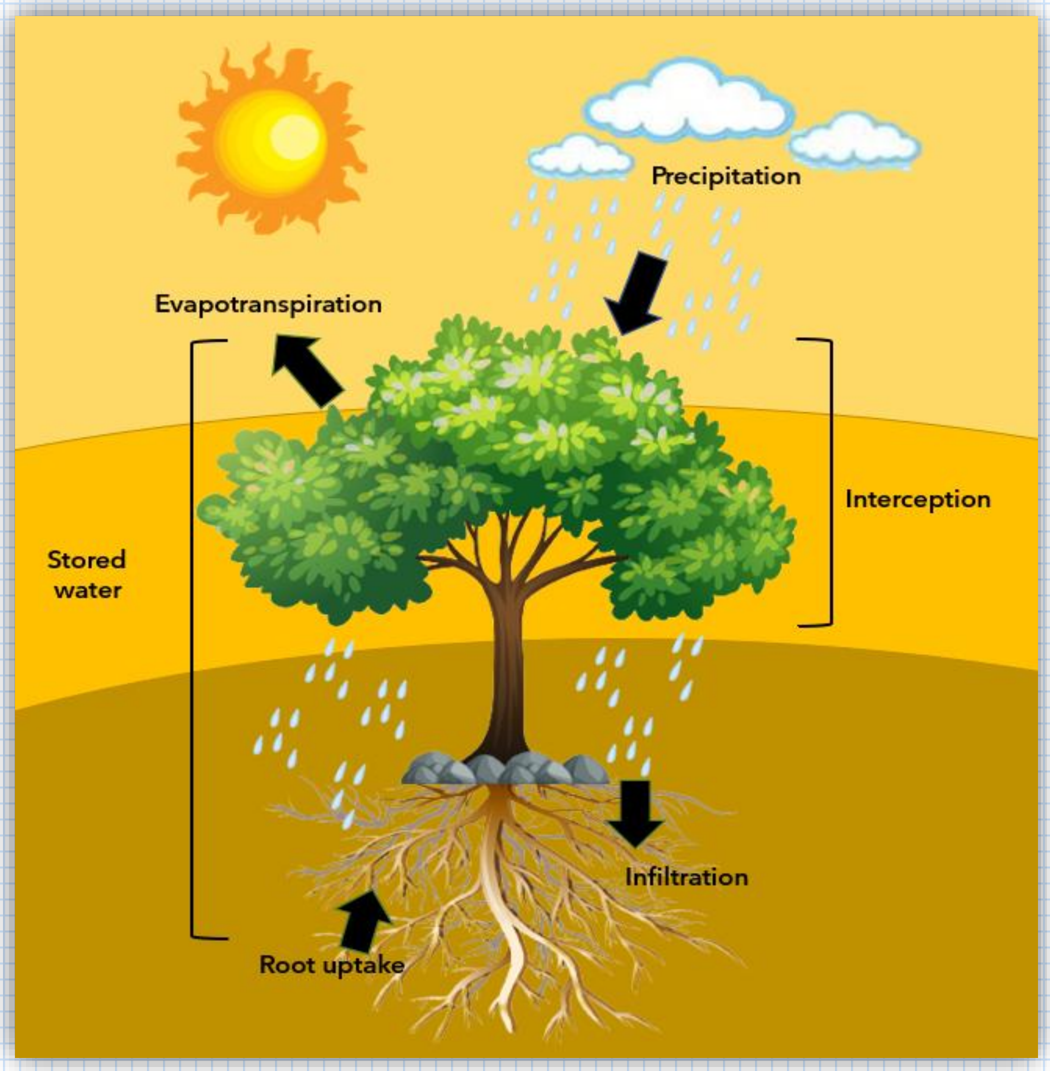
- Groundwater is fresh water (from rain or melting ice and snow) that soaks into the soil and is stored in the tiny spaces (pores) between rocks and particles of soil.

- Groundwater is water that exists underground in saturated zones beneath the land surface. The upper surface of the saturated zone is called the water table.



Interception

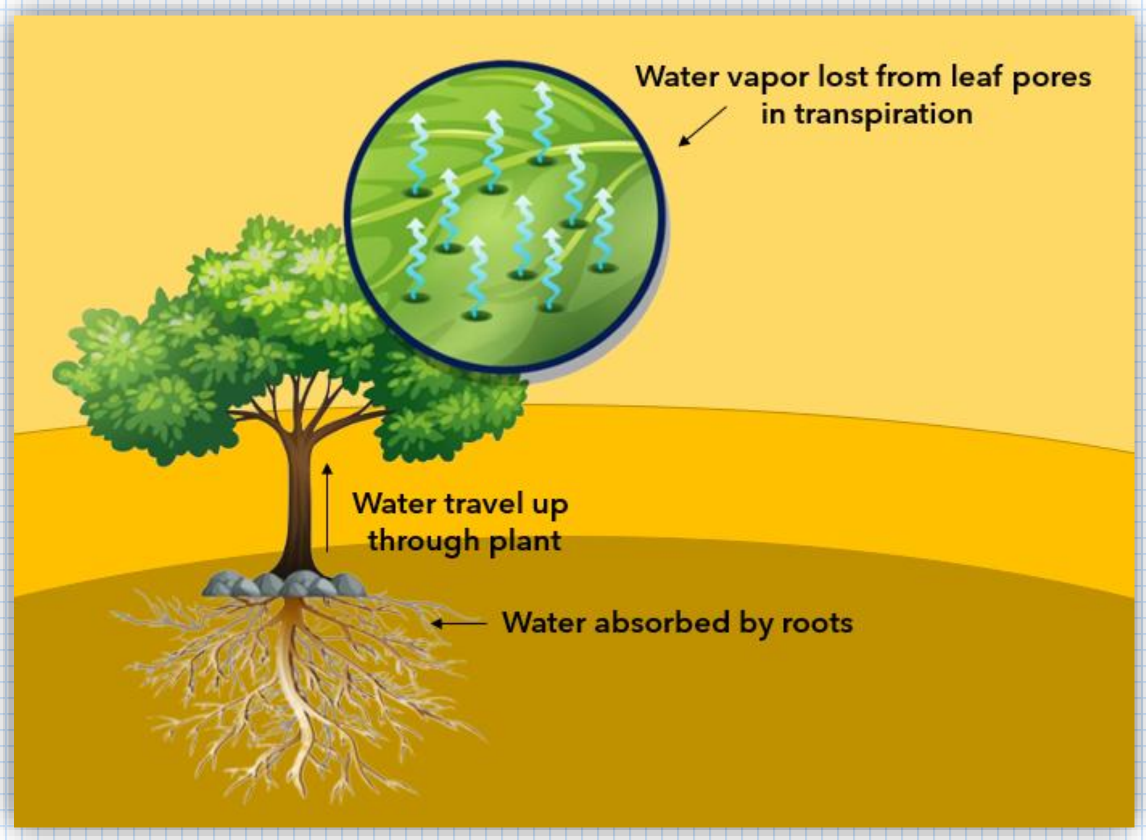
- Interception refers to precipitation that does not reach the soil but is instead intercepted by the leaves and branches of plants and the forest floor.



Transpiration

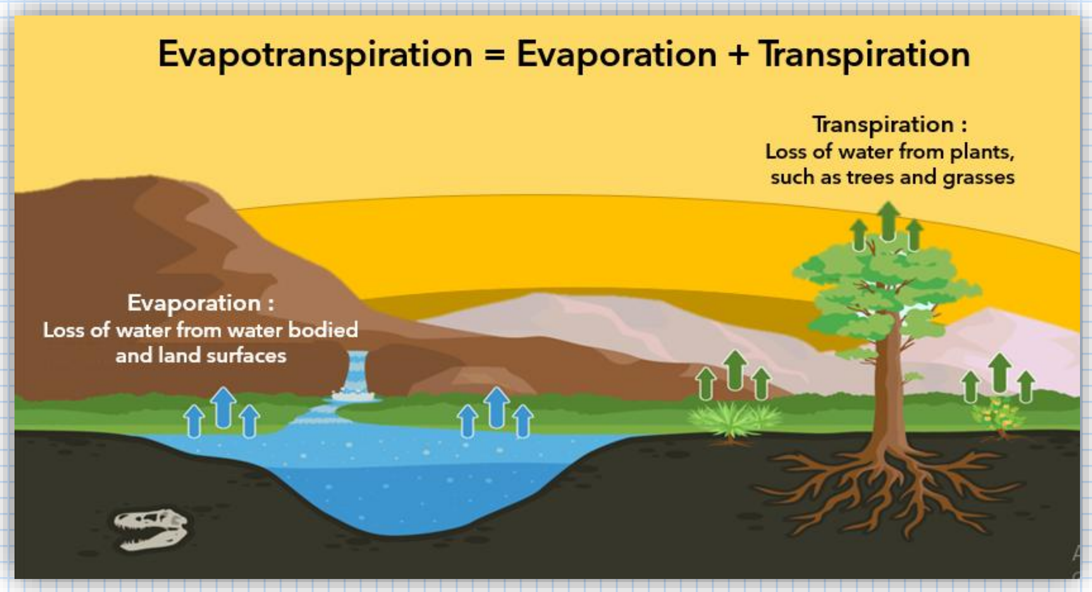
- Transpiration is the process by which water leaves the body of living plant and reaches the atmosphere as water vapor.

- Transpiration is essentially evaporation of water from plant.



Evapotranspiration

- Evapotranspiration is the sum of evaporation from the land surface plus transpiration from plants.
- The typical plant, including any found in a landscape, absorbs water from the soil through its roots.
- In general, evapotranspiration is the sum of evaporation and transpiration.



03 The climate change impact to the hydrological cycle

What is the Climate Change?

- Climate change refers to long-term shifts in temperatures and weather patterns.

- These shifts may be natural, but since the 1800s, human activities have been the main driver of climate change, primarily due to the burning of fossil fuels (like coal, oil, and gas) increasing heat-trapping greenhouse gas levels in the Earth's atmosphere.

- Climate change is likely causing parts of the water cycle to speed up as warming global temperatures increase the rate of evaporation worldwide.

- More evaporation is causing more precipitation, on average.

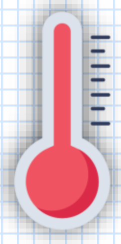
- We are already seeing impacts of higher evaporation and precipitation rates, and the impacts are expected to increase over this century as climate warms.

- Higher evaporation and precipitation rates are not evenly distributed around the world. Some areas may experience heavier than normal precipitation, and other areas may become prone to droughts, as the traditional locations of rain belts and deserts shift in response to a changing climate.

- Some climate models predict that coastal regions will become wetter, and the middle of continents will become drier.

- Also, some models forecast more evaporation and rainfall over oceans, but not necessarily over land.

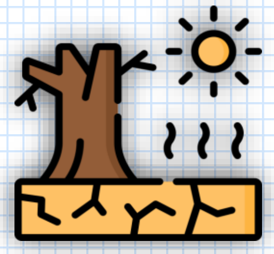
The Climate Change Impact To The Hydrological Cycle



Higher temperatures mean there is more evaporation from the land and sea into the atmosphere.

As air gets warmer, it can hold more water vapor. This can lead to more intense rainstorms.

Intense rainstorms increase the risk of flooding. Much of the water runs off into rivers and streams, doing little to dampen soil.



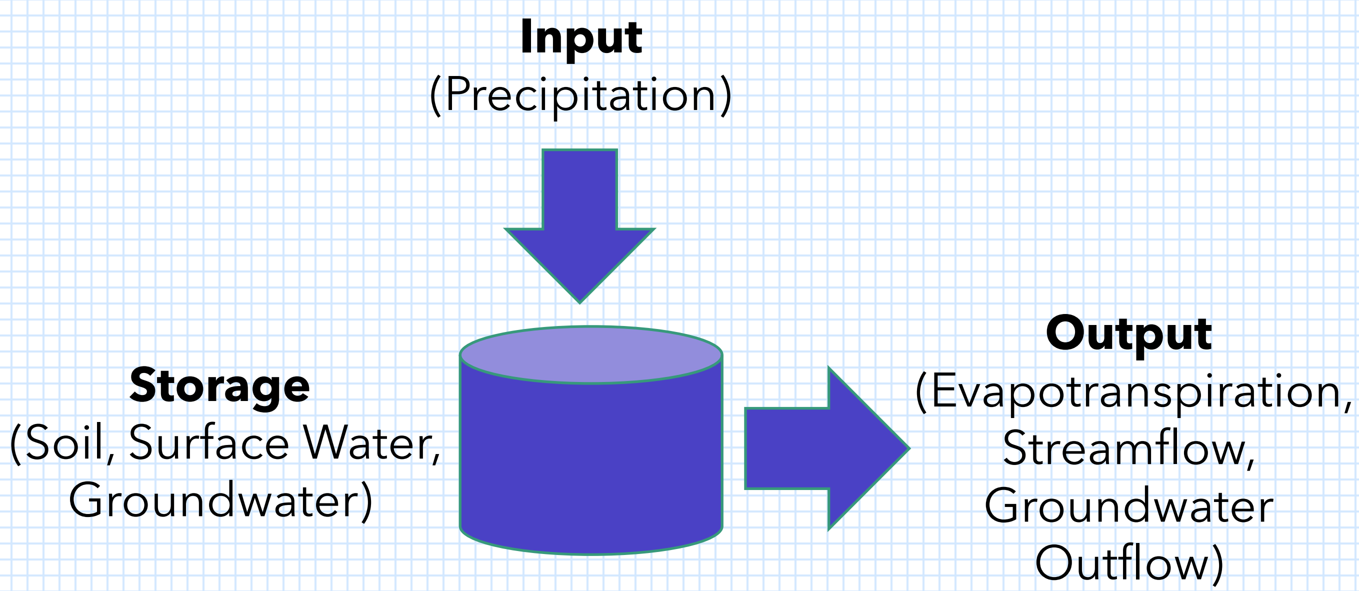
This combined with increased temperatures, increases the risk of drought.

04 The water balance calculation

Calculate The Water Balance

MASS BALANCE

$$\Sigma\, Inflows - \Sigma\, Outflows = \Delta\, Change\ in\ Storage$$



- Water balance equation in its most **fundamentals form** is given by :

$$P - Q - E - \Delta S = 0$$

Where;

P	:	Precipitation
E	:	Evaporation
Q	:	Runoff
ΔS	:	Change in Storage

The Hydrology Continuity Equation

- What comes in must go out or be stored.

$$\Sigma\, Inflows - \Sigma\, Outflows = \Delta\, Storages$$

$$P - R - ET - G - I = \Delta S$$

$$Runoff, R = \frac{Volume\ (m^3)}{Area\ (m^2)}$$

Where;

P	:	Precipitation
R	:	Surface Runoff
ET	:	Evapotranspiration
G	:	Underground Water
I	:	Infiltration
ΔS	:	Change in storage

PLEASE TAKE NOTE :

- ✓ Storage change ΔS = 0, inputs = outputs from year to year. (Average over long time e.g. 30 years)
- ✓ Assumes no significant climate changes, surficial changes, anthropogenic impacts, or major Δ Storage.
- ✓ Time averaging applied to develop conservation equation.

Example 1

In six months, Bukit Bauk watersheds are expected to receive rainfall of 350 mm. Evaporation s estimated at 100 mm and diffusion into the subsurface is estimated at 40 mm. Estimate the volume runoff directly in cubic meters to be stored in reservoirs that are available if the basin area is 85 km^2.

SOLUTION:

Given:

P	:	Precipitation	350 mm
R	:	Surface Runoff	?
E	:	Evaporation	100 mm
I	:	Infiltration	40 mm
A	:	Area	85 km^2

- Convert Area from km^2 to m^2

$$85\ km^2\ x\ \frac{1000\ m}{1\ km}\ x\ \frac{1000\ m}{1\ km} = 8.5\ x10^7 m^2$$

- Find R

P - R - E - I = ΔS
350 mm – R – 100 mm – 40 mm = 0
R = 210 mm

- Convert R from mm to m

$$210\ mm\ x\ \frac{1\ m}{1000\ m} = 0.21\ m$$

R = 0.21 m

- Put the value of R and Area into this equation $Runoff, R = \frac{Volume\ (m^3)}{Area\ (m^2)}$

$$Runoff, R = \frac{Volume\ (m^3)}{Area\ (m^2)}$$

$$0.21m = \frac{Volume\ (m^3)}{8.5\ x\ 10^7 m^2}$$

$$Volume\ (m^3) = 0.21\ m\ x\ (8.5\ x\ 10^7 m^2) = \mathbf{17.85\ x\ 10^6\ m^3}$$

Example 2

Two and half centimeters of rain per day over an area of 200 km^2 is equivalent to average rate of input of how many cubic meters per second of water to that area.

SOLUTION:

Given:

P	:	Precipitation	2.5 cm/day
R	:	Surface Runoff	-
ΔS	:	Change in storage	0
A	:	Area	200 km^2

- Convert Area from km^2 to m^2

$$200\ km^2\ x\ \frac{1000\ m}{1\ km}\ x\ \frac{1000\ m}{1\ km} = 2.0\ x10^8\ m^2$$

- Find R

P – R = ΔS
2.5 cm/day – R = 0
R = 2.5 cm/day

- Convert R from cm/day to m/s

$$2.5\ \frac{cm}{day}\ x\ \frac{1\ m}{100\ cm}\ x\ \frac{1\ day}{86400\ s} = 2.893x10^{-7}\ \frac{m}{s}$$

$$\mathrm{R} = 2.893\ x10^{-7}\ \frac{m}{s}$$

- Put the value of R and Area into this equation $Runoff, R = \frac{Volume\ (m^3)}{Area\ (m^2)}$

$$Runoff, R = \frac{Volume\ (m^3)}{Area\ (m^2)}$$

$$2.893\ x10^{-7}\ \frac{m}{s} = \frac{Volume\ (m^3)}{2.0\ x\ 10^8 m^2}$$

$$Volume\ \left(\frac{m^3}{s}\right) = \left[2.893\ x10^{-7}\ \frac{m}{s}\right] x\ [2.0\ x10^8 m^2] = \mathbf{57.87}\ \frac{\mathbf{m^3}}{\mathbf{s}}$$

Example 3

In a watershed that is 3.5 km^2, the volume of annual precipitation was 5,000 m^3 and the volume of water that was evaporated was 400 m^3. Estimate the volume of annual runoff (m^3). Assume that storage and groundwater flux are negligible.

SOLUTION:

Given:

Volume P	:	$5000\ m^3$
Volume E	:	$4000\ m^3$
Area A	:	$3.5\ km^2$

P - R - E - G - I = ΔS

P - R - E = ΔS

$5000\ m^3 - R - 400\ m^3 = 0$

$5000\ m^3 - R - 400\ m^3 = 4600\ m^3$

$R = 5000\ m^3 - 400\ m^3$

R = **4600 m^3**

Example 4

The Darul Aman Lake capacity storage in the beginning of June 2016 is $25 \times 10^6\ m^3$. During this time, the recorded inflow and outflow of the lake is $10\ m^3/s$ and $15.5\ m^3/s$ respectively. A month later, the lake received a rainfall of 100 cm and the evaporation from the lake was estimated to be 40 cm. The average surface area of the lake was $30km^2$. Calculate the changes of storage and its new storage of the lake (in m^3) at the end of July 2016. Assuming there is no contribution to or from the groundwater storage.

SOLUTION:

Given:

June 2016

Storage (S_1)	:	$25 \times 10^6\ m^3$
Inflow	:	$10\ m^3/s$
Outflow	:	$15.5\ m^3/s$

July 2016

P	:	Precipitation	100 cm	1.0 m
E	:	Evaporation	40 cm	0.40 m
A	:	Area	30 km^2	$30\ x\ 10^6\ m^2$

- Calculate Δt in Second for beginning of June 2016 to end of July 2016 (60 days)

$$\Delta t = 60\ day\ x\ \frac{86400\ s}{1\ day}$$

$$\Delta t = 5.184x\ 10^6\ s$$

- Convert Area (A) from km^2 to m^2

$$Area\ (A) = \ 30\ km^2\ x\ \frac{1000\ m}{1\ km}\ x\ \frac{1000\ m}{1\ km} = 30\ x10^6\ m^2$$

- Convert Inflow from $\frac{m^3}{s}$ to m^3

  $\text{Inflow} = 10 \frac{m^3}{s} \, x \, \Delta t = 10 \frac{m^3}{s} \, x \, (5.184x \, 10^6 s) = 51.84 \, x10^6 \, m^3$

- Convert Outflow from $\frac{m^3}{s}$ to m^3

  $\text{Outflow} = 15.5 \frac{m^3}{s} \, x \, \Delta t = 15.5 \frac{m^3}{s} \, x \, (5.184x \, 10^6 \, s) = 80.352 \, x10^6 \, m^3$

- Convert Precipitation (P) from m to m^3

  $P = 1.0 \, m \, x \, Area \, (A)$

  $P = 1.0 \, m \, x \, (30 \, x \, 10^6 \, m^2) = 30 \, x \, 10^6 \, m^3$

- Convert Evaporation (E) from m to m^3

  $E = 0.40 \, m \, x \, Area \, (A)$

  $E = 0.40 \, m \, x \, (30 \, x \, 10^6 \, m^2) = 12 \, x \, 10^6 \, m^3$

1. Calculate Change in Storage Δs

$\Delta S = [Inflow + \text{Precipitation (P)}] - [\text{Outflow} + \text{Evaporation (E)}]$

$\Delta S = [(51.84 \, x10^6 \, m^3) + (30 \, x \, 10^6 \, m^3)] - [(80.352 \, x10^6 \, m^3) + (12 \, x \, 10^6 \, m^3)]$

$\Delta S = \mathbf{-10.512 \, x \, 10^6 m^3}$

2. Calculate the new storage, S_2

Given $S_1 = 25 \times 10^6 \, m^3$

$\Delta S = S_2 - S_1$

$S_2 = \Delta S + S_1$

$S_2 = (-10.512 \, x \, 10^6 \, m^3) + (25 \times 10^6 \, m^3)$

$S_2 = \mathbf{14.488 \, x \, 10^6 \, m^3}$

Example 5

The water storage in a Kerteh river at a particular time is 20 000 m^3. At that time, the recorded inflow and outflow were 10 m^3/s and 15 m^3/s respectively. One hour later, the inflow and outflow were recorded as 15 m^3/s and 16 m^3/s respectively. Calculate the change of storage and the new storage of water in the river.

SOLUTION:

Given:

Storage	:	20 000 m^3	1 hour later	:	3600s
$Inflow_1$	:	$10\ m^3/s$	$Inflow_2$	:	$15\ m^3/s$
$Outflow_1$	:	$15\ m^3/s$	$Outflow_2$	:	$16\ m^3/s$

- Convert $Inflow_1$ from $\frac{m^3}{s}$ to m^3

$$Inflow_1 = 10\ \frac{m^3}{s}\ x\ \Delta t$$

$$Inflow_1 = 10\ \frac{m^3}{s}\ x\ (3600s) = 36000\ m^3$$

- Convert $Outflow_1$ from $\frac{m^3}{s}$ to m^3

$$Outflow_1 = 15\ \frac{m^3}{s}\ x\ \Delta t$$

$$Outflow_1 = 15\ \frac{m^3}{s}\ x\ (3600\ s) = 54000\ m^3$$

- Convert $Inflow_2$ from $\frac{m^3}{s}$ to m^3

$$Inflow_2 = 15\ \frac{m^3}{s}\ x\ \Delta t$$

$$Inflow_2 = 15\ \frac{m^3}{s}\ x\ (3600\ s) = 54000\ m^3$$

- Convert $Outflow_2$ from $\frac{m^3}{s}$ to m^3 :

$$Outflow_2 = 16\ \frac{m^3}{s}\ x\ \Delta t$$

$$Outflow_2 = 16\ \frac{m^3}{s}\ x\ (3600s) = 57600\ m^3$$

1. Calculate Change in Storage Δs

$$\Delta S = \frac{\sum[Inflow_1 - \ Inflow_2] - \sum[Outflow_1 + \ Outflow_2]}{2}$$

$$\Delta S = \frac{[(36000\ m^3) + (54000\ m^3)] - [(54000\ m^3) + (57600\ m^3)]}{2}$$

$$\Delta S = \frac{90000\ m^3 - 111600\ m^3}{2}$$

$$\Delta S = \mathbf{-108000\ m^3}$$

2. Calculate the new storage, S_2

Given $S_1 = \ 20\ 000\ m^3$

$$\Delta S = S_2 - S_1$$

$$-108000\ m^3 m^3 = S_2 - S_1$$

$$S_2 = \ \Delta S + S_1$$

$$S_2 = (-108000\ m^3\ m^3) + (20\ 000\ m^3)$$

$$S_2 = \mathbf{9200\ m^3}$$

Example 6

Based on observation, the water flow rate that entering Dungun Reservoir in a certain season is 350 m^3/s. If the outflow from the reservoir including infiltration and evaporation loses is 265 m^3/s, calculate the change in storage for 14 days.

SOLUTION:

Given:

$Inflow$: $350\ m^3/s$

$Outflow$: $265\ m^3/s$

14 days : Second?

- Find Δt for 14 days in second

  $\Delta t = 14\ day\ x\ \frac{86400\ s}{1\ day} = 1.2096\ x\ 10^6\ s$

- Convert Inflow from $\frac{m^3}{s}$ to m^3

  $\text{Inflow} = 350\ \frac{m^3}{s}\ x\ \Delta t = 350\ \frac{m^3}{s}\ x\ (1.2096\ x\ 10^6\ s\ ) = 423.36\ x10^6\ m^3$

- Convert Outflow from $\frac{m^3}{s}$ to m^3

  $\text{Outflow} = 265\frac{m^3}{s}\ x\ \Delta t = 265\frac{m^3}{s}\ x\ (1.2096\ x\ 10^6\ s\ ) = 320.544\ x10^6\ m^3$

- **Calculate the Change in Storage Δs for 14 days**

  $\Delta S = [Inflow] - [\text{Outflow}]$

  $\Delta S = [423.36\ x10^6\ m^3] - [320.544\ x10^6\ m^3]$

  $\Delta S = \mathbf{102.816\ x\ 10^6\ m^3}$

Example 7

A Marang river reach had a flood wave passing through it. At a given instant the storage of water in the reach was estimated as 15.5 ha.m. What would be the storage in the reach after an interval of 3 hours if the average inflow and outflow during the time period are 14.2 m^3/s and 10.6 m^3/s respectively.

SOLUTION:

Given:

Storage : 15.5 ha.m (Hectare Meters)

$Inflow$: $14.2\ m^3/s$

$Outflow$: $10.6\ m^3/s$

3 hours : Second?

- Find Δt for 3 hours

  $\Delta t = 3\ hours\ x\ \frac{3600\ s}{1\ hours} = 10.8\ x\ 10^3\ s$

- Convert Storage (S1) from ha.m (Hectare Meters) to m^3

  $\text{Storage (S1)} = 15.5\ \text{ha.m}\ \ x\ (\frac{10000\ m^3}{1\ ha.m}) = 155\ x\ 10^3\ m^3$

  $\text{Storage (S1)} = 155000\ m^3$

- Convert Inflow from $\frac{m^3}{s}$ to m^3

  $\text{Inflow} = 14.2\ \frac{m^3}{s}\ x\ \Delta t = 14.2\ \frac{m^3}{s}\ x\ (10.8\ x\ 10^3\ s\ ) = 153.36\ x\ 10^3\ m^3$

- Convert Outflow from $\frac{m^3}{s}$ to m^3

  $\text{Outflow} = 10.6\ \frac{m^3}{s}\ x\ \Delta t = 10.6\ \frac{m^3}{s}\ x\ (10.8\ x\ 10^3\ s\ ) = 114.48\ x\ 10^3\ m^3$

1. Calculate the Change in Storage Δs for 3 hours

$\Delta S = [Inflow] - [\text{Outflow}]$

$\Delta S = [153.36\ x\ 10^3\ m^3] - [114.48\ x\ 10^3\ m^3]$

$\Delta S = \mathbf{38880\ m^3}$

2. Calculate the new storage, S_2

Given $S_1 = 155000\ m^3$

$\Delta S = S_2 - S_1$

$S_2 = \Delta S + S_1$

$S_2 = 38880\ \text{m}^3 + 155000\ m^3$

$S_2 = \mathbf{193880\ m^3}$

Example 8

The annual evaporation from a lake is found to be 125 cm. If the lake's surface area is 12 km^2. What is the daily evaporation rate in centimeters?

SOLUTION:

Given:

E	:	Evaporation	125 cm
A	:	Area	85 km^2
Δt	:	Annual = 1 year = 365days	

- Convert Evaporation (E) from cm to $\frac{cm}{day}$

$$\text{Evaporation (E)} = \frac{125\ cm}{365\ day} = \mathbf{0.342}\,\frac{\mathbf{cm}}{\mathbf{day}}$$

Example 9

If the mean annual runoff of a drainage basin of 10 000 km^2 is 140 m^3 and the average annual precipitation is 105 cm, estimate the ET losses for the area in 1 year.

SOLUTION:

Given:

R	:	Surface Runoff	$140 \ \frac{m^3}{year}$	
P	:	Precipitation	$105 \ \frac{cm}{year}$	
A	:	Area	10 000 km^2	$10 \ x 10^9 m^2$
Δt	:	Annual = 1 year		

- Convert Area (A) from km^2 to m^2 :

$$Area\ (A) = \ 10\ 000\ km^2\ x\ \frac{1000\ m}{1\ km}\ x\ \frac{1000\ m}{1\ km} = 10\ x 10^9\ m^2$$

- Convert Surface Runoff (R) from $\frac{m^3}{year}$ to $\frac{m}{year}$:

$$R = \frac{1.05\ \frac{m^3}{year}}{Area\ (A)}$$

$$R = \frac{1.05\ \frac{m^3}{year}}{(10\ x 10^9\ m^2)}$$

$$R = 1.05\ x\ 10^{-10}\ \frac{m}{year}$$

- Convert Surface Runoff (R) from $\frac{m}{year}$ to $\frac{cm}{year}$

$$R = \ 1.05\ x\ 10^{-10}\ \frac{m}{year}\ x\ \frac{100\ cm}{1m} = 1.05\ x 10^{-8}\ \frac{cm}{year}$$

- Find ET,

P - E - I - R = 0

P - ET - R = 0

ET = P - R

ET = $\mathbf{105}\ \frac{cm}{year}$

Example 10

A lake has an area of 5000 ha. During a specific month, the lake evaporation was 6.1 cm. During the same month, the inflow to the lake from a river was on average 6 m^3/s and the outflow from the lake via another river was on average 6.5 m^3/s. Also, for the same month a water level increase of 58 mm for the lake was observed. Calculate the precipitation in mm during that month.

SOLUTION:

Given:

A	:	Area	5000 ha	$50.0 \ x \ 10^2 \ m^2$
ΔS	:	58 mm		
E	:	Evaporation	6.1 cm	61 mm
$Inflow$	:		$6.0 \ m^3/s$	
$Outflow$	:		$6.5 \ m^3/s$	
1 month	:	30 days		$2.592 \ x \ 10^6 s$

- Find Δt for 30 days in second

$$\Delta t = 30 \ day \ x \ \frac{86400 \ s}{1 \ day}$$

$$\Delta t = 2.592 \ x \ 10^6 \ s$$

- Convert Area (A) from ha to m^2:

$$Area \ (A) = \ 5000 \ ha \ \ x \ \frac{10\ 000 \ m^2}{1 \ ha} = 50.0 \ x 10^6 \ m^2$$

- Convert E from cm to mm:

$$6.1 \ cm \ x \ \frac{10 \ mm}{1 \ cm} = 61.0 \ mm$$

$$E = 61.0 \ mm$$

- Convert Inflow from $\frac{m^3}{s}$ to mm

$$\text{Inflow} = 6.0\ \frac{m^3}{s}\ x\ \Delta t = 6.0\frac{m^3}{s}\ x\ (2.592\ x\ 10^6 s\ )$$

$$\text{Inflow} = 15.552\ x\ 10^6\ m^3$$

Convert Inflow from m^3 to m

$$\text{Inflow} = \frac{15.552\ x\ 10^6\ m^3}{Area\ (A)}$$

$$\text{Inflow} = \frac{15.552\ x\ 10^6\ m^3}{50.0\ x10^6\ m^2}$$

$$\text{Inflow} = 0.3110\ m$$

Convert Inflow from m to mm :

$$\text{Inflow} = 0.31104\ m\ x\ \frac{1000\ mm}{1m}$$

$$\text{Inflow} = \mathbf{311.0\ mm}$$

- Convert Outflow from $\frac{m^3}{s}$ to mm

$$\text{Outflow} = 6.5\frac{m^3}{s}\ x\ \Delta t = 6.5\frac{m^3}{s}\ x\ (2.592\ x\ 10^6 s\ )$$

$$\text{Outflow} = 16.835\ x\ 10^6\ m^3$$

Convert Outflow from m^3 to m

$$\text{Outflow} = \frac{16.835\ x\ 10^6\ m^3}{Area\ (A)}$$

$$\text{Outflow} = \frac{16.835\ x\ 10^6\ m^3}{50.0\ x10^6\ m^2}$$

$$\text{Outflow} = 0.3367\ m$$

Convert Outflow from m to mm

$$\text{Outflow} = 0.3367\ m\ x\ \frac{1000\ mm}{1m}$$

$$\text{Outflow} = \mathbf{336.7\ mm}$$

- Calculate the precipitation in mm during that month

$\Delta S = [Inflow + \text{Precipitation (P)}] - [\text{Outflow} + \text{Evaporation (E)}]$

$58\ mm = [311.0\ mm + \text{Precipitation (P)}] - [336.7\ mm + 61.0\ \text{mm}]$

$58\ mm = [311.0\ mm + \text{Precipitation (P)}] - [397.96\ \text{mm}]$

$58\ mm\ + 397.96\ \text{mm} = [311.0\ mm + \text{Precipitation (P)}]$

$\text{Precipitation (P)} = \ 58\ mm\ + 397.96\ \text{mm} - \ [311.0\ mm]$

$Precipitation\ (P) = \ \mathbf{144.96\ mm\ \approx 145\ mm}$

Example 11

In a certain month, Klang River catchment area was estimated to receive precipitation of 6.8 m^3/s. During that month, the evaporation and infiltration to subsurface were estimated to be 128 mm and 38 mm respectively. Determine the volume of surface runoff (in m^3) in that month if the catchment area is 86 km^2.

SOLUTION:

Given:

P	:	Precipitation	$6.8\frac{m^3}{s}$	3.15m
R	:	Surface Runoff	?	
E	:	Evaporation	128mm	0.128m
I	:	Infiltration	38 mm	0.038m
A	:	Area	86 km^2	$86\ x10^6 m^2$

- Find Δt for a 1 month (30 days) :

$$\Delta t = 30\ day\ x\ \frac{86400\ s}{1\ day} = 2.592\ x\ 10^6\ s$$

- Convert Area from km^2 to m^2 :

$$Area\ (A) = 86km^2\ x\ \frac{1000m}{1km}\ x\ \frac{1000m}{1km} = 86\ x10^6 m^2$$

- Convert Precipitation (P) from $\frac{m^3}{s}$ to m :

$$P = 6.8\frac{m^3}{s}\ x\ \Delta t$$

$$P = 6.8\frac{m^3}{s}\ x\ (2.592\ x\ 10^6\ s) = 17.626\ x\ 10^6 m^3$$

- Convert Evaporation (E) from m to m^3 :

$E = 0.128m \; x \; Area \; (A) = 0.128m \; x \; (86 \; x10^6 m^2) = 11.008 \; x10^6 m^3$

- Convert Infiltration (I) from m to m^3 :

$I = 0.038m \; x \; Area \; (A) = 0.038m \; x \; (86 \; x10^6 m^2) = 3.268 \; x10^6 m^3$

- Calculate the volume of surface runoff (Find R) :

P – R – E – G – I = $\Delta \boldsymbol{S}$

R = P – E – I

R =$(17.626 \; x \; 10^6 m^3) - (11.008 \; x10^6 m^3) - (3.268 \; x10^6 m^3)$

R = $\mathbf{3.35 \; x10^6 m^3}$

Example 12

In year 2023, a catchment area of 120 km² in Kuantan, Pahang receives an average annual rainfall of 4500 mm. Determine the volume of evaporation (in m³) for the catchment in that year if the runoff and infiltration are 6.8 m³/s and 5.2 m³/s respectively.

SOLUTION:

Given:

P	:	Precipitation	$4500\ mm$	4.5m
R	:	Surface Runoff	$6.8\frac{m^3}{s}$	
E	:	Evaporation	?	
I	:	Infiltration	$5.2\frac{m^3}{s}$	
A	:	Area	120 km²	$120\ x10^6 m^2$

- Find Δt for a 1 year (365 days)

$$\Delta t = 365\ day\ x\ \frac{86400\ s}{1\ day} = 31.536\ x\ 10^6\ s$$

- Convert Area from km² to m² :

$$Area\ (A) = 120km^2\ x\ \frac{1000m}{1km}\ x\ \frac{1000m}{1km} = 120\ x10^6 m^2$$

- Convert Precipitation (P) from m to m^3:

$$P = 4.5m\ x\ Area\ (A)$$

$$P = 4.5m\ x\ (120\ x10^6 m^2) = 540\ x\ 10^6 m^3$$

- Convert Runoff (R) from $\frac{m^3}{s}$ to m^3 :

$R = \ 6.8\frac{m^3}{s}\ x\ \Delta t$

$R = \ 6.8\frac{m^3}{s}\ x\ (31.536\ x\ 10^6\ s) = 214.44\ x\ 10^6 m^3$

- Convert I from $\frac{m^3}{s}$ to m^3 :

$I = 5.2\frac{m^3}{s}\ x\ \Delta t = 5.2\frac{m^3}{s}\ x\ (31.536\ x\ 10^6\ s\ ) = 163.987\ x10^6 m^3$

- Calculate the volume of evaporation (Find E)

P - R - E - G - I = $\Delta\boldsymbol{S}$

E = P - R - I

E = $(540\ x\ 10^6 m^3) - (214.44\ x\ 10^6 m^3) - (163.987\ x10^6 m^3)$

E = $\mathbf{161.573\ x10^6 m^3}$

Example 13

The storage of a lake at beginning of March 2016 is 25 x 106 m^3. During this time, the recorded inflow and out flow the lake is 10.0 m^3/s and 15.5 m^3/s respectively. A month later, the lake received a rainfall of 100 cm and the evaporation from the lake was estimated to be 40 cm. The average surface area of the lake was 30 km^2. Calculate the change of storage and the new storage of the river (in m^3) at the end of April 2016. Assume there is no contribution to or from the groundwater storage.

SOLUTION:

Given:

March 2016

Storage (S_1)	:	$25 \times 10^6 m^3$
Inflow	:	$10\ m^3/s$
Outflow	:	$15.5 m^3/s$

April 2016

P	:	Precipitation	100 cm	1.0 m
E	:	Evaporation	40 cm	0.40 m
A	:	Area	30 km^2	$30\ x\ 10^6 m^2$

- Calculate Δt in Second for beginning of March 2016 to end of April 2016 (60 days)

$$\Delta t = 60 day\ x\ \frac{86400s}{1day}$$

$$\Delta t = 5.184x\ 10^6 s$$

- Convert Area (A) from km^2 to m^2 :

$$Area\ (A) = \ 30km^2\ x\ \frac{1000m}{1km}\, x\, \frac{1000m}{1km} = 30\ x10^6 m^2$$

- Convert Inflow from $\frac{m^3}{s}$ to m^3 :

$$Inflow = 10\frac{m^3}{s}\ x\ \Delta t = 10\frac{m^3}{s}\ x\ (5.184x\ 10^6 s\ ) = 51.84\ x10^6 m^3$$

- Convert Outflow from $\frac{m^3}{s}$ to m^3 :

$$Outflow = 15.5\frac{m^3}{s}\ x\ \Delta t = 15.5\frac{m^3}{s}\ x\ (5.184x\ 10^6 s\ ) = 80.352\ x10^6 m^3$$

- Convert Precipitation (P) from m to m^3:

$P = \ \ 1.0m\ x\ Area\ (A)$

$P = \ \ 1.0m\ x\ (30\ x\ 10^6 m^2) = 30\ x\ 10^6 m^3$

- Convert Evaporation (E) from m to m^3:

$E = \ \ 0.40m\ x\ Area\ (A)$

$E = \ \ 0.40m\ x\ (30\ x\ 10^6 m^2) = 12\ x\ 10^6 m^3$

1. Calculate Change in Storage Δs

$\Delta S = [Inflow + \text{Precipitation (P)}] - [\text{Outflow} + \text{Evaporation (E)}]$

$\Delta S = [(51.84\ x10^6 m^3) + (30\ x\ 10^6 m^3)] - [(80.352\ x10^6 m^3) + (12\ x\ 10^6 m^3)]$

$\Delta S = [81.84\ x10^6 m^3] - [92.352\ x10^6 m^3]$

$\Delta S = \mathbf{-10.512\ x\ 10^6 m^3}$

2. Calculate the new storage, S_2

Given $S_1 = \ 25 \times 10^6 m^3$

$\Delta S = S_2 - S_1$

$S_2 = \ \Delta S + S_1$

$S_2 = (-10.512\ x\ 10^6 m^3) + (25 \times 10^6 m^3)$

$S_2 = \mathbf{14.488\ x\ 10^6 m^3}$

Example 14

A beginning storage of a lake is 100 000 m³. The recorded inflow and outflow of the lake is 5m3/s and 5.5 m3/s respectively. The lake had an area of 25 ha received a rainfall of intensity 4mm/hr and experienced evaporation of 0.32 cm for 5 hr. Determine the change of storage and the new storage (in m³) of the lake at the end of 5 hr. Assume there is no contribution to or from the groundwater storage.

SOLUTION:

Given:

S_1	:	Storage	$100\ 000 m^3$
Inflow	:		$5\ m^3/s$
Outflow	:		$5.5\ m^3/s$
P	:	Precipitation	4 mm/hr
E	:	Evaporation	0.32 cm
A	:	Area	25 ha
Δt	:	Time	5 hours

- Calculate Δt in Second for 5 hours

$$\Delta t = 5\ hours\ x\ \frac{3600s}{1\ hours}$$

$$\Delta t = 18000s$$

- Convert Area (A) from ha to m² :

$$Area\ (A) = \ 25\ ha\ x\ \frac{10000\ m^2}{1\ ha} x = 25.0\ x10^4 m^2$$

- Convert Inflow from $\frac{m^3}{s}$ to m^3 :

$$\text{Inflow} = 5\frac{m^3}{s}\ x\ \Delta t = 5\frac{m^3}{s}\ x\ (18000s\ ) = 90.0\ x10^3 m^3$$

- Convert Outflow from $\frac{m^3}{s}$ to m^3 :

$$Outflow = 5.5\frac{m^3}{s}\ x\ \Delta t = 5.5\frac{m^3}{s}\ x\ (18000s\ ) = 99.0\ x10^3 m^3$$

- Convert Precipitation (P) from mm/hr to m^3:

$$P = \ 4\frac{mm}{hr}\ x\ \frac{1m}{1000mm} = \ 0.004\ \frac{m}{hr}$$

$$P = \ 0.004\frac{m}{hr}\ x\ \Delta t$$

$$P = \ 0.004\frac{m}{hr}\ x\ 5\ hr = \ 0.02\ m$$

$$P = \ 0.02\ m\ x\ Area\ (A)$$

$$P = \ 0.02\ m\ x\ (25.0\ x10^4 m^2) = 5000m^3$$

- Convert Evaporation (E) from m to m^3 :

$$E = \ 0.32cm\ x\ \frac{1m}{100cm} = \ 3.2\ x\ 10^{-3}m$$

$$E = (3.2\ x\ 10^{-3}m)\ x\ Area\ (A)$$

$$E = (3.2\ x\ 10^{-3}m) x\ (25.0\ x10^4 m^2) = 800m^3$$

1. Calculate Change in Storage Δs

$$\Delta S = [Inflow + \text{Precipitation (P)}] - [\text{Outflow} + \text{Evaporation (E)}]$$

$$\Delta S = [(90.0\ x10^3 m^3) + (5000m^3)] - [(99.0\ x10^3 m^3) + (800m^3)]$$

$$\Delta S = [95000\ m^3] - [99800\ m^3]$$

$$\boldsymbol{\Delta S = -4800m^3\ \approx\ -4.8\ x10^3 m^3}$$

2. Calculate the new storage, S_2

Given $S_1 = \ 100\ 000m^3$

$$\Delta S = S_2 - S_1$$

$$S_2 = \ \Delta S + S_1$$

$$S_2 = (-4800\text{m}^3) + (100\ 000m^3)$$

$$\boldsymbol{S_2 = 95200m^3\ \approx\ 95.2\ x10^3 m^3}$$

INTRODUCTION TO HYDROLOGY

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