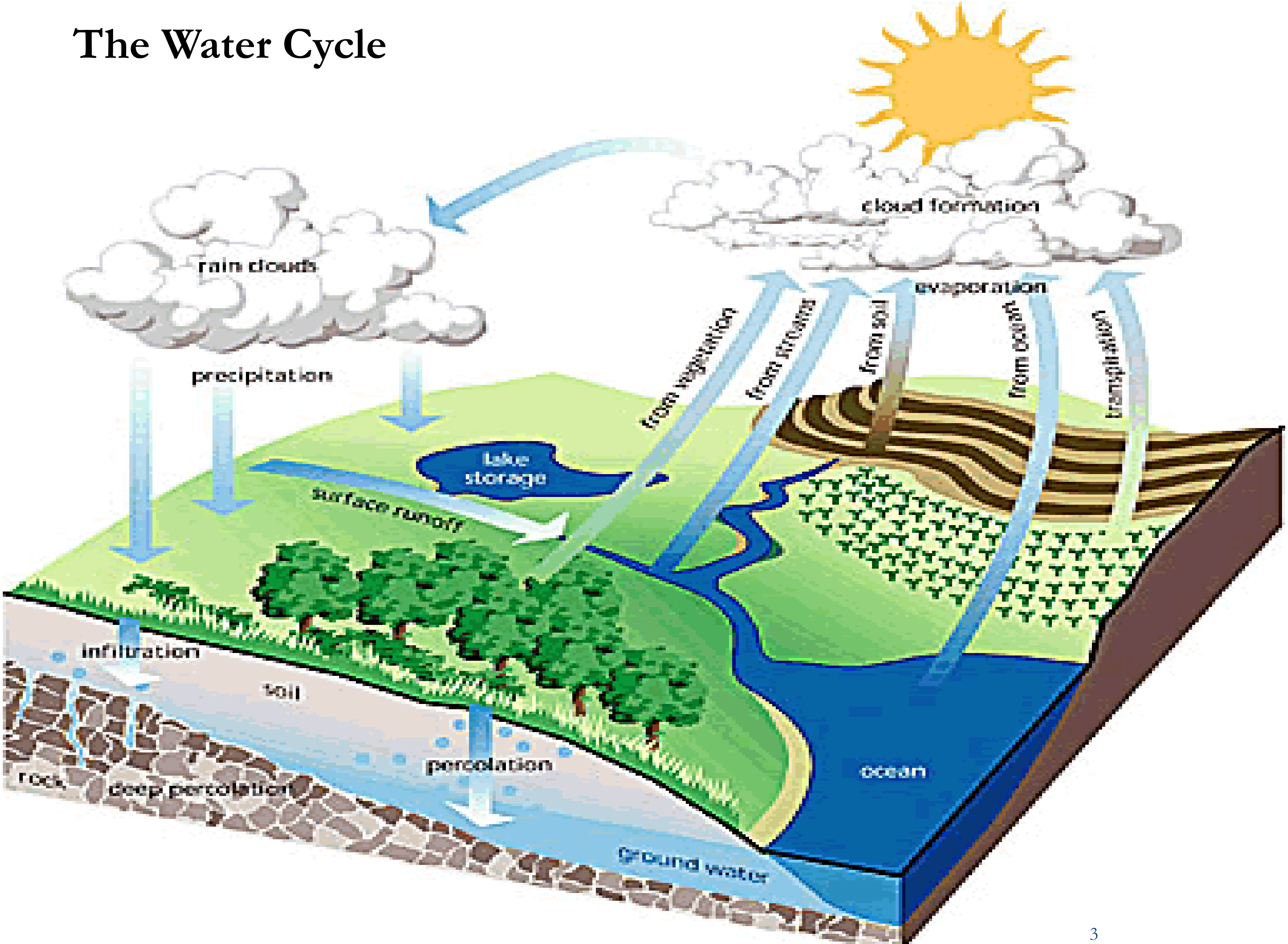
HYDROLOGY - BASIC CONCEPTS

Hydrology

* Hydrology is the science of the waters of the earth and its atmosphere. It deals with occurrence, circulation, distribution and movements of these waters over the globe and their interaction with the physical and biological environments.

The Water Cycle



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.

Floods & Droughts

Need for the Hydrologic Studies

* The need of the hydrologic studies arises from the following problems:
  * Uncertainty of precipitation and its seasonal occurrence
  * Seasonal flow of rivers, and
  * Population growth and rising standards of living

Continued….

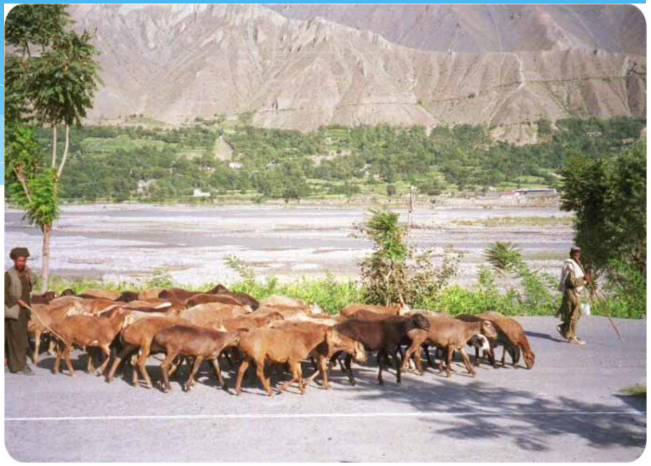
Need for the Hydrologic Studies

* In many countries water is the main source of energy and the agriculture is an important sector for their economic growth. Although water is vital to life, but the precipitation which is the main source of water, is an uncertain phenomenon i. e. there might be plenty of rainfall when we do not need it and no rain when it is required. So we need to plan accordingly. It is necessary to store surplus water when and where available and to use it when and where required. Uncertainty of precipitation makes the study of various features of hydrology exceedingly important, which then will be helpful in better planning and development of water resources.

Continued….

Need for the Hydrologic Studies

* The flow in rivers varies from season to season. There are low flows during lean period and high flows during floods. The floods although bringing fertile silts, but are hazardous to human life and property. Flood mitigation is necessary to safeguard human life, livestock, cash crops and against spread of disease.
* The increased population and rising standards of living have greatly increased the demands of water. Hydrologic studies are of utmost importance for planning and development of water resources to meet these demands.



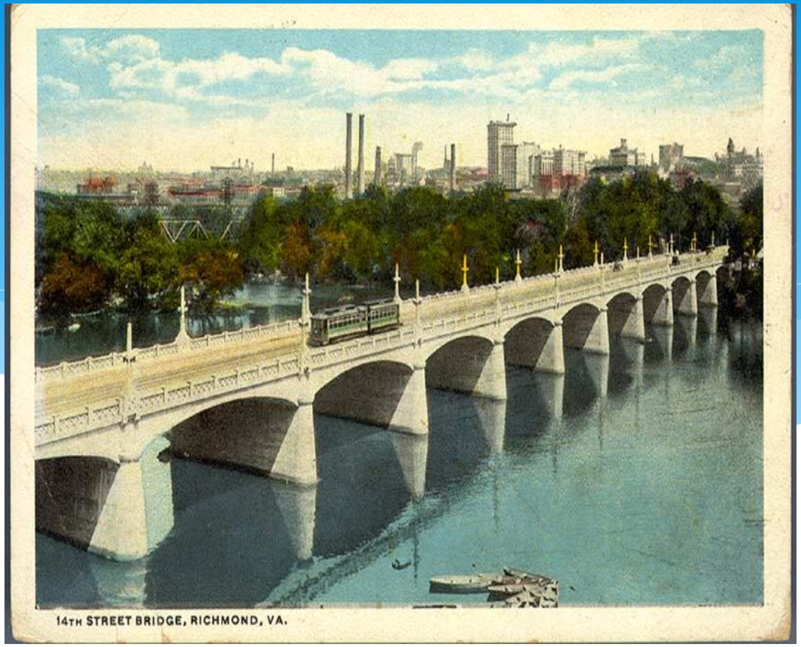
Importance of Hydrology in Civil Engineering

* 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 dollars may fail due to improper hydrologic design.

Continued….

Importance of Hydrology in Civil Engineering

* For example, a dam may fail due to inadequate spillway capacity. There may be reservoir operational problems due to lack of hydrologic data like probable inflows, evaporation and seepage. There might be failure of a bridge or a culvert if its maximum design flood is not estimated properly. Construction of a dam may cause problem for bridges upstream and downstream if proper hydrologic studies regarding floods and erosion downstream are not estimated and taken into account in design. Groundwater studies are important for installation of tube wells and irrigation projects. These are just a few examples which show the importance of hydrologic studies for civil engineering projects.


14TH STREET BRIDGE, RICHMOND, VA.

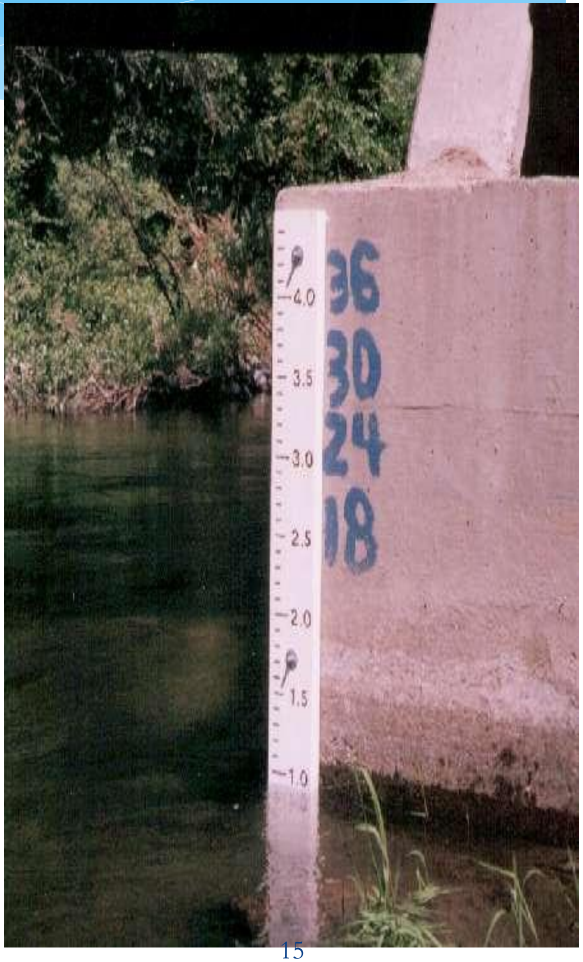
Major Aspects of Hydrology

* 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:
    * a. Rainfall Data
    * b. Snowfall and Snowmelt Data
    * c. Runoff Data (Catchment Runoff and Stream Flows), and
    * d. Groundwater Data

Continued….

Major Aspects of Hydrology

* 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:
    * Statistical Approach
    * Physical Approach
    * Deterministic Approach



Sciences Involved

* Hydrology is a very broad subject and it needs support from allied sciences such as Physics, Mathematics, Geology, Geography, Meteorology, Forestry, Agriculture and Hydraulics.

Major Hydrologic Projects

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

Continued….


N
Spillways
Tarbela Dam
Indus River

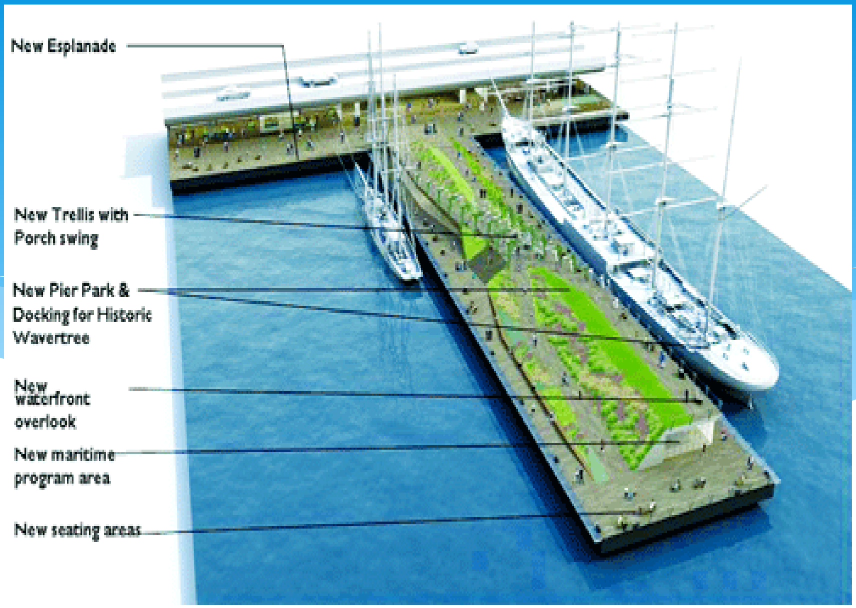

Cardiff Bay
Sluice Gates
Fish Pass
Barrage Control
Locks
The 'Pink Hut'
Water Bus Stop
Car Park
Penarth
Permitted Sea Angling.
'The Zone'
Custom House

Major Hydrologic Projects

Following is an exhaustive list of projects dealt with in Hydrology:

- Design of:
  - Surface water reservoirs
  - Groundwater reservoirs
  - Urban storm water sewers and airport drainage systems
  - Urban water distribution systems
  - Flood control structures (Dikes, River Improvement Works, etc.)
  - Navigational systems (Locks, Ports, etc.)
  - Agricultural drainage systems
  - Temporary construction and mining drainage systems

Continued….


New Esplanade
New Trellis with Porch swing
New Pier Park & Docking for Historic Wavertree
New waterfront overlook
New maritime program area
New seating areas

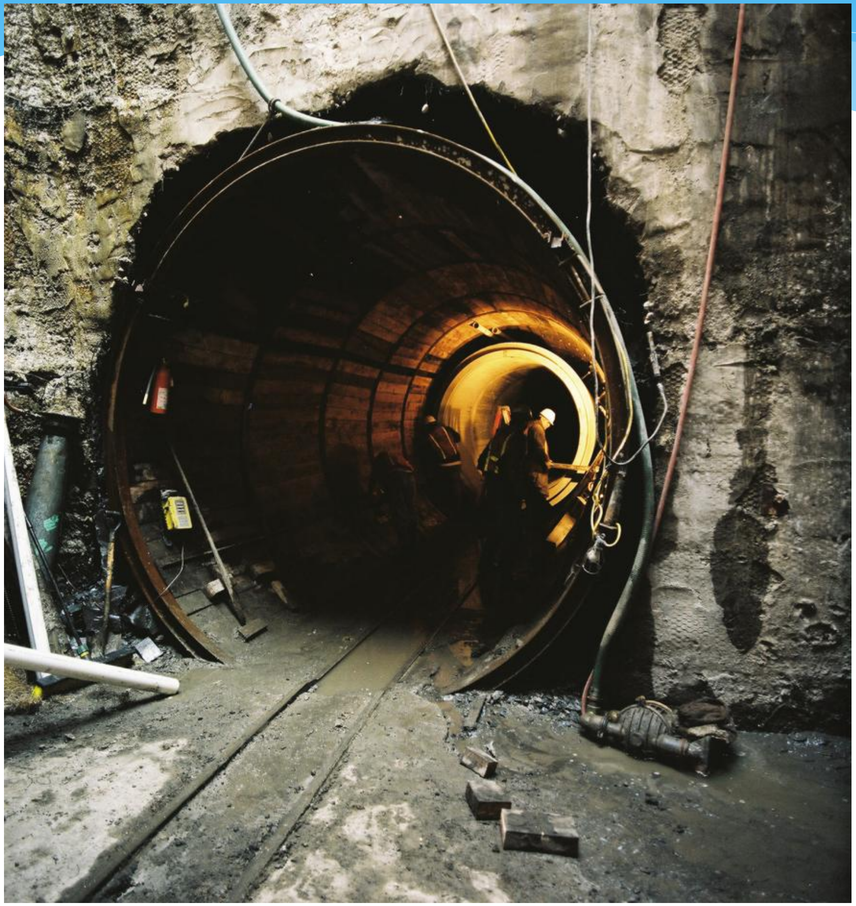
SEA PORT

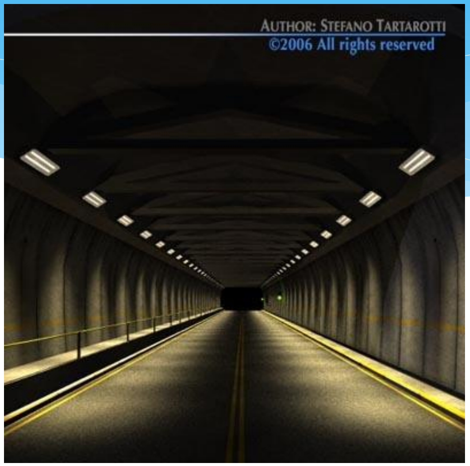

Trees
Pavilions
Benches
Bike Path
Improved Boardwalk
Railing
Plantings

Major Hydrologic Projects

- Design of:
  - Tunnels and underground excavations
  - Flow control systems for highway development
  - Hydraulic structures (Bridges, Culverts, Dams, Barrages)
  - Open channels and other river flow control structures
  - Flood waves propagation
  - Soil conservation
  - Sanitary landfills and waste disposal facilities
  - Contaminated-soil remedial systems
  - Polluted-aquifer containment or restoration systems

Continued….





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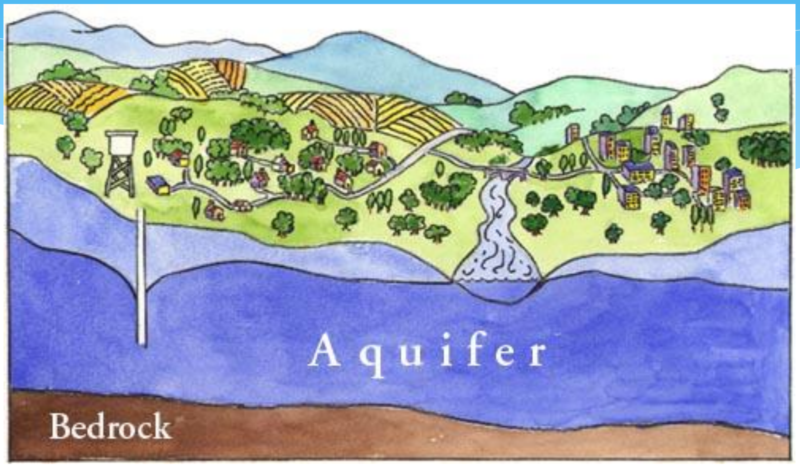
Major Hydrologic Projects

* Management of:
  * Rivers, lakes, wetlands, estuaries and aquifers
  * Crops, forests and pasture lands



Continued….

Major Hydrologic Projects

* Prediction and Forecasting of:
  * Contamination effects on rivers and lakes
  * Contamination propagation in soils and groundwater
  * Effect of drainage on flood flows
  * Environmental impact of water resources projects
  * Environmental impact of deforestation
  * Environmental impact of urbanization
  * Environmental impact of chemical spills
  * Environmental impact of chemical leaks from tanks
  * Environmental impact of leachates from landfills
  * Environmental impact of pesticide application
  * Environmental impact of global climate change
  * Flood waves propagation

Questions - A Hydrologist has to Answer

- Some of the typical questions that a hydrologist has to answer are:
  - Is the flow of stream sufficient to meet the needs of a city or industry seeking the water supply, or an irrigation project, or a proposed water resource development, or navigation, or recreation?
  - Would a reservoir be required in connection with any of the proposed uses and if so, what should be its capacity?
  - In the design of a flood protection system a barrage, a culvert or a spillway for a dam, what is the design flood that may be expected to occur with any specified frequency?

Continued….

Questions - A Hydrologist has to Answer

- What would be the effect of draining an upland area or a marshy region upon the flow of stream from the water shed?
- How would certain changes, removal of forests etc., affect the ground water level or the stream flow from such an area?

Continued….

Questions - A Hydrologist has to Answer

* In order to answer the above and other similar questions work is undertaken in three phases (as also explained), which are collection of data, analysis of data and making predictions out of this analysis.
* The data that must be collected includes stream flow records, precipitation records, topographic maps, groundwater data, evaporation data and transpiration data.

Hydrologic Cycle

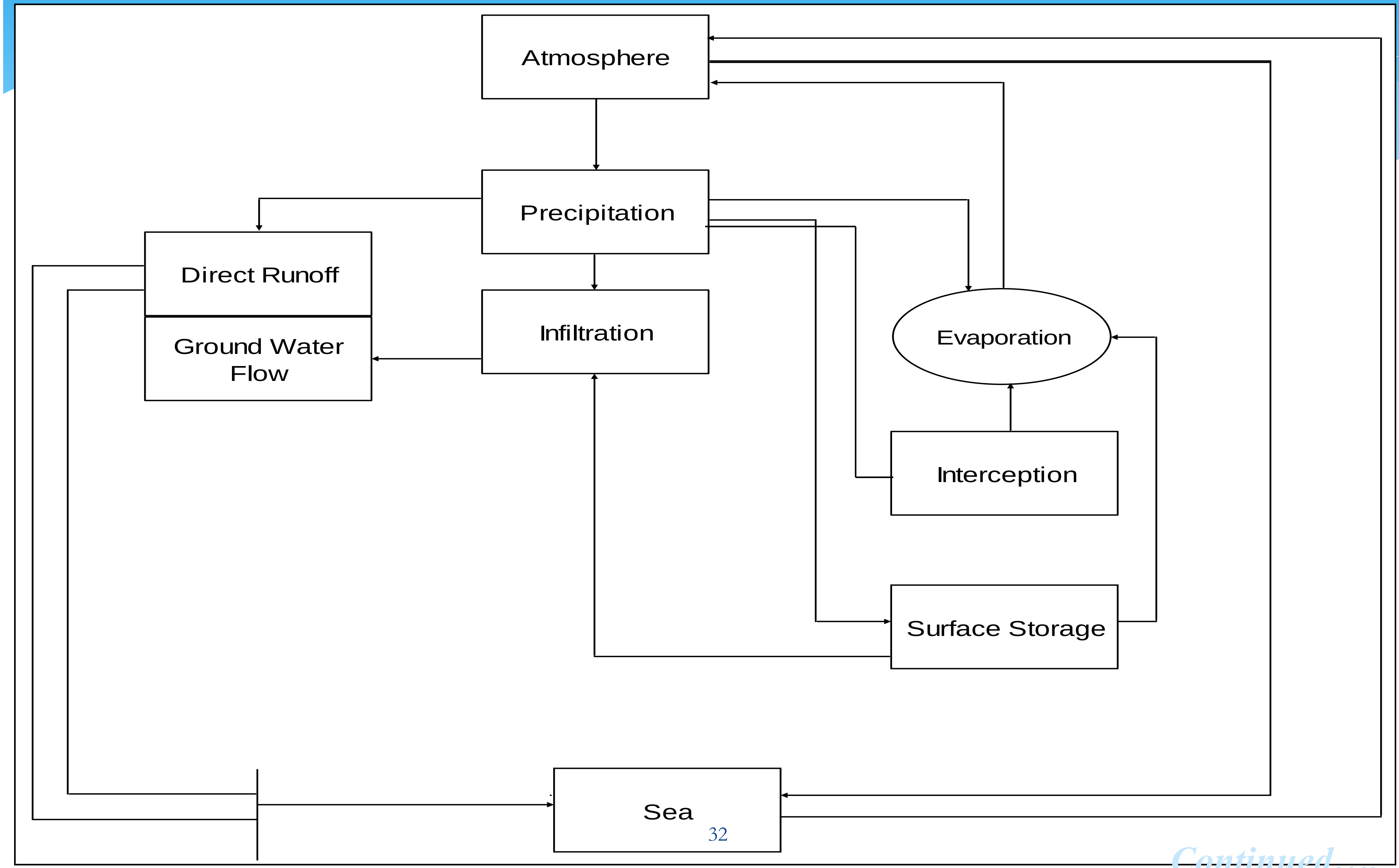
- Journey of water from the ocean to atmosphere and back to the earth and ultimately to the ocean through the processes of evaporation, precipitation, percolation, runoff and return to the ocean is called hydrologic cycle. The importance of hydrologic cycle in hydrology is such that Hydrology is also briefly defined as the science of hydrologic cycle.
- Figure 1.1 shows a schematic flow chart of the hydrologic cycle. Though the actual hydrologic cycle is quite complex, this figure just broadly depicts the sequence of major events of the cycle. The hydrologic cycle can be broadly divided into two phases - land phase, and atmospheric phase.

Continued….

Hydrologic Cycle

- Before discussing the two phases of hydrologic cycle, some of the related terms are defined below:
- Infiltration
  - Precipitation falling on the ground is, to some extent, absorbed by the land. This absorption of precipitation water by land from the surface of earth is called infiltration.
- Interception
  - A part of the precipitation is obstructed by vegetation and temporarily remains there. This process is called interception. Later the intercepted water is either evaporated or infiltrated.

Hydrologic Cycle



Continued….

Hydrologic Cycle

* Depression Storage
  * A part of precipitation is stored in depressions on the catchment area. This is called depression storage.
* Detention Storage
  * When the precipitation occurs for a longer duration and at a rate greater than the rate of infiltration some water is collected on the surface of the earth up to a certain depth. On attaining a certain depth, the action of gravity makes this water flow. Before it starts flowing, the water stored on the surface of earth is called detention storage.

Continued….

Hydrologic Cycle

* Runoff
  * After the detention storage is built up, as explained above, the water will start flowing over the ground and is called runoff.
* Inter Flow
  * The part of infiltrated water which moves laterally through the upper soil layers above the groundwater level and soon joins the stream is called inter flow.

Continued….

Hydrologic Cycle

- Total Runoff
  - A part of infiltrated water moves in the form of inter flow which soon joins the stream, the remaining portion of infiltrated water percolates to deeper layers of the ground and is stored as groundwater. This groundwater sometimes also joins the stream flow through springs and seepage process. The stream flow is then called the total runoff i. e. it is sum of all the components of precipitation water. Direct runoff plus the losses gives total runoff.
  - The runoff can be expressed in depth units for a certain area or it can be expressed in volume units. It can also be expressed in discharge units for a specified time.

Continued….

Hydrologic Cycle

* Atmospheric Phase of Hydrologic Cycle
  * Atmospheric phase of hydrologic cycle starts with the formation of clouds after vaporization from water bodies and ends after the occurrence of precipitation.
* Land Phase of Hydrologic Cycle
  * After occurrence of precipitation, water comes in contact with the earth surface and hydrologic cycle enters the land phase. Part of precipitation is infiltrated and a part of it, depending upon circumstances, is intercepted by trees and vegetation. If there are depressions in the surface upon which precipitation falls, a part of precipitation will be stored in the depressions in the form of depression storage. All of these parts are liable to vaporization. Rainwater stands on the surface of earth where it falls, after various losses, depending upon the rate of rainfall

Continued….

Hydrologic Cycle

* When the depth of standing water becomes sufficient it starts flowing over the ground surface in the form of surface runoff. During the travel of surface runoff towards streams, again a part of water is infiltrated and a part of it is evaporated. A part of infiltrated water moves laterally through the upper soil layers above the groundwater level, in the form of interflow which soon joins the stream flow. The remaining portion of infiltrated water percolates to deeper layers of the ground and is stored as groundwater. Sometimes this ground water joins the stream flow through spring or seepage process. The stream flow is then called the total runoff. The total runoff from the streams goes back to the oceans subjected to vaporization throughout its travel. The depression storage is either evaporated or infiltrated into the ground and similar is the case of interception. The ground water also may go to oceans after a long time.

Continued….

Hydrologic Cycle

- ***Example 1.1***
- A precipitation measuring 125 mm occurred over a catchment. If the infiltration, interception, depression storage and other losses are 50 mm, find direct runoff and total runoff.

  Solution

Precipitation P	= 125 mm
Losses L	= 50 mm
Direct runoff (DRO)	= P – L = 125 – 50 = 75 mm
Total runoff	= DRO + L = 75+50 = 125 mm

- Note that ‘x’ inches of runoff means that water is spread uniformly over the catchment having ‘x’ inches depth. Runoff in volume units can be obtained by multiplying the depth with the area of the catchment.

Hydrologic Equation

- The hydrologic equation states that for a given time interval, difference of inflow to and outflow from a system is equal to change of storage of the system. In its differential form it states that rate of volume inflow minus the rate of volume outflow is equal to the rate of change of storage.
- Mathematically

$$I - O = \Delta S/\Delta t \qquad \text{Eq.1.1}$$

Where,

I = Rate of volume inflow (volume/time), measured in m3/sec, ft3/sec, etc.

O = Rate of volume outflow (volume/time) measured in m3/sec, ft3/sec, etc.

$\Delta S/\Delta t$ = Rate of change of storage in time ('S' represents storage and 't' represents time i.e. Volume/time)

- The above equation is a storage equation which only approximates some hydrologic processes.

Continued….

Hydrologic Equation

* Components of Inflow
  * There are two components of inflow, viz.
    * precipitation over the catchment and reservoir, and
    * surface or groundwater flow from other catchment areas.
* Components of Outflow
  * Three components of outflow are:
    * surface evaporation
    * groundwater seepage, and
    * direct runoff i.e water taken for irrigation or to spill ways for producing power

Continued….

Hydrologic Equation

- If we fix the time and take the volume units, then the hydrologic equation can be written as,

  Total volume inflow – The volume outflow = Total change in volume of the system

- This is hydrologic or storage equation. It is used in many different ways. If, for example, assuming inflow changes linearly from ‘I_1’ to ‘I_2’ in time ‘Δt’, the outflow changes linearly from ‘O_1’ to ‘O_2’ and storage changes from ‘S_1’ to ‘S_2’ in this time, the equation can be written as:

  $(I_1 + I_2)/2 - (O_1 + O_2)/2 = (S_2 - S_1)/\Delta t$ - - - - *Eq. 1.2*

Continued….

Hydrologic Equation

* If we fix time ‘Δt’ and talk about total inflow in certain time ‘Δt’, total outflow and total change in storage in that time, the hydrologic equation can be written as:

  Volume inflow-Volume outflow = Total change in storage
* If further, we fix the area of the system (for example, we talk of a catchment) and assume inflow as precipitation ‘p’, the outflow as the losses ‘L’ and runoff ‘R’ then the equation can be written as:

  $P - L - R = D$ ---------------------------*Eq. 1.3*

  Where ‘D’ is the depression storage.
* This concept is further applied to discuss the water budget of a catchment.

Continued….

* ***Example 1.2***
  * Flow of River Chenab at Marala Barrage varied linearly from 34 cumec (m^3/sec) to
    283 cumec in 10-hours during a flood. The flow variation at Khanki Barrage, downstream of Marala was observed to be from 28 to 255 cumec during the above mentioned time. Assuming no lateral flow in or out of the reach, find out the rate of change of storage of the river reach between Marala and Khanki. What is total change in storage of the reach in this period?

Continued….

Solution

$I_1 = 34$ cumec $I_2 = 283$ cumec

$O_1 = 28$ cumec $O_2 = 255$ cumec

$I = (I_1 + I_2) / 2 = (34 + 283) / 2 = 158.5$ cumec

$O = (O_1 + O_2) / 2 = (28 + 255) = 141.5$ cumec

$\Delta S/\Delta t = ?$

According to hydrologic equation

$(I_1 + I_2)/2 - (O_1 + O_2) / 2 = \Delta S/\Delta t$

$158.5 - 141.5 = \Delta S/\Delta t = 17$ cumec

$\Delta t = 10$ hours $= 10 \times 60 \times 60 = 36{,}000$ sec

Total change in storage $= \Delta S = (\Delta S/\Delta t) \times \Delta t$

$= 17 \times 36{,}000 = 612 \times 10^3$ m3

Continued….

* ***Example 1.3***
  * Water at a constant rate of 370 cumec was observed to be entering into Tarbela Reservoir in a certain season. If outflow from the reservoir including infiltration and evaporation losses is 280 cumec, find out the change in storage of reservoir for 10 such days. Also convert your answer into Hectare-Meter.

Continued….

Solution

$I = 370$ cumec

$O = 280$ cumec

$\Delta S = ?$

According to hydrologic equation,

$I - O = \Delta S / \Delta t$

$370 – 280 = \Delta S / \Delta t = 90$ cumec

$\Delta t = 10 \times 24 = 240$ hours $= 240 \times 60 \times 60 = 864\times10^3$ sec

Total change in storage $= \Delta S = (\Delta S / \Delta t) \times \Delta t$

$= 90 \times 864\times10^3 = 777.6\times104$ m3

$= 777.6\times10$^$4/10$^$4 = 777.6$ Hectare-m

Water Budget in a Catchment

* The water budget of a catchment is similar to budget of a country. The water budget in a catchment can be given by hydrologic equation. If we take the inflow as the precipitation 'P' on the ground surface , outflow as interception losses 'Li', surface runoff 'R' and evaporation 'Le' and the change in storage due to Infiltration 'F' and Depression storage 'D', the hydrologic equation is expressed as:

$$P - (Li + R + Le) = D + F$$

or $$R = P - (Li + Le + D + F)$$

$$R = P - \text{The Losses.}$$

$$R = P - L$$

Continued….

Water Budget in a Catchment

* If all the quantities on right-hand-side of the above equation could be measured, the surface runoff of a given catchment as result of a known precipitation could easily be determined. But unfortunately, it is very difficult to get these values directly. The hydrologists have therefore evolved a number of direct and indirect techniques to find the rainfall - runoff relationship described by the above equation.

Continued….

* **Example 1.4**
  * A part of catchment area of Hub River measuring 78 km^2 received 100 mm of rainfall in 3 hours due to a storm. A drainage stream joins this part of catchment to the Hub River. The stream was dry before rainfall and there was flow in the stream for a period of 2.5 days with an average discharge of 10 cumec. After the storm runoff, the stream again became dry. Find the losses, direct runoff and total runoff in cumec and Hectare-meter.

Continued….

Solution

According to hydrologic equation,

Area of catchment A = 78 km2 =78x106 m2

P = 100 mm =0.1 m

Q = 10 m3/sec

t = 2.5 days = 2.5 24x60x60 sec

Total runoff = PxA = (0.1) x 78 x 106 = 7.8x106m3

= 7.8x106 / 104 = 780 Hectare-m

DRO = 10x2.5x24x60x60=2.16x106 m3=216Hectare-m

L = P - R = 7.8x106 - 2.16x106 = 5.64x106m3

= 564 Hectare-m

Continued….

* **Example 1.5**
  * Assume that Mangla Reservoir has surface area of 39 sq. km in the beginning of a certain month and the water depth is 76.20 m for this whole surface of the lake. Further assume that sides of reservoir are nearly vertical. Now in that month the reservoir received an average inflow of 226.50 cumec as a direct runoff, and direct precipitation of 125 mm. The outflow from the reservoir was 170 cumec and evaporation and seepage losses were estimated to be 113 mm during that month. Find out depth of reservoir at the end of that month and total increase or decrease in the storage.

Continued….

Solution

The hydrologic equation will be applied to solve this water budget related problem.

Δt = 1 month = 30 x 24 x 60 x 60 = 2.592x106 sec.

Total inflow as direct runoff = I x Δt = 226.50 x 2.592x106 m3
= 587.088x106 m^3

Addition from precipitation = precipitation x surface area of reservoir
= $(125/10^3)$x39x106 = 4.875x106 m3

Total outflow = O xΔt = 170 x 2.592x106 = 440.64x106 m3

Losses = (Evaporation + Seepage) x Surface area of reservoir
= $(113/10^3)$x39x106 = 4.407x106 m3

Continued….

Now the total change in volume of storage

= total volume of inflow + total volume of precipitation – (total volume of outflow + total volume of losses)

= 587.088x106 + 4.875x106 – (440.64x106 + 4.407x106)

= 146.916x106 m3

Change in depth of reservoir = change in storage / surface area

= 146.916x106/ 39x106=3.77 m

Depth at the end of month = depth in the beginning + change in depth

= 76.20 + 3.77 = 79.97 m

Application of Hydrology to Environmental Problems

* Most of environmental aspects are directly or indirectly related to water. Floods have environmental effects, droughts affect the environment, constructing a dam or a barrage has environmental effects, groundwater pollution affects environment. All forms of life are water-dependent. Land, air and water are interrelated. As world’s population is increasing, living standards are rising and the recreational demands are growing, as a result of which, there are new developments in industry and food production.

Continued….

Application of Hydrology to Environmental Problems

- Due to these man-made activities, water demands are increasing and the environment is changing day by day. Planning and development of sustainable water resources has become a challenging job for hydrologists. It is very important to understand the hydrologic process in order to develop water resources with least harm to the environment.

Questions

* Write a note on importance of Hydrology in Civil Engineering.
* Explain "Hydrologic Cycle".
* What is Hydrologic Equation?
* What is meant by Catchment Area, Why is it studied? Do Basin and Watershed mean the same? Explain.
* Define the term Runoff and describe various units to express runoff.

Exercise

* During July, 1996 monthly inflow to Tarbela Reservoir was 20 billion cubic meters and outflow was 18.70 billion cubic meters. Find the rate of change of storage and change in storage during the period.
* At Basha Reservoir the storage volume is 11,410 million cubic meters at elevation of 1,180 m. If inflow is 11,500 cubic meters per second. Find the time to fill the reservoir up to mentioned elevation. Assume that losses are negligible.

Exercise

* Mangla Lake had a water surface level of 650 m above a datum at the beginning of a certain month. In that month the lake received an average inflow of 250 cumecs. There was an outflow of 150 cumecs. In the same month, the lake received a rainfall of 150 mm and the evaporation from the lake surface was 5 cm. Using hydrologic equation, estimate the water surface elevation of the lake at the end of the month. Assume the lake surface area as 450 hectares and that there was no contribution to or from the groundwater storage.
* A catchment area of 100 Sq. Km. in Gilgit received a rainfall of 12 cm from a 3-hours storm. At the outlet of the catchment, a natural stream had a steady flow of 10 cumecs before the storm and experienced a runoff lasting for 20 hours with an average discharge value of 90 cumecs. The stream was again to its original steady state with a flow of 10 cumecs. Estimate the losses and ratio of runoff to precipitation.