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FACULTY OF ENGINEERING & TECHNOLOGY

TOPIC : HYDROLOGY (L-4)

- **Potential Evapotranspiration** is the rate at which evapotranspiration would occur from a large area uniformly covered by vegetation with unlimited access to soil water and disregarding heat flow and storage effects. It cannot exceed free water evaporation under similar climate.
- **Infiltration** is the entry of waters into the ground. The rate and quantity of water which infiltrates is a function of soil type, soil moisture, soil permeability, ground cover, drainage conditions, depth of water table, and intensity and volume of precipitation (Wanielista et al. 1997). The infiltrated water replenishes soil moisture, recharges groundwater aquifers, and ultimately augment base flow in streams. After water crosses the surface interface, its rate of downward movement is controlled by the transmission characteristics of the underlying soil profile. The volume of storage available below ground is also a factor affecting infiltration rate. The major influencing factors of infiltration are soil type and moisture content. The soil type characterizes the size and number of passages through which the water must flow while the moisture content sets the capillary potential and relative conductivity of the soil.
- Infiltration, together with other hydrologic losses, determines the rate of runoff from a catchment.
- **Runoff**
- Runoff analysis is a very important component of surface hydrology. Although the process appears to be simple as it occurs frequently around us, the relationship between precipitation and runoff is affected by various storm and basin

- characteristics and is very complex. Various techniques which range from simple lumped models to sophisticated continuous simulation models have been developed for runoff prediction. Simple lumped models may be suitable for planning analysis of runoff while continuous simulation may be appropriate for design analysis.
- Runoff occur when precipitation exceeds the hydrologic losses. It starts with overland flow which is then collected and transported by various drainage pathways such as streams and storage reservoirs and eventually discharged to receiving water bodies such as rivers and lakes. The precipitation-runoff process is complex as it involves numerous flow routing interactions in the watershed. Additionally, the spatial and temporal characteristics of precipitation also make the prediction of runoff a challenge to engineers.
- Watershed characteristics which affect runoff include:

  - **Stream patterns**

    Stream patterns affect the pathways of runoff at a watershed. Runoff from different parts of a watershed will interact with each other in accordance with their runoff pathways

  - **Geomorphology of drainage basins**

    Both large scale and local geologic activity and structure affect the storage and movement of surface waters. The nature of land forms determines drainage pattern which in turn also affects the surface geometry through the process of erosion.

- **Overland Flow Lengths and Stream Lengths**

  Overland flow length is the distance from the ridge line or drainage divide, measured along the path of surface flow which is not confined in any defined channel, to the intersection of this flow path with an established flow channel. The flow length to any point is the sum of overland flow lengths and stream lengths. The flow length is important in the application of Rational Method of runoff peak calculations.

- **Areal Characteristics**

  Drainage area has been used as a parameter in regression models of precipitation-runoff process. As drainage basins increase in size, they become longer and narrower. Drainage density is defined as the ratio of total channel segment lengths cumulated for all stream orders within a basin to the basin area.

- **Channel and Basin Gradients**

  The slopes of a drainage basin and its channels have a strong influence on the runoff process as they affect the runoff rate.

- **Area-elevation Relation**

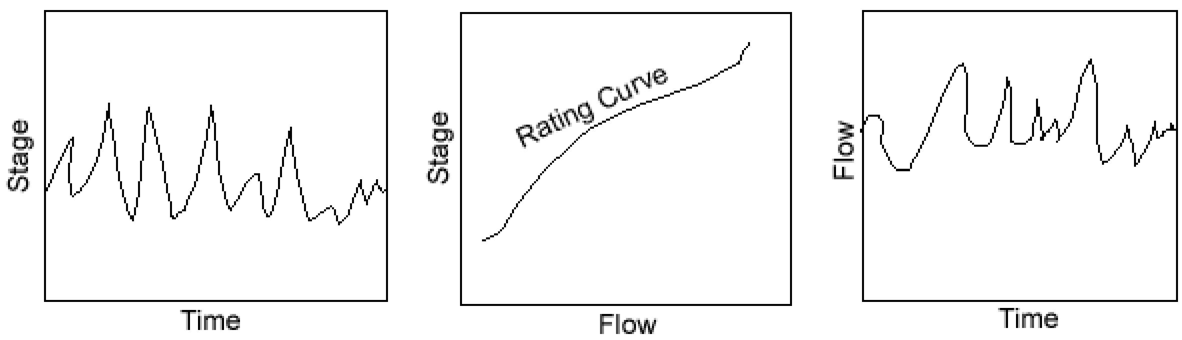
  The distribution of area between contour in a drainage basin is an important characteristics as it relates to the storage and flow characteristics of the basin.

- **Stream Hydrograph** is a continuous plot of discharge rate versus time at a point along a stream during a storm event. Stream flow is usually measured by stage (i.e., depth). Therefore, it starts with the plot of stage versus time. Then, it is transformed into flow versus time using a rating curve (i.e., stage-discharge curve) at the point of measurement.

- **Stream Flow Hydrographs** provide information on peak flows, time distribution of flows, the total flow volume over a certain duration which can be used to determine flooding potential and size reservoirs, storage tanks, detention ponds, and other facilities.

- **A Hydrograph has four components:**

- Direct Surface Runoff;
- Interflow
- Ground Water or Base Flow;
- Channel Precipitation.



The rising limb is called concentration curve, the region in the vicinity of the peak is called the crest segment, and the falling limb is called the recession curve. The shape of a hydrograph is a function of precipitation pattern characteristics and basin properties.

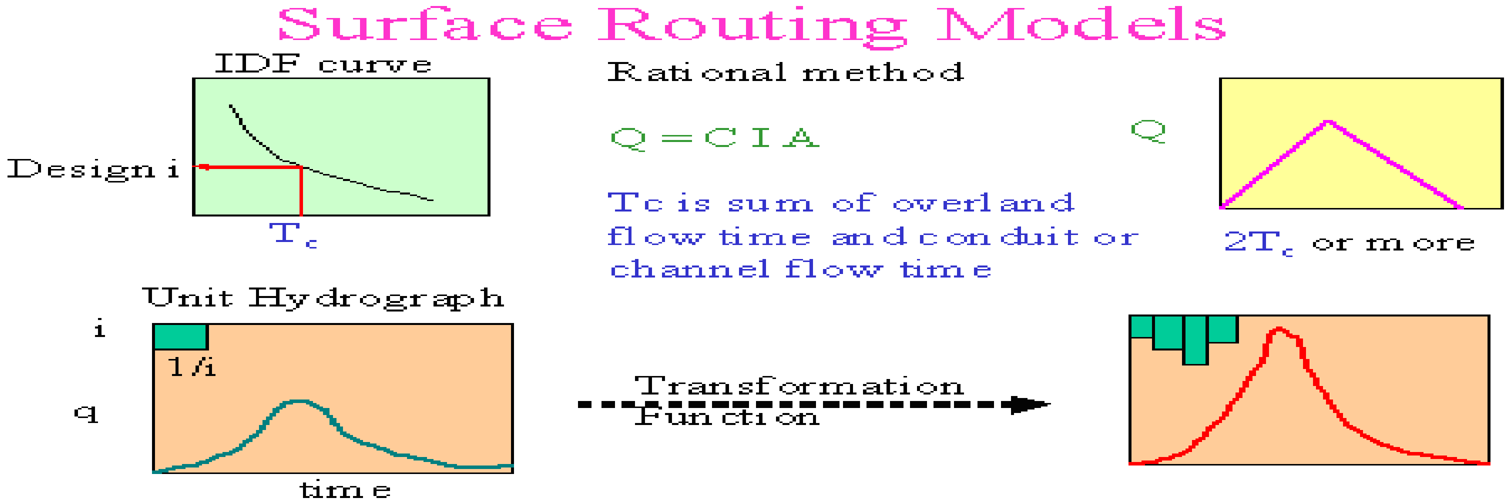
In general, there is a base flow component which are considered to be normal day-to-day flow. The runoff component can be divided into the abstraction and direct runoff. If base flow and abstraction are removed from the stream flow hydrograph, the resulting hydrograph is called direct runoff hydrograph. The main component to be separated from the streamflow hydrograph is the base flow.

There are two main approaches in modelling rainfall to runoff.

Deterministic models assume the same inputs will produce the same outputs.

On the other hands, stochastic models assume both inputs and outputs are random variables and the same inputs may produce different outputs.

However, the preferable modelling approach is a function of time, budget, expertise of the users and the purpose of the analysis. The following diagram shows two common deterministic models for rainfall-runoff transformation.



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Hydrologic Channel Routing

Hydrologic routing is used to simulate the temporal and spatial variations of a flood wave as it traverses a river reach or detention reservoir. In hydrologic routing, the equation of continuity and a linear or curvilinear relation between discharge and storage within a river and reservoir are used.

When a flood wave enters a river section, the water surface within the section is not always parallel to the channel bed.

The storage in a channel can be considered as a combination of prism storage and wedge storage as shown in the following figure. The prism storage is the volume of water that would exist if the flow were uniform at the downstream depth. The wedge storage is the volume of water between the actual water surface profile and the top surface of the prism storage. The wedge storage increases the flood volume during the rising stage and decreases it during the receding stage.

Thus, the storage-discharge curve of the river section is a loop reflecting the rising and falling stages. Additionally, local inflows and seepage within the river section should be accounted for in hydrologic river routing.

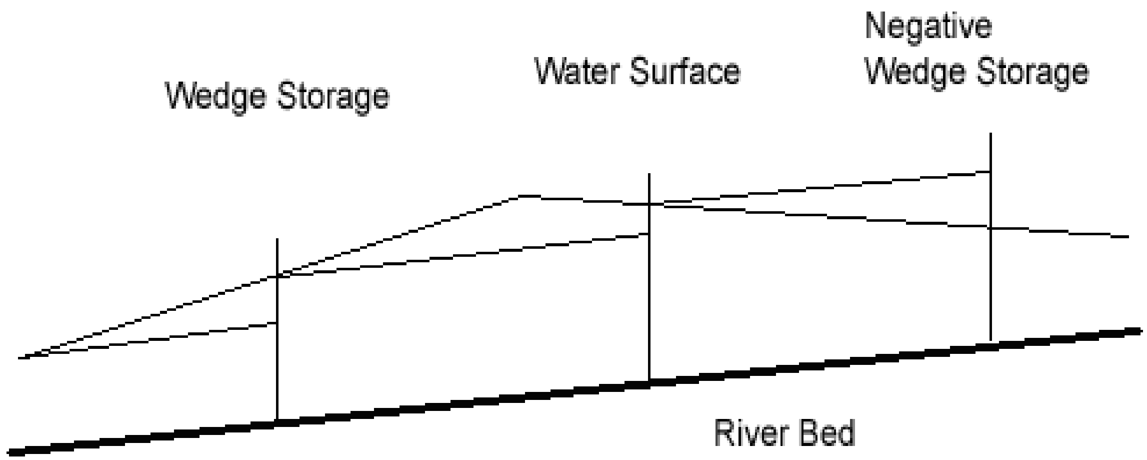
Hydrologic river routing are all based upon the following equation of continuity:

$$\frac{dS}{dt} = I - O$$

where I is the inflow rate to the reach;

O is the outflow rate from the research; and

$\frac{dS}{dt}$ is the rate of change of storage within the reach. This lecture introduces the Muskingum Method.



Muskingum Method

In order to solve the above equation, a relationship between storage and inflow and outflow is required. This method utilizes the following relationship:

$$S = K\left[XI + (1 - X)O \right]$$

where K is the storage time constant for the reach and
X (or c in the textbook) is a weighting factor that varies between O and S. Substituting Eq. (2) into Eq. (1) and denote subscripts 1 and 2 as the beginning and ending times, Eq. (1) becomes

$$O_2 = C_o I_2 + C_1 I_1 + C_2 O_1$$

$$C_1 = \frac{KX + 0.5\Delta t}{K - KX + 0.5\Delta t}$$

$$C_2 = \frac{K - KX - 0.5\Delta t}{K - KX + 0.5\Delta t}$$

$$C_o = \frac{-KX + 0.5\Delta t}{K - KX + 0.5\Delta t}$$

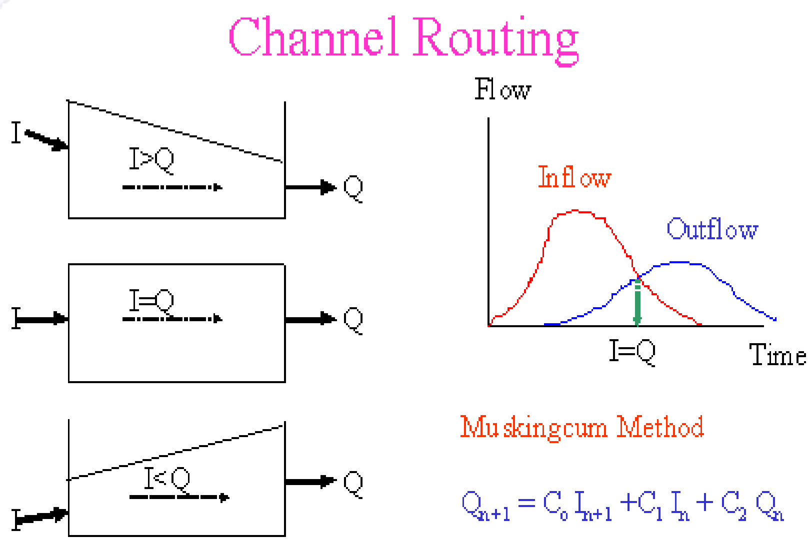
Values of K and X (or c in the textbook) for this method are commonly estimated using K equal to the travel time in the reach and an average value of X equal 0.2.

If inflow and outflow hydrograph records are available, they can be used to estimate K and X.

This method works best for

- slowly changing flows,
- streams with small slopes where the storage-discharge curve is approximately linear,
- delta t is much smaller than the travel time of flood wave and small enough to ensure linear variation of inflows and outflows. A rule of thumb of delta t is given by

$$\Delta t \;\_\; 2KX$$



Hydrologic Reservoir Routing

A flood wave which passes through a storage reservoir is delayed and attenuated as it enters and spreads over the reservoir surface. Water that is stored is then released through either a controlled or uncontrolled outlet. To route a flood wave through a nonlinear reservoir, the storage-outflow relation and the continuity equation are combined to determine outflow and storage at the end of each time step. Thus, both the elevation-storage curve and elevation-discharge curve must be developed.

Elevation-storage relation can be estimated by

$$S = \frac{h}{2}(A_1 + A_2)$$

where A_1 is the surface area of the reservoir when h equals zero

A_2 is the surface are of the reservoir when h equals the depth of flow.

- Elevation-discharge curve is assumed to be unique for a reservoir and is described by the following equations:

- **Uncontrolled Weir Outflows**

$$Q_w = CBH^{1.5}$$

where Q_w is the weir discharge rate;

C is the weir coefficient;

B is the weir length; and

H is the hydraulic head above the weir crest..

- **Controlled Orifice Outflows**

$$Q_o = C\,A_o\sqrt{2gH}$$

where Q_o is the orifice discharge rate;

C is the orifice coefficient;

A_o is the orifice area;

g is the gravitational constant (9.81 m/s^2); and

H is the depth of water above the centre line of orifice.

- The hydrologic volumetric balance equation can be rearranged as follows:

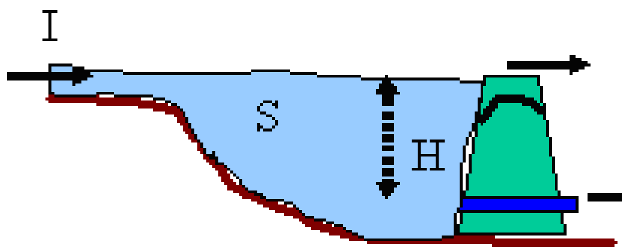
$$I_n + I_{n+1} + \left(\frac{2S_n}{\Delta t} - O_n \right) = \frac{2S_{n+1}}{\Delta t} + O_{n+1}$$

where the unknowns are the terms on the right side. Routing time (Δ t) should not be too short or too long.

❑ The Procedure for Hydrologic Reservoir Routing is listed below:

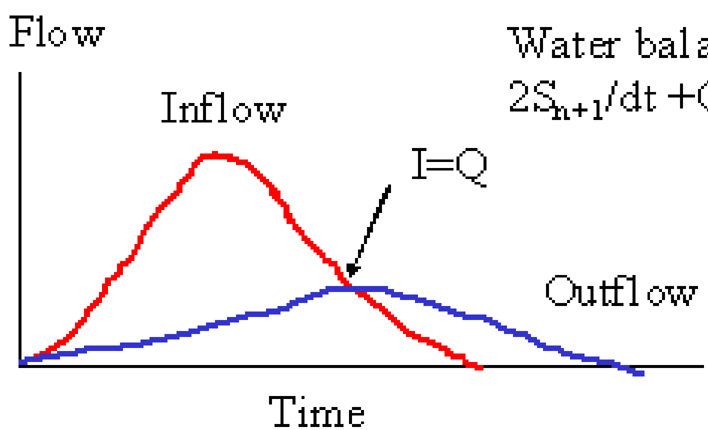
1. Develop elevation-storage and elevation-discharge curves and combine them to a storage indication curve (i.e., a plot of (2S/Δ t + O) versus O).
2. Knowing I_n, I_{n+1}, S_n, and O_n, compute the left hand side of Eq. (11), i.e., ($2S_n$+1/Δ t + O_{n+1}).
3. Determine O_n+1 from the storage indication curve (i.e., a plot of (2S/Δ t + O) versus O).
4. Compute ($2S_n$+1/Δ t- On+1) by subtracting 2O_n+1 from ($2S_n$+1/Δ t + O_{n+1}).
5. Add I_{n+1} , I_{n+2} and ($2S_n$+1/Δ t - O_{n+1}) to determine the left hand side of Eq. (11) and to back to step (3) for the next time step.

Reservoir Routing



$Q_o = CLH_w^{1.5}$ L is the width of weir

$Q_p = C(2gH)^{0.5}$



Water balance equation:

$$2S_{n+1}/dt + Q_{n+1} = 2S_n/dt - Q_n + I_n + I_{n+1}$$

Thank You