CE 15015

WATER RESOURCES ENGINEERING

LECTURE NOTES

MODULE-IV

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Course Contents

Module – IV

Flood frequency analysis: Gumbel's method. Flood routing: Hydrologic channel routing,
Muskingum equation, hydrologic reservoir routing: Modified Plus method, Flood control measures.

Lecture Note 1

Flood

1.1 Introduction

A **flood** is an overflow of water that submerges land that is usually dry. The European Union (EU) Floods Directive defines a flood as a covering by water of land not normally covered by water. In the sense of "flowing water", the word may also be applied to the inflow of the tide. Floods are an area of study of the discipline hydrology and are of significant concern in agriculture, civil engineering and public health.

Flooding may occur as an overflow of water from water bodies, such as a river, lake, or ocean, in which the water overtops or breaks levees, resulting in some of that water escaping its usual boundaries,[3] or it may occur due to an accumulation of rainwater on saturated ground in an areal flood. While the size of a lake or other body of water will vary with seasonal changes in precipitation and snow melt, these changes in size are unlikely to be considered significant unless they flood property or drown domestic animals.

Floods can also occur in rivers when the flow rate exceeds the capacity of the river channel, particularly at bends or meanders in the waterway. Floods often cause damage to homes and businesses if they are in the natural flood plains of rivers. While riverine flood damage can be eliminated by moving away from rivers and other bodies of water, people have traditionally lived and worked by rivers because the land is usually flat and fertile and because rivers provide easy travel and access to commerce and industry.

Some floods develop slowly, while others such as flash floods, can develop in just a few minutes and without visible signs of rain. Additionally, floods can be local, impacting a neighborhood or community, or very large, affecting entire river basins.

In the planning and design of water resources projects, engineers and planners are often interested to determine the magnitude and frequency of floods that will occur at the project areas. Besides the rational method, unit hydrograph method and rainfall-runoff models method, frequency analysis is one of the main techniques used to define the relationship between the magnitude of an event and the frequency with which that event is exceeded. Flood Frequency Analysis is the estimation of how often a specified event will occur. Before the estimation is carried out, analysis of the stream flow data plays a very important role in order to obtain a probability distribution of floods. **Flood frequency analysis (FFA)** is most commonly used by engineers and hydrologists worldwide and basically consists of estimating flood peak quantities for a set of non-exceedance probabilities. Flood frequency analysis involves the fitting of a probability model to the sample of annual flood peaks recorded over a period of observation, for a catchment of a given region. The model parameters established can then be used to predict the extreme events of large recurrence interval. Reliable flood frequency estimates are vital for floodplain management; to protect the public, minimize flood related costs to government and private enterprises, for designing and locating hydraulic structures and assessing hazards related to the development of flood plains.

1.2 Flood Frequency Analysis

Return Period: A return period, also known as a recurrence interval (sometimes repeat interval) is an estimate of the likelihood of flood or a river discharge flow to occur. For example, a 10 year flood has a 1/10=0.1 or 10% chance of being exceeded in any one year. This does not mean that if a flood with such a return period occurs, then the next will occur in about ten years' time - instead, it means that, in any given year, there is a 10% chance that it will happen, regardless of when the last similar event was.

Return Period is a statistical measurement typically based on historic data and is usually used for risk analysis (e.g. to decide whether a project should be allowed to go forward in a zone of a certain risk, or to design structures to withstand an event with a certain return period). Methods:

1. Weibull Method
2. Gumbell Method
3. Log Pearson Method

1.2.1 Weibull Method:

-In probability theory and statistics, it is a continuous probability distribution.

• Most commonly used method

• If 'n' values are distributed uniformly between 0 and 100 percent¬ probability, then there must be n+1 intervals, n–1 between the data points and 2 at the ends.

Probability, P = m / n+1

where, m = rank

1.2.2 Gumbel's Extreme Value Distribution Method:

• E.J. Gumbel in 1941 was consider that annual flood peaks are extreme values of floods in each of the annual series of recorded data. Hence, floods follow the extreme value distribution.

Probability, P = 1 – $e^{-e^{-y}}$

Return Period, T = 1/P

Where y = reduced variate = [1.282 (Q – Q) / σ] + 0.577

e = base of Naperian Logarithm

Flood Magnitude for a given Return Period, $Q_T = Q + K_T \sigma$

Where Frequency Factor,

$$K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + \ln\left[\ln\left(\frac{T}{T-1}\right)\right]\right\}$$

T = Return Period Q = Mean σ = Standard Deviation

1.2.3 Log Pearson Type III Distribution Method:

Person (1930) developed this method. In this method, it is recommended to convert the data series to logarithms and then compute the following.

1. Compute Logarithms of flow log Q
2. Estimate Average of log Q
3. Compute Standard Deviation σ log Q
4. Compute Skew Coefficient, $C_s = (N\ \Sigma\ (\log Q - \log Q)^3\ ) / (N-1)(N-2)\ (\sigma \log Q)^3$
5. QT = log Q + K (σ log Q) where K = log Pearson Frequency Factor based on C_s & Return Period

Lecture Note 2

Flood routing

2.1 Introduction

Flood routing is the technique of determining the flood hydrograph at a section of a river by utilizing the data of flood flow at one or more upstream sections. The hydrologic analysis of problems such as flood forecasting, flood protection, reservoir design and spillway design invariably include flood routing. In these applications two broad categories of routing can be recognized. These are:

1. Reservoir routing, and

2. Channel routing

A variety of routing methods are available and they can be broadly classified into two categories as:

1. Hydrologic routing/Lumped: Flow is calculated as a function of time alone at a particular location. Hydrologic routing methods employ essentially the equation of continuity and ϖ flow/storage relationship.

2. Hydraulic routing/Distributed: Flow is calculated as a function of space and time throughout the system. Hydraulic methods use continuity and momentum equation along with the ϖ equation of motion of unsteady flow (St. Venant equations).

Hydrologic-routing methods employ essentially the equation of continuity. Hydraulic methods, on the other hand, employ the continuity equation together with the equation of motion of unsteady.

2.2 Applications of Flood Routing

For accounting changes in flow hydrograph as a flood wave passes downstream

Flood:

•Flood Forecasting

•Flood Protection

• Flood Warning

Design:

•Water conveyance (Spillway) system

• Protective measures

•Hydro-system operation

Water Dynamics:

•Ungauged rivers

•Peak flow estimation

•River-aquifer interaction

2.3 Types of flood routing

•**Lumped/hydrologic**

flow ⟶ f(time)
Continuity equation and Flow/Storage relationship

•**Distributed/hydraulic**
Flow ⟶ f(space, time)
Continuity and Momentum equations

2.4 Flow Routing Analysis

•It is a procedure to determine the flow hydrograph at a point on a watershed from a known hydrograph upstream.

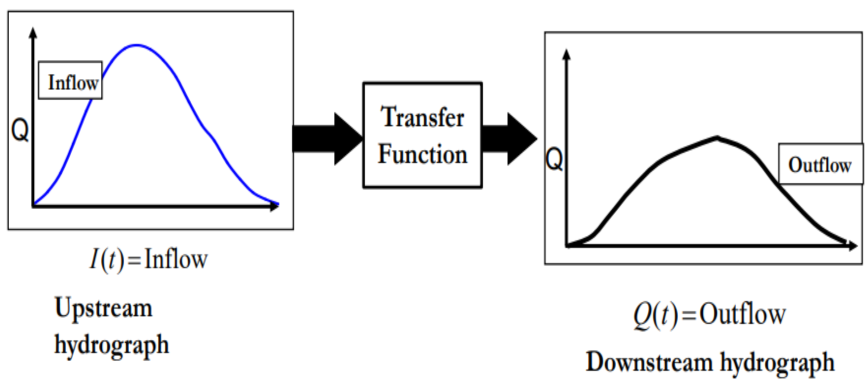


Fig (1)

- As flood wave travels downstream, it undergoes

•Peak attenuation

•Translation

ATENUATION The peak of the outflow hydrograph will be smaller than of the inflow hydrograph. This reduction in the peak value is called attenuation.

TIME LAG The peak of the outflow occurs after the peak of the inflow; the time difference between the two peaks is known as lag. The attenuation and lag of a flood hydrograph at a reservoir are two very important aspects of a reservoir operating under a flood-control criteria.

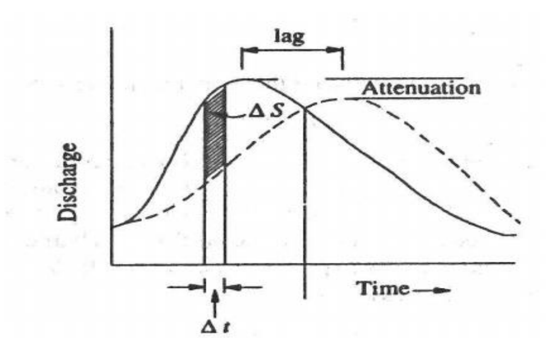


Fig (2)

2.5 Basic Equation

The equation of continuity used in all hydrologic routing as the primary equation states that the difference between the inflow and outflow rate is equal to the rate of change of storage, i.e.

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

where I = inflow rate, Q = outflow rate and S = storage. Alternatively, in a small time interval Δt the difference between the total inflow volume and total outflow volume in a reach is equal to the change in storage in that reach

$$\bar{I}\Delta t - \bar{Q}\Delta t = \Delta S$$

where $\bar{I}$ = average inflow in time Δt, $\bar{Q}$ = average outflow in time Δt and ΔS = change in storage. By taking $\bar{I} = (I_1 + I_2)/2$, $\bar{Q} = (Q_1 + Q_2)/2$ and $\Delta S = S_2 - S_1$ with suffixes 1 and 2 to denote the beginning and end of time interval Δt Eq.

$$\left(\frac{I_1 + I_2}{2}\right)\Delta t - \left(\frac{Q_1 + Q_2}{2}\right)\Delta t = S_2 - S_1$$

The time interval Δt should be sufficiently short so that the inflow and outflow hydrographs can be assumed to be straight lines in that time interval.

2.6 Hydrologic Storage Routing (Level Pool Routing)

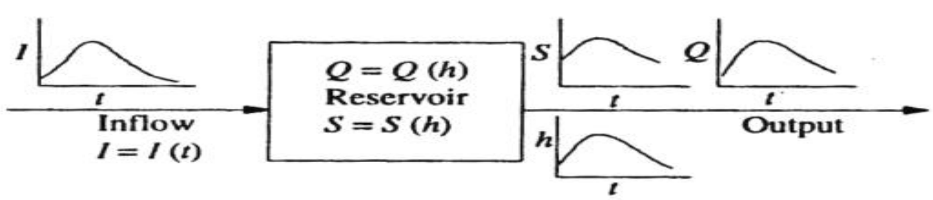


Fig. 8.1 Storage routing (Schematic)

For reservoir routing, the following data have to be known:

1. Storage volume *vs* elevation for the reservoir;
2. Water-surface elevation *vs* outflow and hence storage *vs* outflow discharge;
3. Inflow hydrograph, $I = I(t)$; and
4. Initial values of S, I and Q at time $t = 0$.

As the horizontal water surface is assumed in the reservoir, the storage routing is also known as Level Pool Routing.

2.7 Modified Pul's Method

$$\left(\frac{I_1 + I_2}{2}\right)\Delta t + \left(S_1 - \frac{Q_1 \Delta t}{2}\right) = \left(S_2 + \frac{Q_2 \Delta t}{2}\right)$$

Here Δt is any chosen interval, approximately 20 to 40% of the time of rise of the inflow hydrograph.

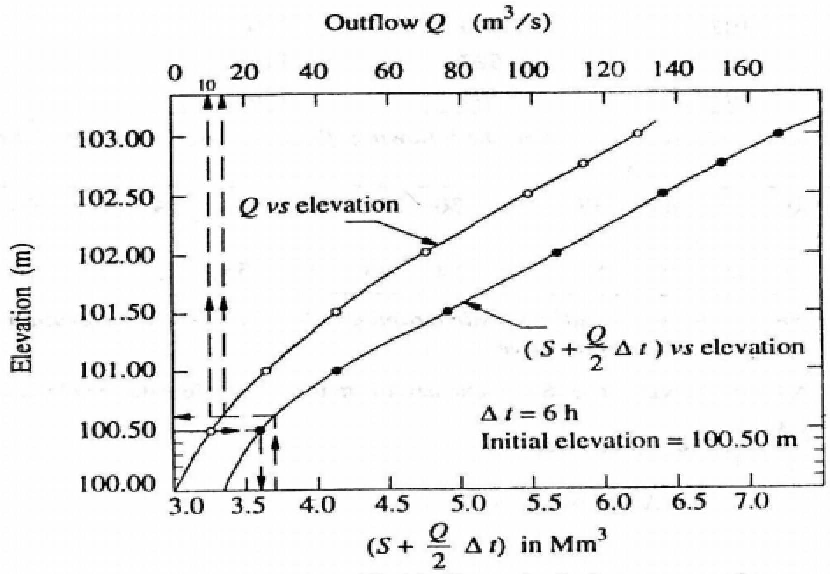


Fig (3) Modified Pul's Method of Storage Routing

EXAMPLE 8.1: *A reservoir has the following elevation, discharge and storage relationships:*

Elevattion (m)	Storage (10^6 m^3)	Outflow dischange (m^3/s)
100.00	3.350	0
100.50	3.472	10
101.00	3.880	26
101.50	4.383	46
102.00	4.882	72
102.50	5.370	100
102.75	5.527	116
103.00	5.856	130

When the reservoir level was at 100.50m, the following flood hydrograph entered the reservoir.

Time (h)	0	6	12	18	24	30	36	42	48	54	60	66	72
Discharge (m^3/s)	10	20	55	80	73	58	46	36	55	20	15	13	11

Route the flood and obtain(i) the outflow hydrograph and (ii) the reservoir elevation vs time curve during the passage of the flood wave.

SOLUTION: A time interval $\Delta t = 6$ h is chosen. From the available data the elevation–discharge—$\left(S + \frac{Q\Delta t}{2}\right)$table is prepared.

$$\Delta t = 6 \times 60 \times 60 = 0.0216 \times 10^6 \text{ s}$$

Elevation (m)	100.00	100.50	101.00	101.50	102.00	102.50	102.75	103.00
Dischange Q (m^3/s)	0	10	26	46	72	100	116	130
$\left(S+\frac{Q\Delta t}{2}\right)$ (Mm^3)	3.35	3.58	4.16	4.88	5.66	6.45	6.78	7.26

A graph of Q vs elevation and $\left(S+\frac{Q\Delta t}{2}\right)$ vs elevation is prepared (Fig. 8.2). At the start of routing, elevation = 100.50 m, Q = 10.0 m^3/s, and $\left(S-\frac{Q\Delta t}{2}\right)$ = 3.362 Mm^3. Starting from this value of $\left(S-\frac{Q\Delta t}{2}\right)$ Eq. (8.6) is used to get $\left(S+\frac{Q\Delta t}{2}\right)$ at the end of first time step of 6 h as

$$\left(S+\frac{Q\Delta t}{2}\right)_2 = (I_1+I_2)\frac{\Delta t}{2} + \left(S-\frac{Q\Delta t}{2}\right)_1$$

$$= (10+20)\times\frac{0.0216}{2} + (3.362) = 3.686 \text{ Mm}^3.$$

Looking up in Fig. 8.2, the water-surface elevation corresponding to $\left(S+\frac{Q\Delta t}{2}\right)$ = 3.686 Mm^3 is 100.62 m and the corresponding outflow discharge Q is 13 m^3/s, For the next step,

Initial value of $\left(S-\frac{Q\Delta t}{2}\right) = \left(S+\frac{Q\Delta t}{2}\right)$ of the previous step $-\ Q\,\Delta t$

$$= (3.686 - 13\times 0.0216) = 3.405 \text{ Mm}^3$$

The process is repeated for the entire duration of the inflow hydrograph in a tabular form as shown in Table 8.1.

TABLE 8.1 FLOOD ROUTING THROUGH A RESERVOIIR—*EXAMPLE 8.1* —Modified Pul's method.

Δt = 6 h = 0.0216 Ms, $\bar{I} = (I_1 + I_2)/2$

Time (h)	Inflow I (m^3/s)	$\bar{I}$ (m^3/s)	$\bar{I}.\Delta t$ (Mm^3)	$S-\frac{\Delta t Q}{2}$ (Mm^3)	$S+\frac{\Delta t Q}{2}$ (Mm^3)	Elevation (m)	Q (m^3/s)
1	2	3	4	5	6	7	8
0	10					100.50	10
		15.00	0.324	3.362	3.636		
6	20					100.62	13
		37.50	0.810	3.405	4.215		
12	55					101.04	27
		67.50	1.458	3.632	5.090		
18	80					101.64	53
		76.50	1.652	3.945	5.597		
24	73					101.96	69
		65.50	1.415	4.107	5.522		
30	58					101.91	66
		52.00	1.123	4.096	5.219		
36	46					101.72	57
		41.00	0.886	3.988	4.874		

TABLE 8.1 (Continued)

1	2	3	4	5	6	7	8
42	36					101.48	48
		31.75	0.686	3.902	4.588		
48	27.5					101.30	37
		23.75	0.513	3.789	4.302		
54	20					100.10	25
		17.50	0.378	3.676	4.054		
60	15					100.93	23
		14.00	0.302	3.557	3.859		
66	13					100.77	18
		12.00	0.259	3.470	3.729		
72	11					100.65	14
				3.427			

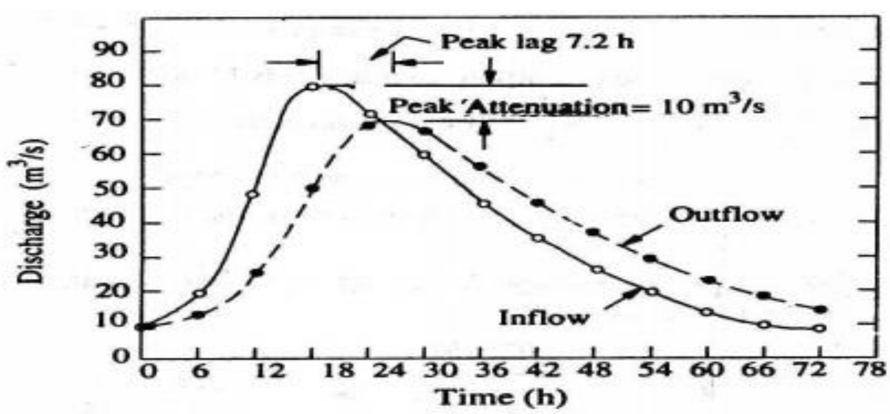


Fig. 8.3 Variation of inflow and outflow discharges—Example 8.1

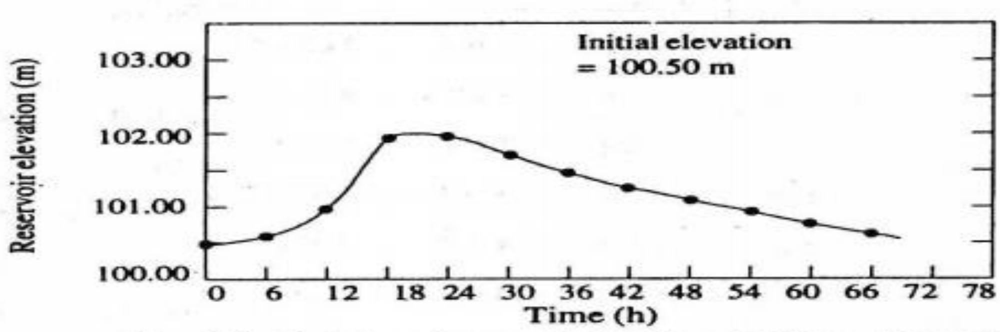
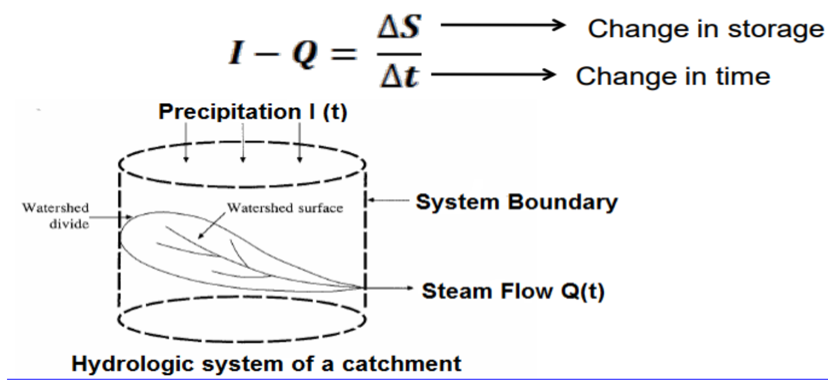


Fig. 8.4 Variation of reservoir elevation with time—Example 8.1

2.8 Continuity equation for hydrologic routing

Flood hydrograph through a reservoir or a channel reach is a gradually varied unsteady flow. If we consider some hydrologic system with input I(t), output Q(t), and storage S(t), then the equation of continuity in hydrologic routing methods is the following:



Fig(3)

Rate change of flow storage can be also represented by this following equation:

$I - Q = \frac{\Delta S}{\Delta t}$ ……………………………………………………………………(1)

$\Delta S = change\ in\ storage$

$\Delta t = change\ in\ time$

Even if the inflow hydrograph, I(t) is known, this equation cannot be solved directly to obtain the outflow hydrograph, Q(t), because both Q and S are unknown. A second relation, the storage function is needed to relate S, I, and Q. The particular form of the storage equation depends on the system: a reservoir or a river reach.

2.9 Hydrologic Channel Routing

Channel routing the storage is a function of both outflow and inflow discharges. The total volume in storage can be considered under two categories as:

1. Prism storage, and
2. Wedge storage.

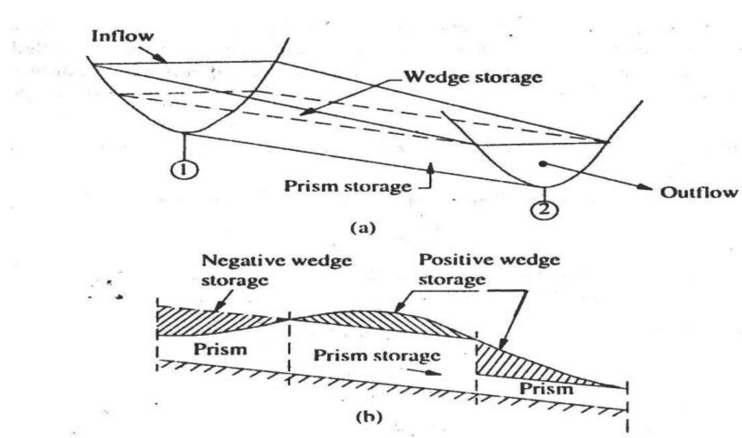


Fig (4)Storage in a channel reach

•The total storage in the channel reach can then be expressed as

$S = K[xI^m + (1 - x)Q^m]$,………………………………………………………(2)

Where K and x are coefficients and m = a constant exponent. It has been found that the value of m varies from 0.6 for rectangular channels to a value of about 1.0 for natural channels.

Muskingum Equation

Using m=1, equation 2 reduces to a linear relationship for S in terms of I and Q as

$S = K[xI + (1-x)Q]$ ……………………………………………………………….(3)

And this relationship is known as the Muskingum equation. In this the parameters x is known as weighting factor and takes value between 0 and 0.5. When x=0,

$S = KQ$ ……………………………………………………………………………………(4)

Such a storage is known as linear storage or linear reservoir.

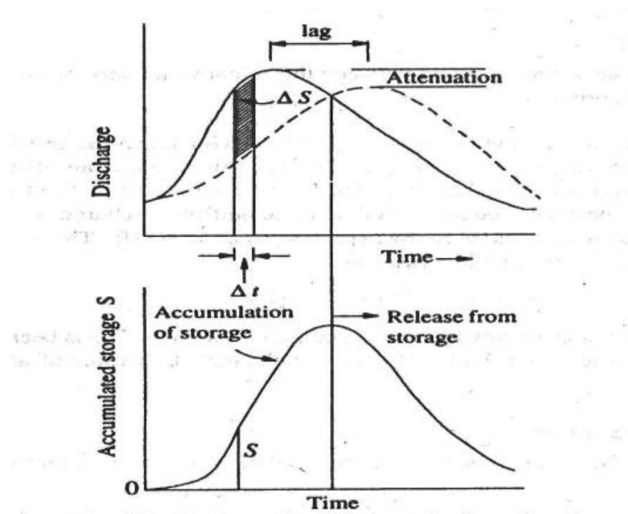
The coefficient of K is known as Storage-time constant.

➢ Estimation of K and x

Figure 5 shows typical inflow and outflow hydrograph through a channel reach. Note that the outflow peak does not occur at the point of intersection of the inflow and outflow hydrographs.

Using the continuity equation

$(I_{1+}I_2)\frac{\Delta t}{2} - (Q_1 + Q_2)\frac{\Delta t}{2} = \Delta S$…………………………………………………………(5)



Fig(5) Hydrographs and storage in channel routing

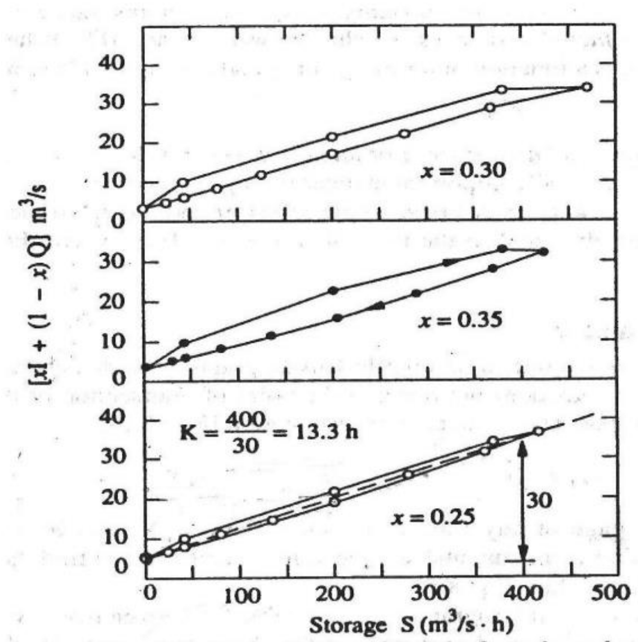


Fig (6) Determination of K and x in a Channel reach

A note on channel routing

- Channel routing is widely used in flood forecasting. Large projects, like the one used during the Red Deer River flood in 2005, use sophisticated computer simulations, but their algorithm is based on channel routing. So, it is important to understand the concept.
- When there are no gauging stations in a given stream reach, it is useful to set up gauging stations and obtain at least one inflow and outflow hydrograph by planners themselves.
- Once the hydrographs are obtained, planners can calculate K and x from the data and simulate the propagation of a design flood.
- K has a unit of time, and is a rough measure of the residence time of flood peak in the channel reach. Change in channel morphology may change the value of K.

2.10 Clark Unit Hydrograph (UH) Computation

Clark's method also known as time-area histogram method, aims at developing an IUH due to an instantaneous rainfall excess over a catchment. It is assumed that the rainfall excess first undergoes pure translation and then attenuation. The translation is achieved by a travel time-area histogram and the attenuation by routing the results of the above through a linear reservoir at the catchment outlet.

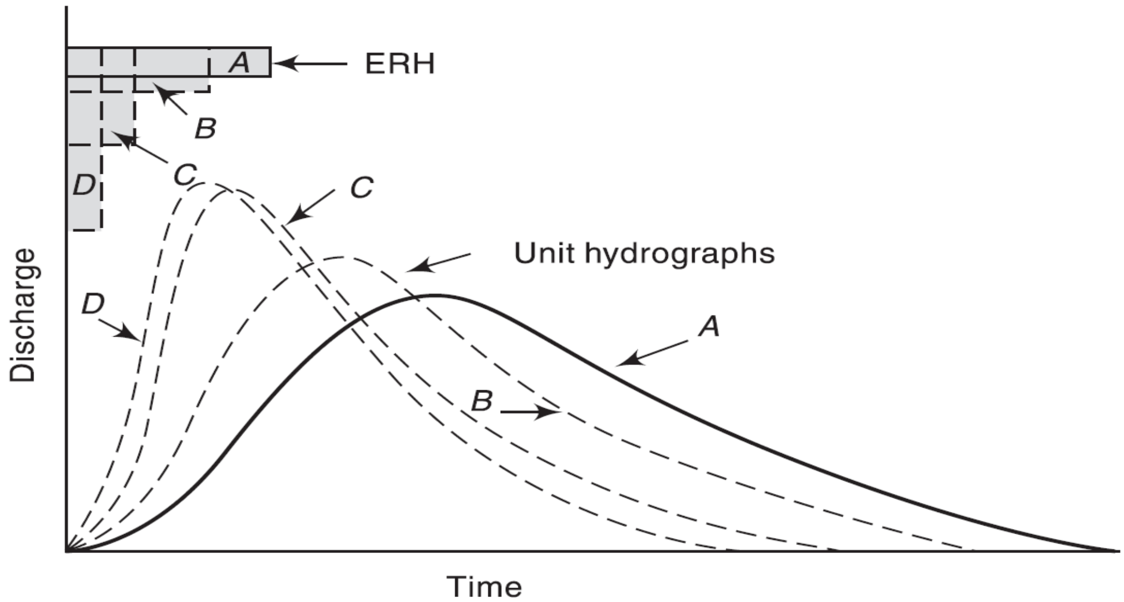


Fig (7) Unit Hydrograph of Different Duration

- Figure 6.23 shows the shape of different hydrographs for different D values.
- As D is reduced, the intensity of rainfall excess being equal to 1/D increases and the UH becomes more skewed.
- A finite UH indicated as D →0.
- The limiting case of UH of zero duration is known as *instantaneous unit hydrograph (IUH).*

<u>Method of IUH</u>

1. Develop a time area (TA) curve
2. Route the time area curve through a linear reservoir with a Clark routing parameter

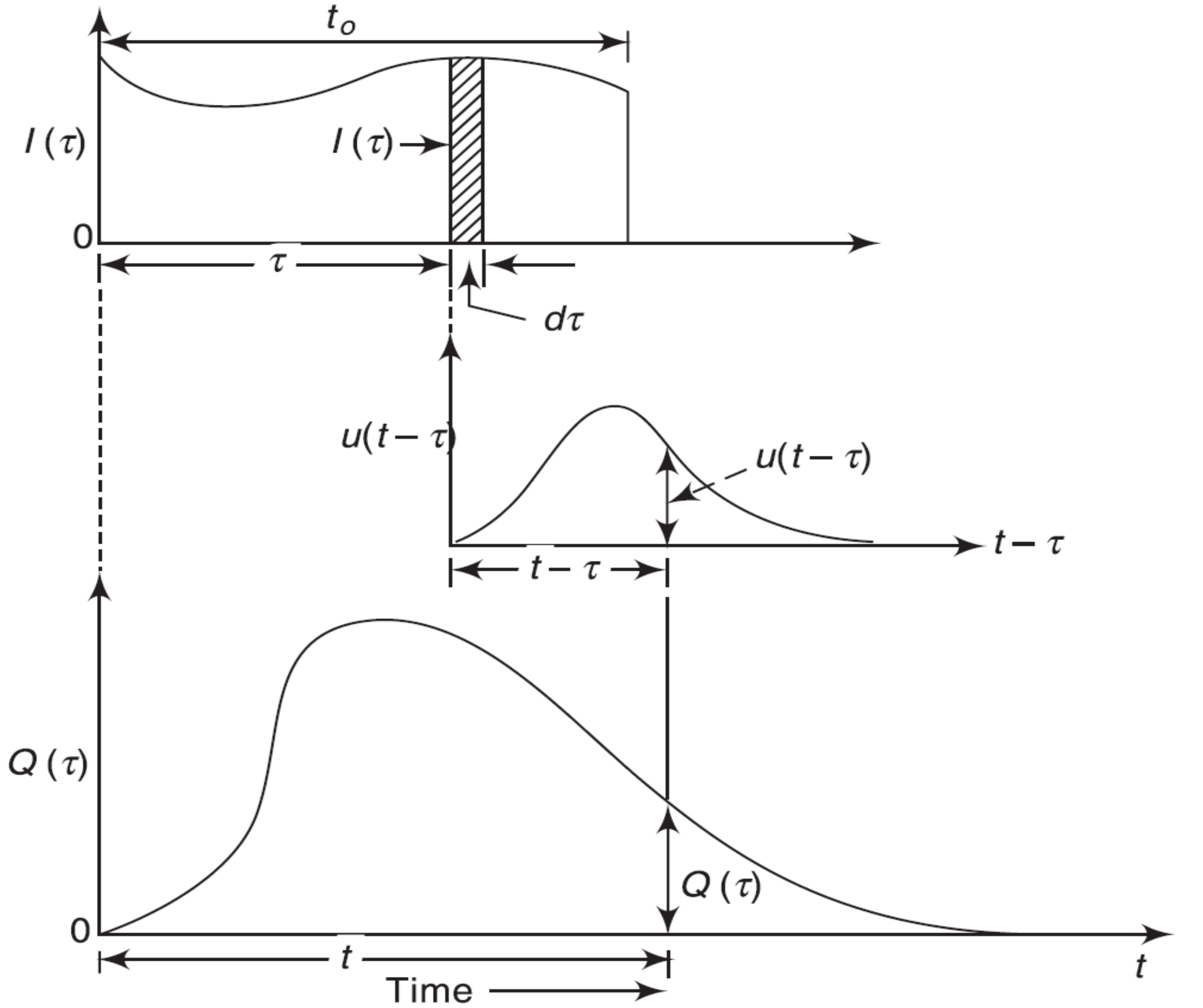


Fig (6) Convolution of I(τ) and IUH

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