15A01704 - WATER RESOURCES ENGINEERING-II

B. Tech IV-I Sem. (C.E)

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Referred Resource: Water Resources Engineering 2016 Prof P.C.Swain

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STREAM GAUGING

Necessity; Selection of gauging sites; methods of DischargeMeasurement; Area-Velocity method; Slope-Area method; Tracer method,Electromagnetic induction method; Ultrasonic method; Measurement of depth – Sounding rod, Echo-sounder; Measurement of velocity: Floats – Surface floats, Sub– surface float or Double float, Velocity rod; Pitot tube; Current meter- rating of current meter, measurement of velocity; chemical method; Measurementof stage-Staff gauge, wire gauge, water stage recorder, bubble gauge recorder; stage-dischargecurve.

Stream Gauging

- It is a technique used to measure the discharge, or the volume of water moving through a channel per unit time, of a stream.
- The height of water in the stream channel, known as a stage or gage height, can be used to determine the dischage in a stream.
- Streamflow representing the runoff phase of the hydrological cycle is the most important basic data for hydrologic studies.
- Streamflow is the only part of hydrological cycle that can be measured accurately.
- Runoff from a catchment can be determined by measuring the discharge of the stream draining it.

Necessity of gauging

- By measuring the discharge in river the irrigation water can be distributed uniformly.
- By measuring flow in rivers flood warning can be issued.
- By measuring flow in canal quantity of loses can be known.
- The quantity of water flowing in the river helps for future research

Selection of gauging sites;

1. The bed and banks of the stream should be firm and stable so as to ensure consistency of area- discharge relationship.
2. The bed and banks should be free from vegetal growth, boulders or other obstructions like bridge piers, etc.

3. There should be no larger overflow section at flood stage.
4. To ensure good consistency between stage and discharge there should be a good control section far downstream of the gauging site.
5. The stream course is straight for about 300 feet upstream and downstream of the gage site.
6. At all stages, the total flow is confined to a single channel. There is also no subsurface or groundwater flow that bypasses the site.
7. The streambed in the vicinity of the site is not subject to scour and fill. It is also free of aquatic plants.
8. The banks of the stream channel are permanent. The are free of brush and high enough to contain floods.
9. The stream channel has unchanging natural controls. These controls are bedrock outcrops or stable riffle for low flow conditions. During high flows, the controls are channel constrictions or a cascade or falls that is unsubmerged at all stages.
10. At extremely low stages, a pool is present upstream from the site. This will ensure the recording of extremely low flows and avoid the high velocities associated with high streamflows.
11. The gaging site is far enough removed from the confluence with another stream or from tidal effects to avoid any possible impacts on the measurement of stream stage.
12. Within the proximity of the gage site, a reach for the measurement of discharge at all stages is available.
13. The site is accessible for installation and operation and maintenance of the gaging site.

CATEGORISATION OF STREAM FLOW MEASUREMENT

Stream flow techniques are broadly classified into two categories:-

- Direct determination of discharge
- Indirect determination of discharge

2.5.1 Direct Method

Direct determination of stream discharge measurement includes :-

a. Area velocity method
b. Dilution techniques
c. Electromagnetic method
d. Ultrasonic method

2.5.2 Indirect Method

Indirect method of stream discharge measurement includes :-

a. Slope area method
b. Hydraulic structures

- Continuous measurement of stream discharge is very difficult. As a rule direct measurement of discharge is a very time consuming and costly procedure. Hence a two step procedure is followed.

- At first the discharge in a given stream is related to the elevation of the water surface (stage) through avg. series of careful measurement.

- In the next step, the stage of the stream is observedvroutinely in a relatively inexpensive manner and thev discharge is estimated by using the previously determined stage-discharge relationship.

- This method of discharge determination of streams is adopted universally.

a) Area Velocity Method

- This method of discharge measurement consists essentially of the area of cross section of the river at a selected section called the **gauging site** and measuring the velocity of flow through the cross sectional area.

- The gauging site must be selected with care to ensure that the stage discharge curve is reasonably constant over a long period over a few years. Toward the statement given in the previous slide the following criteria are adopted

(a) The stream should have a well defined cross section which does not change in various seasons.

(b) It should be easily accessible all through the year.

(c) The site should be in straight, stable reach.

(d) The gauging site should be free from backwater effects in the channel Water Resources Engineering **2016** Prof P.C.Swain Page 21

b). Dilution Technique

- Also known as chemical method.
- Depends on the continuity principle. This principle is applied to a tracer which is allowed to mix completely with the flow.

Two methods of dilution technique:-

(a) sudden injection method/ gulp / integration method.

(b) constant rate injection method/plateau gauging

NOTE

- Dilution method of gauging is based on the assumption of steady flow. If the flow is unsteady and the flow changes appreciably during gauging. There will be a change in the storage volume in the reach and the steady state continuity equation is not valid.

ii) Constant Rate Injection Method

It is one particular way of using the dilution principle by injecting the tracer of a concentration c1 at constant rate Q1 at section1. At section 2 the concentration gradually rises from the background value of c0 at time t1 to a constant value c2 .so at the steady state, the continuity equation for the tracer is :-

$$\mathbf{QtC1 + QC0 = (Q+Qt)C2}$$

$$\mathbf{Q = Qt(C1- C2)/(C2-C0)}$$

IMPORTANT POINTS REGARDING TRACERS

Tracers are of three main types:-

(a) Chemicals (sodium chloride, sodium dichromate)
(b) Fluorescent dyes (rhodamine- WT, sulpho-rhodamine)
(c) Radioactive materials(bromine-82, sodium-22,iodine-132)

Tracers should ideally follow the following property:-

- 1 non-toxic
- 2 not be very expensive
- 3 should be capable of being detected even at a very small concentrations
- 4 should not get absorbed by the sediments or vegetation.
- 5 it should be lost by evaporation.
- 6 should not chemically react with any of the surfaces like channel boundary or channel beds

2.14 Length Of Reach

- It is the distance between the dosing section and sampling section which should be large enough to have the proper mixing of the tracer with the flow.

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- The length depends on the geometric dimensions of the channel cross section , discharge and turbulence levels.
- Empirical formula suggested by **RIMMAR (1960**) for the estimation of the mixing length

. **L = 0.13B2C{0.7C+2(g1/2)}/gd**

l= mixing length, b= avg width, d= avg depth, c= chezy's constant g = accln due to gravity

- The dilution method has the major advantage that the discharge is estimated directly in an absolute way. It is particularly attractive for small streams such as mountainous rivers
- It can be used occasionally for checking the calibration , stage discharge ,curves etc obtained by other methods.

d) . Ultrasonic Methods

- It is essentially an area velocity method.
- The average velocity is only measured using ultrasonic signals.
- Reported by SWENGEL(1955)

INDIRECT METHODS

These category include those methods which make use of the relationship between the flow discharge and the depths at specified locations.

Two broad categories under this method is:-

(a) Flow measuring structures

(b) Slope area method

a) **Flow Measuring Structures**

- Structures like notches, weir, flumes and sluice gates for flow measurements in hydraulic laboratories are well known.
- These conventional structures are used in the field conditions but their use is limited by the ranges of head, debris or sediment load of the stream and the backwater effects produced by the streams.
- The basic principle governing the use of these structure is that these structure produce a unique control section in the flow. At these structure the discharge Q is the function of the water surface elevation measured from the specified datum.

Q = f(H)

H= water surface elevation measured from the specified datum

E.g. Q = KHn

Where [K =2/3 cd b(2g)1/2] used basically for weirs. K and n are system constants.

- The above red marked equation is valid as long the downstream water level is below a certain limiting water level known as modular limit.
- The flows which are independent of downstream water level are known as free flows.
    - If the tail water conditions do affect the flow then the flow is called drowned flow /submerged flow.
    - Discharges under drowned conditions are estimated by VILLEMONTE FORMULA.

$$Q_s = Q_1 [1-(H_2 / H_1)^n]^{0.85}$$

Q_s = submerged discharge
Q_1 = free flow discharge under H_1
H_1 = Upstream water surface elevation measured above weir crest

Categorization Of hydraulic Structure

(a) Thin plate structures
(b) Long base weirs [broad crested structures]
(c) Flumes [made of concrete, masonry, metal sheets etc]

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b) SLOPE AREA METHOD

- Manning's formula is used to relate depth at either section with the discharge.
- Knowing the water surface elevation at the two section, it is required to estimate the discharge. Applying the energy equation to sections 1 and 2,

$$Z_1 + Y_1 + \{V_1^2 / 2g\} = Z_2 + Y_2 + \{V_2^2 / 2g\} + h_L$$

$h_L = h_e + h_f$ where h_e = eddy loss and h_f = frictional loss.

$$h_f = (h_1 - h_2) + \{(v_1^2 /2g) - (v_2^2 /2g)\} - h_e$$

If L = Length of the reach then $h_f / L = S_f = Q^2 / K^2$ = Energy slope
K= conveyance of the channel $=(1/n)A(R^{2/3})$
n= manning's roughness coefficients

In non uniform flow $k=\{k_1 k_2\}^{1/2}$

$H_e = K_e [(v_1^2/2g) - (v_2^2 /2g)]$ where K_e = eddy loss coefficient .

Stage Discharge Relationship

- The stage discharge relationship is also known as **rating curve**.
- The measured value of discharges when plotted against the corresponding stages gives relationship that represents the integrated effects of a wide range of channel and flow parameters.
- The combined effects of these parameters is known as **control**.
- If the (G-Q) relationship for a gauging section is constant and does not change with time, the control is called **permanent**.

If it changes with time , it is called **shifting control**

MEASUREMENT OF DEPTH OF A RIVER

At the selected site, the section line is marked off by permanent survey markings and the cross section is determined.

Case 1 – Sounding rods or sounding weights.

When the stream depth is small.

The depth at various locations are measured by sounding rods or sounding weights.

Case 2 – Eho Recorder

When the stream depth is large or when result is needed with higher accuracy.

An instrument named echo-depth recorder is used. In this, a high frequency sound wave is sent down by a transducer kept immersed in water surface and the echo reflected by the bed is recorded by the same transducer. By comparing the time interval between the transmission of the signal and the receipt of the echo the distance is measured and is shown . It is particularly advantageous in high velocity streams.

MEASUREMENT OF VELOCITY

- For the accurate determination of velocity in a stream we have a mechanical device known as

CURRENT METER.

- It is the most commonly used instrument in Hydrometry to measure the velocity at a point in the flow cross-section.
- It essentially consists of a rotating element which rotates due to the reaction of the stream current with an angular velocity proportional to the stream velocity.
- Robert Hooke(1663) invented a propeller type current meter for traversing the distance covered by ship.
- Later on it was Henry(1868) who invented present day cup- type instrument and the electrical make-and-break mechanism.

Types Of Current Meter

a. Vertical Axis Meters

b. Horizontal Axis Meters

A current meter is so designed that its rotation speed varies linearly with the stream velocity v.

A typical relationship is:-

$$v = a\,N_s + b$$

Where v = Stream velocity at the instrument location.
Ns = No of revolutions per second of the meter
a, b= Constants of the meter.

Calibration Equation

- Now we need to find out the relation between the stream velocity and revolutions per second of the meters which is nothing but the calibration equation.
- The calibration equation is unique to each instrument .

It is determined by towing the instrument in a special tank

- A towing tank is a long channel containing still water with arrangements for moving a carriage longitudinally over its surface at constant speed.

- The instrument to be calibrated is mounted on the carriage with the rotating element immersed to a specified depth in the water body in the tank.
- The carriage is then towed at a predetermined constant speed(v) and the corresponding avg value of revolutions per second is determined.

- In India we have an excellent towing tank facilities for calibration of current meters at CWPRS(Central Water And Power Research Station) and IIT MADRAS.

Value Of Velocity For Field Use

The velocity distribution in a stream across a vertical section is logarithmic in nature. The velocity distribution is given by

$$v = 5.75 v^* \log_{10} (30y/k_s)$$

- V= velocity at a point y above the bed
- V* = shear velocity
- Ks = equivalent sand grain roughness
- In order to determine the accurate avg velocity in a vertical section one has to measure the velocity at large no of points which is quite time consuming. So certain specified procedure have been evolved.
- For the streams of depth 3.0 m the velocity measured at 0.6 times the depth of flow below the water surface is taken as the average velocity.(single point observation model)

V(avg)= v0.6

For the depth between 3.0m to 6.0 m we have

V(avg)= (v0.2 +v0.8)/2

For the river having flood flow we have

v(avg)= k*vs

where vs(surface velocity) and k(reduction coefficient) Value of k lies between 0.85 to 0.95

Vertical Axis Meters

• This instrument consist of a series of conical cups mounted around a vertical axis. The cups rotate in a horizontal plane .

- The cam attached to the vertical axial spindle records generated signals proportional to the revolutions of the cup assembly.
- Range of velocity is **0.155m/s to 2.0m/s**.
- It can not be used in situations where there are appreciable vertical components of velocities.

- Price current meter and Gurley current meter are some of its type. Water Resources Engineering 2016 Prof P.C.Swain Page 20

Horizontal Axis Meters

- This instrument consist of a propeller mounted at the end of horizontal shaft .
- The propeller **diameter is in the range of 6 to 12cm**
- It can register velocities from **0.155m/s to 4.0m/s.**
- This meter is not affected by **oblique flows of as much as 150 .**
- **Ott, Neyrtec, Watt** type meters are typical instruments under this kind.

Fig (2) Propeller type Current Meter

MEASUREMENT OF CROSS SECTION OF A RIVER

- The cross section is considered to be divided into large number of subsections by verticals. The average velocity in these subsections are measured by current meters or by floats.
- It is quite obvious that the accuracy of discharge estimation increases with the increase in number of subsections.
- The following are some of the guidelines to select the number of segments
- (a) the segment width should not be greater than 1/15 or 1/20 of the width of the river.
- (b) the discharge in each segment should be smaller than the 10% of the total discharge.
- (c) the difference of velocities in adjacent segments should not be more than 20%
- This is also called Standard Current Meter Method.

2.11 Moving Boat Method

- Discharge measurement of large alluvial rivers, such as the ganga by the standard current meter method is very time consuming even the flow is low or moderate.
- When the river is spate, it is impossible to use the standard current meter technique due to the difficulty in keeping the boat stationary on the fast moving surface of the stream .
- It is such circumstances that the moving boat techniques prove very helpful
- In this method, a special propeller- type current meter which is free to move about a vertical axis is towed in a boat at a velocity vb at right angle to the stream flow . If the flow velocity is vf, the meter will align itself in the direction of the resultant velocity vg making an angle θ with the direction of the boat . The meter will register the velocity vr .

If the time of transit between two verticals is Δt then the width between the two verticals is

$$\mathbf{w = vb\ \Delta t}$$

The flow in the sub-area between two verticals i and i+1 where the depths are yi and yi+1 respectively by assuming the current meter to measure the average velocity in the vertical is :-

$$\mathbf{\Delta Qi = [\{yi + yi{+}1\}/2]wi{+}1\ vf}$$

$$\mathbf{\Delta Qi = [\{yi + yi{+}1\}/2]v2\ r\ \sin\theta \cos\theta\ \Delta t}$$

Summation of the partial discharges ΔQi over the whole width of the stream gives the stream discharge.

MEASUREMENT OF STAGE

The stage of a river is defined as its water surface elevation measured above a datum(Mean Sea Level or any datum connected independently to MSL)
For the measurement of stage we have:-

- Manual gauges
- Automatic stage recorder

Under Manual gauges we have

- Staff gauge
- Wire gauge

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Staff gauge :

The simplest of stage measurements are made by noting the elevationof the water surface in contact with a **fixed graduated staff**. The staff is made of a durable material with a low coefficient of expansion with respect to both temperature and moisture. It is fixed rigidly to a structure, such as an abutment, pier, wall, etc.

- The markings are distinctive, easy to read from a distance and are similar to those on a surveying staff.
- Sometimes, it may not be possible to read the entire range of water-surface elevations of a stream by a single gauge and
- In such cases the gauge is built in sections at different locations. Such gauges are called ***sectional gauges*.**
- When installing sectional gauges, care must be taken to provide an overlap between various gauges and to refer all the sections to the same common datum.

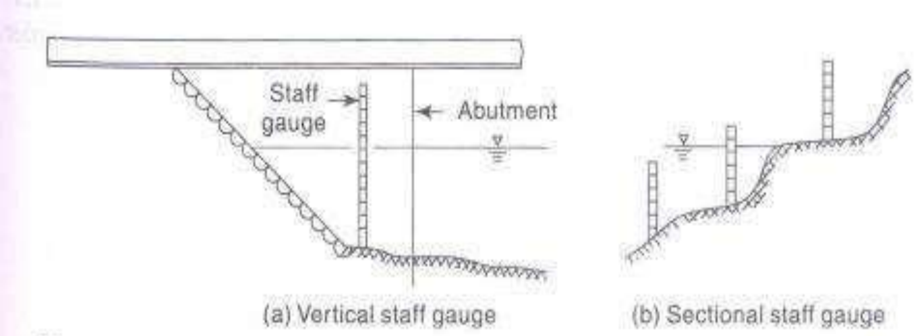


Fig. 4.1 *Staff Gauge*

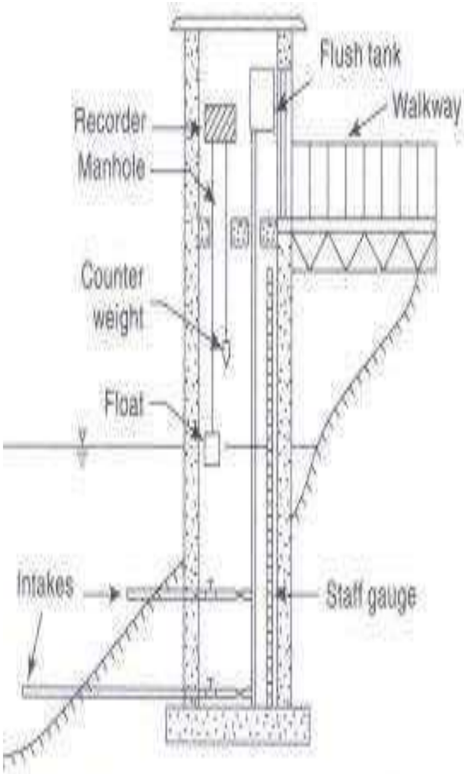
Wire Gauge

- It is a gauge used to measure the water- surface elevation from above the surface such as from a bridge or similar structure. In this, a weight is lowered by a reel to touch the water surface.
- A mechanical counter measures the rotation of the wheel which is proportional to the length of the wire paid out. The operating range of this kind of gauge is about 25 m.
- It is a gauge used to measure the water- surface elevation from above the surface such as from a bridge or similar structure. In this, a weight is lowered by a reel to touch the water surface.
- A mechanical counter measures the rotation of the wheel which is proportional to the length of the wire paid out. The operating range of this kind of gauge is about 25 m.

Automatic Stage Recorders

Float-Gauge Recorder

- The staff gauge and wire gauge described earlier are manual gauges. While they are simple and inexpensive, they have to be read at frequent intervals to define the variation of stage with time accurately.
- The float-operated stage recorder is the most common type of automatic stage recorder in use. In this, a float operating in a stilling well is balanced by means of a counterweight over the pulley of a recorder.
- Displacement of the float due to the rising or lowering of the water-surface elevation causes an angular displacement of the pulley and hence of the input shaft of the recorder.



. 4.2 Stilling well Installation

Water-depth recorder—Stevens Type F recorder
(Courtesy: Leupold and Stevens, Inc. Beaverton, Oregon, USA)

- Mechanical linkages convert this angulardisplacement to the linear displacement of a pen to record over a drum driven by clockwork.
- The pen traverse is continuous with automatic reversing when it reaches the full width of the chart.
- A clockwork mechanism runs the recorder for a day, week or fortnight and provides a continuous plot of stage vs time.
- A good instrument will have a large-size float and least friction.
- Improvements over this basic analogue model consists of models that give digital signals recorded on a storage device or transmit directly onto a central data-processing centre.
- To protect the float from debris and to reduce the water surface wave effects on the recording, stilling wells are provided in all float-type stage recorder installations.
- Note the intake pipes that communicate with the river and flushing arrangement to flush these intake pipes off the sediment and debris occasionally.

- The water-stage recorder has to be located above the highest water level expected in the stream to prevent it from getting inundated during floods. Further, the instrument must be properly housed in a suitable enclosure to protect it from weather elements and vandalism.
- On account of these, the water stage-recorder installations prove to be costly in most instances.

2. Bubble Gauge

- In this gauge, compressed air or gas is made to bleed out at a very small rate through an outlet placed at the bottom of the river. A pressure gauge measures the gas pressure which in turn is equal to the water column above the outlet.
- A small change in the water-surface elevation is felt as a change in pressure from the present value at the pressure gauge and this in turn is adjusted by a servo-mechanism

to bring the gas to bleed at the original rate under the new head. The pressure gauge reads the new water depth which is transmitted to a recorder.

The bubble gauge has certain specific advantages over a float-operated water stage recorder and these can be listed as under:

1. There is no need for costly stilling wells;
2. A large change in the stage, as much as 30 m, can be measured;
3. The recorder assembly can be quite far away from the sensing point; and
4. Due to constant bleeding action there is less likelihood of the inlet getting blocked or choked.

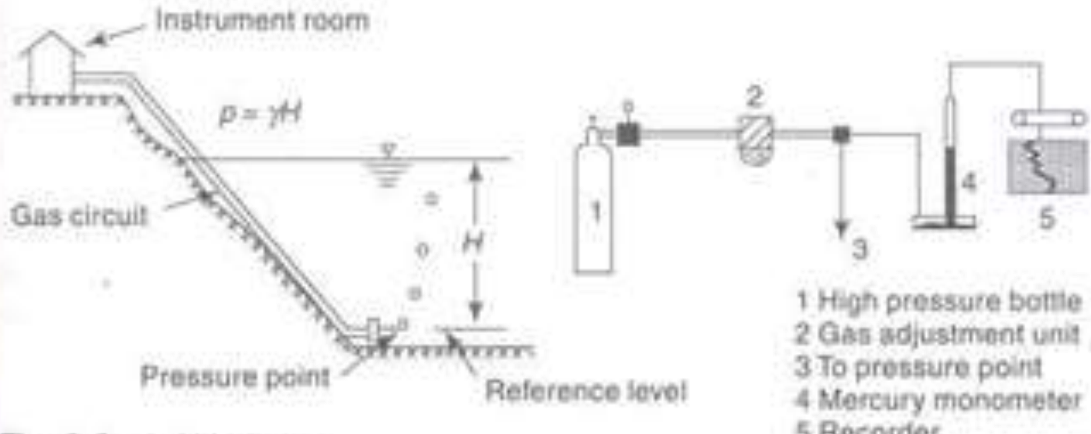


Fig. 4.4 *Bubble Gauge*

Fig. 4.5 *Bubble Gauge Installation—Telemnip*
(Courtesy: Neyrtec, Grenoble, France)

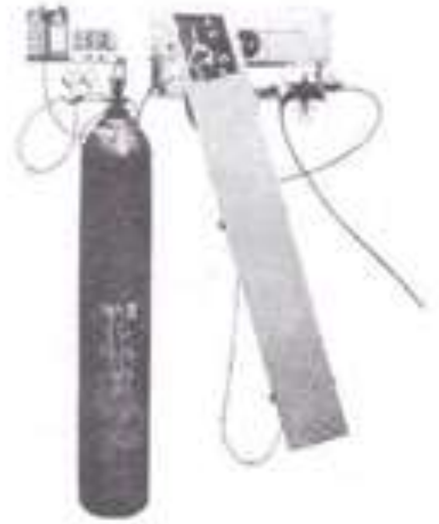


Fig. 4.6 *Bubble Gauge—Stevens Manometer Servo*
(Courtesy: Leupold and Stevens, Inc. Beaverton, Oregon, USA)

The stage data

- In addition to its use in the determination of stream discharge, stage data itself is of importance in design of hydraulic structures, flood warning and flood-protection works.
- The stage data is often presented in the form of a plot of stage against chronological time known as stage hydrograph.
- Historic flood stages are important in the indirect estimation of corresponding flood discharges. In view of these diverse uses, the river stage forms an important hydrologic parameter chosen for regular observation and recording.
- Reliable long-term stage data corresponding to peak floods can be analyzed statistically to estimate the design peak river stages for use in the design of hydraulic structures, such as bridges, weirs, etc.

Stage Data

- The stage data is often represented in the form of a plot of stage against chronological time.
- This is popularly known as stage hydrograph
- Stage data is of utmost importance in design of hydraulic structures, flood warning and flood protection work.

Fig. 4.7 Stage Hydrograph

UNIT – 3

<u>RESERVOIR PLANNING</u>

Introduction; Investigations for reservoir planning; Selection of site for a reservoir; Zones of storage in a reservoir; Storage capacity and yield; Mass inflow curve and demand curve; Calculation of reservoir capacity for a specified yield from the mass inflow curve; Determination of safe yield from a reservoir of a given capacity; Sediment flow in streams: Reservoir sedimentation; Life of reservoir; Reservoir sediment control; Flood routing; Methods of flood routing-Graphical Method (Inflow – storage discharge curves method).

INTRODUCTION

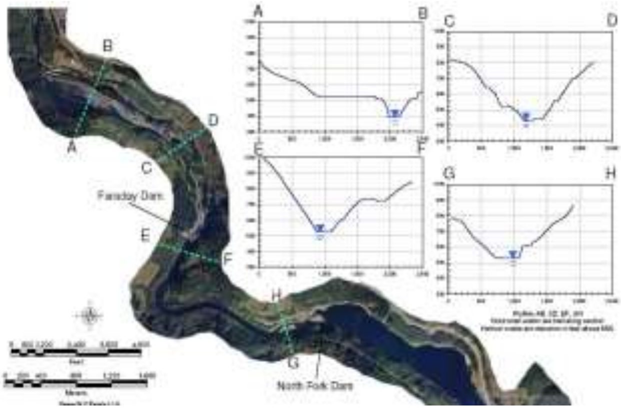
RESERVOIR

- A reservoir usually means an enlarged natural or artificial lake, storage pond or impoundment created using a dam or lock to store water.

- When barrier is constructed across some river in the form of dam, water gets stored on upstream side of the barrier forming a pool of water.

- Reservoir is the portion where Water is stored behind the dam. It is designed to accumulate to store all water flowing throughout the year considering the valley storage capacity behind the dam. Reservoir is designed to accommodate to store the Silt expected in the inflow.

- Dam and Reservoir are both designed normally for 100 year life time.



PURPOSE OF RESERVOIR

- Storage and control of water for irrigation
- Storage and diversion of water for domestic uses
- Water supply for industrial uses
- Development of Hydroelectric Power
- Increasing water depth for navigation
- Storage space for flood control
- Reclamation of low laying land
- Debris Control
- Preservation and cultivation of useful aquatic life
- Recreation

TYPES OF RESERVOIR

- **S**torage of Conservation Reservoir
- Flood Control Reservoir
- Multipurpose Reservoir
- Distribution Reservoir
- Balancing Reservoir

STORAGE RESERVOIR

- Constructed to store the water in rainy season and to release it later when river flow is low.

- Also helps in moderating the floods and reducing the flood damage to some extent on the downstream.

FLOOD CONTROL RESERVOIR

Protect the areas laying on its downstream side from damage due to flood Also known as flood mitigation reservoir or flood protection reservoir

MULTIPURPOSE RESERVIOR

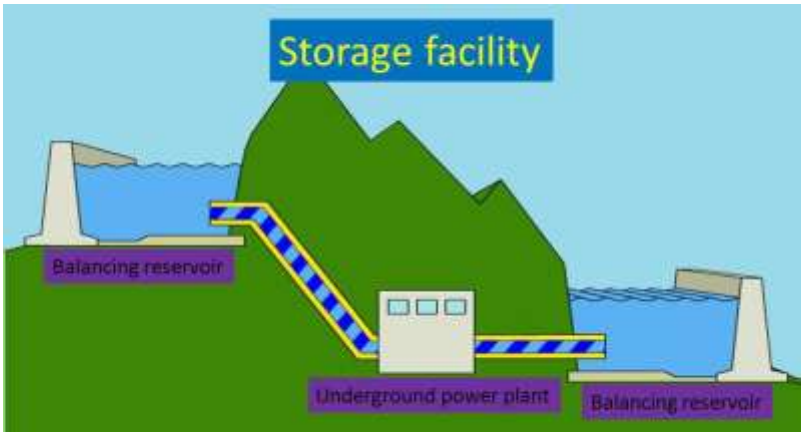
Design or Construct to serve two or more two or more purpose In our Country most of the reservoir are designed as multipurpose reservoir to store water for irrigation, hydropower generation and also to control flood

DISTRIBUTION RESERVIOR

Stores the during the period of lean demand and supplies the same during the period of high demand.

BALANCING RESERVIOR

Small reservoir constructed at downstream side of the main reservoir for holding the water.



INVESTIGATION FOR RESERVOIR PLANNING

- Engineering Survey
- Geological Survey
- Hydrological Survey

ENGINEERING SURVEY

- Area at dam site is surveyed in details
- Preparation of Contour plan,
- Preparation of Area elevation curve
- Preparation of Storage elevation curve

➢ Survey is carried out on Properties of proposed area of land
➢ Selection of suitable site for Dam

FIG. 6.2. A TYPICAL CONTOUR PLAN.

GEOLOGICAL SURVEY

➢ Water tightness of reservoir basin
➢ Stability of foundation for the Dam
➢ Geological and Structural features, such as fold, faults, fissure of rock basin

➢ Type and depth of overburden
➢ Location of permeable and soluble rocks, if any
➢ Ground water condition if any

➢ Location of Quarry sites for material requirement for dam construction

➢ And the Geology of the catchment area should also be studied, since it affects the proportions of run off percolation.

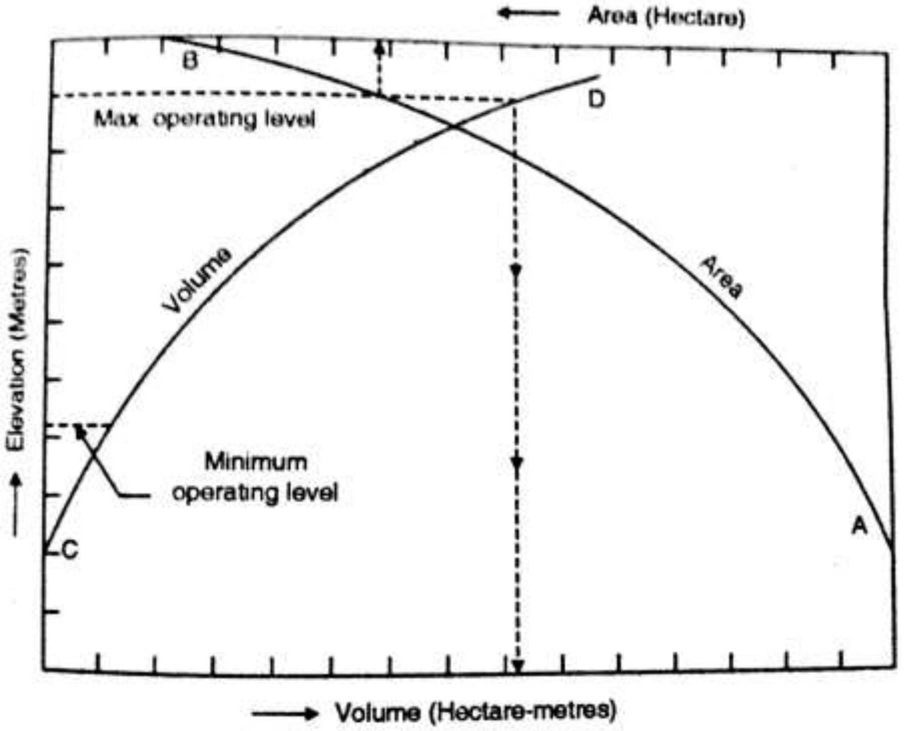


FIG. 6.3. ELEVATION AREA AND ELEVATION-STORAGE CURVES.

HYDROLOGICAL SURVEY

- Study of Run-off pattern at the proposed dam site, to determine the storage capacity corresponding to a given demand.

- Determination of the hydrograph of the worst flood, to determine the spillway capacity and design.

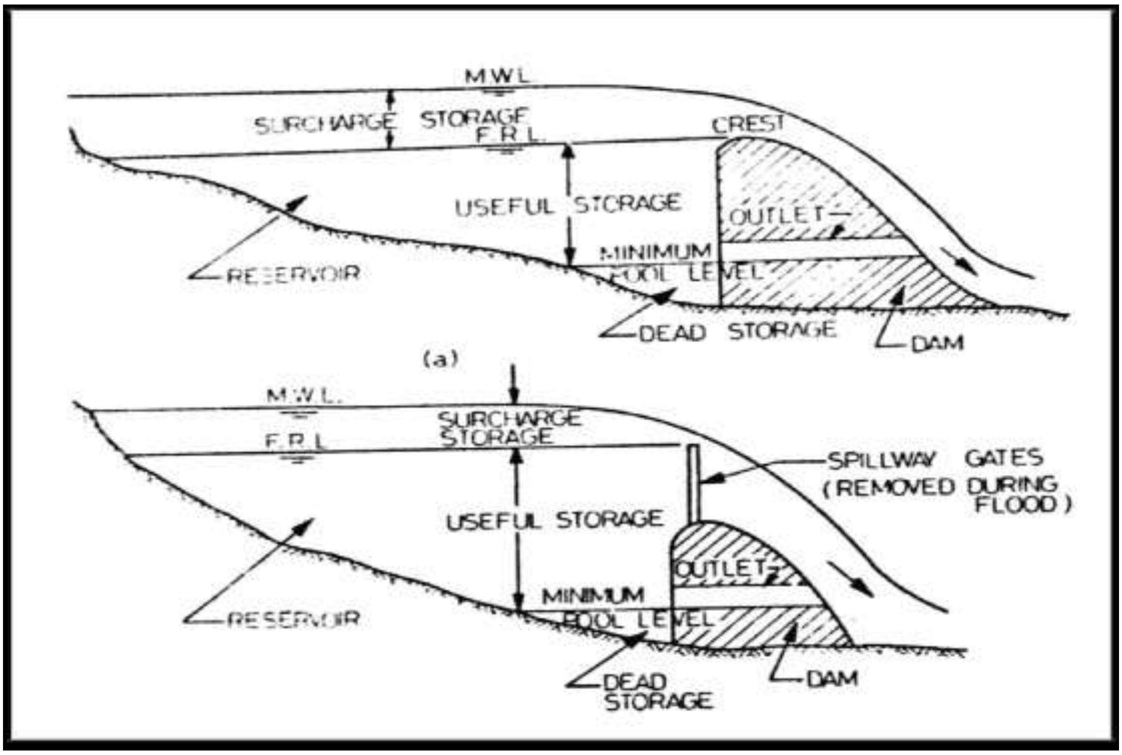
SELECTION OF SITE FOR RESERVOIR

SELECTION OF SITE FOR RESERVOIR

- Large Storage Capacity
- Suitable Site for the Dam
- Water tightening of reservoir

- Good Hydrological Conditions
- Deep Reservoir
- Small Submerged Area
- Low Silt Flow
- No Objectionable Minerals
- Low Cost of real Instate

BASIC TERMS AND DEFINATIONS



BASIC TERMS AND DEFINATIONS

1. **FULL RESERVOIR LEVEL (FRL)**

- Highest water level to which the water surface will rise during normal operating conditions.

- Highest level at which the water is intended to be held for various uses without any passage through spillway

- In case of Dam without spillway gates the FRL is equal to the crest of the spillway.

- Also called as Full Tank Level (FTL) or the Normal Pool Level (NPL)

2. **NORMAL CONSERVATION LEVEL (NCL)**

- Highest level of reservoir at which water is intended to be stored for various uses other than flood. NCL is different from the FRL as the latter may includes a part of the flood.

3. MAXIMUM WATER LEVEL (MWL)

- Maximum level to which the water surface will rise when the design flood passes over the spillway
- MWL is also called as Maximum Pool Level (MPL) or Maximum Flood Level (MFL)

4. MINIMUM POOL LEVEL (MPL)

- Lowest level up to which the water is withdrawn from the reservoir under any ordinary conditions.

- MPL is generally corresponds to the elevation of the lowest outlet (or sluiceway) of the Dam. 5. USEFUL STOREAGE The volume of water stored between the Full reservoir Level (FRL) and Minimum pool level (MPL) The useful storage is also called as Live Storage

ZONES OF THE RESERVOIR:

1. SURCHARGE STORAGE

- Volume of water above Full reservoir level (FRL) up to Maximum water level (MWL).

- It is uncontrolled storage which exists only when the river is in flood and flood water is passing over the spillway.

- This Storage is available only for absorption of flood.

2. DEAD STOREAGE

Volume of water held below the minimum pool level.

- Dead storage is not useful.

3.BANK STORAGE

- If banks of the reservoir are porous some water is temporarily stored by them, when reservoir is full.

- The stored water in the banks is drains latter in to the reservoir when water level of the reservoir falls

4. VALLEY STOREAGE

- The volume of water held by the natural river channel in its valley up to the top of its banks before the construction of reservoir is called valley storage.

STORAGE CAPACITY AND YIELD

1. YIELD FROM THE RESERVOIR

Volume of water which can be withdrawn from a reservoir in a specified period of time.

Expressed as Mha_m/year or Mm3/Year for Large Storage

10. SAFE YIELD OR FIRM YIELD

Maximum quantity of water which can be supplied from a reservoir in a specified period of time during a critical dry year. Generally the lowest recorded natural flow of the river for a number of year is taken as the critical dry period for determining the safe yield.

11. SECONDARY YIELD

- Quantity of water which is available during the period of high flow in the rivers when the yield is more than the safe yield.

12. DESIGN YIELD

The Design yield is the yield adopted in the design of reservoir.

- The Design yield is usually fixed after considering the urgency of the water needs and the amount of risk involved.

13. AVERAGE YIELD

- The arithmetic average of the Firm and the Secondary yield over a long period of time.

RESERVOIR CAPACITY

1. **FLOOD HYDROGRAPH OF FLOW**

   It is the Flood Hydrograph of Inflow for several years

2. **MASS INFLOW CURVE**

   It is a plot between cumulative inflow in the reservoir with time

3. **DEMAND CURVE**

   It is a plot between accumulated demand with time

1. **FLOOD HYDROGRAPH OF FLOW**

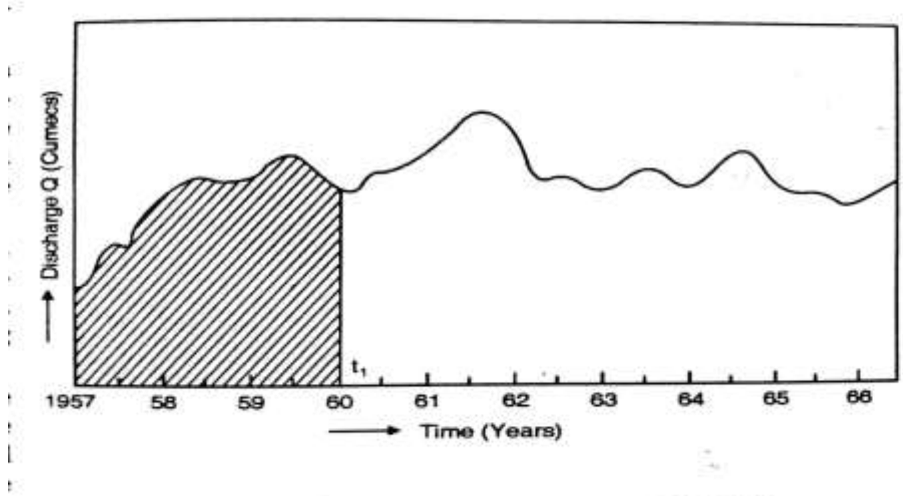


FIG. 6.5. FLOOD HYDROGRAPH OF INFLOW.

2. **MASS INFLOW CURVE**

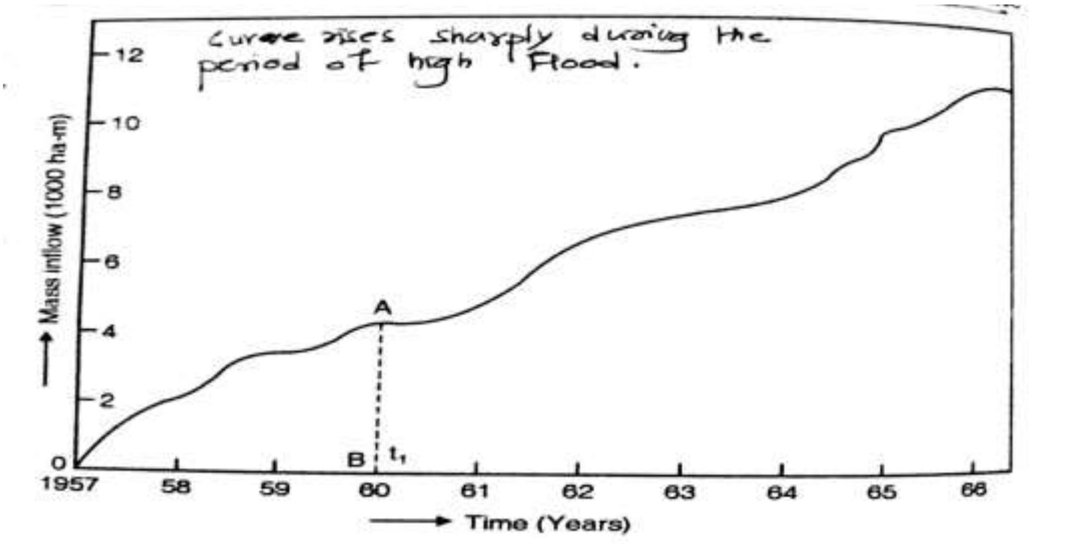
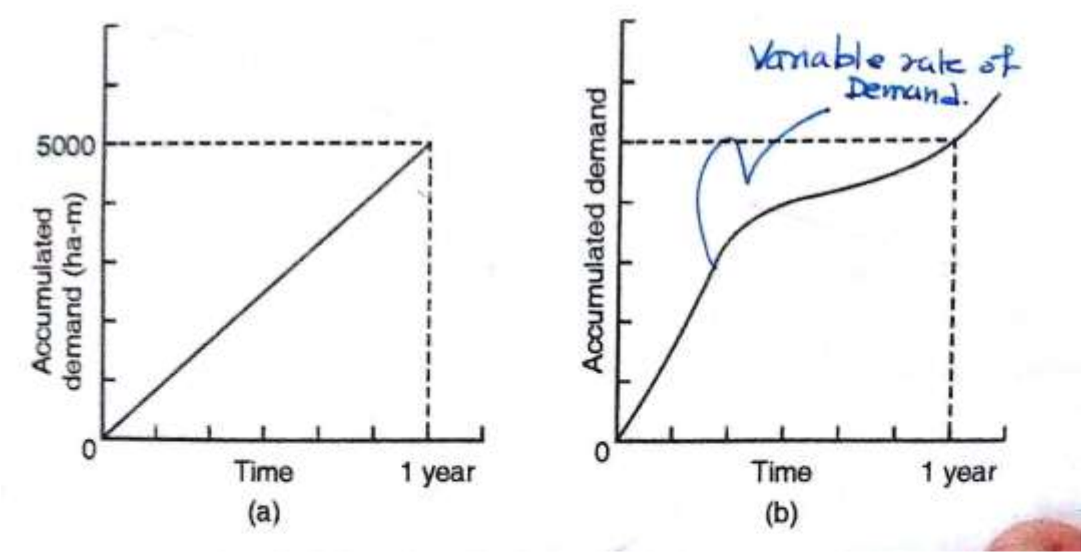


FIG. 6.6. MASS INFLOW CURVE.

3. DEMAND CURVE

4. 

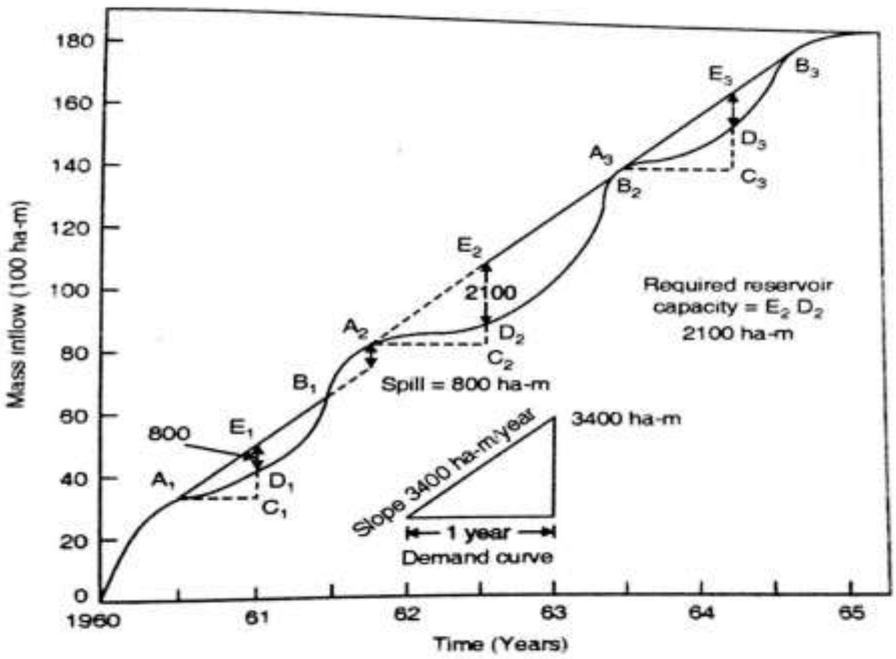
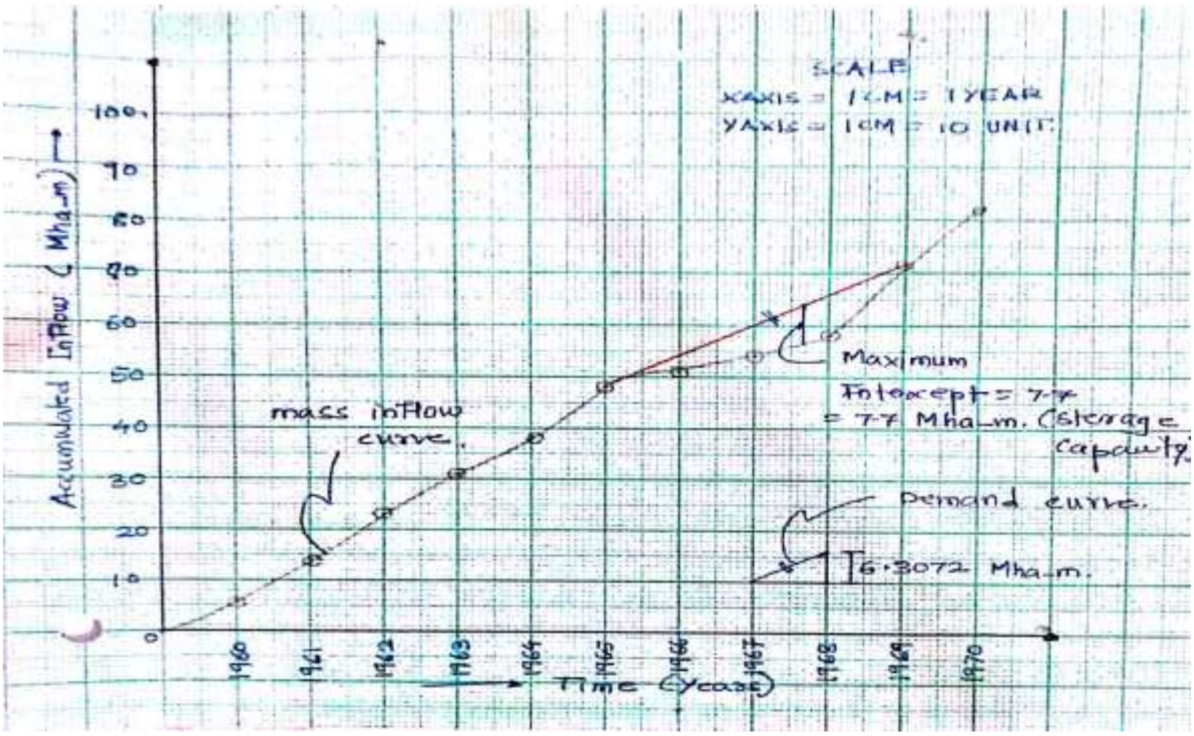


FIG. 6.8. DETERMINATION OF RESERVOIR CAPACITY

CALCULATION OF CAPACITY OF RESERVOIR

The average annual discharge of a river for 11 years is as fallows, (need to correct following table) Determine the storage capacity required to meet a demand of 2000 cumecs throughout the year.

YEAR	1960	1961	1962	1962	1962	1962	1962	1962	1962	1962	1962
DISCHARGE (cumecs)	1750	2650	3010	2240	2630	3200	1000	950	1200	4150	3500



LIFE OF RESERVOIR

- Useful life terminates when the capacity reduces to 20% of design capacity.
- This reducing the capacity is due to reservoir sedimentation.
- Reservoir sedimentation is measure in terms of Trap efficiency (ɳ).
- Trap efficiency is a function of the ratio of reservoir capacity to the total inflow.

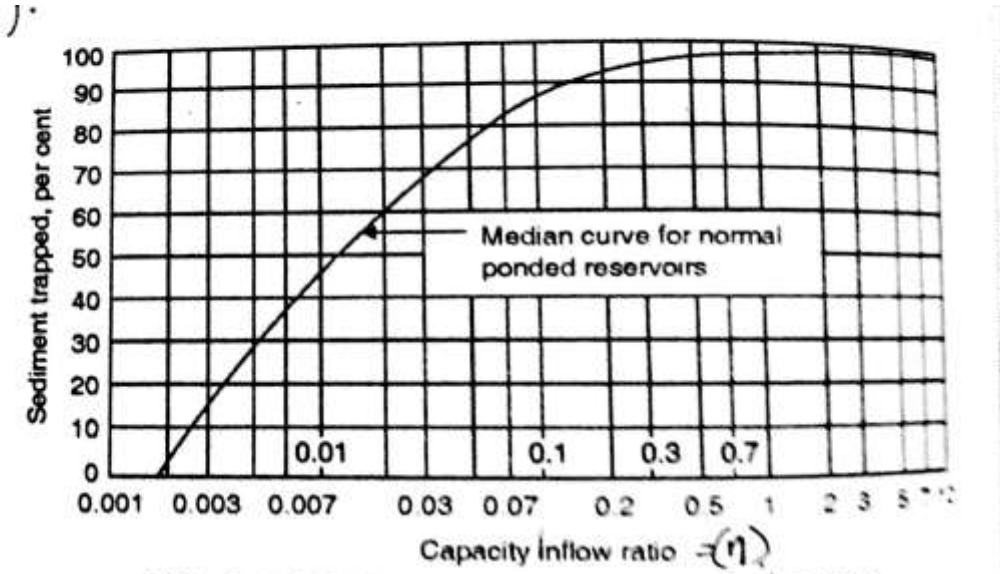


FIG. 6.11 TRAP EFFICIENCY OF RESERVOIRS

1. ɳ $= \boldsymbol{f}\ (\boldsymbol{Capacity}/\ \boldsymbol{Inflow})$
2. Trap efficiency reduces with reduction in reservoir capacity.
3. The rate of silting is higher in initial stage and it decreases as the silting takes place.

4. The complete filling of reservoir may takes very long time.
5. Small reservoir on a large stream (large inflow rate) has a very small capacity/inflow ratio.
6. A huge reservoir having a small stream (less inflow rate) has a greater capacity/inflow ratio.
7. Such reservoir has greater trap efficiency.
8. Such reservoir may retain water for several year and permit almost complete deposition of sediment.

CALCULATION OF LIFE OF RESERVOIR

The following information is available regarding the relationship between trap efficiency and capacity-inflow ratio for a reservoir Find the probable life of reservoir with an initial reservoir capacity of 30 million cubic meters, if the annual flood inflow is 60 million cubic meters and the average annual sediment inflow is 3600000 kN. Assume a specific weight equal to 12kN/m3 . The useful life of reservoir will terminates when 80% of initial capacity is filled with sediment.

Capacity/Inflow	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Trap Efficiency η (%)	87	93	95	95.5	96	96.5	97	97.2	97.3	97.5

PROCEDURE FOR LIFE OF RESERVOIR

1. By knowing the inflow rate calculate the capacity inflow ratio and obtained trap efficiency from the curve.

2. Divide the total capacity into suitable interval (10 or 20) of reduction in % capacity and volume.

3. Write the respective capacity/inflow ration and trap efficiency (not in percentage).

4. For assumed % reduction in capacity find the average trap efficiency.

5. Determine the sediment inflow rate by taking the water sample and drying the sediments.

6. Volume of sediment inflow is the ratio of

$$= \textit{Weight of annual sediment inflow} / \textit{Specific weight of sediment}$$

7.Calculate Annual sediment trapped,

$= Vol.\ of\ sediment\ inflow \times average\ trap\ efficiency$

8.Calculate the numbers of year to fill reservoir with sediments

$$= \boldsymbol{Interval\ of\ reduction\ in\ volumeAnnual\ sedimen\ trapped}\ (St)$$

9.Repeat this procedure for further reduction in capacity.

Life of reservoir is equal to the total numbers of years required to fill each of the volume interval.

RESERVOIR SEDIMENTATION

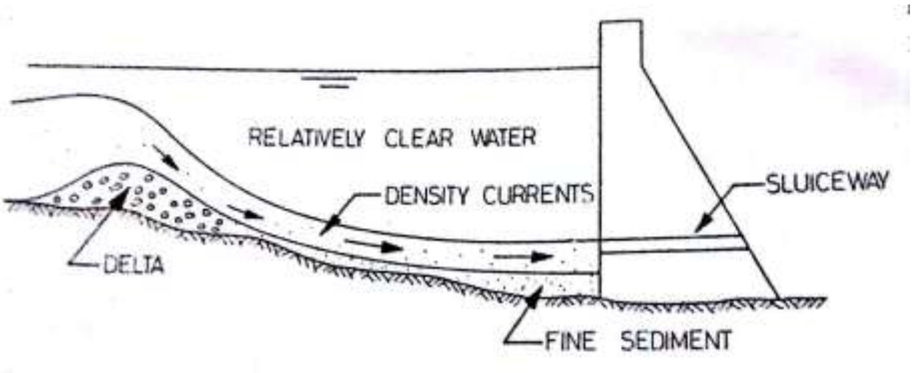


Fig. 7·26

- Rivers carry a large amount of sediment load along with water, these sediments are deposited in the reservoir on the upstream of the dam because of reduction of velocity.

- Sedimentation reduces the available capacity of the reservoir, with continuous sedimentation, the useful life of reservoir goes on decreasing.

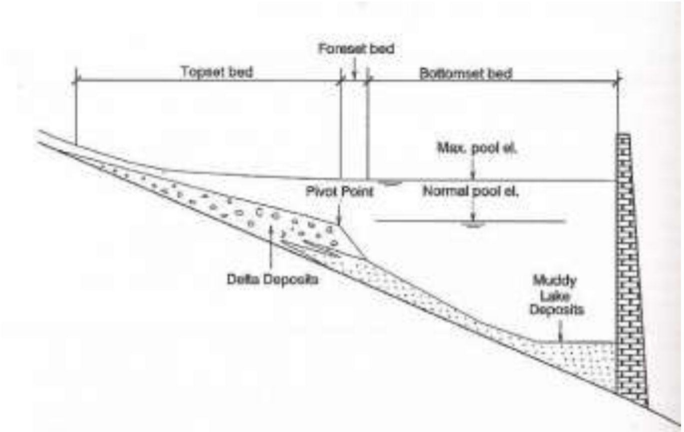


FIGURE 10.1 Generalized depositional zones in a reservoir

FACTORS AFFECTING SEDIMENTATION

- Nature of Soil in the Catchment.
- Vegetal Cover.
- Topography of the Catchment.
- Intensity of Rainfall.

MEASUREMENT OF SEDIMENT LOAD

SUSPENDED LOAD

Water samples are taken from various depths in river Samples are then filtered and sediments are collected After drying the weight of sediments are taken Generally expressed in Parts per million.

1. BED LOAD There is no practical method for measurement of bed load Bed load is usually 5 to 25 % of suspended load An average valve of 15% is generally taken

AVERAGE ANNUAL SEDIMENT

Average annual sediment is transported by the river

Annual Sediment = Mass of sediment per unit volume of water × Annual volume of water

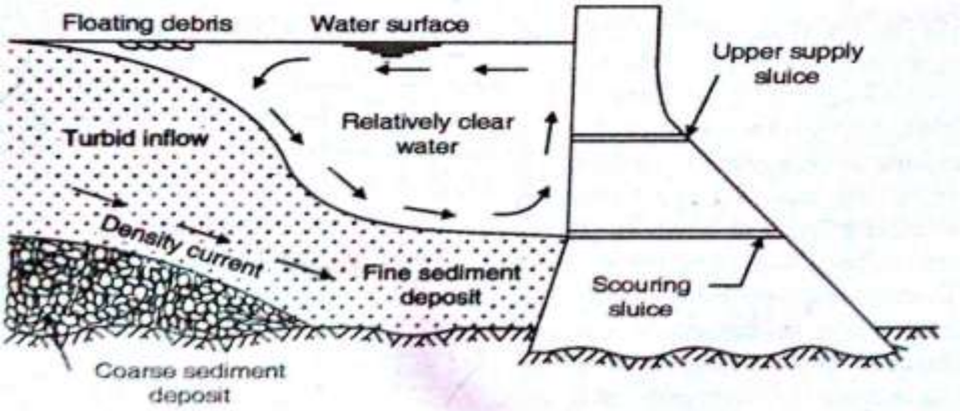


FIG. 6.10. RESERVOIR SEDIMENTATION.

DENSITY CURRENT

1. Gravity flow of fluid under another fluid of approximately equal density.
2. In reservoir water is stored is usually clear but during flood water inflow is muddy or turbid water.
3. These two fluids with different densities flow toward reservoir and heavy fluid (muddy water) flows towards bottom due to gravity action this is known as density current
4. The rate of silting or sedimentation is reduce if density currents are vented by proper location and operation of outlet and sluice gates.

5. RESERVOIR SEDIMENT CONTROL

1. PROPER SELECTION OF RESERVOIR SITE
Catchment area having soft or loose soil with steep slopes may carry more sediment load.
2. CONTROL OF SEDIMENT INFLOW Small check dams may be constructed across those tributaries which carries more silt. Increase in vegetle cover over the catchment area also decrease the soil erosion.

3.PROPER DESIGNING AND RESERVOIR PLANNING

If the dam is constructed lower in the first instance, and is being raised in stages, then the life of reservoir is very much increase. Sufficient outlet should be provided in dam at various elevation, so that the flood can be discharged to the downstream without much silt deposit

4.CONTROL OF SEDIMENT DIPOSIT

During flood proper operating of gates of scouring sluices and the head regulators for sediment control

5.REMOVAL OF SEDIMENT DEPOSIT

Scouring sluices are not completely efficient to remove the silt. Silt deposits can also be removed by excavating and dredging Best way is first disturb the deposited silt and then pushes toward sluices for removing 6. EROSION CONTROL IN THE CATCHMENT AREA Provision of control bunds and provision of vegetation screen helps in reducing the sheet erosion

FACTORS GOVERNING THE SELECTION OF SITE FOR THE RESERVOIR

(a) Water tightness of the basins
(b) Stability of the reservoir rim
(c) Availability of construction material in the reservoir area
(d) Silting
(e) Direct and indirect submergence of economic mineral wealth
(f) Seismo-techtonics

FLOOD ROUTING

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 and 2. hydraulic routing

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.

BASIC EQUATIONS

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.

HYDROLOGIC STORAGE ROUINGT (Level pool Routing)

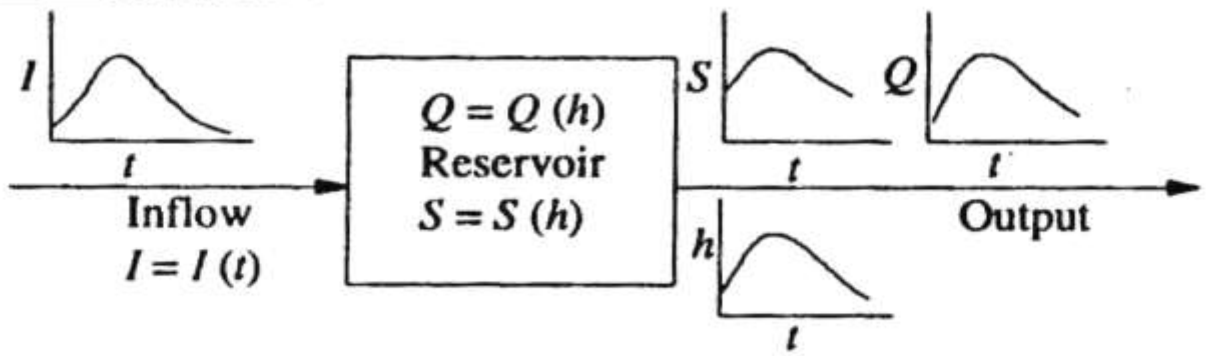


Fig. 8.1 Storage routing (Schematic)

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.

Modified Pul's Method

Equation (8.3) is rearranged as

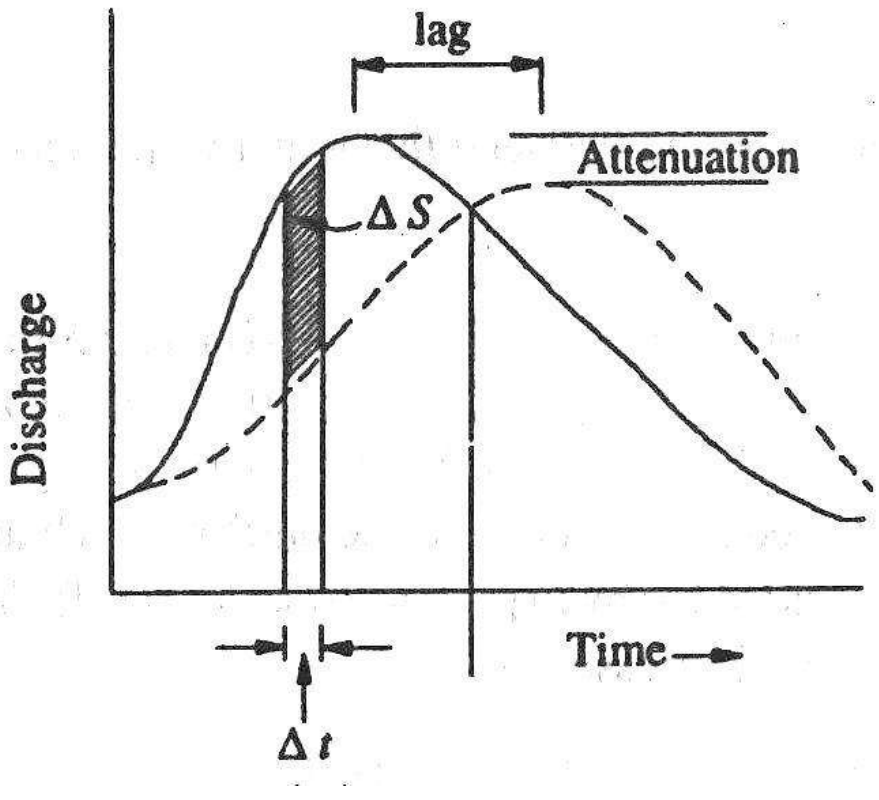
$$\left(\frac{I_1 + I_2}{2}\right)\Delta t + \left(S_1 - \frac{Q_1 \Delta t}{2}\right) = \left(S_2 + \frac{Q_2 \Delta t}{2}\right)$$

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.



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.

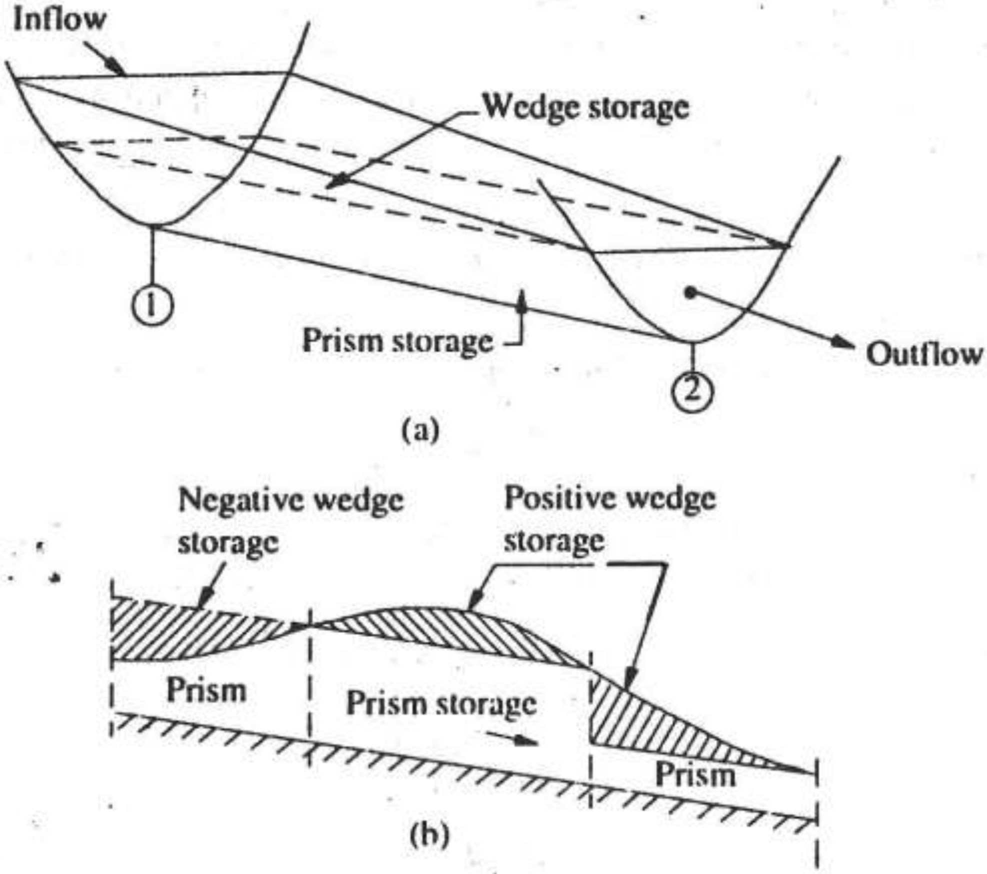


Fig. 8.7 Storage in a channel reach

$$S = K[x\, I^m + (1-x)\, Q^m]$$

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 = 1.0, Eq. (8.11) reduces to a linear relationship for S in terms of I and Q as

$$S = K[x\, I + (1-x)\, Q]$$

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

$$S = KQ$$

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

The coefficient K is known as *storage-time constant*

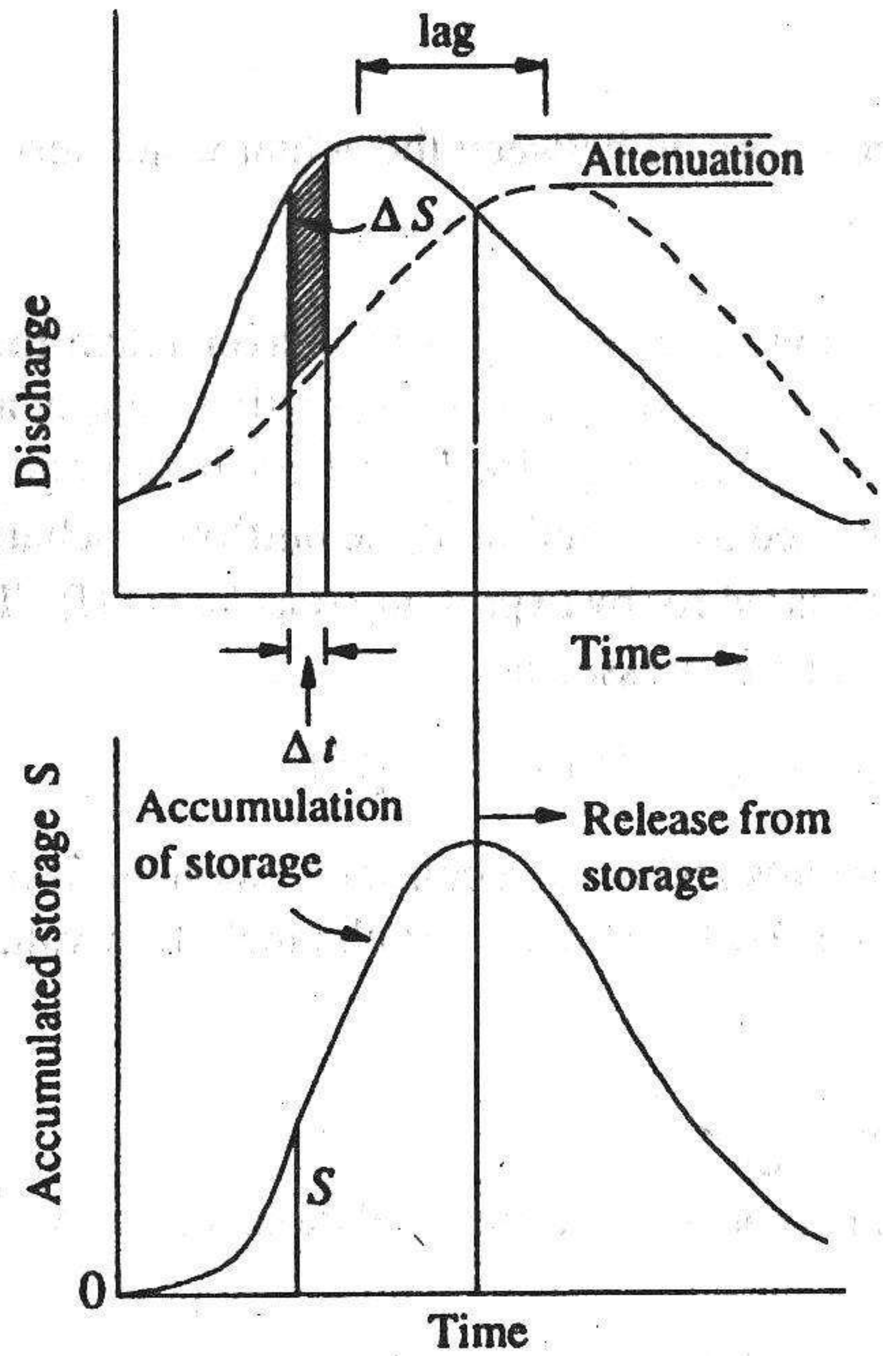


Fig. 8.8 Hydrographs and storage in channel routing

Muskingum Method of Routing

For a given channel reach by selecting a routing interval Δt and using the Muskingum equation, the change in storage is

$$S_2 - S_1 = K[x(I_2 - I_1) + (1 - x)(Q_2 - Q_1)]$$

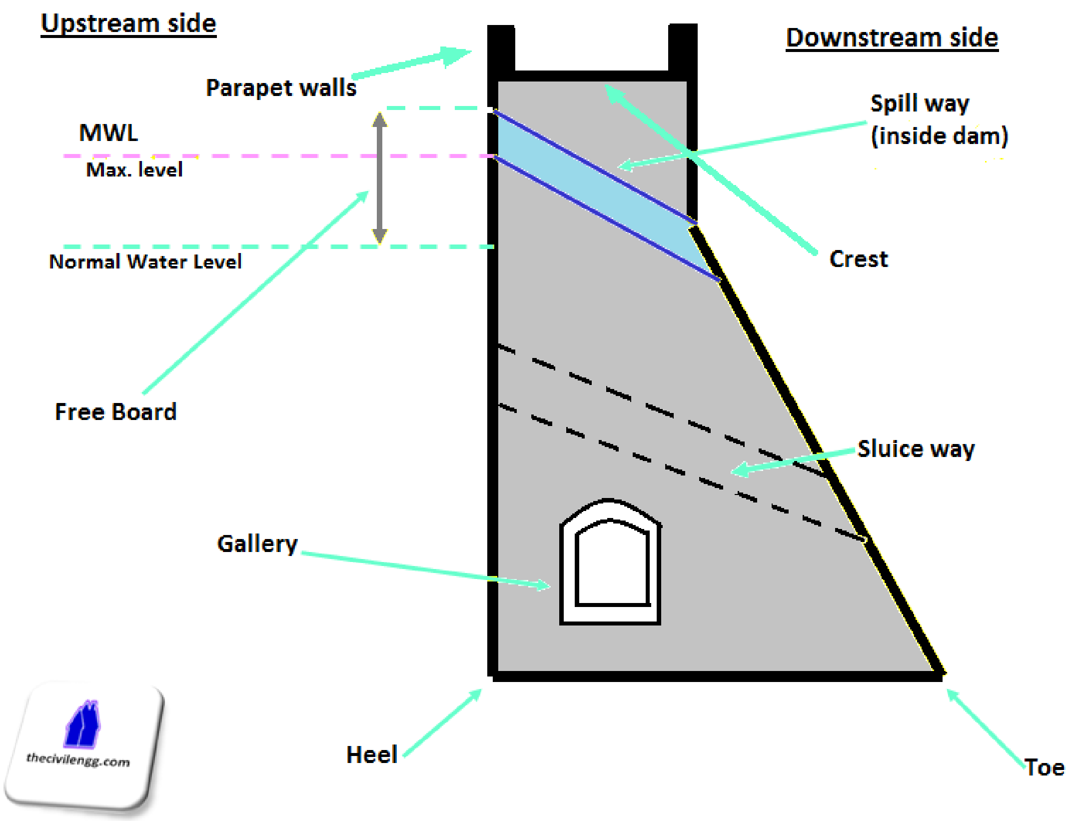
$$\therefore \; Q_2 = C_0 I_2 + C_1 I_1 + C_2 Q_1$$

DAM

- A dam is a hydraulic structure of impervious material built across a river or stream to
  create a reservoir on its upstream side for storing water for various purposes.
- These purposes may be irrigation, hydropower, water-supply, flood control, navigation, fishing and recreation.

Dam is an obstruction to the flow of the river. It could be a masonry wall, concrete wall across River to stop the flow. This is called Dam. The dam even could be Earthen or Rock fill bund. These dams are properly designed and constructed to stop the flowing water completely. Suitable Spillways are provided at top of the dam to allow flood waters to flow downstream safely.

Damisasolidbarrierconstructedatasuitablelocationacrossarivervalleytostoreflowingwater.



Structure of Dam

Storageofwaterisutilizedforfollowingobjectives:

- Hydropower
- Irrigation

- Waterfordomesticconsumption
- Droughtandfloodcontrol
- Fornavigationalfacilities
- Otheradditionalutilizationistodevelopfisheries

CLASSIFICATION OF DAM

- Classification based on function Served
- Classification based on hydraulic Design
- Classification based on material used
- Classification based on rigidity
- Classification based on structural behavior

BASED ON FUNCTION SERVED

- Storage Dam
- Detention Dam
- Diversion Dam
- Debris Dam
- Coffer Dam

BASED ON MATERIAL OF CONSTRUCTION

- Masonry Dam
- Concrete Dam
- Earth Dam
- Rock fill Dam
- Timber Dam
- Steel Dam

BASED ON STRUCTURAL BEHAVIOR

- Gravity Dam
- Earth Dam
- Rock fill Dam
- Arch Dam
- Buttress Dam
- Steel Dam
- Timber Dam

Arch dam:
Situated at narrow canyon with steep side walls

- Constant angle dams are more common than constant radius
- Double curvature
- Require good rock foundation

Gravity Dam

Force that holds dam is earth's gravity pulling down on mass of dam

- Well suited for blocking rivers in wide valleys
- Dam is made from concrete or masonry or both
- Foundation must have high bearing strength

Arch Dam

- It has characteristics of arch dam and gravity dam
- They are made up of conventional concrete or RCC or masonry
- It is thinner than pure gravity dams and require less internal fill

Rock fill Dam

- These are embankments of compact granular soil in combination with impervious areas
- If clay is used then it is composite dam
- These dams are resistant to damage from earthquakes

Photo courtesy Carmargo Corrêa

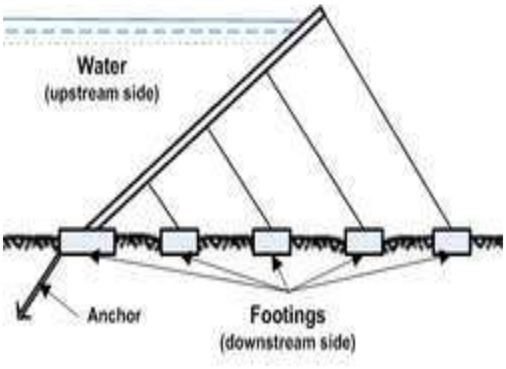
Earth fill Dam

They are generally made up of one type of material

- Earthen dams can be constructed from materials found on site or nearby
- They are cost effective

Steel dam

Steel dam is a type of dam that is made of steel, rather than common masonry ,earthworks , concrete or construction material Steel dams - an experiment which failed Maintenance cost is high due to rust and corrosion



Timber Dam

- Timber dams were widely used in early part of industrial
  revolution and rarely used now
- Suitable location for construction
- In order to maintain water retension property they must be kept wet

Selection of Dam Site

The selection of Dam site for constructing a dam should be governed by the following factors.

- Suitable foundation must be available.
- For economy, the length of the dam should be as small as possible, and for a given height, it should store the maximum volume of water.
- The general bed level at dam site should preferably be higher than that of the river basin. This will reduce the height of the dam.
- A suitable site for the spillway should be available in the near vicinity.
- Materials required for the construction of dam should be easily available, either locally or in the near vicinity.
- The value of land and property submerged by the proposed dam should be as low as possible.
- The dam site should be easily accessible, so that it can be economically connected to important towns and cities.
- Site for establishing labor colonies and a healthy environment should be available near the site.

Factors Affecting Selection of Dam

These factors are discussed one by one.

Topography

- Topography dictates the first choice of the type of dam.
- A narrow U-shaped valley, i.e. a narrow stream flowing between high rocky walls, would suggest a concrete overflow dam.
- A low plain country, would suggest an earth fill dam with separate spillways.
- A narrow V-shaped valley indicates the choice of an Arch dam

Geological and Foundation Conditions

- Geological and Foundation conditions should be thoroughly surveyed because the foundations have to carry the weight of the dam. Various kind of foundations generally encountered are
- Solid rock foundations such as granite have strong bearing power and almost every kind of dam can be built on such foundations.
- Gravel foundations are suitable for earthen and rock fill dams.
- Silt and fine sand foundations suggest construction of earth dams or very low gravity dams.
- Clay foundations are likely to cause enormous settlement of the dam. Constructions of gravity dams or rock fill dams are not suitable on such foundations. Earthen dams after special treatments can be built.

Availability of Materials

- Availability of materials is another important factor in selecting the type of dam. In order to achieve economy in
- dam construction, the materials required must be available locally or at short distances from the construction site.

Spillway Size and Location

- spillway disposes the surplus river discharge. The capacity of the spillway will depend on the magnitude of the
- floods to be by-passed. The spillway is therefore much more important on rivers and streams with large flood potential.

Earthquake Zone

- If dam is situated in an earthquake zone, its design must include earthquake forces. The type of structure best suited to resist earthquake shocks without danger are earthen dams and concrete gravity dams.

Height of Dam

- Earthen dams are usually not provided for heights more than 30 m or so. For greater heights, gravity dams are generally preferred.

Hint: The availability of spillway site is very important in selection of a particular type of dam