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HYDRAULIC STRUCTURES & IRRIGATION DESIGN-DRAWING
10CV65

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10CV65 HYDRAULIC STRUCTURES & IRRIGATION DESIGN-DRAWING

UNIT I

RESERVOIR PLANNING

Introduction, classification of Reservoirs, Storage zones of a reservoir, Mass curve, fixing capacity of a reservoir, safe yield, problems, density currents, Trap efficiency, Reservoir sedimentation, life of a reservoir, economic height of a dam, problems. environmental effects of reservoirs.

1.1 Introduction, Classification of Reservoirs

Introduction:

A reservoir is a large artificial lake created by building a dam across a river. Broadly speaking, any water pool or a lake can be termed as a reservoir. However the term reservoir in the context of water resources engineering is used in a restricted sense for comparatively large body of water stored on upstream of a dam constructed for this purpose. Thus a reservoir and a dam exist together. The discharge in a river generally varies considerably during different periods of the year.

If a reservoir is for serving only one purpose, it is known as a single-purpose reservoir. On the other hand if it serves more than one purpose, it is known as multipurpose reservoir.

Classification of Reservoirs

It has two main purposes.

(i) Flood control storage

(ii) Conservation storage

The aim of flood control storage is to store some of the flood water of river when discharge rate reaches a stage likely to cause damage downstream of the valley and release this flood storage slowly at a safe rate when flood subsides.

Conservation storage is meant to store water for different purposes likes are,

(i) Hydropower

(ii) Irrigation

(iii) Public and industrial water supply

(iv) Navigation

(v) Soil conservation and land reclamation

(vi) Fishery and wild life

(vii) Recreation

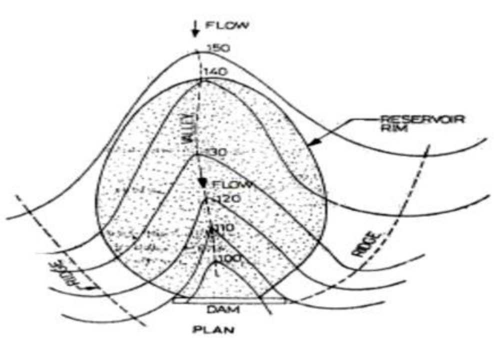
(viii) Debris control

(ix) Sediment control of river, etc.

Thus, a reservoir is called single purpose reservoir if it serves only one purpose and is called multipurpose if it is used for almost all the purposes mentioned above.

A reservoir is called a distribution reservoir without a dam in which water from river is pumped into some concrete tank constructed at suitable places. Water stored in those reservoirs is mainly used for supplying to the consumers through distribution networks.

The flood control storage discussed above may be retarding type or detention type. In retarding type, it simply retards the flood flow by storing flood water without control like gates or spillway, whereas in detention type it detains a major portion flood water with the help of gates, etc. and releases the extra water when flood subsides.



Reservoir

Types of Reservoirs:

Depending upon the purpose served the reservoirs may be broadly classified into five types:

1. Storage (or conservation) reservoirs.

2. Single purpose (or) Flood control reservoirs.

3. Multipurpose reservoirs.

4. Distribution reservoirs.

5. Balancing reservoirs

1. Storage reservoirs:

Storage reservoirs also are known as conservation reservoirs as a result of they're wont to conserve water. Storage reservoirs area unit created to. Store the water within the time of year and to unharness it later once the stream flow is low store reservoirs area unit typically created for irrigation, the municipal installation and hydropower.

Though the storage reservoirs area unit created for storing water for varied functions incidentally they conjointly facilitate in tempering the floods and reducing the flood injury to some extent on the downstream. However they're not designed as control reservoirs.

2. Single Purpose Reservoirs:

The common principles of single purpose reservoir operation are given below:

Flood control:

Operation of flood control reservoirs is primarily governed by the available flood storage capacity of damage centers to be protected, flood characteristics, ability and accuracy of flood/ storm forecast and size of the uncontrolled drainage area.

A regulation plan to cover all the complicated situations may be difficult to evolve but generally it should be possible according to one of the following principles.

Effective use of available flood control storage:

This principle aims at reducing flood damages of the locations to be protected to the maximum extent possible by effective use of flood event.

Hence, the release under this plan would obviously be lower than those required for controlling the reservoir design flood, there is distinct possibility of having a portion of the flood control space occupied during the occurrence of a subsequent heavy flood.

In order to reduce this element of risk, maintenance of an adequate network of flood forecasting stations both in the upstream and down stream areas would be absolutely necessary.

Control of reservoir design flood:

According to this principle, releases from flood control reservoirs operated on this concept are made on the same hypothesis as adopted for controlling the reservoir design flood. Full storage capacity would be utilized only when the flood develops into the reservoir design flood.

As the design flood is usually an extreme event regulation of minor and major floods which occur more often is less satisfactory when this method is applied.

Flood control in emergencies:

It is advisable to prepare an emergency release schedule that uses information on reservoir data immediately available to the operator.

Such schedule should be available with the operator to enable him to comply with necessary precautions under extreme flood conditions.

Conservation:

Reservoirs meant for augmentation of supplies during lean period should usually be operated to fill during filling period while meeting the requirements. All water in excess of the requirements of the filling period shall be impounded. No spilling of water over the spillway will normally be permitted until the FRL is reached.

Flood occur when the reservoir is at or near the FRL, then release of flood waters should be affected so as not to exceed the discharge that would have occurred had there been no reservoir.

In case the year happens to be dry, the draft for filling period should be curtailed by applying suitable factors. The depletion period should begin thereafter.

In case the reservoir is planned with carry-over capacity, it is necessary to ensure that the regulation will provide the required carry-over capacity at the end of the depletion period.

Operation of multi purpose reservoirs:

The general principles of operation of reservoirs with these multiple storage spaces are described below:

Separate allocation of capacities:

Separate allocations of capacity have been made for each of the conservation uses in addition to that required for flood control operation for each of the function shall follow the principles of respective functions.

Storage available for flood control could be utilized for generation of secondary power to the extent possible. Allocation of specific storage space to several purposes with the conservation zone may some times be impossible or very costly to provide water for the various purposes in the quantities needed and at the time they are needed.

Joint use of storage space:

In multi-purpose reservoir where joint use of some of the storage space or storage water has been envisaged, operation becomes complicated due to competing and conflicting demands. Flood control requires low reservoir level.

Objectives of these functions are not compatible and a compromise will have to be effected in flood control operations by sacrificing the requirements of these functions.

Parts of the conservational storage space is utilized for flood moderation during the earlier stages of the monsoon.

This space has to be filled up for conservation purpose towards the end of monsoon progressively as it might not be possible to fill up this space during the post-monsoon periods, when the flows are insufficient even to meet the current requirements.

Multipurpose reservoirs:

- Water supply
- Soil erosion
- Flood control
- Hydroelectric power generation
- Environmental management
- Recreation
- Navigation
- Irrigation

The multipurpose nature of these facilities dictates that the agencies which manage them are responsible for balancing competing demands. For example, managers responsible for hydroelectric power generation often want to keep lake levels as high as possible since the water stored in the reservoir serves as a kind of "fuel" for their generators.

Managers responsible for flood control often want to keep lake levels as low as possible to provide the maximum amount of storage capacity for rainwater runoff.

Water supply:

Water supply is the provision of water by public utilities, commercial organizations, community endeavors or by individuals, usually via a system of pumps and pipes.

Flood control:

Floods are caused by many factors: heavy rainfall, highly accelerated snow melt, severe winds over water, unusual high tides, tsunamis or failure of dams, levees, retention ponds or other structures that retained the water.

Flooding can be exacerbated by increased amounts of impervious surface or by other natural hazards such as wildfires, which reduce the supply of vegetation that can absorb rainfall. Periodic floods occur on many rivers forming a surrounding region known as the flood plain.

During times of rain, some of the water is retained in ponds or soil, some is absorbed by, grass and vegetation, some evaporates and the rest travels over the land as surface runoff.

Floods occur when ponds, lakes, riverbeds, soil and vegetation cannot absorb all the water.

Water then runs off the land in quantities that cannot be carried within stream channels or retained in natural ponds, lakes and man-made reservoirs. About 30% of all precipitation becomes runoff and that amount might be increased by water from melting snow.

River flooding is often caused by heavy rain sometimes increased by melting snow.

A flood that rises rapidly with little or no advance warning is called a flash flood. Flash usually result from intense rainfall over a relatively small area or if the area was already saturated from previous precipitation.

Soil erosion:

In geo morphology and geology erosion refers to the actions of exogamic processes which remove soil and rock from one location on the Earth's crust then transport it to another location where it is deposited.

• Eroded sediment may be transported just a few millimeters or for thousands of kilometers. While erosion is a natural process human activities have increased 10-40 times the rate at which erosion is occurring globally.

• On-site impacts include decreases in agricultural and ecological collapse, both because of loss of the nutrient-rich upper soil layers. In some cases, the eventual end result is desertification.

• Excessive (or accelerated) erosion causes both 'on-site' and 'off-site' problems.

• Off-site effects include sedimentation of waterways and eutrophication of water bodies as well as sediment-related damage to roads and houses.

• Water and wind erosion are now the two primary causes of land degradation Jointly they are responsible for about 84% of the global extent of degraded making excessive erosion one of the most significant environmental problems world-wide.

• Intensive agriculture, deforestation, roads, climate change and urban sprawl are amongst the most significant human activities in regard to their effect on stimulating erosion.

Environmental resource management:

It is the management of the interaction and impact of human societies on the environment.

It aims to ensure that ecosystem services are protected and maintained for future human generations. Maintains ecosystem integrity by considering ethical, economic and scientific (ecological) variables.

It is not the management of the environment itself.

It tries to identify factors affected by conflicts that rise between meeting needs and protecting resources. Linked to protection and sustainability.

Navigation:

It is a field of study that focuses on the process of monitoring and controlling the movement of a craft or vehicle from one place to another.

The field of navigation includes four general categories:

1. Land navigation.

2. Marine navigation.

3. Aeronautic navigation.

4. Space navigation.

Art used for the specialized knowledge by navigators to perform navigation tasks. All navigational techniques involve locating the navigator's position compared to known locations or patterns.

Navigation includes orienteering and pedestrian navigation.

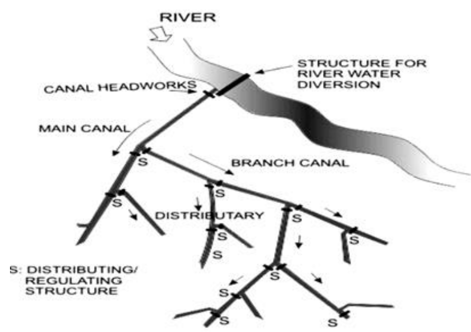
Irrigation:

• Irrigation is the artificial application of water to the land or soil. Irrigation is used to assist in the growing of agricultural crops, maintenance of landscapes and re-vegetation of disturbed soils in dry areas and during periods of inadequate rainfall.

• Irrigation also has a few other uses in crop production which include protecting plants against frost suppressing weed growth in grain fields and preventing soil consolidation. Irrigation systems are also used for dust suppression, disposal of sewage and in mining.

• Irrigation is often studied together with drainage which is the natural or artificial removal of surface and sub-surface water from a given area.

• Irrigation has been a central feature of agriculture for over 5000 years and was the basis of the economy and society of numerous societies ranging from Asia to Arizona.



Typical layout of an irrigation canal system

Distribution Reservoir:

A distribution reservoir may be a little storage reservoir to bridge over the height demand of water for municipal installation or irrigation. The distribution reservoir is useful in allowing the pumps to figure at a homogeneous rate.

It stores water throughout the amount of lean demand and provides an equivalent throughout the amount of high demand, because the storage is restricted, it just helps in distribution of water as per demand for daily more or less and not for storing it for a protracted amount.

Water is pumped-up from a water supply at a homogeneous rate throughout the day for twenty-four hours however the demand varies from time to time, throughout the amount once the demand of water is a smaller amount than the pumping rate, the water is hold on within the distribution reservoir.

On the opposite hand, once the demand of water is over the pumping rate, the distribution reservoir is used for supply water at rates larger than the pumping rate. Distribution reservoirs area unit seldom used for the availability of water for irrigation. These area unit in the main used for municipal installation.

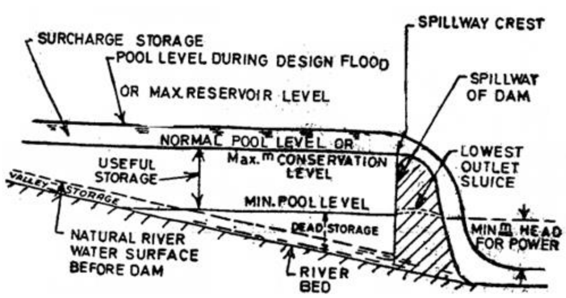
Balancing reservoir:

A reservoir downstream of the main reservoir for holding water let down from the main reservoir in excess of that required for irrigation, power generation or other purposes.

A reconciliation reservoir may be a little reservoir created d/s of the most reservoir for holding water free from the most reservoir.

1.2 Storage zones of a reservoir, Mass curve, fixing capacity of a reservoir, Safe yield

Storage zones of a reservoir



Storage zones of a reservoir

Normal Pool Level or Maximum Conservation Level:

It is the maxi-mum elevation to which the reservoir water surface will rise during normal operating conditions. It is equivalent to the elevation of the spillway crest or the top of the spillway gates, for most of the cases.

Minimum Pool Level:

The lowest water surface elevation, which has to be kept under normal operating conditions in a reservoir, is called the minimum pool level. This level may be fixed by the elevation of the lowest outlet in the dam or may be guided by the minimum head required for efficient functioning of turbines.

Useful and Dead Storage:

The volume of water stored in a reservoir between the minimum pool and normal pool levels is known as the useful storage.

Water stored in the reservoir below the minimum pool level is known as the Dead Storage and it is not of much use in the operation of the reservoirs. The useful storage may be subdivided into conservation storage and flood-mitigation storage, in a multipurpose reservoir.

Maximum Pool Level or Full Reservoir Level:

During high floods, water is discharged over the spillway, but will cause the water level to rise in the reservoir above the normal pool level. The maximum level to which the water rises during the worst design flood is known as the maximum pool level.

Surcharge Storage:

The volume of water stored between the normal pool level and the maximum pool level is called surcharge storage. Surcharge storage is an uncontrolled storage, in the sense that it exists only till the flood is in progress and cannot be retained for later use.

Bank Storage:

When the reservoir is filled up, certain amount of water seeps into the permeable reservoir banks. This water comes out as soon as the reservoir gets depleted. This volume of water is known as the bank storage and may amount to several percent of the reservoir volume depending upon the geological formations.

The bank storage effectively increases the capacity of the reservoir above that indicated by the elevation capacity curve of the reservoir.

Valley Storage:

Even before a dam is constructed, certain variable amount of water is stored in the stream channel, called valley storage. After the reservoir is formed, the storage increases and the actual net increase in the storage is equal to the storage capacity of the reservoir minus the natural valley storage.

The valley storage thus reduces the effective storage capacity of a reservoir. It is not of much importance in conservation reservoirs, but the available storage for flood mitigation is reduced, as given by the following relation:

Effective storage for flood mitigation = Useful Storage + Surcharge Storage — Valley Storage corresponding to the rate of inflow in the reservoir.

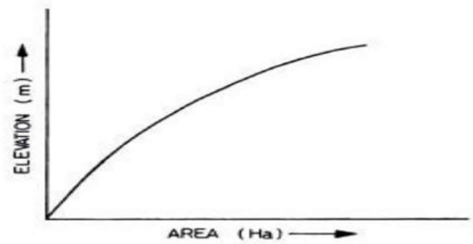
Storage Capacity of a Reservoir:

Whatever is also the utilization of a reservoir, its most vital operate is to store water throughout floods and to unharness it later. The storage capability of a reservoir is, therefore, its most vital characteristics.

The accessible storage capability of a reservoir depends upon the topography of the location and therefore the height of dam to work out the accessible storage capability of a reservoir upto a precise level of water, engineering surveys area unit typically conducted.

For correct determination of the capability, a geographics survey of the reservoir space is typically conducted and a relief map of the world is ready. A contour set up of the world is ready to a scale of one cm = 100m or a hundred and fifty with a contour interval of one to three m, relying upon the dimensions of the reservoir.

The storage capability and therefore the water unfold space at completely different elevations is determined from the relief map as explained below.



Area-Elevation Curve

(a) Area-Elevation Curve: From the contour plan the water spread area of the reservoir at any elevation is determined by measuring the area enclosed by the corresponding contour.

Generally a planimeter is used for measuring the area. An elevation-area curve is then drawn between the surface area as abscissa and the elevation as ordinate.

(b) Elevation-Capacity Curve: The storage capacity of the reservoir at any elevation is determined from the water spread area at various elevations. The following formulae are commonly used to determine the storage capacity (i.e. storage volumes).

Trapezoidal formula:

According to the trapezoidal formula, the storage volume between the two successive contours of areas A_1 and A_2 is given by ,

$$\Delta V_1 = \frac{h}{2}(A_1 + A_2)$$

where h is the contour interval.

Therefore the total volume V of the storage is given by,

$$V = \Delta V_1 + \Delta V_2 + \Delta V_3 + \ldots\ldots\ldots\ldots = \Sigma \Delta V$$

$$V = \frac{h}{2}\,[\,A_1 + 2A_2 + 2A_3 + \ldots\ldots\ldots\ldots\ldots + 2\,A_{n-1} + A_n\,]$$

where n is the total number of areas.

Cone formula:

According to the cone formula the storage volume between two successive contours of areas A_1 and A_2 is given by,

$$\Delta V_1 = \frac{h}{3}(A_1 + A_2 + \sqrt{A_1 A_2})$$

The total volume V is given by,

$V = \Delta V_1 + \Delta V_2 + \Delta V_3 + \ldots.. = \Sigma \Delta V$

Prismoidal formula:

According to the prismoidal formula, the storage volume between 3 successive contours is given as,

$$\Delta V_1 = \frac{h}{3}(A_1 + 4A_2 + A_3)$$

The total volume is given by,

$$V = \frac{h}{3}\,[(A_1 + A_n) + 4(A_2 + A_4 +. A_6 + \ldots\ldots.) + 2\,(A_3 + A_5 + \ldots..)]$$

where A_3, A_5, etc are the areas with odd numbers : A_2, A_4, A_6, etc are the areas with even numbers A_1 and A_n are respectively the first and the last area.

The prismoidal formula is applicable only when there are odd numbers of areas. In the case of even number of areas the volume upto the last but one area is calculated by the prismoidal formula and that of the last segment is determined by the trapezoidal formula.

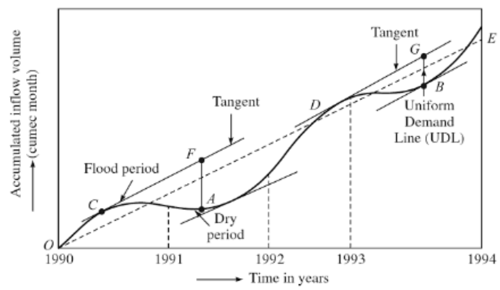
Mass curve: Mass Curve of Inflow

It is called Rippl Mass curve after its originator W. Rippl. Mass curve of inflow is a plot of accumulated flow volume against time. It is used to determine,

(i) Reservoir capacity from uniform demand of flow

(ii) Safe yield from reservoir from reservoir capacity

The curve is developed by W. Rippl in 1883, usually from records of mean monthly flow of the river available for few consecutive years. From this flood hydrograph, ordinates of the mass curve (accumulated inflow volume) at any time can be obtained. When accumulated inflow volumes (in cumec month or ha-m or 10^6 m^3) are plotted against time, mass curve is obtained as shown in the figure .



Mass curve of inflow

Characteristics of mass curve

The mass curve is a continuously rising curve as it shows the accumulated inflow volume with time.

• The slope of the curve at any point indicates the rate of inflow at that particular time. If the curve becomes horizontal at some point, it indicates that rate of flow at that particular time is zero.

• If the curve rises sharply, it indicates the high rate of inflow within that period.

• Relatively convex rise and concave depression indicate flood and dry period respectively. The points A and B in mass curve indicate dry periods, whereas points C and D indicate flood or high flow.

• The dotted line OE indicates Uniform Demand Line (UDL), slope of which gives the uniform rate of demand.

• If OE is the uniform demand line, tangents at highest point C and D are drawn parallel to OE.

• The maximum vertical intercept between the mass curve (Here AF) gives the reservoir capacity.

1.2.1 Fixing the capacity of the reservoirs, problem

Once it is decided to build a reservoir on river by building a dam across it, it is required to arrive at a suitable design capacity of reservoir. The reservoir storage usually consists of three main parts which can be broadly classified as:

1.Active or conservation storage,

2.Flood and surcharge storage.

3.Inactive storage including dead storage

In general, these storage capacities are to be designed based on certain specified considerations, which have been discussed separately in the following Bureau of Indian Standard codes.

IS: 5477 Fixing the capacities of reservoirs- Methods

(Part 1): 1999 General requirements

(Part 2): 1994 Dead storage

(Part 3): 1969 Line storage

(Part 4): 1911 Flood storage

The data and information that is required for fixing the various components of the design capacity of a reservoir are given by the following:

1) Precipitation, run-off and the silt records available in region

2) Erodibility of the catchment upstream of the reservoir for estimating the sediment yield

3) Area capacity curves at the proposed location

4) Trap efficiency

5) Losses in the reservoir

6) Water demand from the reservoir for different uses

7) Committed and future upstream uses

8) Criteria for assessing the success of the project

9) Density current aspects and location of outlets

10) Data required for economic analysis and

11) Data on engineering and geological aspects.

These aspects are explained in detail in the following sections.

Precipitation, Run-Off and Silt Record:

The network of precipitation and the discharge measuring stations in the catchment upstream and near the project has to be considered to test the capacity of the same in order to adequately sample both spatially and temporally, along the precipitation and the stream flows.

The measurement procedures and gap filling procedures in respect to the missing data as also any rating tables or curves has to be critically tested so that they are according to instructions of World Meteorological Organization (WMO).

Long-term data need to be checked for the internal consistency between rainfall and discharges, as between data sets by double mass analysis to highlight any changes in test data for detection of any long term trends as also for stationary. It is only after such testing that the data must be used for generating the long term inflows of water into the reservoir.

Sufficiently long term precipitation and run-off records are necessary for preparing the water inflow series. For working out the catchment average sediment yield, long-term data of silt measurement records from existing reservoirs are essential. These are prerequisites for fixing the storage capacity of reservoirs.

If long term run-off records are not available, concurrent rainfall and run-off data shall be used to convert the long term rainfall data into long-term run-off series adopting appropriate statistical/conceptual models. In some cases regression analysis can also be resorted to for data extension.

Estimation of average sediment yield from the catchment area above the reservoir :

It is generally attempted using river sediment observation data or more commonly from the experience of sedimentation of the existing reservoirs with similar characteristics where observations of stage/flow data is available only for short periods, these have to be suitably extended with help of longer data on rainfall to estimate as far as possible sampling errors due to scanty records.

Sediment discharge rating curve can also be prepared from hydraulic considerations using any of standard sediment load formulae, like, modified Einstein's procedure, Young's stream power, etc.

It is also required to account for the bed load which is not been measured. Bed load measurement is preferable and it is often estimated as a percentage generally ranging from 5 to 20% of the suspended sediment load,when it is not possible. However actual measurement of bed load has to be undertaken particularly in cases where high bed loads are anticipated.

To assess the volume of the sediment that would deposit in the reservoir, it is moreover necessary to make estimates of average trap efficiency of the reservoir and the likely unit weight of the sediment deposits, along with time average over the period selected.

The trap efficiency will depend on the capacity inflow ratio but may also vary with the locations of controlling outlets and reservoir operating procedures. Computations of reservoir trap efficiency can be made using the trap efficiency curves such as those developed by Brune and by Churchill .

Elevation Area Capacity Curves:

Topographic survey of a reservoir area should form the basis for obtaining these curves, which are respectively the plots of elevation of the reservoir versus surface area and elevation of the reservoir versus volume.

For preliminary studies, in case suitable topographic map with contours, say at intervals less than 2.5 m is not available, stream profile and valley cross sections carried out at regular intervals may form the basis for computing volume. Aerial survey can also be adopted when available facilities are there.

Safe yield (Firm yield):

Safe yield is the 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 years is taken as the critical dry period for determining the safe yield.

However there is a possibility that a still drier period may occur in future and the yield available may be even less than that determined on the basis of past records. This factor should be kept in mind while fixing the safe yield.

There is generally a firm commitment by the organization to the consumers that the safe yield will be available to them. It is therefore also called the firm yield or the guaranteed yield.

Problems

1. A reservoir has the following areas enclosed by contours at various elevations. Let us determine the capacity of the reservoir between elevations of 200.00 to 300.00.

Elevation	**200.00**	**220.00**	**240.00**	**260.00**	**280.00**	**300.00**
Area of contour (Km^2)	**150.00**	**175.00**	**210.00**	**270.00**	**320.00**	**400.00**

Use (a) trapezoidal formula, (b) prismoidal formula.

Solution:

Given:

Elevation	200.00	220.00	240.00	260.00	280.00	300.00
Area of contour (Km^2)	150.00	175.00	210.00	270.00	320.00	400.00

From Equation,

$$V = \frac{h}{2}\,(A_1 + 2A_2 + 2\,A_3 + 2A_4 + 2A_5 + A_6)$$

= 20/2 (150 + 2 x 175 + 2 x 210 + 2 x 270 + 2 x 320 + 400)

= 25000 m-km^2= 25000 Mm^3 = 2.5 Mha-m.

(b) In this case there are even number of areas. The prismoidal formula is applied to first 5 areas.

From equation considering the first 5 areas,

$$V_1 = \frac{h}{3}\,[(A_1 + A_5) + 4\,(A_2 + A_4) + 2A_3]$$

=20/3 [(150.00 + 320.00) + 4(175 + 270) + 2 x 210]

= 17800 m-km^2 = 17800 Mm^3.

1.3 Density currents, Trap efficiency

Density Current:

Density current is defined as the gravitational flow of one fluid under another having slightly different density. The water stored in reservoir is usually free from silt but the inflow during floods is generally muddy.

There are, hence two layers that has different densities resulting in the formation of the density currents. The density currents separates the water from the clearer water and make the turbid water flow along river bottom.

The reservoir silting rate may be reduced by venting the density currents by properly locating and operating outlets and sluice ways.

Water at various levels of a reservoir often contains radically different concentrations of suspended sediment particularly during and after flood flows and if all waste-water could be withdrawn at those levels where the concentration is highest, a significant amount of sediment might be removed from the reservoir.

Because a submerged outlet draws water towards it from all directions, the vertical dimension of the opening should be small with respect to the thickness of the layer and the rate of withdrawal also should be low.

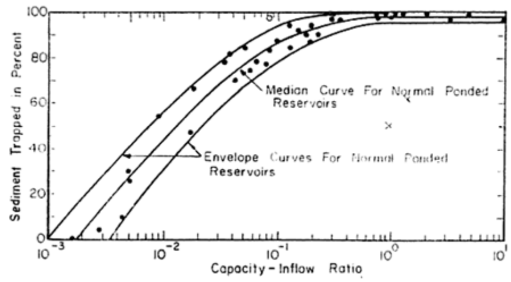
With a view to passing the density current by sluices that might be existed, it is necessary to trace the movement of density currents and observation stations (consisting of permanently anchored rafts from which measurements could be made of temperature and conductivity gradient from the surface of the lake to the bottom, besides collecting water samples at various depths) at least one just above the dam and two or more additional stations in the upstream (one in the inlet and one in the middle) should be located.

Trap Efficiency

The trap efficiency of a reservoir is defined as the ratio of the deposited sediment to the total sediment inflow. It depends mainly on the sediment characteristics, the detention time of water in the reservoir and the degree of reservoir siltation.

A number of empirical relationships have been developed for the trap efficiency of large reservoirs. Discussions are given by Borland (1971), US Bureau of Reclamation (1977) and Bogardi (1971). Among the various methods, that by Brune (1953) is the most widely used. It expresses the efficiency in terms of the ratio of capacity of the reservoir to annual inflow of water (m^3/m^3).

The trap efficiency relationship by Brune is based on records of 44 normal ponded reservoirs and is shown in the figure below. No systematic comparisons of the predicted values with the actual measured sedimentation of the reservoirs are known.



Trap efficiency cure

A significant addition to the Brune-curves was published by Chen (1975). Chen presented the trap efficiency for the various particle sizes, in mm, as a function of the ratio of reservoir area, A (m^2), to the outflow rate, Q (m^3/s) and compared the results with Brune and Churchill predictions. The results show that the Brune and Churchill methods underestimate the trap efficiency for coarser sediment and overestimate it for finer sediment.

1.3.1 Reservoir sedimentation, Life of a reservoir

Reservoir Sedimentation:

Reservoir sedimentation is a difficult problem economical solution of which has not yet been developed except by providing a bit greater dead storage to accommodate the sediment deposit during the life of the reservoir.

This difficult problem of sedimentation has been investigated by Chow, U.S. Deptt of Agriculture., CBIP, Garde and Ranga Raju and fourth congress of large dams. River water normally carries certain amount of silt eroded from the catchment during heavy rain or due to the high velocity of runoff over the ground. The extent of erosion, i.e., silt or sediment load it carries depends on,

(i) Nature of soil of watershed

(ii) Topography of the watershed

(iii) Vegetation cover of the watershed

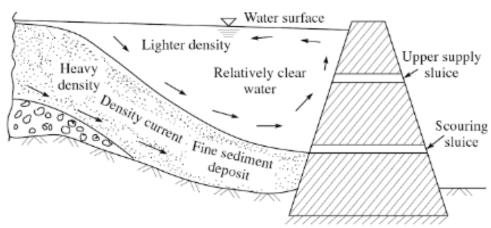
(iv) Intensity of rainfall, i.e., higher intensity produces higher run-off or high velocity which erodes and carries silt along with water.

(v) Soil conservation and watershed management methods adopted in the catchment.

Sheet erosion takes place on soft soil of the catchment resulting more sediment in river flow. Conversely hard soil is not eroded easily resulting less sediment. In steep topography, velocity of run-off is more and hence, more sediment due to erosion. If the vegetation cover is more, both velocity and erosion are checked producing less sediment.

Deforestation of the catchment and improper soil conservation of watershed add more sediment to the reservoir. In any case, river water carries always a certain amount of sediment load. The sediment transported may be bed load or suspended load. When river water with sediment-laden water approaches the reservoir, the velocity decreases due to greater area.

Due to this reduction of velocity, coarser particles settle in head reaches of the river and while suspended and finer particles take sufficient time to settle just upstream of the dam shown in the figure below. A part of finer particles may pass through sluice ways to turbines or spillways.



Reservoir Sedimentation

LIFE OF A RESERVOIR

The ultimate destiny of a reservoir is to be filled with silt deposits. To allow for silting, a certain percentage of the total storage is usually left unutilized and is called 'dead storge'. However, as the time passes on, more and more silting takes place and the give' or 'effective storage ' is gradually reduced.

The useful life of reservoir is terminated when its capacity is reduced to 20 % of the designed capacity. The reservoir planning must, therefore, include the consideration of probable rate of silting so that the useful life of the reservoir may be determined.

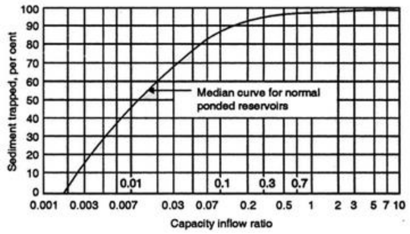
The reservoir sedimentation is measured in terms of its trap efficiency (η).

Trap efficiency of a reservoir is the percent of inflowing sediment which is retained in reservoir. Detailed observations show that the trap efficiency is a function of the ratio of reservoir capacity to the total inflow, i.e.

$$\eta = f\left(\frac{\text{Capacity}}{\text{Inflow}}\right)$$

The figure shows a plot between trap efficiency and capacity inflow ratio on the basis of the existing reservoirs. It is clear from the above curve that for a given inflow rate, the trap efficiency decreases with the reduction in reservoir capacity due to sediment deposit.

Hence the rate of silting is higher in the initial stages and it decreases as silting take place. Thus the complete filling of a reservoir with silt may take a very long time.



Trap Efficiency Of Reservoirs

At the same time, a small reservoir (having small capacity) on a large stream (having large inflow rates) has a very small (Capacity / Inflow ratio. The trap efficiency for such a reservoir is extremely small and the stream passes most of its inflow so quickly that the finer sediments do not settle but are discharged downstream.

On the other hand, large reservoir constructed on small stream (having less inflow rates) has greater Capacity / Inflow) ratio. Such a reservoir has a greater trap efficiency. Such a reservoir may retain water for several years and permit almost complete deposition of the sediment.

Procedure for Calculation of Life of a Reservoir :

(1) The required reservoir capacity is determined from th considerations sed in the previous article. Knowing the inflow rate calculate the Capacity Inflow ratio and obtain the trap efficiency from the curve as shown in the figure above, for the full capacity of the reservoir.

(2) Divide the total capacity into any suitable interval, say 10%. Assuming that 10 % capacity has been reduced due to sediment deposit, find the trap efficiency for the reduced capacity (i.e., 90 % of the original) and the inflow ratio.

(3) For this interval of 10 % capacity, find the average trap efficiency by taking the average of found in steps (2) and (3).

(4) Determine the sediment inflow rate by taking water samples and drying the sediment. Multiply the total annual sediment transported by the trap efficiency found in step (3). Convert this sediment deposited into hectare-metre (volumetric) units deposited in one year.

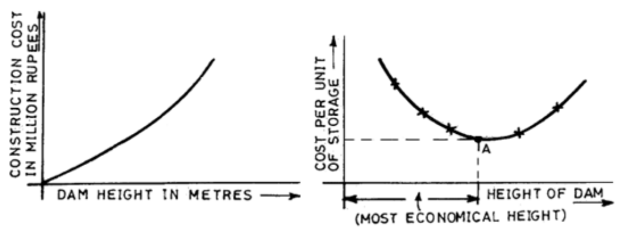
(5) Divide the volume interval (i.e.,10 % of the capacity) by the sediment deposited (determined in step 4) to get the number of years to fill this volume interval of 10 % capacity.

(6) Repeat this procedure for further intervals, i.e. at 80%, 70% , 20% of the capacity. The total life of the reservoir will be equal to the total of the number of years required to fill each of the volume intervals.

1.3.2 Economic height of a dam

The economic height of a dam is that height of the dam, corresponding to which, the cost of the dam per unit of storage is minimum.

For this purpose, the estimates are prepared for construction costs, for several heights of the dam, somewhat above and below the level at which the elevation-storage curve shows a fairly high rate of increase of storage per unit rise of elevation, keeping the length of the dam moderate.



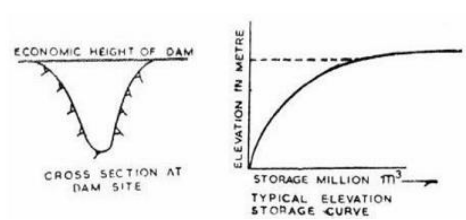
The construction cost is found to increase with the dam height, as shown in the figure(a).

(a)(b)

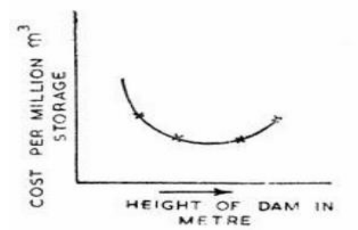
For each dam height, the reservoir storage is known from the reservoir-capacity curve. The construction cost per unit of storage for all the possible dam heights can then be worked out and plotted, as shown in the figure(b).

The lowest point A on this curve, gives the dam height for which the cost per unit of storage is minimum and hence, most economical.

Theoretically, economic height of dam is that the height of dam cherish that the price of dam per million cubic meter of storage is that the minimum.



Economic height of a dam



After thus determining the approximate cost per million cubic metre of storage for four or five alternative heights the cost per million cubic metre of storage is plotted against height to assess the most economical height of dam as shown in figure.

Problem

1. The following information is available regarding the relationship between trap efficiency and capacity inflow ratio.

Capacity inflow ratio	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**
Trap efficiency percent	**87**	**93**	**95**	**95.5**	**96**	**96.5**	**97**	**97**	**97**	**97.5**

Let us determine the probable life of the reservoir with an initial reservoir capacity of 30 million cubic metres, if the average annual flood inflow is 60 million cubic metres and the average annual sediment inflow is 2,00,000 tonnes. Assume a specific weight of the sediment equal to 1.2 gm per c.c. The usual life of the reservoir will terminate when 80% of its initial capacity is filled with sediment.

Given:

Capacity inflow ratio	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Trap efficiency percent	87	93	95	95.5	96	96.5	97	97	97	97.5

Average annual sediment inflow = 2,00,000 tonnes

= 2 x 10^5 tonnes = 2 x 10^{11} gm

Volume of average annual sediment inflow,

$$= \frac{2 \times 10^{11}}{1.2} \text{ c.c.} = \frac{2 \times 10^{11}}{1.2 \times 10^{6}} \text{ m}^3$$

$$= \frac{0.2}{1.2} \times 10^{6} \text{ cubic metres} = \frac{1}{6} \text{ million cubic metre} = \frac{1}{6} \text{ M.m}^3$$

Initial Reservoir Capacity = 30 M.m^3

Annual flood inflow = 60 M.m^3

Let us assume that 20% of the capacity, i.e. 6 M.m^3 is filled up in the first interval.

Capacity inflow ratio at the start of the interval = 30/60 = 0.5

Trap efficiency at the start of the interval= 0.96

Capacity inflow ratio at the end of the interval =24/60=0.4

Trap efficiency at the end of interval = 0.955

Average trap efficiency during the interval = $\frac{0.96 + 0.955}{2} = \mathbf{0.9575.}$

Volume of sediment deposited annually till the 20% capacity is filled,

$$= \frac{1}{6} \times 0.9575 \text{ M.m}^3$$

Number of years during which 20% of the capacity, i.e. 6 M.m^3 shall be filled up,

$$= \frac{6}{\frac{1}{6} \times 0.9575} \text{ years} = \frac{36}{0.9575} = \mathbf{37.6 \text{ years}}$$

Similarly, in the 2nd interval

Capacity inflow ratio at the start =24/60=0.4

Capacity inflow ratio at the end =18/60=0.3

Trap efficiency at the start =0.955 .

Trap efficiency at the end =0.95

Average trap efficiency =0.9525.

Number of years during which the next 20% of capacity shall be filled up,

$$= \frac{6}{\frac{1}{6} \times 0.9525} = \frac{36}{0.9525} = \mathbf{37.8 \text{ years}}$$

Similarly, in the 3rd interval

Capacity inflow ratio at start =18/60=0.3

Capacity inflow ratio at the end =12/60=0.2

Trap efficiency at the start =0.95

Trap efficiency at the end =0.93

Average trap efficiency during the interval = 0.94

Number of years during which the next 20% of the capacity shall be filled up,

$$= \frac{6}{\frac{1}{6} \times 0.94} = \frac{36}{0.94} = \mathbf{38.3\,years}.$$

Similarly, in the 4th interval

Capacity inflow ratio at the start =12/60=0.2

Capacity inflow ratio at the end = 6/60= 0.1

Trap efficiency at the start = 0.93

Trap efficiency at the end =0.87

Average trap efficiency during the interval = 0.90

Number of years during which the next 20% of the capacity shall be filled up,

$$= \frac{6}{\frac{1}{6} \times 0.9} = \frac{36}{0.9} = \mathbf{40\,years}$$

Total probable life till 80% capacity gets filled up,

= 37.6 + 37.8 + 38.3 + 40.0 = 153.7 years.

The above calculations of dividing the entire capacity into intervals (20% each in the above case) can also be carried out in a tabular form, as shown below in the table below.

Capacity		Capacity/inflow $= \frac{Col.\,(2)}{60\,Mcum}$ **(3)**	**Trap efficiency (η)** **(4)**	**Avg. Trap efficiency (η_{av}) during the interval** **(5)**	**Sediment trapped per year : col.(5) x Av. Annual sediment inflow = col.(5)x(1/6)** **M.cum. (6)**	**Years required to fill up 20% capacity (6 M.cum.)** $= \frac{6}{Col.\,(6)}$ **In years (7)**
%	**Capacity vol.**					

(1)	**in M.cum**					
	(2)					
100	30	0.5	0.96			
80	24	0.4	0.955	0.9575	0.1596	36.6
60	18	0.3	0.95	0.9525	0.1588	37.8
40	12	0.2	0.93	0.94	0.1566	38.3
20		0.1	0.8	0.90	0.15	40.0
						Σ = 153.7 yrs

2. A proposed reservoir has a capacity of 500 ha-m. The catchment area is 125 km^2 and the annual stream flow averages 12 cm of runoff. If the annual sediment production is 0.03 ha.m/km^2, what is the probable life of the reservoir before its capacity is reduced by 10% of its initial capacity by sedimentation? The relationship between trap efficiency η (%) and capacity inflow ratio C/I, is as under :

C/I	**0.01**	**0.02**	**0.04**	**0.06**	**0.08**	**0.1**	**0.2**	**0.3**	**0.5**	**0.7**
η%	**43**	**60**	**74**	**80**	**84**	**87**	**93**	**95**	**96**	**97**

Solution

Given:

C/I	0.01	0.02	0.04	0.06	0.08	0.1	0.2	0.3	0.5	0.7
η%	43	60	74	80	84	87	93	95	96	97

Average annual stream flow = 12 cm of runoff

Area of catchment = 125 km^2 = 125x10^6 m^2

$\therefore$ Annual flood inflow $= (125 \times 10^6) \cdot \frac{12}{100} m^3$

=15 x 10^6 m^3= 15 M.m^3 (Mcum).

Annual sediment inflow = 0.03 ha-m/km^2 of the catchment,

= 0.03 x 125 ha-m= 0.03 x 125 x 10^4 m^3

= 3.75 x 10^4 m^3

$= \frac{3.75}{100} \times 10^6 m^3 = \mathbf{0.0375\ M\text{–}m^3\ (Mcum)}$

It means that 0.0375 Mcum of sediment flows every year into the dam/reservoir site, but the quantum of this, which is trapped in the reservoir, depends upon the average trap efficiency (η) during that year and this trap efficiency, in turn. depends upon the capacity/inflow ratio.

In the question, the total capacity to be filled up by sediment is 10% of the initial reservoir capacity, i.e. 10%x 5 Mcum= 0.5 Mcum.

Now, we have to calculate the time during which this 0.5 Mcum of sediment will get deposited in the reservoir, as follows :

Capacity of the reservoir at the start = 5 Mcum

Capacity of the reservoir at the end (i.e., when 0.5 Mcum of sediment is filled up) = 4.5 Mcum

Capacity/inflow at the start $= \frac{5\ \text{Mcum}}{15\ \text{Mcum}} = 0.333$

η at start = 95%.

Capacity/inflow at the end $= \frac{4.5}{15} = 0.30$

η at the end of the interval = 95%.

Average η = 95%

Sediment load trapped/yr. = 0.0375 x 95% = 0.035625

No. of years during which 0.5 Mcum of sediment will get trapped,

$= \frac{0.5}{0.035625}$ years = 14.04 years ,say 14 years.

Hence, after 14 years, 10% reservoir capacity will get filled up.

3. The construction costs for certain possible heights of a dam at a given site have been estimated and are tabulated in the table below. The storage capacity for all these dam heights are also given.

S.No. (1)	**Height of the dam in metres (2)**	**Construction cost in million Rs.(3)**	**Storage in million cubic metres (4)**
1	**10**	**4**	**50**
2	**20**	**8**	**110**
3	**30**	**12**	**180**
4	**40**	**18**	**250**
5	**50**	**27**	**350**
6	**60**	**39**	**500**
7	**65**	**50**	**600**

Let us determine the most economical height of the dam from purely construction point of view.

Solution

Given:

S.No.(1)	Height of the dam in metres (2)	Construction cost in million Rs.(3)	Storage in million cubic metres (4)

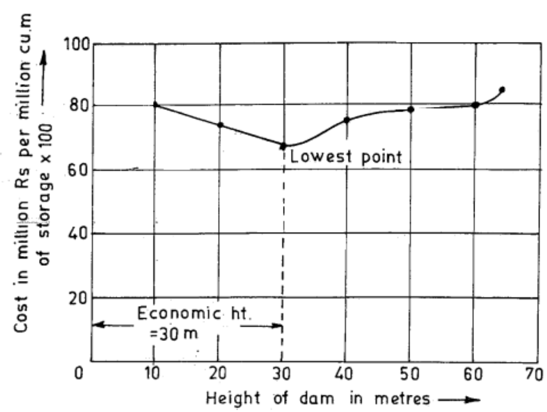
1	10	4	50
2	20	8	110
3	30	12	180
4	40	18	250
5	50	27	350
6	60	39	500
7	65	50	600

The given table is extended, so as to workout the cost per million cubic metre of storage, as shown in col. (5) of below table.

S.No. (1)	**Height of the dam in metres** (2)	**Construction cost in million Rs.** (3)	**Storage in million cubic metres** (4)	**Cost per unit of storage** $= \frac{Col. 3}{Col. 4}$ (5)
1	10	4	50	0.080
2	20	8	110	0.073
3	30	12	180	0.067
4	40	18	250	0.072

5	50	27	350	0.077
6	60	39	500	0.078
7	65	50	600	0.083

The cost per unit of storage is plotted against the height of the dam, as shown in below figure. The most economical height is the lowest point of this curve and it works out to be 30 metres.



4. The monthly inflow and monthly pan-evaporation during a critical dry year at the site of a proposed reservoir are given below.

Month	**Jan.**	**Feb.**	**March**	**April**	**May**	**June**	**July**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
Inflow (ha-m)	**10**	**10**	**4**	**2**	**1**	**200**	**2000**	**4000**	**1500**	**100**	**15**	**10**
Pan evaporation (cm)	**8**	**10**	**10**	**12**	**15**	**20**	**15**	**15**	**15**	**12**	**10**	**8**
Precipitation (cm)	**2**	**0**	**0**	**0**	**0**	**30**	**40**	**45**	**40**	**10**	**0**	**2**
Demand (ha-m)	**150**	**150**	**50**	**50**	**50**	**50**	**50**	**50**	**150**	**150**	**150**	**150**

The net increase in pool area is 500 ha and the prior rights require the release of the full stream flow or 10 ha-m, whichever is less. Assume that 40% of the precipitation that has fallen on the submerged area reached the stream earlier and 60% of that directly falls on the reservoir. Let us determine the storage capacity. Take pan coefficient as 0.80.

Solution

Given:

Month	**Jan.**	**Feb.**	**March**	**April**	**May**	**June**	**July**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
Inflow (ha-m)	10	10	4	2	1	200	2000	4000	1500	100	15	10
Pan evaporation (cm)	8	10	10	12	15	20	15	15	15	12	10	8
Precipitation (cm)	2	0	0	0	0	30	40	45	40	10	0	2
Demand (ha-m)	150	150	50	50	50	50	50	50	150	150	150	150

Month	**Inflow (ha-m)**	**Pan evaporation (cm)**	**Precipitation (cm)**	**Demand (ha-m)**	**Water right (ha-m)**	**Evaporation (ha-m)**	**Precipitation (ha-m)**	**Adjusted inflow (ha-m)**	**Required storage (ha-m)**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Jan.	10	8	2	150	10	32	6	-26	-176
Feb.	10	10	0	150	10	40	0	-40	-190

March	4	10	0	50	4	40	0	-40	-90
April	2	12	0	50	2	48	0	-48	-98
May	1	15	0	50	1	60	0	-60	-110
June	200	20	30	50	10	80	90	200	-
July	2000	15	40	50	10	60	120	2050	-
August	4000	15	45	50	10	60	135	4065	-
Sep.	1500	15	40	150	10	60	120	1550	-
Oct.	100	12	10	150	10	48	30	72	-78
Nov.	15	10	0	150	10	40	0	-35	-185
Dec.	10	8	2	150	10	32	6	-26	-176
									=-1103

Columns (1) to (6) are the given data in the above table.

$$\text{Column (7)} = \frac{\textit{Column (3) x 500 x 0.8}}{100} = 4.0 \text{ x colm. (3)}$$

$$\text{Column (8)} = \frac{\textit{Column (4) x 500 x 0.6}}{100} = 3.0 \text{ x colm. (4)}$$

Column (9) = Columns (2) + (8) - (6) - (7)

Column (10) = Columns (9) - Column (5), whenever negative.

Required capacity = Total of column (10) = 1103 ha-m.

1.3.3 Environmental effects of reservoirs

It is important to note that storage reservoirs built across rivers and streams loose their capacity on account of deposition of sediment. This deposition which takes place progressively in time reduces the active capacity of the reservoir to provide the outputs of water through passage of time.

Accumulation of sediment at or near the dam may interfere with the future functioning of water intakes and hence affects decisions regarding location and height of various outlets.

It may also result in greater inflow into canals/water conveyance systems drawing water from the reservoir.

Problems of rise in flood levels in the head reaches and unsightly deposition of sediment from recreation point of may also crop up in course of time. In this regard the Bureau of Indian Standard code IS: 12182 - 1987 "Guidelines for determination of effects of sedimentation in planning and performance of reservoir" is an important document which discusses some of the aspects of sedimentation that have to be considered while planning reservoirs.

Some of the important points from the code are as follows:

While planning a reservoir, the degree of seriousness and the effect of sedimentation at the proposed location has to be judged from studies, which normally combination consists of:

Performance Assessment (Simulation) Studies with varying rate of sedimentation.

Likely effects of sedimentation at dam face. In special cases where the effects of sedimentation on backwater levels are likely to be significant, backwater studies would be useful to understand the size of river water levels. Similarly, special studies to bring out delta formation region changes may be of interest.

The steps to be followed for performance assessment studies with varying rates of sedimentation are as follows:

a. Estimation of annual sediment yields into the reservoir or the average annual sediment yield and of expected.

b. Distribution of sediment within reservoir to obtain a sediment elevation and capacity curve at any appropriate time.

c. Simulation studies with varying rates of sedimentation.

d. Assessment of effect of sedimentation.

In general the performance assessment of reservoir projects has to be done for varying hydrologic inputs to meet varying demands. Although analytical probability based methods are available to some extent, simulation of the reservoir system is the standard method.

The method is also known as the working tables or sequential routing. In this method, the water balance of the reservoirs and of other specific locations of water use and constraints in the systems are considered.

All inflows to and outflows from the reservoirs are worked out to decide the changed storage during the period. In simulation studies, the inflows to be used may be either historical inflow series, adjusted for future up stream water use changes or an adjusted synthetically generated series.

• The flow in the river changes seasonally and from year to year due to temporal and spatial variation in precipitation.

• Water available abundantly during monsoon season becomes scarce during the non-monsoon season when it is most needed.

• The traditional method followed commonly for meeting the needs of water during the scarce period is construction of storage reservoir on the river course.

• The excess water during the monsoon season is stored in such reservoirs for eventual use in lean period.

• Construction of storages will also help in control of flood as well as generation of electricity power.

• To meet the objective set forth in planning a reservoir or a group of reservoirs and to achieve maximum benefits out of the storage created it is imperative to evolve guidelines for operation of reservoirs.

• Without proper regulation schedules the reservoir may not meet the full objective for which it was planned and may also pose danger to the structure itself.

• Control of flood is better achieved if the reservoir level is kept low in the early stages of the monsoon season.

• However, at a later stage, if the anticipated inflows do not result the reservoir may not get filled up to FRL in the early stages of monsoon to avoid the risk of reservoir remaining unfilled at later stage there may be problem of accommodating high floods occurring at later stage.

• In some cases while planning reservoirs, social and other considerations occasionally result in adoption of a plan that may not be economically the best.