CE 2031 WATER RESOURCES ENGINEERING

UNIT IV RESERVOIR PLANNING AND MANAGEMENT
Reservoir - Single and multipurpose – Multi objective - Fixation of Storage capacity - Strategies for reservoir operation - Sedimentation of reservoirs - Design flood-levees and flood walls - Channel improvement.

Reservoir

INTRODUCTION
✓ In the process of illustrating the primary functions of a reservoir engineer, namely, the estimation of hydrocarbons in place, the calculation of a recovery factor and the attachment of a time scale to the recovery; this chapter introduces many of the fundamental concepts in reservoir engineering.
✓ The description of the calculation of oil in place concentrates largely on the determination of fluid pressure regimes and the problem of locating fluid contacts in the reservoir.
✓ Primary recovery is described in general terms by considering the significance of the isothermal compressibility of the reservoir fluids; while the determination of the recovery factor and attachment of a time scale are illustrated by describing volumetric gas reservoir engineering.
✓ The chapter finishes with a brief quantitative account of the phase behavior of multi-component hydrocarbon systems.

Operation of system of reservoirs
✓ It is not very uncommon to find a group or ‘system’ of reservoirs either in a single river or in a river and its tributaries. An example of the former are the dams proposed on the river Narmada (Figure 7) and an example of the latter are the dams of the Dam odor Valley project (Figure 8).
✓ In case of system of reservoirs, it is necessary to adopt a strategy for integrated operated of reservoirs to achieve optimum utilization of the water resources available and to benefit the best out of the reservoir system.
✓ In the preparation of regulation plans for an integrated operation of system of reservoirs, principles applicable to separate units are first applied to the individual reservoirs.
✓ Modifications of schedule so developed should then be considered by working out several alternative plans. In these studies optimization and simulation techniques
may be extensively used with the application of computers in water resources development.

VOLUMETRIC GAS RESERVOIR ENGINEERING

✓ Volumetric gas reservoir engineering is introduced at this early stage in the book because of the relative simplicity of the subject.
It will therefore be used to illustrate how a recovery factor can be determined and a time scale attached to the recovery.

The reason for the simplicity is because gas is one of the few substances whose state, as defined by pressure, volume and temperature (PVT), can be described by a simple relation involving all three parameters.

One other such substance is saturated steam, but for oil containing dissolved gas, for instance, no such relation exists and, as shown in Chapter 2, PVT parameters must be empirically derived which serve the purpose of defining the state of the mixture.

RESERVOIR DRIVE MECHANISMS

If none of the terms in the material balance equation can be neglected, then the reservoir can be described as having a combination drive in which all possible sources of energy contribute a significant part in producing the reservoir fluids and determining the primary recovery factor.

In many cases, however, reservoirs can be singled out as having predominantly one main type of drive mechanism in comparison to which all other mechanisms have a negligible effect.

In the following sections, such reservoirs will be described in order to isolate and study the contribution of the individual components in the material balance in influencing the recovery factor and determining the production policy of the field.

The mechanisms which will be studied are:
- solution gas drive
- gas cap drive
- natural water drive
- compaction drive

And these individual reservoir drive mechanisms will be investigated in terms of: reducing the material balance to a compact form, in many cases using the technique of Helena and Odeh, in order to quantify reservoir performance.

MATERIAL BALANCE APPLIED TO OIL RESERVOIRS

- determining the main producing characteristics, the producing gas oil ratio and water cut
- determining the pressure decline in the reservoir
- estimating the primary recovery factor
- investigating the possibilities of increasing the primary recovery.

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

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a) **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:

1) **Effective use of available flood control storage**: Operation under this principle aims at reducing flood damages of the locations to be protected to the maximum extent possible, by effective use of flood event. Since 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 downstream areas would be absolutely necessary.

2) **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, that is the full storage capacity would be utilized only when the flood develops into the reservoir design flood. However, 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.

3) **Combination of principle (1) and (2)**: In this method, a combination of the principles (1) and (2) is followed. The principle (1) is followed for the lower portion of the flood reserve to achieve the maximum benefits by controlling the earlier part of the flood. Thereafter releases are made as scheduled for the reservoir design flood as in principle (2). In most cases this plan will result in the best overall regulation, as it combines the good points of both the methods.

4) **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.

b) **Conservation**: Reservoirs meant for augmentation of supplies during lean period should usually be operated to fill as early as possible 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. Should any flood occur when the reservoir is at or near the FRL, 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. However, 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:

1. Separate allocation of capacities- When separate allocations of capacity have been made for each of the conservational uses, in addition to that required for flood control, operation for each of the function shall follow the principles of respective functions. The storage available for flood control could, however 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.

2. 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. While flood control requires low reservoir level, conservation interests require as high a level as is attainable. Thus, the 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. In some cases 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. This will naturally involve some sacrifice of the flood control interests towards the end of the monsoon.

**Multipurpose reservoirs**

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

✓ However, 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.
✓ Irrigation is covered separately.

Flood control
✓ Floods are caused by many factors: heavy rainfall, highly accelerated snowmelt, 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 percent 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 geomorphology and geology, erosion refers to the actions of exogamic processes (such as water flow or wind) 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 by 10-40 times the rate at which erosion is occurring globally.
✓ Excessive (or accelerated) erosion causes both 'on-site' and 'off-site' problems.
✓ On-site impacts include decreases in agricultural and (on natural landscapes) ecological collapse, both because of loss of the nutrient-rich upper soil layers. In some cases, the eventual end result is desertification.
✓ 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; combined, they are responsible for about 84% of the global extent of degraded, making excessive erosion one of the most significant environmental problems worldwide.
✓ Intensive agriculture, deforestation, roads, anthropogenic climate change and urban sprawl are amongst the most significant human activities in regard to their effect on stimulating erosion.
✓ However, there are many remediation practices that can curtail or limit erosion of vulnerable soils.

**Environmental resource management**
Environmental resource management is the management of the interaction and impact of human societies on the environment.

It is not, as the phrase might suggest, the management of the environment itself.

Environmental resources management aims to ensure that ecosystem services are protected and maintained for future human generations, and also maintain ecosystem integrity through considering ethical, economic, and scientific (ecological) variables.

Environmental resource management tries to identify factors affected by conflicts that rise between meeting needs and protecting resources.

It is thus linked to protection and sustainability.

Hydroelectricity

Hydroelectricity is the term referring to electricity generated by hydropower; the production of electrical power through the use of the gravitational force of falling or flowing water.

It is the most widely used form of renewable, accounting for 16 percent of global electricity generation – 3,427 terawatt-hours of electricity production in 2010, and is expected to increase about 3.1% each year for the next 25 years.

Hydropower is produced in 150 countries, with the Asia-Pacific region generating 32 percent of global hydropower in 2010.

China is the largest hydroelectricity producer, with 721 terawatt-hours of production in 2010, representing around 17 percent of domestic electricity use.

There are now four hydroelectricity plants larger than 10 GW: the Three Gorges Dam and Xiluodu Dam in China, Itapúa Dam across the Brazil/Paraguay border, and Guru Dam in Venezuela.[1]

The cost of hydroelectricity is relatively low, making it a competitive source of renewable electricity.

The average cost of electricity from a hydro plant larger than 10 megawatts is 3 to 5 U.S. cents per kilowatt-hour. It is also a flexible source of electricity.
since the amount produced by the plant can be changed up or down very quickly to adapt to changing energy demands.

- However, damming interrupts the flow of rivers and can harm local ecosystems, and building large dams and reservoirs often involves displacing people and wildlife.
- Once a hydroelectric complex is constructed, the project produces no direct waste, and has a considerably lower output level of the greenhouse gas carbon dioxide (CO2) than fossil fuel powered energy plants.

Navigation

- Navigation 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: land navigation, marine navigation, aeronautic navigation, and space navigation.
- It is also the term of art used for the specialized knowledge used by navigators to perform navigation tasks.
- All navigational techniques involve locating the navigator's position compared to known locations or patterns.
- Navigation, in a broader sense, can refer to any skill or study that involves the determination of position and direction.
- In this sense, navigation includes orienteering and pedestrian navigation.
- For information about different navigation strategies that people use, visit human navigation.

Irrigation

- Irrigation is the artificial application of water to the land or soil.
- It 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.
Additionally, 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.

In contrast, agriculture that relies only on direct rainfall is referred to as rain-fed or dry land farming.

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.

Channel improvement.

- At the diversion structure, a headwork regulates the flow into a canal.
- This canal, which takes its supplies directly from the river, is called the main canal and usually direct irrigation from the waters of this canal is not carried out.
- This acts as a feeder channel to the branch canals, or branches.
- Branch canals generally carry a discharge higher than $5 \text{ m}^3/\text{s}$ and acts as feeder channel for major distributaries which, in turn carry $0.25$ to $5 \text{ m}^3/\text{s}$ of discharge.
- The major distributaries either feed the water courses or the minor distributaries, which generally carry discharge less than $0.25 \text{ m}^3/\text{s}$.
- Though irrigation canals may be constructed in natural or compacted earth, these suffer from certain disadvantages, like the following:
  - Maximum velocity limited to prevent erosion
  - Seepage of water into the ground
  - Possibility of vegetation growth in banks, leading to increased friction
  - Possibility of bank failure, either due to erosion or activities of burrowing animals
All these reasons lead to adoption of lining of canals, though the cost may be prohibitive. Hence, before suggesting a possible lining for a canal, it is necessary to evaluate the cost vis-à-vis the savings due to reduction in water loss through seepage. Apart from avoiding all the disadvantages of an unlined canal, a lined canal also has the advantage of giving low resistance and thus reducing the frictional loss and maintaining the energy and water surface slopes for the canal as less as possible. This is advantageous as it means that the canal slope may also be smaller, to maintain the same discharge than for a canal with higher friction loss. A smaller canal slope means a larger command area.

**Fixation of Storage capacity**

**Instructional objectives**

On completion of this lesson, the student shall learn:

1. The usual classification of the zones of a reservoir
2. The primary types of reservoirs and their functions
3. The steps for planning reservoirs
4. Effect of sedimentation in reservoirs
5. What are the geological explorations required to be carried out for reservoirs
6. How to determine the capacities of reservoirs
7. How to determine the dead, live and flood storages of reservoirs
8. How to reduce the loss of water from reservoirs
9. How to control sedimentation of reservoirs
10. The principles to be followed for reservoir operations

Introduction

- Water storage reservoirs may be created by constructing a dam across a river, along with suitable appurtenant structures. However, in that lesson not much was discussed about fixing the size of reservoir based on the demand for which it is being constructed.
- Further, reservoirs are also meant to absorb a part of flood water and the excess is discharged through a spillway.
- It is also essential to study the relation between flood discharge, reservoirs capacity and spillway size in order to propose an economic solution to the whole project.

- These and topics on reservoir sedimentation have been discussed in this lesson which shall give an idea as to how a reservoir should be built and optimally operated.
- Fundamentally, a reservoir serves to store water and the size of the reservoir is governed by the volume of the water that must be stored, which in turn is affected by the variability of the inflow available for the reservoir.
- Reservoirs are of two main categories: (a) Impounding reservoirs into which a river flows naturally, and (b) Service or balancing reservoirs receiving supplies that are pumped or channeled into them artificially.
- In general, service or balancing reservoirs are required to balance supply with demand. Reservoirs of the second type are relatively small in volume because the storage required by them is to balance flows for a few hours or a few days at the most.
- Impounding or storage reservoirs are intended to accumulate a part of the flood flow of the river for use during the non-flood months.
- In this lesson, our discussions would be centered on these types of reservoirs

Reservoir storage zone and uses of reservoir

- The storage capacity in a reservoir is nationally divided into three or four parts (Figure 1) distinguished by corresponding levels.
**Full Reservoir Level (FRL):** It is the level corresponding to the storage which includes both inactive and active storages and also the flood storage, if provided for. In fact, this is the highest reservoir level that can be maintained without spillway discharge or without passing water downstream through sluice ways.

**Minimum Drawdown Level (MDDL):** It is the level below which the reservoir will not be drawn down so as to maintain a minimum head required in power projects.

**Dead Storage Level (DSL):** Below the level, there are no outlets to drain the water in the reservoir by gravity.

**Maximum Water Level (MWL):** This is the water level that is ever likely to be attained during the passage of the design flood. It depends upon the specified initial reservoir level and the spillway gate operation rule. This level is also called sometimes as the *Highest Reservoir Level* or the *Highest Flood Level*.

**Live storage:** This is the storage available for the intended purpose between Full Supply Level and the Invert Level of the lowest discharge outlet. The Full Supply Level is normally that level above which over spill to waste would take place. The minimum operating level must be
sufficiently above the lowest discharge outlet to avoid vortex formation and air entrainment. This may also be termed as the volume of water actually available at any time between the Dead Storage Level and the lower of the actual water level and Full Reservoir Level. **Dead storage:** It is the total storage below the invert level of the lowest discharge outlet from the reservoir. It may be available to contain sedimentation, provided the sediment does not adversely affect the lowest discharge. **Outlet Surcharge or Flood storage:** This is required as a reserve between Full Reservoir Level and the Maximum Water level to contain the peaks of floods that might occur when there is insufficient storage capacity for them below Full Reservoir Level. Some other terms related to reservoirs are defined as follows: **Buffer Storage:** This is the space located just above the Dead Storage Level up to Minimum Drawdown Level. As the name implies, this zone is a buffer between the active and dead storage zones and releases from this zone are made in dry situations to cater for essential requirements only. Dead Storage and Buffer Storage together is called Interactive Storage. **Within-the-Year Storage:** This term is used to denote the storage of a reservoir meant for meeting the demands of a specific hydrologic year used for planning the project. **Carry-Over Storage:** When the entire water stored in a reservoir is not used up in a year, the unused water is stored as carry-over storage for use in subsequent years. **Silt / Sedimentation zones:** The space occupied by the sediment in the reservoir can be divided into separate zones. A schematic diagram showing these zones is illustrated in Figure 2 (as defined in IS: 5477).
Freeboard: It is the margin kept for safety between the level at which the dam would be overtopped and the maximum still water level. This is required to allow for settlement of the dam, for wave run up above still water level and for unforeseen rises in water level, because of surges resulting from landslides into the reservoir from the peripheral hills, earthquakes or unforeseen floods or operational deficiencies.

The functions of reservoirs are to provide water for one or more of the following purposes. Reservoirs that provide water for a combination of these purpose, are termed as ‘Multi Purpose’ reservoirs.

Human consumption and/or industrial use:

• **Irrigation**: usually to supplement insufficient rainfall.

• **Hydropower**: to generate power and energy whenever water is available or to provide reliable supplies of power and energy at all times when needed to meet demand.

• **Pumped storage hydropower schemes**: in which the water flows from an upper to a lower reservoir, generating power and energy at times of high demand through turbines, which
may be reversible, and the water is pumped back to the upper reservoir when surplus energy is available. The cycle is usually daily or twice daily to meet peak demands. Inflow to such a reservoir is not essential, provided it is required to replace water losses through leakage and evaporation or to generate additional electricity. In such facilities, the power stations, conduits and either or both of the reservoirs could be constructed underground if it was found to do so.

• **Flood control:** storage capacity is required to be maintained to absorb foreseeable flood inflows to the reservoirs, so far as they would cause excess of acceptable discharge spillway opening. Storage allows future use of the flood water retained.

• **Amenity use:** this may include provision for boating, water sports, fishing, sight seeing.

Formally, the Bureau of Indian Standards code IS: 4410 (part 6)1983 “Glossary of terms relating to river valley projects -Reservoirs” defines the following types of reservoirs:

• **Auxiliary or Compensatory Reservoir:** A reservoir which supplements and absorbed the spill of a main reservoir.

• **Balancing Reservoirs:** 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.

• **Conservation Reservoir:** A reservoir impounding water for useful purposes, such as irrigation, power generation, recreation, domestic, industrial and municipal supply etc.

• **Detention Reservoir:** A reservoir where in water is stored for a relatively brief period of time, past of it being retained until the stream can safely carry the ordinary flow plus the released water. Such reservoirs usually have outlets without control gates and are used for flood regulation. These reservoirs are also called as the **Flood Control Reservoir** or **Retarding Reservoir**.

• **Distribution Reservoir:** A reservoir connected with distribution system a water supply project, used primarily to care for fluctuations in demand which occur over short periods and as local storage in case of emergency such as a break in a main supply line failure of a pumping plant.

• **Impounding or Storage Reservoir:** A reservoir with gate-controlled outlets wherein surface water may be retained for a considerable period of time and released for use at a time when the normal flow of the stream is in sufficient to satisfy requirements.

• **Multipurpose Reservoir:**
  ✓ A reservoir constructed and equipped to provide storage and release of water for two or more purposes such as irrigation, flood control, power generation, navigation, pollution abatement, domestic and industrial water supply, fish culture, recreation, etc.
  ✓ It may be observed that some of these objectives may be incompatible in combination.
For example, water may have to be released for irrigation to suit crop growing seasons, while water releases for hydropower are required to suit the time of public and industrial demands.
The latter will be affected not only by variations in economic conditions but also by variations over a day and night cycle.
Compatibility between irrigation demand and flood control strategy in operating a reservoir is even more difficult for a reservoir which intends to serve both, like the Hirakud Dam reservoir on the river Mahanadi.
Flood wave moderation requires that the reservoir be emptied as much as possible so that it may absorb any incoming flood peak.
However, this decision means reducing the water stored for irrigation. Usually, such a reservoir would be gradually emptied just before the arrival of monsoon rains, anticipating a certain flood and hoping that the reservoir would be filled to the brim at the end of the flood season.
However, this anticipation may not hold good for all years and the reservoir does not get filled up to the optimal height. On the other hand, if the reservoir is not depleted sufficiently well, and actually a flood of high magnitude arrives, then the situation may lead to the flood inundations on the downstream.

Sedimentation 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.
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:
1. Performance Assessment (Simulation) Studies with varying rate of sedimentation.
2. 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 trap efficiency 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.

Control of sedimentation in reservoirs

Sedimentation of a reservoir is a natural phenomenon and is a matter of vital concern for storage projects in meeting various demands, like irrigation, hydroelectric power, flood control, etc.

Since it affects the useful capacity of the reservoir based on which projects are expected to be productive for a design period.

Further, the deposited sediment adds to the forces on structures in dams, spillways, etc.

The rate of sedimentation will depend largely on the annual sediment load carried by the stream and the extent to which the same will be retained in the reservoir.

This, in turn, depends upon a number of factors such as the area and nature of the catchment, level use pattern (cultivation practices, grazing, logging, construction activities and conservation practices), rainfall pattern, storage capacity, period of storage in relation to the sediment load of the stream, particle size distribution in the suspended sediment, channel hydraulics, location and size of sluices, outlet works, configuration of the reservoir, and the method and purpose of releases through the dam.

Therefore, attention is required to each one of these factors for the efficient control of sedimentation of reservoirs with a view to enhancing their useful life and some of these
methods are discussed in the Bureau of Indian Standard code IS: 6518-1992 “Code of practice for control of sediment in reservoirs”.

✓ In this section, these factors are briefly discussed.

There are different techniques of controlling sedimentation in reservoirs which may broadly be classified as follows:

• Adequate design of reservoir
• Control of sediment inflow
• Control of sediment deposition
• Removal of deposited sediment.

**Strategies for reservoir operation**

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

✓ Thus, the 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.

**Levees and Floodwalls**

✓ Levees and floodwalls are barriers that hold back floodwaters.

✓ A levee is constructed of compacted soil and requires more land area.

✓ Floodwalls are built of manmade materials, such as concrete and masonry.
✓ These structures may completely surround the building or may tie into high ground at each end. If openings are left for the driveway and/or sidewalk, closures must be installed to seal these access points prior to a flood.

Applicability
Because levees and floodwalls are located away from the structure or area to be protected, they provide flood protection without altering the building.

Flood hazard:
- Although levees and floodwalls can be built to any height, they are usually limited to four feet for floodwalls and six feet for levees (due to cost, aesthetics, access, water pressure, and space).
- The structure should be built at least one foot higher than the anticipated flood depth (freeboard protection).
- No matter how high the barrier is, it can always be overtopped by a larger flood, which would cause as much damage as if no protection were provided (or more).
- In areas with high velocity flow, erosion protection may be necessary to protect an earthen levee or prevent undermining of a floodwall.
- Flash flooding precludes the use of closures that require human intervention to install.
- If flooding lasts more than 3 to 4 days, seepage is more likely to pose problems.

Site requirements:
- A levee or floodwall is not feasible if it would impede flow or block natural drainage in a manner that results in damage to surrounding property.
- Considerable horizontal space is required for levees; floodwalls are generally more appropriate for small sites.
- The underlying soil must support the levee or floodwall and resist seepage of water under the structure.

Building characteristics:
- A house with a basement can still experience flood damage even if a levee or floodwater protects the structure from surface water.
- Saturated soil can exert hydrostatic pressure on basement walls, causing them to crack, buckle, or event collapse.

Access:
- Access to the structure can be enabled by providing a means of crossing over a levee or floodwall, such as a ramp or stairway.
- If this is not feasible, it may be necessary to design openings at driveways, sidewalks, or other entrances and a mechanism for closing all such openings.
Designs that do not require human intervention are preferable. If a closure requires manual installation, the effectiveness of the flood protection system depends on the availability of a capable person who is aware of the flood threat and has sufficient time to install closures and make certain they are properly sealed.

Aesthetics:
- The rounded outlines of an earthen levee can be shaped to blend into the natural landscape.
- Floodwalls can be designed as attractive features by incorporating them into the landscape design and utilizing decorative bricks or blocks (although this will generally increase the cost).

 Regulations:
A levee or floodwall cannot be used to bring a substantially damaged or substantially improved structure into compliance with current floodplain development standards.

Costs
- Depending on the availability of suitable local soil, levees may be less expensive than other flood proofing options.
- However, if suitable fill material is not locally available, the expense of transporting proper material to the site can be significant.
- The cost of floodwalls is usually greater than that of levees.

Techniques
Levees:
- To be effective, a levee must be constructed with compacted, impervious soils.
- The practice of piling stream sediment on the bank does not provide flood protection.
- The embankment slopes must be gentle (usually a ratio of one vertical to two or three horizontal) to provide adequate stability and minimize erosion.
- The levee’s width will thus be several times its height.

Floodwalls:
- Floodwalls are generally constructed of solid concrete (alone or in combination with masonry).
  They must be designed to withstand water pressure without overturning or displacement.

Closures:
- Mechanisms for closing access openings in a levee or floodwall include automated systems (usually expensive) or manually operated flood gates, stop logs, or panels.
- There are often hinges or sliding mechanisms for installation.
- If the closure is not permanently attached, it must be stored in a readily accessible location.
- Any sewers or drain pipes passing through or under a floodwall or levee require closure valves to prevent backup and flooding inside the building and protected area.
Interior drainage:
- Rain, snow melt, and seepage water must be removed from the protected side of a levee or floodwall using drains (with flap valves to prevent backflow during a flood) and a sump pump.
- An emergency power source for the electric sump pump enables operation during a power outage.

Maintenance:
- Routine inspection enables identification and repair of problems while they are still minor.
- Levees should be checked for signs of erosion, settlement, loss of vegetation, animal burrows, and trees.
- Inspect floodwalls for cracking, spelling, or scour.
- Routine maintenance is needed to make sure that sump pumps, valves, drain pipes, and closures operate properly.

Advantages and Disadvantages of Levees and Floodwalls

Advantages
- Levees and floodwalls can protect a building and the surrounding area from inundation without significant changes to the structure if the design flood level is not exceeded.
- There is no pressure from floodwater to cause structural damage to the building.
- These barriers are usually less expensive than elevating or relocating the structure.
- Occupants do not have to leave the structure during construction.

Disadvantages
- This technique cannot be used to bring a substantially damaged or improved structure into compliance with floodplain development standards.
- May violate floodplain development standards, particularly in floodway locations, by causing obstructed flow or in increased flood heights.
- Failure or overtopping of a levee or floodwall results in as much damage as if there was no protection (or more).
- May restrict access to the structure. If human intervention is required for closures, there must be adequate warning time.
- May be expensive.
- For buildings with basements, hydrostatic pressure from groundwater may still cause damage.
- Local drainage can be affected, possibly creating water problems for others.
- Interior drainage must be provided.
- Levees require considerable land area.
- Require periodic maintenance.
- No reduction in flood insurance premiums.
- Do not eliminate the need to evacuate during floods.