UNIT 1 RESERVOIR PLANNING

Structure

1.1 INTRODUCTION

Reservoir planning means an orderly consideration of a reservoir project from the original statement of purpose through the evaluation of alternatives to the final decision on a course of action. It is the basis for the decision makers to take up or abandon the project. This unit will help in understanding the various components of a reservoir and the various factors associated with it.

Objectives

After studying this unit, you will be able to

- describe the purpose of reservoirs,
- classify reservoirs,
- use a mass curve,
- define trap efficiency,
- explain reservoir sedimentation, and
- describe the effects of reservoirs on the environment.

1.2 RESERVOIRS

Reservoirs are artificial lakes created by the construction of dams across rivers. They are also called storages. These are developed to retain excess water during periods of high flow for use during periods of drought or demand.

1.3 PURPOSE

Reservoirs mainly serve the purposes of water conservation and flood control.

A conservation storage reservoir is meant to save excess water carried down by a river during the wet season when the demand is less and release it during the dry season when the river flow is less than the demand. The storage may serve any of the following requirements:

1) Domestic water supply,
2) Industrial water supply,
3) Municipal water supply,
4) Irrigation,
5) Hydroelectric power,
6) Navigation,
7) Recreation, and
8) Fish and wild life conservation.

A flood control reservoir holds some of the flood waters when the river discharge is such as to cause damage to the cities and inhabitants in the valley downstream if it is allowed to flow down and release them at a slow rate when the flood recedes.

SAQ 1

i) What are the various uses of a reservoir?

ii) What do you understand by a conservation and a flood control project?

1.4 CLASSIFICATION OF RESERVOIRS

Reservoirs may be classified as :

a) Single purpose conservation reservoir,
b) Single purpose flood control reservoir, such as,
    i) Retarding reservoir,
    ii) Detention basin, and
c) Multipurpose reservoir.

These may briefly be described as follows:

1.4.1 Single Purpose Conservation Reservoir

Such reservoirs serve only one purpose which could be for supplying water for domestic and industrial needs of a town, or for irrigating a specific area, or for generating hydroelectric power, and so on. In all these cases the requirement of water may be assessed for different parts of the year with as much accuracy as possible, based on which the capacity of reservoir may be estimated. When making an estimate of water required, the growth in demand over time must be considered.

1.4.2 Single Purpose Flood Control Reservoir

Such a reservoir helps to reduce, in the downstream reaches, the peak discharge of a flood by absorbing a part of the flood volume, while the flood is rising and release the same quantity, while the flood is falling. It reduces the flood levels and hence the consequent damages downstream. This may be seen from Figure 1.1, which is a definition sketch of flood routing. By knowing the hydrograph of the worst flood and the allowable peak flood, the storage needed to moderate the flood can be worked out by trial and error. The capacity of a single purpose flood control reservoir, thus depends on the maximum flood hydrograph and the safe flood conveying capacity of the river downstream. Flood control reservoirs are of two types : i) Retarding reservoir, and ii) Detention basins.

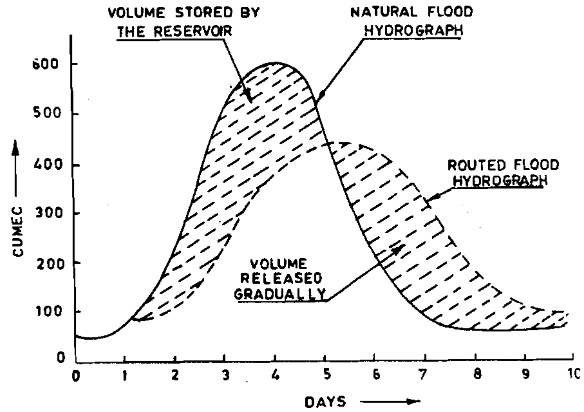

Figure 1.1 : Flood Routing : Definition Sketch

Retarding Reservoir

A retarding reservoir is provided with a spillway and outlets that are not controlled by gates or valves and hence is simpler than a detention basin. The discharging capacity of the spillway or outlets is kept lower than the safe carrying capacity of the river downstream for the worst flood. Such retarding reservoirs are cheaper in initial cost and eliminate all possible errors or negligence in their operation. However, the advantages of flood control reservoirs get reduced if they are constructed on a number of tributaries of the same river because such a control may cause all the flood crests of the tributaries to coincide with that of the main stream. A single retarding reservoir is best located just above the city required to be protected, or reservoirs on tributaries just above their confluence to protect the area just below the confluence.

Detention Basin

A detention basin is a flood control reservoir having spillway or outlets controlled by gates. Though a detention basin is more costly on account of gates, lifting equipment, and staff for operation and maintenance, it provides greater flexibility and allows release of a desired discharge, subject to the maximum discharge carrying capacity of the river below. This allows the desired use of the reservoir by permitting the reservoir to be emptied quickly through the larger outlets that are provided, and making available the reservoir for absorbing a possible subsequent flood after a short period of time. If many detention basins are provided on various tributaries of a main river the release of water may be regulated from the individual basins to keep the peak rate of discharge in the latter at a lower stage than could have been attained with uncontrolled retarding reservoirs. However, there are chances of human error and negligence in its operation. Detention basins are provided where the area to be protected is large.

1.4.3 Multipurpose Reservoir

A multipurpose reservoir is provided for two or more uses, say flood control, irrigation, hydropower generation, etc. For instance, a reservoir constructed on a tributary of a major river may be designed to protect downstream areas against flood damage, increase flow during low-water season for purposes of irrigation, and to create sufficient head at the dam site to generate hydropower. The reservoir may be operated with a view to :

a) reserve a certain minimum storage at all times for flood control,

b) supply a constant discharge during summer irrigation period,

c) supply a larger constant discharge during winter irrigation period, and

d) obtain maximum firm power.

Planning the reservoir operation is carried out by preparing a number of "Reservoir working tables", by adopting many tentative schedules for a number of years with observed discharge data and depending upon the hydrological data and frequency cycle of high floods in the basin. The schedule giving the largest total benefits from the various intended purposes without interfering with the lower or upper limits of storage is adopted for purposes of estimating. Based on the actual experience these tables can be modified.

SAQ 2

What are the different types of reservoirs?

1.5 STORAGE ZONES OF A RESERVOIR

The storage zones of a reservoir are shown in Figure 1.2. The water stored between different levels of the reservoir have different purposes, and these various levels and zones may be described as under:

1.5.1 Normal Pool Level

It is the maximum elevation to which the reservoir surface will rise during normal operating conditions. This corresponds to the elevation of the spillway crest or the top of the spillway gates as the case may be.

1.5.2 Minimum Pool Level

It is the lowest level to which the reservoir is to be lowered under normal conditions. This level may be fixed by the elevation of the lowest outlet in the dam or by conditions of operating efficiency of turbines in hydroelectric reservoirs.

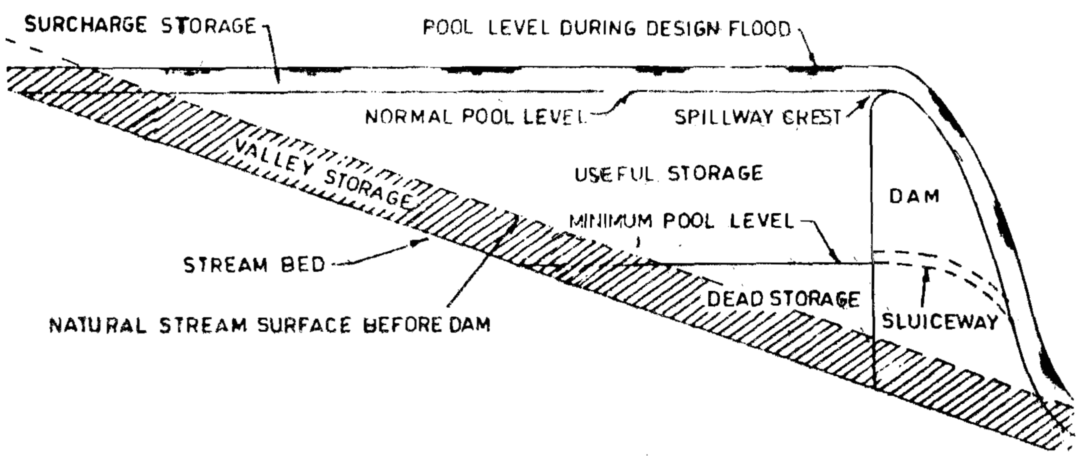

Figure 1.2 : Zones of Storage in a Reservoir

1.5.3 Dead Storage

It is the water held below the minimum pool level which is also termed as the **dead storage level.**

1.5.4 Live or Useful Storage

It is the volume of storage between the minimum and normal pool levels. In multipurpose reservoirs the useful storage may be subdivided into conservation storage and flood-mitigation storage depending on the adopted plan of operation.

1.5.5 Surcharge Storage

It occurs during floods, while the discharge over the spillway is taking place, and the water level rises above the normal pool level. This surcharge storage is normally uncontrolled, i.e., it exists only when a flood occurs and cannot be retained for later use.

1.5.6 Bank Storage

It is the water that enters the permeable reservoir banks when the reservoir fills, and this water drains out when the water level in the reservoir is lowered. The bank storage effectively increases the capacity of the reservoir over and above that indicated by the elevation-storage curve. The volume of bank storage depends on the geologic conditions of the flanking hills.

1.5.7 Valley Storage

It is the volume of water occupied in a natural stream channel entering the reservoir.

1.5.8 Prism Storage

It is the volume of water between a plane drawn through a line drawn parallel to the stream bed and the stream bed itself.

1.5.9 Wedge Storage

It is the volume of water between a line parallel to the stream bed and the actual water surface profile.

SAQ 3

> What do you understand by normal pool level, minimum pool level, dead storage, live storage, and valley storage?

1.6 MASS CURVE

A mass curve is a cumulative plotting of net reservoir inflow against time.

1.6.1 Reservoir Capacity from a Mass Curve

Figure 1.3 shows a mass curve for a 4-year period, to help determine the appropriate reservoir capacity required to satisfy a specified demand. The slope of the mass curve at any time is a measure of the inflow rate at that time. Demand curves represent a uniform rate of

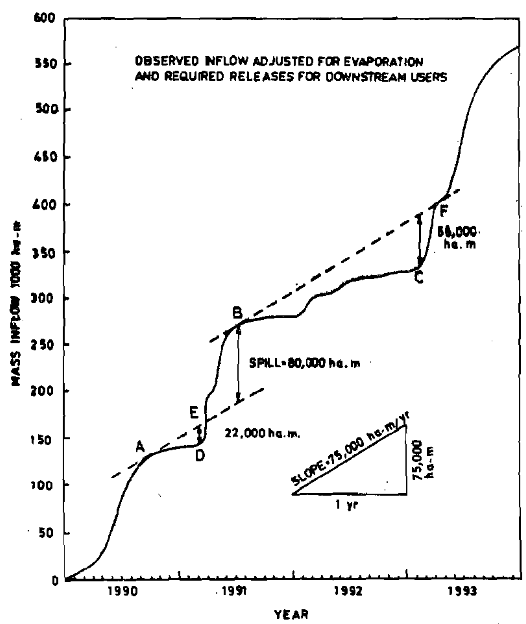

Figure 1.3 : Use of Mass Curve to Determine the Reservoir Capacity Required to Produce a Specified Yield (Example 1.1)

demand and are straight lines parallel whose slope represents demand rate. Demand lines drawn tangential to the high points of the mass curve (P,Q) represent rates of withdrawal of water from the reservoir. Supposing that the reservoir is full wherever a demand line intersects the mass curve, therefore the maximum deviation between the demand line and the mass curve indicates the reservoir capacity needed to satisfy the demand. The ordinate between successive tangents represents water spilled over the spillway. If the demand is varying, the demand line becomes a curve but the principles underlying the analysis remain the same. But, it is necessary that the demand line for varying demand coincides chronologically with the mass curve, i.e., March demand coincides with March inflow, etc.

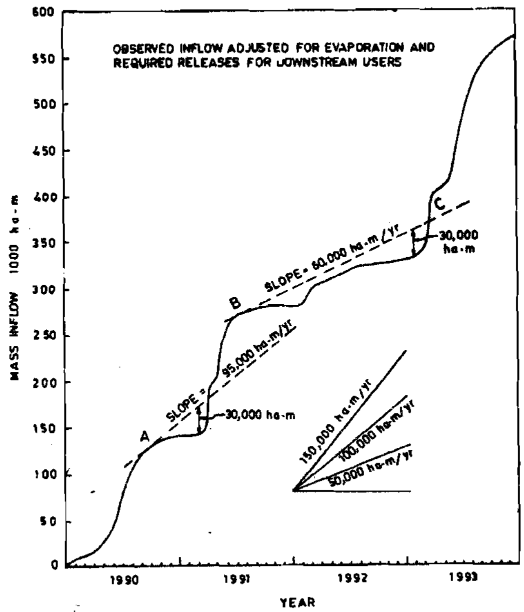

Figure 1.4 : Use of Mass Curve to Determine the Possible Yield from a Reservoir of Specific Capacity (Example 1.2)

Example 1.1

For the inflow shown in Figure 1.3, what should be the reservoir capacity to assure a yield of 75,000 ha–m per year?

Solution

Tangents to the mass curve at A and B have slopes equal to the demand of 75,000 ha–m/year. The maximum ordinate occurs at C which represents a volume of 56,000 ha–m. This is the required reservoir capacity. Such a reservoir would be full at A, depleted to 34,000 ha–m of storage at D, and would be full again at E. Between E and B the reservoir would remain full, and all the inflow greater than the demand would be wasted downstream. At C, the reservoir would be empty, and at F it would be full again. It may be noted that in this case the storage must carry over 2 years.

1.6.2 Yield from a Mass Curve

Mass curves may also be utilised to find the possible yield which may be expected from a reservoir of specified capacity (Figure 1.4). Here tangents are drawn to connect high points of the mass curve (X,Y) such that their maximum deviation from the mass curve is less than the specified reservoir capacity. The yields that can be attained in each year with the specified storage capacity is indicated by the slopes of the resulting lines. The slope of each demand line is the yield for the period. A demand line should intersect the mass curve when extended forward. And, if it does not, the reservoir will not refill.

Example 1.2

If a reservoir of 30,000 ha–m capacity is provided at the site for which the mass curve of Figure 1.4 applies, what will be the yield?

Solution

The tangents to the mass curve of Figure 1.4 are drawn such that maximum deviation from the mass curve is 30,000 ha–m. The tangent at B, has minimum slope of 60,000 ha–m/year, and this is the minimum yield. The tangent at A shows a possible yield of 95,000 ha–m/year in that year, but this demand could not be fulfilled between points B and C without storage in excess of 30,000 ha–m.

SAQ 4

What are the uses of a mass curve?

1.7 FILLING CAPACITY OF RESERVOIRS

The principal objective of reservoirs is to provide storage. The filling capacity of a reservoir of a regular shape can be determined with formulas for the volumes of solids. Topographic surveys are used to find the capacity of reservoirs built at natural sites. An area-elevation curve is developed by planimetering the area enclosed within each contour that close at the reservoir site (Figure 1.5). The integral of the area-elevation curve is the **elevation-storage**, or **capacity** curve for the reservoir. The volume between two elevations is usually determined by multiplying the average of the areas at the two elevations by the difference in elevation. The summation of the increments below any elevation is the storage capacity below that level. If topographic maps are not available, cross-sections of the reservoir are sometimes surveyed and the capacity calculated from the vertical cross-sections by using the prismoidal formula.

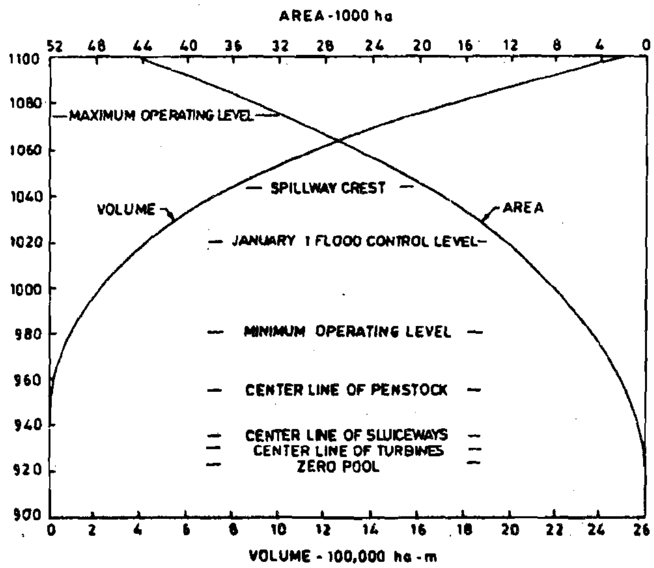

Figure 1.5 : A Typical Area–Capacity Curve of a Reservoir

SAQ 5

How is the capacity curve of a reservoir prepared?

1.8 RESERVOIR SEDIMENTATION

Reservoirs are eventually to get filled with sediments over a period of time. Figure 1.6 shows the sediment accumulation in a typical reservoir. If the sediment inflow is large compared with the reservoir capacity, the useful life of the reservoir gets reduced. Reservoir planning must consider the probable rate of sedimentation to determine whether the useful life of the proposed reservoir will be sufficient to justify its construction. The useful life of the reservoir may be calculated by determining the total time needed to fill the storage volume by the sediments. If the average sediment load of a stream is known then the life of the reservoir can be computed. Various relations, in this regard, as applied to Indian rivers are given as under :

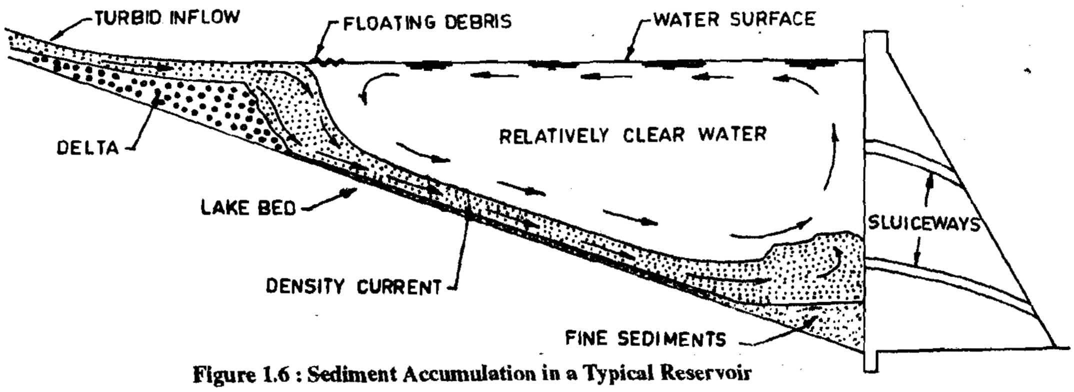

Figure 1.6 : Sediment Accumulation in a Typical Reservoir

1) **A. N. Khosla's Formula**

The annual silting rate = 0.036 million m^3 per 100 sq km of catchment area. ...(1.1)

2) **D. V. Joglekar's Enveloping Curve**

The annual silting rate = $Y = 0.597\, A^{-0.24}$ ...(1.2)

where, Y is the sediment yield in million m^3 per 100 sq km, and A is the catchment area at the dam site in sq km, and

3) **R. S. Varshney and M. G. Raichur's Formula**

Their relations have been developed for rivers north and south of the Vindhyas since the two systems of rivers show their own distinct characteristics.

For North Indian Rivers

a) For mountainous rivers with catchments upto 130 sq km,

$$Y = 0.395\, A^{-0.311} \quad ...(1.3)$$

b) For river in plains and with catchment areas upto 130 sq km

$$Y = 0.392\, A^{-0.202} \quad ...(1.4)$$

c) For catchment areas over 130 sq km,

$$Y = 1.534\, A^{-0.264} \quad ...(1.5)$$

For South Indian Rivers

a) For rivers with catchments upto 130 sq km,

$$Y = 0.46\, A^{-0.468} \quad ...(1.6)$$

b) For catchment areas over 130 sq km,

$$Y = 0.277\, A^{-0.194} \quad ...(1.7)$$

SAQ 6

What are the empirical relations for estimating sedimentation rates of Indian rivers?

1.9 TRAP EFFICIENCIES

The percent of the inflowing sediment that is retained in the reservoir is a function of the ratio of reservoir capacity to total inflow and is known as the **trap efficiency** of the reservoir. This trap efficiency gets reduced with age as the reservoir capacity decreases by sediment deposition. Complete filling of a reservoir takes a very long period, however, the useful life of the reservoir is terminated when the capacity occupied by the sediment prevents the reservoir from serving the desired purpose.

SAQ 7

What do you understand by "trap efficiency"?

1.10 ENVIRONMENTAL EFFECTS OF RESERVOIRS

Reservoirs have some adverse impacts on the environment of the area where they are situated. These adverse environmental effects should be minimised while planning a reservoir project by studying alternative plans of dams and reservoirs.

Environment consists of all the external factors and conditions that affect the lives of living creatures. The environmental requirements of different living beings are interrelated, and thus each creature is dependent on and affect the other creature. Environmental effects are not subject to monetary evaluation, different people evaluate the degree of importance of each environmental condition in a different manner, hence the evaluation is purely subjective. People living in the plains would like the dam and reservoir to be located in the hills to protect them from the ravages of floods whereas the hill folks feel the location of a dam in their area would deprive them of land which is the very source of their livelihood.

Of major concern are the environmental conditions that directly affect the population. The environmental effects that benefit mankind are irrigation, flood protection, improved land use and water supplies for domestic and industrial needs, power generation, water quality, fish-culture, recreational and health improvements. However, there are various adverse environmental effects caused by the construction and operation of dams and reservoirs as pointed out earlier. While some are unavoidable others can be reduced to some extent. Table 1.1 presents the adverse effects of reservoirs on the environment.

SAQ 8

What are the effects of a reservoir on the environment?

Table 1.1 : Adverse Impact of Dams and Reservoirs on Environment

Potential Adverse Effect	Method of Mitigation	Probable Degree or Importance of Adverse Effect
A) Land use for reservoir		
1) Loss of fish and aquatic habitat	Change of species	New species may be less desirable than original species
2) Loss of wild life habitat	Improve other area for habitat	Full mitigation probably not possible
3) Loss of future access to mineral deposits	None	Is of importance only if mineral deposits exist
4) Loss of mountain valley areas	None	Important only in extremely mountainous areas
5) Inundation of historical or archaeological sites	By transfering items, if possible, to a museum	Varies with each indiviual site
6) Inundation of exceptional geological formation	Usually not possible	Varies with each individual site
B) Alteration of downstream flows		
1) Reduction of fish and aquatic habitat	Maintain regulated flows	Full mitigation possible, but frequently not acceptable because of large sacrifice of project accomplishments
2) Reduction of stream flushing flows	Release occasional flushing flows	Mitigation method not proven to be worthwhile. Degree of environmental effect depends upon specific stream situation
3) Changes of water quality	Selective reservoir outlet levels; water aeration if needed	Somewhat limited experience with selective level outlets indicates good prospects of full mitigation
C) Interference with fish and wildlife migrations		
1) Blocking fish runs	Fish hatcheries	Usually capable of full mitigation
2) Blocking animal migration routes	None practical	Importance depends upon the specific site
D) Landscape appearance		
1) Excavation and waste disposal	Project expenditure required to landscape sites	Satisfactory mitigation usually possible without excessive expenditure
2) Reservoir banks below maximum waterline	Minor areas may be developed for beaches	Degree of impact depends upon the specific reservoir
3) Abandoned construction facilities	Construction clean up	Full mitigation possible; important only if not done
4) Erosion scars caused by construction roads	Mainly by careful drainage scheme	Adverse effects can be reduced but not entirely eliminated within reasonable cost
5) Reservoir - clearing waste disposal	Controlled burning; marketing maximum amounts of wood products	Temporary effect; usually minor, but not entirely avoidable

1.11 SUMMARY

In planning a reservoir project due care must be given to aspects like sedimentation, and trap efficiency. Storage capacity of a reservoir and the yield from a reservoir are determinable from the mass curve at the site. The classification of reservoirs and the nomenclature defining the various levels of the reservoir are features the planner should be knowing. The purpose of a reservoir determines how the reservoir should be operated. The operation should be such as not to damage the environment of the dam structure. This unit covers all these aspects.

1.12 KEY WORDS

Conservation Project : A project in which the flow in the river is conserved to meet the requirements of irrigation, power generation or domestic or industrial needs of a town or a region.

Dead Storage Level : It is the level below which the reservoir cannot be depleted any further.

Detention Basins : A reservoir for the purpose of flood control and provided with a spillway or outlets is a detention reservoir.

Fish and Wild Life Conservation : Aquatic and wild life require a source of water for their sustenance. Any water resources project planned should aim at conserving the water body for their needs.

Flood Control Reservoir : A reservoir that is meant to reduce the damages due to uncontrolled flood in a river by storing the water during the flood season and releasing it slowly after the flood recedes.

Live Storage : This is the storage available for meeting the requirements of the project.

Minimum Pool Level : It is the lowest level below which the reservoir cannot be lowered under normal working conditions.

Multipurpose Reservoir : A reservoir that serves to meet more than one purpose is economical as the same water can be utilised for deriving more benefits.

Normal Pool Level : It is the level in a reservoir at which the water surface would be maintained in normal conditions.

Reservoir Capacity : The volume of water that can be held in the space behind the dam upto the full reservoir level is its capacity.

Retarding Reservoir : A reservoir with a spillway and outlets not regulated by gates or valves is a retarding reservoir.

Single Purpose Conservation Reservoir : A reservoir that meets any one of the requirements of domestic households or industrial needs of an area covered by irrigation.

Single Purpose Flood Control Reservoir : A reservoir with the only purpose of controlling the flood from damaging the downstream reaches.

Trap Efficiency : The ratio of sediment retained in a reservoir to the total inflowing sediment into the reservoir expressed as a percentage is the trap efficiency.

Valley Storage : The quantity of water held in a natural stream channel and which flows into the reservoir.

1.13 ANSWERS TO SAQs

SAQ 1

i) Domestic water supply, industrial water supply, municipal water supply, irrigation, hydroelectric power, navigation, recreation, fish and wild life conservation.

ii) A conservation storage project saves excess water carried down by a river during the wet season when the demand is less, and releases it during the dry season when the river flow is less than the demand. A flood control reservoir retains the flood waters when the river discharge is such as to cause damage to the cities and inhabitants in the valley downstream if it is allowed to flow down, and releases them at a slow rate when the flood recedes.

SAQ 2

Single purpose conservation reservoir; Single purpose flood control reservoir; Retarding reservoir; Detention basins; Multipurpose reservoir.

SAQ 3

Normal pool level is the maximum elevation to which the reservoir surface will rise during normal operating conditions. This corresponds to the elevation of the spillway crest or the top of the spillway gates.

Minimum pool level is the lowest level to which the reservoir is to be lowered under normal conditions. This level may be fixed by the elevation of the lowest outlet in the dam or by conditions of operating efficiency of turbines in hydroelectric reservoirs.

Dead storage is the water held below the minimum pool level, and is also termed as the dead storage level.

Live or useful storage is the volume of storage between the minimum and normal pool levels. In multipurpose reservoirs the useful storage may be subdivided into conservation storage and flood-mitigation storage depending on the adopted plan of operation.

Valley storage is the volume of water occupied in a natural-stream channel.

SAQ 4

Reservoir capacity and yield from a mass curve.

SAQ 5

Refer Section 1.7.

SAQ 6

Refer Section 1.8.

SAQ 7

The percent of the inflowing sediment that is retained in the reservoir is a function of the ratio of reservoir capacity to total inflow and is known as the trap efficiency.

SAQ 8

Refer Section 1.10.