CHAPTER 1

Storage Works

1.1 DETERMINATION OF STORAGE CAPACITY

Storage of water is necessary to ensure an assured supply of water throughout the year to encourage the raising of crops twice or thrice in a year from the same plot of land. Long-term storage aims at fighting droughts in certain years due to scanty or no rainfall. The capacity of storage reservoirs is determined by the nature of supply and demand. Even when the supply is uniform all the time, some storage is still required because of variations in demand. When both the supply and demand vary widely and they are distributed unfavorably (Fig. 1.1) maximum storage capacity is required. Usually, small storage is required in minor schemes which are designed on the basis of seasonal variation. A large storage capacity has to be provided in major projects where the variations of demand and supply are considered over a number of years (usually 25 to 30 years). India has a storage capacity of about 300 billion cubic meter (BCM) as of date and it needs to further increase the storage capacity to about 1000 BCM in order to address the vagaries of nature.

1.1.1 Seasonal Storage

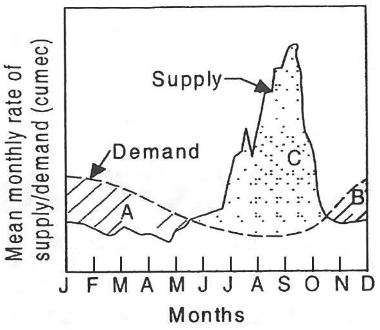

Fig. 1.1: Nature of supply and demand

The nature of supply and demand has been plotted in Fig. 1.1 for a typical year in India. During January to mid-June the demand is higher than supply. From mid-June to mid-October the supply far exceeds the demand and again from mid-October to December the demand is higher than supply. It may be noticed that the area under the demand and supply curves (representing the total volume of water demanded or supplied) is more or less the same, but the distribution is not favorable since the supply does not match with demand over the year. The shaded area marked A will be the total volume of storage required in the first phase and the area marked B in the second phase to meet the deficit. These deficits are met by storing the excess volume of supply marked C. If the areas under demand and supply are the same, then A + B = C and the storage capacity will be given by A + B or by C. The storage can also be found from a table giving the cumulative demand

and supply and getting the cumulative shortage (–). The maximum value of shortage is the required storage in a typical year.

1.1.2 Holdover Storage Needed for Fighting Droughts

Figure 1.1 depicts the storage needed for an average year so that the mismatch between the demand and supply can be addressed over the year and the annual volume of flow equals the demand. Over the years, however, there are drought like situations when the precipitation is scanty and the supply is too little to meet the demand resulting in droughts. To fight such situation, large storage (also called holdover storage) of higher capacity is needed so that the excess volume of water supply in earlier years may be used to meet the scarcity in the drought years. Such holdover storage is much larger and can be found by plotting varying cumulative supply and fixed demand as illustrated in Fig. 1.2. Since S_2 is greater than S_1, the required holdover storage is S_2. With rise in population, demand also increases requiring still higher storage capacity which may be found graphically or in tabular form.

1.2 DEAD AND LIVE STORAGE

1.2.1 Dead Storage

It is the volume of storage which cannot be used for irrigation or any other useful purpose. Dead storage is provided for the deposition of sediments borne by the river upstream of the dam. Any withdrawal of water from dead storage will result in a fall in the water level below the designed dead storage level, causing health problems (due to exposure and organic decomposition), loss in hydropower (due to loss of head), loss of wildlife and forestry, hamper recreational facilities.

1.2.2 Live Storage

It is the useful storage lying above the dead storage level as shown in Fig. 1.3. Live storage is meant to supply water for irrigation, water supply, hydropower generation, industrial and municipal use and other purposes. This part of the storage is regularly evacuated during the demand period and filled in again during the monsoon period. In other words, the reservoir level will vary between the full reservoir level (after monsoon) to the dead storage level (before monsoon commences). In computing live storage, one should consider not only the present demand but also the growth in demand in future after the completion of the project.

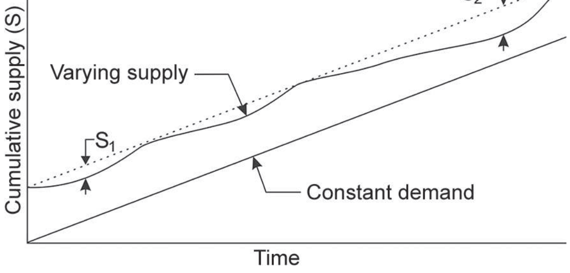

Fig. 1. 2: Indicating holdover storage (S_2) required to fight drought

1.2.3 Surcharge

The storage space available in between the full reservoir level and maximum reservoir level (during very high flow in some years) is termed surcharge (Fig. 1.3). Normally, the surcharge space is kept empty in expectation of high flood in certain years, when the excess flood water is stored temporarily in the surcharge space relieving thereby the flood damage to the area lying downstream of the dam. Surcharge space helps in reducing the flood peak downstream.

1.2.4 Freeboard

The distance between the maximum reservoir level and the top of the dam is termed freeboard. Adequate freeboard is necessary to prevent overtopping of dam during extra ordinary flood higher than the design flood. Freeboard should be above the height of wave so that the water level due to wave does not overtop the top of dam. For the same flood, MRL may increase after some period due to siltation of reservoir space.

Different kinds of storage and corresponding water levels are shown in Fig. 1.3.

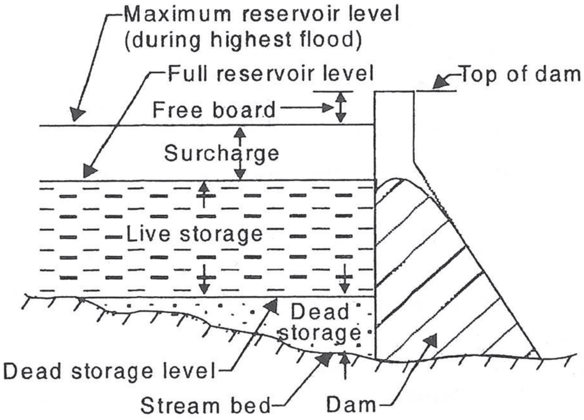

Fig. 1.3: Section of a dam showing different types of storages

1.2.5 Area-capacity-elevation Curve

The elevation of the top of the dam is related to storage capacity and the area submerged in the reservoir. Figure 1.4 indicates the interrelation between the height of dam, storage capacity and submerged area also called area-capacity-elevation curve. Such curves which can be prepared from the contour map, help in deciding the maximum height of the dam to be built and the corresponding capacity of storage needed for irrigation and other requirements and the corresponding submerged area that has to be acquired and compensated.

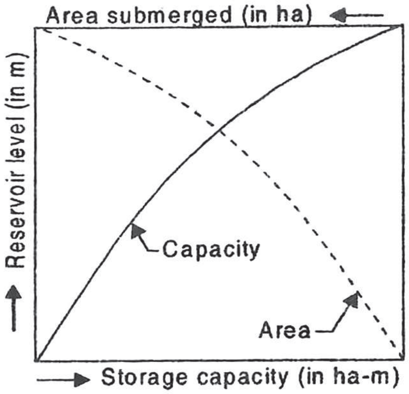

Fig.1.4: Area-capacity elevation curve

1.3 SELECTION OF SITE FOR STORAGE DAMS/RESERVOIRS

The site of a storage dam has to be very carefully selected considering a number of factors, such as:

i. Topography
ii. Foundation of the dam
iii. Nature of the soil and sub-soil
iv. Water tightness of the reservoir space determining the amount of grouting required
v. Proximity of the agricultural land
vi. Availability of construction materials
vii. Communication facilities
viii. River diversion facility
ix. Geology of the area
x. Susceptibility to earthquake
xi. Glacial lake outburst flood (GLOF)
xii. Land loss outburst flood (LLOF)

1.3.1 Reconnaissance, Preliminary and Location Surveys

The various investigations required from the point of conception to the completion of a project are normally carried out in three different phases. In the first phase, rough investigations regarding the topography, nature of the soil and sub-soil and various other physical factors, e.g. topography, geology of the area, availability of construction materials, communication facility, etc. are carried out to decide location of a dam as well as the type of dam. Such surveys are known as the reconnaissance or feasibility surveys. Report submitted on the basis of such surveys is called the feasibility report. In the preliminary survey, a more detailed survey is carried out with the objective of preparing preliminary drawings to estimate the approximate cost of the project. When the project is approved on the basis of the preliminary survey and the feasibility report which includes approximate cost, a more detailed survey known as the final or location survey is carried out for preparing detailed project report (DPR) with detailed drawings, specifications and cost estimate for bidding purposes. DPR is required to implement the project and supervise the works at every stage of the construction work. DPR is prepared on the basis of detailed engineering surveys, designs, drawings and specifications.

1.3.2 Data Collections

Some of the important data to be collected for a storage dam are discussed below.

Topographic Data

This involves preparing a contour map of the area showing the various physical features, e.g. cultivable land, wood and forest, habitations, roads, streams, etc. It is the topographic map which helps in the selection of a proper site for the storage reservoir and dam type. Topographic maps will reveal whether the dam is feasible. For example, in plain rolling country, an alternate storage such as ponds or underground storages by recharging may be more profitable than the construction of dams which involves the submergence of a vast area and construction of levees and their maintenance.

Topographic sheets prepared by the Survey of India in scales 1:25,000, 1:50,000, and 1:2,50,000 are very useful for finding topographic data. Remote sensing data based on satellite observations are extremely useful, especially in remote inaccessible mountainous areas. These data are needed for finding river course, catchment area, estimation of flow and sediments, floods, etc. It helps in preparing area-capacity-elevation curves for the storage reservoir as shown in Fig. 1.4.

Climatic Data

Data like rainfall, evaporation, temperature, humidity, wind velocity, etc. are required for assessing the availability of water, floods, water requirement of crops, evaporation loss, irrigation scheduling, etc.

Hydrologic and Stream Flow Data

These include the hydrologic survey of rainfall, snowfall, stream flow, runoff, sediment flow, floods, plan form and bed form of stream, L-section and cross-section of stream, etc. This information is vitally needed in the planning, design, construction and operation of storage reservoirs.

Geologic and Foundation Data

From the borehole logs, a geologic map of the area showing the different types of strata at different depths below ground surface is prepared for deciding the height and type of dam, depth of foundation, the extent of grouting required, etc. A site may have to be rejected due to the presence of faults and fissures, soluble stones, etc.

Soil and Crop Data

The purpose of irrigation is to improve the agricultural yield. If the soil is not suitable for agricultural use, there is no need of irrigation. The amount of extra water required by the various crops and it's scheduling, etc. can be determined only by collecting extensive data in regard to the agricultural landuse, soil and crop data, keeping in view the existing practice and the future changes envisaged.

Construction Materials

The availability of construction materials locally has to be explored thoroughly before deciding the type and height of the dam to be constructed.

Miscellaneous (Other) Data

Additional data regarding hydropower, flood damage, wildlife, forestry, recreational opportunities, sewage pollution, etc. are to be collected when a storage scheme is intended to serve, besides irrigation, other multiple purposes, such as generation of hydroelectricity, control of flood, protection of wildlife, afforestation, recreation, abatement of river pollution, etc. For clearance of the project by the department of environment and forests, socio-economic survey, displacement and rehabilitation of people affected, possible environmental and ecological damage, loss of forests and sanctuaries are required for preparing environment impact assessment (EIA) report of the proposed scheme for clearance by the Ministry of Environment and Forest, Government of India.

1.3.3 Service Reservoir/Irrigation Tank

The main purpose of a service reservoir is to conserve that part of the water supply which cannot be utilized for irrigation at the instant of supply. It can also help the farmer to apply water at a higher rate (in relation to the supply rate) to his farm at a time and in a manner convenient for him. For example, the use of water during night can save a substantial amount of water by way of reduction in evaporation losses. Where the topography is very flat, the building of a overhead storage reservoir by constructing dams may not be economic due to the inundation of a large tract of land upstream of the dam. Storing water in tanks, partly excavated and partly filled as in Fig. 1.5 is advisable under such situations.

Service reservoirs constructed near the farm can save water substantially, especially in projects where the nature of supply does not match the pattern of demand. The efficiency of use of irrigation water in most of the river valley projects in India, which are constructed and maintained at a great cost, can be improved substantially through the construction of service reservoirs for a village or a block or community of farmers. Besides saving water, such tanks can be used for other multiple purposes, e.g. domestic use, fisheries, poultry, dairy development and recharge of groundwater.

Depending on the topography of the area to be irrigated, location of the reservoir, nature of supply (open channel or pressure flow) and method of application of irrigation water, a service reservoir can be any one of the following types:

i. A low dug-in reservoir with the top water level equal to that of the supply canal. The outflow into the irrigation network can be accomplished by pumping. A built-up reservoir commanding the entire irrigation area by gravity outflow. The inflow into the reservoir can be maintained by a pump drawing on the low-level conveyor.

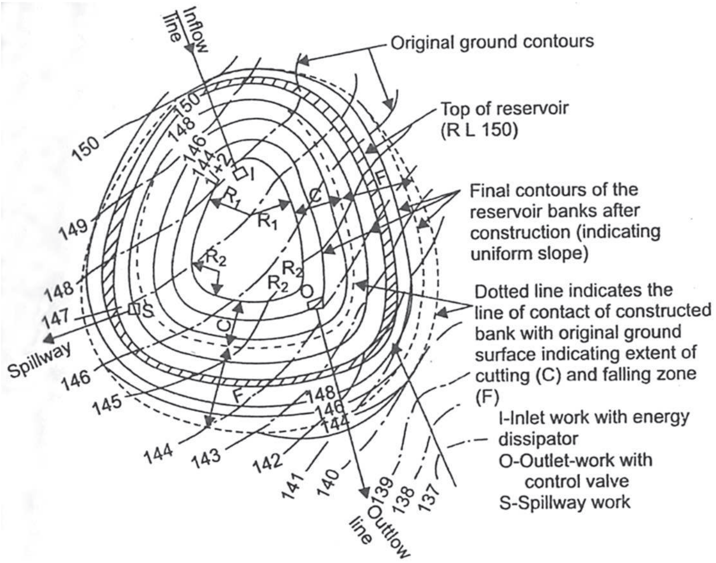

Fig. 1.5: Plan view of service reservoir/tank

ii. A built-up reservoir commanding the entire irrigation area by gravity outflow. The inflow into the reservoir can be maintained by a pump drawing on the low-level conveyor.

iii. Partly dug-in and partly built-up reservoir so that the higher areas can be irrigated from the storage in the built-up part, whereas the lower reaches can be irrigated from the dug-in part, all by gravity.

iv. A dual-purpose reservoir designed to supply surface irrigated areas by gravity and the same areas or others by pumping used for sprinkling purposes.

The service reservoirs should be deep so that the surface area is less to minimise evaporation losses. It should be provided with an intake, an outlet and a spillway at the top as illustrated in Fig. 1.5.

1.3.4 Detention and Retention Storages

Detention and retention basins are widely used to control flooding due to urbanization of undeveloped areas. Both are used for storing flood water for routing of incoming flood. While detention basins detain the stormwater for a specific period of time and evacuated for absorption of the following flood, the retention basin is not fully evacuated and retain flood water upto a certain minimum level/pond level so that a pool is created for use, e.g. river pollution control, fish culture, percolation for recharging groundwater, etc. Water stored temporarily in the space above pond level help in flood routing and reduction of flood peak. These basins offer excellent water quality since pollutants are removed from incoming flood runoff through sedimentation, degradation and other mechanisms. Detention basins are also called dry ponds since they store runoff only during wet weather. Outlet structures are designed to completely evacuate the water so that the basin is dry and ready for moderation of the following flood during subsequent storms. Retention

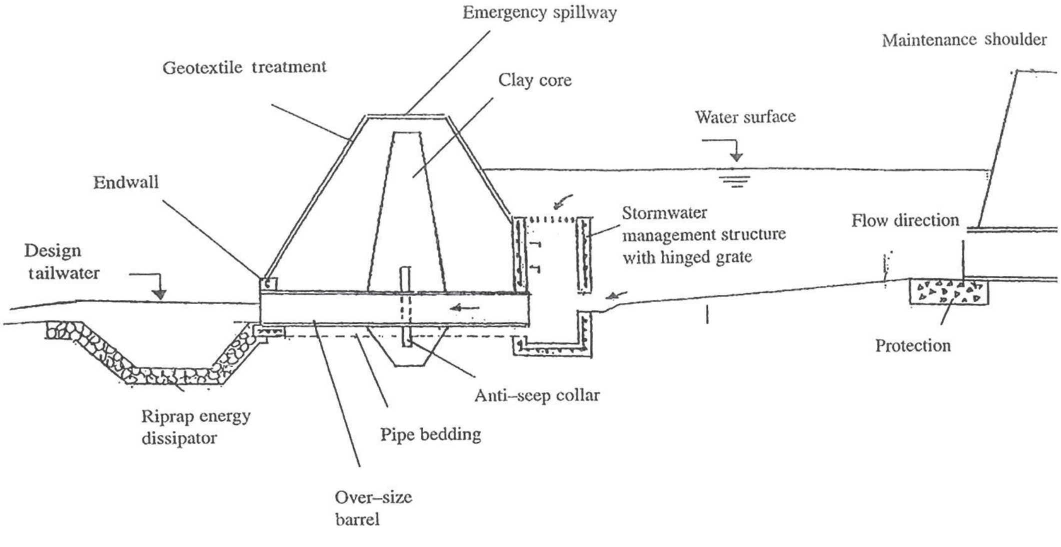

Fig. 1.6: Sectional view of detention basin
(*Source: Hydraulic Structures–Design and Construction Handbook* by Mays, McGraw-Hill, 1999)

basins are called wet pools as they retain a permanent water pool, space above which is used for flood routing. Figure 1.6 illustrates typical L-section of a detention/retention basin. Emergency spillways are provided to take care of extraordinary flood higher than design peak flood.

1.3.5 Silting of Reservoirs

All rivers and streams carry both water and sediments. The flow of sediments is more predominant during the flood season. Whenever an artificial obstruction is made by the construction of a dam with a reservoir, such sediments get obstructed and gradually fill up the storage space. The economic life of a reservoir is virtually over when the dead storage is filled with sediments and the silting starts encroaching the live storage space. The estimation of the annual silt deposition can be made knowing the silt charge, silt grade, specific weight and trap-efficiency. Use of remote sensing maps and pond level observations is very helpful. Brune's trap efficiency equations can be used for the valume and distribution of sediments within the reservoir.

Preserving the existing reservoirs and increasing their useful life is essential for sustainable development in order to meet the future water requirements of the country. In a vision paper on reservoir sedimentation, *Schleiss et al* stated that "an inadequate sediment management can greatly accelerate the process of eutrophication and organisms dissemination at levels which compromise the functions of the reservoir (Anton J. Schleiss, Mario J. Franca, Carmelo Juez and Giovanni De Cesare (2016). Reservoir sedimentation, *Journal of Hydraulic Research*, 54:6,595–614, DOI: >10.1080/00221686.2016.1225320). Dam construction creates an extremely efficient sink of sediments in the valley. Without efficient sediment management, it strongly alters the natural equilibrium between sediment dynamics and morphology in a river catchment. Over the years, as the sediments accumulate, the reservoir loses the storage capacity for which it was initially designed. The installed water storage capacity of reservoirs worldwide is about 7000 km^3, from which some 4000 km^3 are used for energy production, irrigation, and water supply. The mean age of existing reservoirs is between 30 and 40 years, and it is estimated that 0.5–1% of the worldwide water storage capacity is lost annually due to sedimentation".

1.3.6 Prediction of Reservoir Life

The old assumption that the average annual decrease in the dead storage of the dam by 1% at the design stage has been negated in practice with siltation entering in the live storage much ahead of filling of dead storage. Besides sediment load, its size and gradation of sediments in the incoming flow, depends upon the type of reservoir as established by Borland and Miller. Variation of sediment deposition along depth of reservoir, is shown in Fig. 1.7.

The Central Water Commission (CWC) undertook a coordinated research scheme of reservoir sedimentation across the country. Sedimentation rate in the major reservoirs (storage capacity >100 MCM) which completed 50 years of useful life was found to vary from 0.3 to 4.89 ha-m/100 km^2/year and those reservoirs which have served less than 50 years of useful life, it varied from 0.34 to 27.85 ha-m/100 km^2/year. As the reservoir capacity reduces with sedimentation, the capacity-inflow (C/I) ratio and the trap efficiency decrease (Fig. 1.8) resulting in reduction of sedimentation rate thereby prolonging full life of reservoir upto dam crest. Table 1.1 shows sedimentation rate

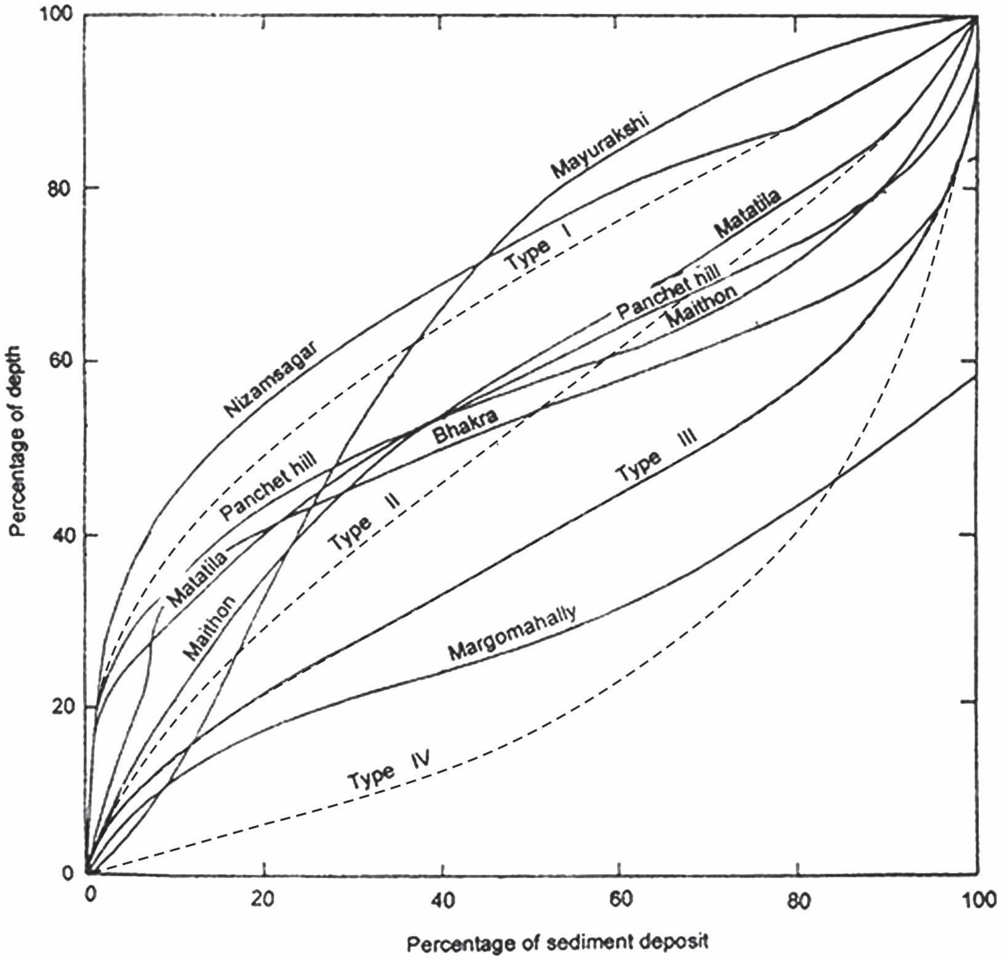

Fig. 1.7: Boreland-Miller curves for sediment distribution in different types (I,II,III and IV) of reservoirs (note: comparison made with some important reservoirs in India)

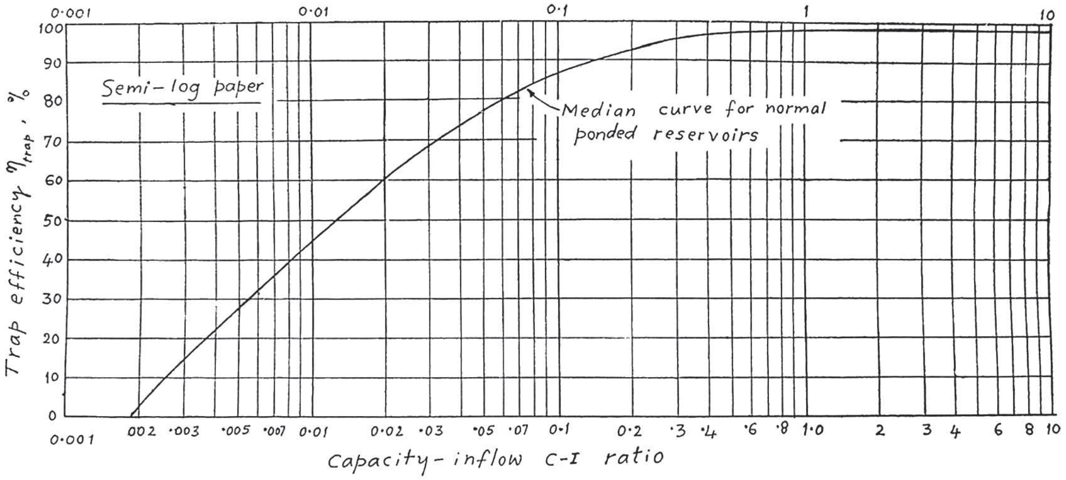

Fig. 1.8: Variation of trap efficiency with capacity-inflow ratio

Table 1.1: Sedimentation rate of some Indian reservoirs

Name of reservoir	*Gross storage capacity (M–m^3) and year*		*Average sedimentation rate (%)*	*Seriousness of sedimentation problem*	*Loss of gross capacity till 2014 (%)*	*Calendar year in which useful life shall be over*
	Initial survey	*Last survey*				
Matatila	1133 (1956)	764 (1994)	0.86	Serious	49.76	2014
Hirakud	8105 (1957)	6146 (1994)	0.65	Serious	37.24	2034
Maithon	1349 (1955)	1085 (1994)	0.50	Serious	29.60	2055
Tungabhadra	3751 (1953)	3158 (1993)	0.40	Significant	24.13	2078
Koyna	2798 (1961)	2779 (1986)	0.03	Insignificant	2.73	3628

and expected useful life of a few storage reservoirs in India which was found to vary regionwise.

1.3.7 Useful life of the Gobind Sagar Reservoir behind Bhakra Dam

The results of useful life computation of Bhakra/Govind Sagar reservoir by different methods are presented in Table 1.2. The useful life estimated using different criteria is significantly different. Using the average sedimentation rate, the useful life can approximately be taken as 140 years. According to the Bhakra Management Board, the time period for 100% depletion of dead storage is 260 years which is much higher. The discrepancy may be due to the assumptions made during the planning stage that entire fine silt including clay, i.e. 10% of suspended silt load and 5% of the remaining silt load will be passing over the spillway during flood and through dam sluice outlets as density currents. With C/I value of 0.59, the trap efficiency of the reservoir is nearly 99% which makes the assumption invalid. Most of the suspended silt load is trapped in the live and dead storage zones, reducing the useful/economic life of the reservoir.

The rate of sedimentation for reservoirs in the Himalayan region (Indus, Ganga, Brahmaputra basin) was found to vary from 5.658 to 27.85 ha-m/100 km^2/year. Based on the different approaches, the Bhakra Project Authority computed the useful life of Bhakra dam given in Table 1.2.

Table 1.2: Useful life of Govind Sagar reservoir in Bhakra dam with different approaches

Data and period	*Methodology*	*Approach and criteria*	*Useful life (yrs)*	*Calendar year in which useful life shall be over*
Sedimentation rate based on hydrographic survey data (1958 and 1998)	Extrapolation	100% depletion of dead storage capacity @ 17.62 M-m^3/year	138 109	2096 2067
		50% depletion of gross storage capacity@ 34.76 M-m^3/year	142	2100
Sedimentation rate based on hydrographic survey (1958–2003)	Extrapolation	Time-series analysis using increasing trend in annual sedimentation	127	2085

(*Contd.*)

Table 1.2: Useful life of Govind Sagar reservoir in Bhakra dam with different approaches (*Contd.*)

Data and period	***Methodology***	***Approach and criteria***	***Useful life (yrs)***	***Calendar year in which useful life shall be over***
Annual sedimentation inflow observation (1958–1998)	Gill's approach	50% depletion of gross storage capacity assuming a dominant coarse sediment inflow	143	2101
Annual sedimentation inflow observation during planning stage (prior to 1957)	Brune's step method	50% depletion of gross storage capacity considering variation in trap efficiency with time	150	2108
Design criteria employed during planning stage (prior to 1957)	Analogy of Lake Mead and Elephant Butte reservoirs	100% depletion of dead storage capacity based on the advance of delta formation towards the dam	260	2218

1.3.8 Useful life of the Reservoir Behind Kiri-Chu Dam in Sikkim

Using Churchill's sedimentation index method, the author (Mazumder SK), studied the life of a Himalayan reservoir in Sikkim province and determined its life by area incremental method to find the loss of reservoir capacity at an interval of every 6 years (Fig. 1.9). Sedimentation rate was found to be decreasing with time as shown in Fig. 1.9.

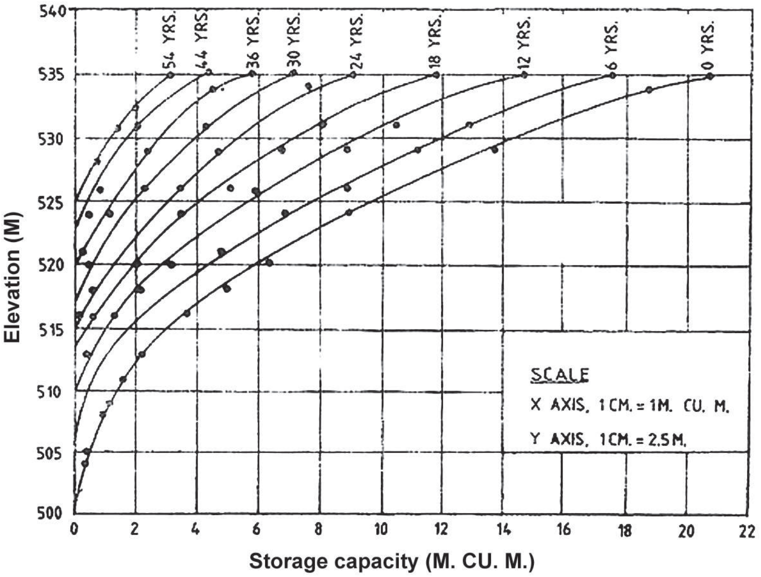

Fig. 1.9: Prediction of storage capacity in Kiri-Chu dam in Sikkim, India

1.3.9 Desilting Measures/Sediment Management

The extent of silting is dependent on the grade of silt and the quantity of silt present in a unit volume of flow. The higher the dam, more will be the silting. As the removal of deposited silts from a reservoir is extremely difficult and costly, the objective should be to eliminate silt at its source in the catchment area by adopting appropriate measures.

It is estimated that on a global scale, reservoirs intercept upto 25% of the sediment that would otherwise flow to the ocean. Approximately 1% of global reservoir water storage capacity is lost every year through the deposition of sediment. The life of a reservoir is usually limited by sediment accumulation. For existing structures, sustainable sediment management should seek to balance sediment inflow and outflow within the impounded reach, while maximizing long-term benefits. Different levels at which sediment management efforts can be targeted to reduce sediment retention by reservoirs either by using broad scale land management strategies upstream, or targeting options for managing sediment within the reservoir itself or at dam level are summarised below.

In the catchment area

- Soil conservation
- Settling basins
- Slope and bank protection
- Bypassing sediment
- Off-stream storage
- Afforestation
- Construction of check dams on tributaries
- Construction of contour bundhs in sloped cultivated areas, etc.

In the reservoir

- Dredging
- Flushing
- Hydro suction
- Air lift
- Avoiding the settling of fine sediments
- Controlling the turbidity currents

At the dam

- Sluicing
- Turbidity current venting
- Turbining the suspended sediments
- Dam heightening
- Heightening of intake and bottom outlet structures

1.3.10 Sediment Flushing

It is a technique whereby sediment previously accumulated and deposited in a reservoir is hydraulically eroded and removed by accelerated flows created when the bottom outlets of a reservoir are opened. In order to address the issue of sedimentation at the Xiaolangdi reservoir on the lower Yellow River in China, two sediment flushing trials were conducted in July 2002 and September 2003 (Fig. 1.10). As a result of these two trials, it was reported that 66.4 million tonnes and 120.7 million tonnes of sediment, respectively, were flushed downstream to the sea, considerably reducing the amount of sediment accumulation in the Xiaolangdi reservoir as well as in the Lower Yellow River channel. After the trials, 13 further sediment flushing operations were organised, flushing a total of 752 million tonnes of sediment to the sea by 2015 and decreasing the average elevation in the lower Yellow River channel by 2.03 m.

1.3.11 Sediment Dredging

An alternative to flushing or routing of sediment through a reservoir involves removing sediment by underwater dredging or dry excavation of the deposited material. While this technique can prove successful in some areas, it is generally associated with very high operating costs. In some areas, such as the Roseires Reservoir in the Nile River Basin in Egypt, dredging was necessary as flushing and sluicing were insufficient to control sedimentation. In addition to the dredging of the reservoir itself, the impounded reach of the river may also require dredging due to the continued accumulation of sediment in the channel, as in both the Yellow River and the Mississippi Riverbasins. If the sediment is contaminated, its disposal can give rise to further problems. Disposal of dredged sediments requires appropriate and adequate areas.

1.3.12 Control of Turbidity Current

Another technique for managing the sedimentation of reservoirs is to adopt methods that prevent or reduce the settling and deposition of fine sediments. Such methods include exploiting and controlling turbidity currents. The ISI case study from the Rhine River basin provides an example from Lake Grimsel in Switzerland, where the construction of submerged obstacles has been used to reduce the deposition of sediment in the reservoir by obstructing the movement of turbidity currents. The results from a high flood event that occurred in October 2000 revealed that turbidity currents developed and propagated in the deepest area of the lake, close to the intake and bottom outlet structures of the reservoir. In such instances, deposits as much as 10 cm thick can be produced by a single event. To prevent sediment deposition, submerged dams that block the flow and deflect a major part of the turbidity current away from the dam wall were constructed. This led to larger amounts of sediment being deposited upstream of the obstacles, and away from the dam wall and intake and outlet structures of the reservoir. It is estimated that the retention of sediment behind these obstacles should continue for at least 20 to 50 years, and provide a valuable contribution to the control of reservoir sedimentation.

1.3.13 Sluicing by Use of High Head Gates

Sluice outlets kept near the bottom of the dam also help the removal of a part of silts accumulated in the reservoir. With the advent of high head gates now-a-days, a very little solid obstruction is made across the river and most of the storages are due to these gates as illustrated in Fig. 1.11. During flood season these gates are lifted temporarily for flushing out the silt deposited upstream.

1.3.14 Removal of Sediments Manually

Silts deposited in small storages/tanks may be cleaned manually once in a year or once in five years, depending on the extent of the rate of silting. Such manual removal of sediments are used for service tanks and detention/retention tanks. They can be included under Govt. of India’s 100 days program of PMGSJ.

Fig. 1.10: Sediment flushing from the Xiaolangdi dam on Yellow River in China

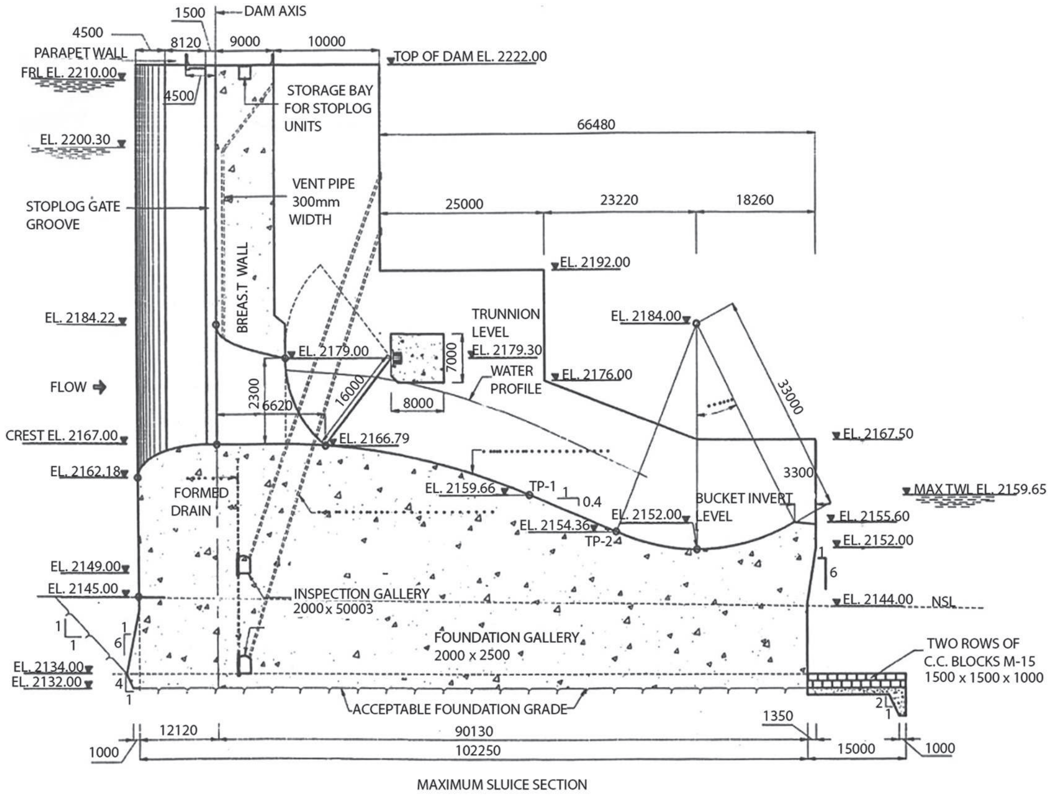

Fig. 1.11: Showing low-height dam, breast wall and radial sluice gates for flushing (*Source:* L&T, Himachal Hydropower Ltd.)

1.4 TYPES OF DAMS

Depending on the materials used, dams can be classified as:

i. Earth dam (Fig. 1.11a).
ii. Rock-fill dam (Fig. 1.12)
iii. Concrete dam (Figs 1.13–1.15)

Structurally, a concrete dam can be sub-divided into:

- Gravity type (Fig. 1.13)
- Arch type (Fig. 1.14)
- Buttress type (Fig. 1.15)

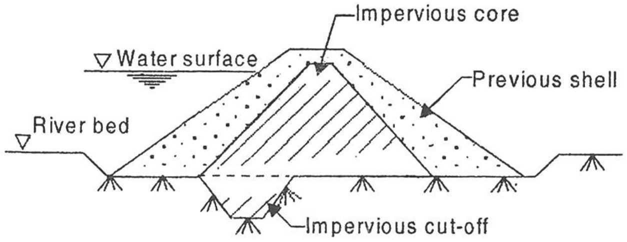

Fig. 1.11a: Earth dam section

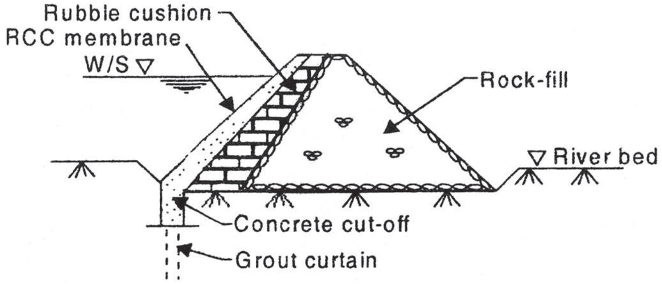

Fig. 1.12: Rock-fill dam section

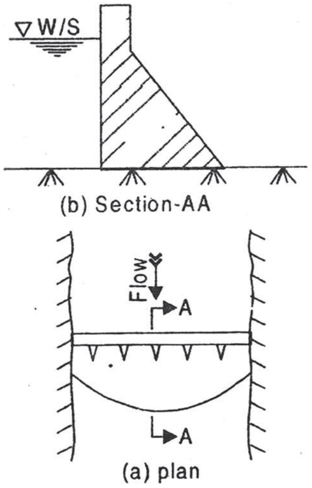

Fig. 1.13: (a) Plan (b) section of a concrete gravity dam

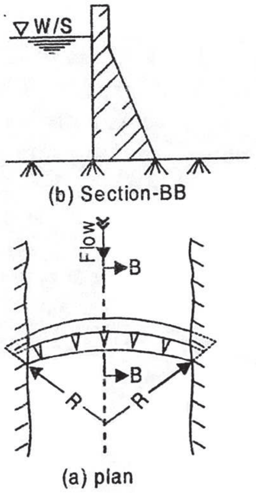

Fig.1.14: (a) Plan (b) section of concrete arch dam