Module
4

Hydraulic Structures for Flow Diversion and Storage

Lesson
5

Planning Of Water Storage Reservoirs

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

4.5.0 Introduction

As seen from Lesson 4.4, water storage reservoirs may be created by constructing a dam across a river, along with suitable appurtenant structures. How ever, 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.

4.5.1 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.
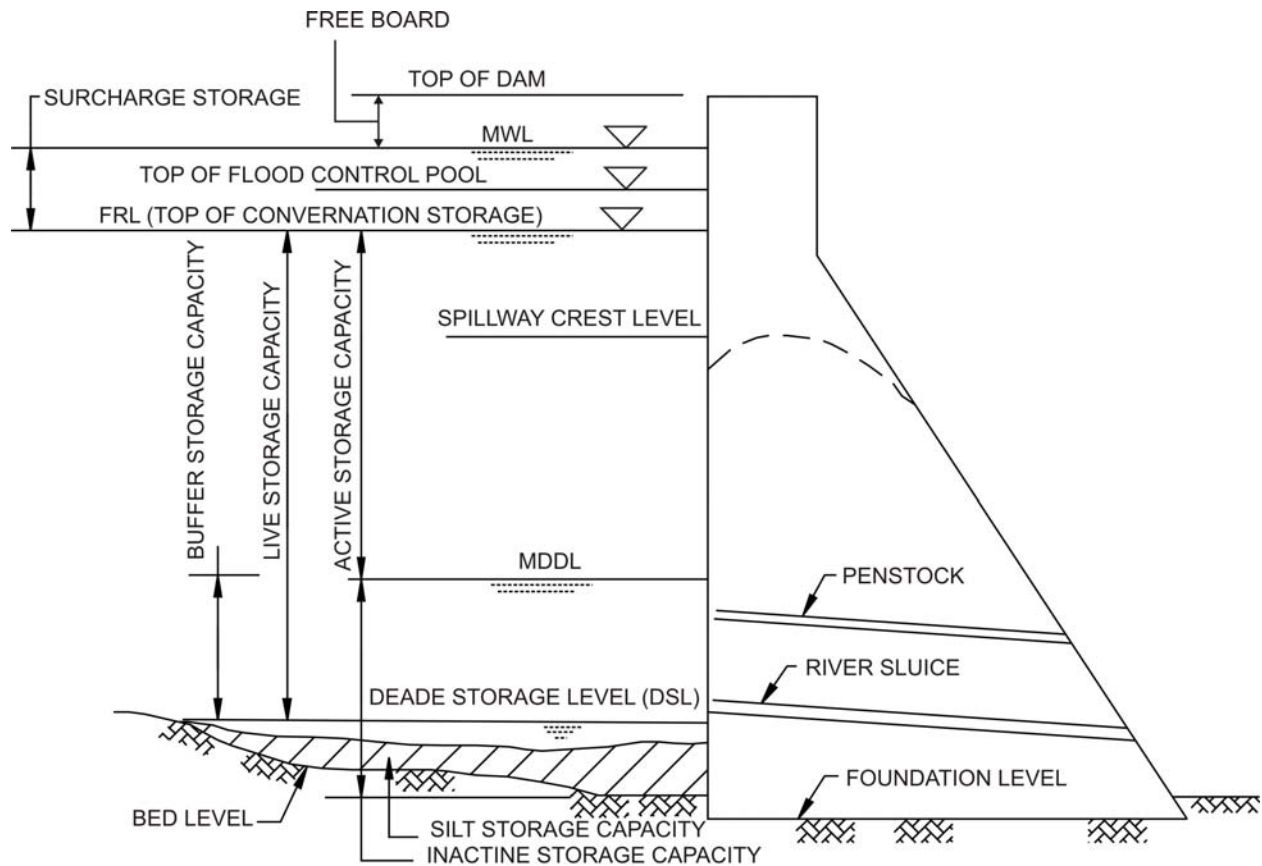
FIGURE 1. SCHEMATIC DIAGRAM SHOWING STORAGE ZONES (OF CAPACITY) NOMENCLATURE

These specific levels and parts are generally defined as follows:

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 id 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).
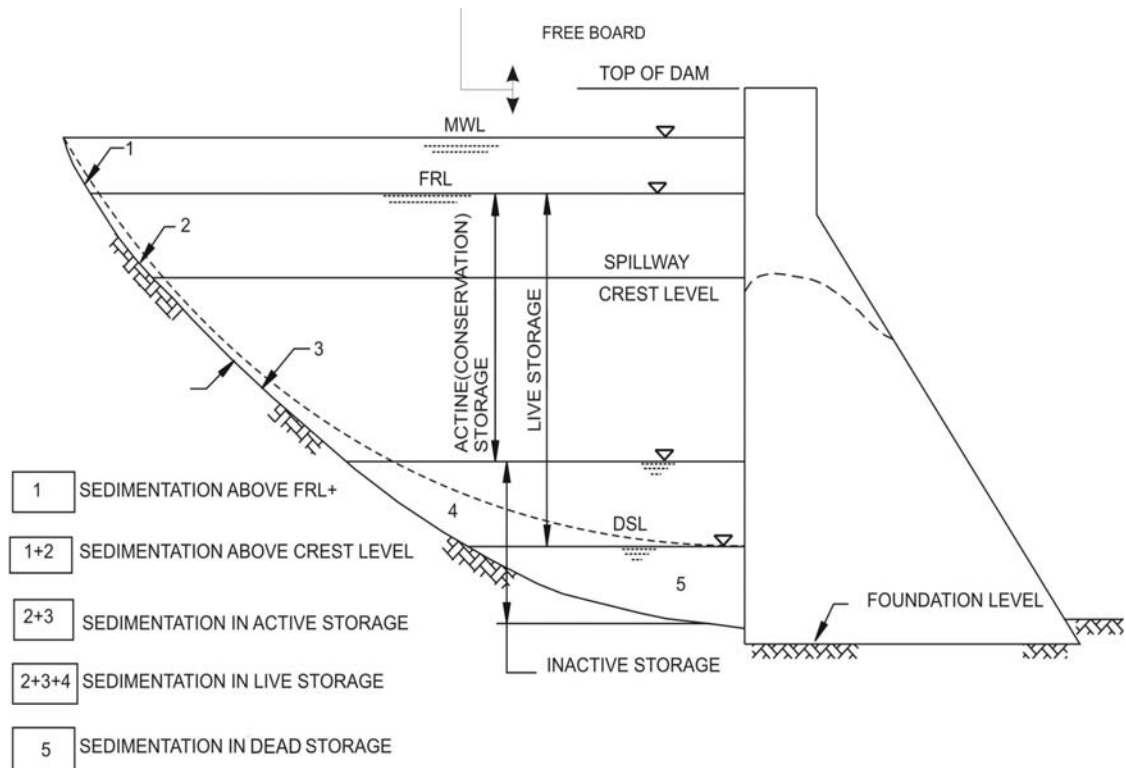
FIGURE 2. SCHEMATIC DIAGRAM SHOWING ZONES OF RESEERVOIR SEDIMENTION

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 has 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.

4.5.2 Planning of reservoirs

The first step in planning the construction of a reservoir with the help of a dam is for the decision makers to be sure of the needs and purposes for which the reservoir is going to be built together with the known constraints (including financial), desired benefits. There may be social constraints, for examples people's activism may not allow a reservoir to be built up to the desired level or even the submergence of good agricultural level may be a constraint. Some times, the construction of a dam may be done that is labour intensive and using local materials, which helps the community for whom the dam is being built. This sort of work is quite common in the minor irrigation departments of various steps, especially in the drought prone areas. The Food-for-Work schemes can be utilised in creating small reservoirs that helps to serve the community. In a larger scale, similar strategy was adopted for the construction of the Nagarjuna Sagar Dam on the River Krishna, which was built entirely of coursed rubble masonry and using manual labour in thousands.

The second step is the assembly of all relevant existing information, which includes the following:

- Reports of any previous investigations and studies, if any.
- Reports on projects similar to that proposed which have already been constructed in the region.
- A geographical information system (GIS) for the area of interest may be created

using a base survey map of the region.

- Topographical data in the form of maps and satellite pictures, which may be integrated within the GIS.
- Geological data in the form of maps and borehole logs, along with the values of relevant parameters.
- Seismic activity data of the region that includes recorded peak accelerations or ground motion record.
- Meteorological and hydrological data - of available parameters like rainfall, atmospheric and water temperatures, evaporation, humidity, wind speed, hours of sunshine, river flows, river levels, sediment concentration in rivers, etc.
- For water supply projects, data on population and future population growth based on some acceptable forecast method, industrial water requirement and probable future industrial development.
- For irrigation projects, data on soils in the project area and on the crops already grown, including water requirement for the crops.
- For hydropower projects, data on past demand and forecasts of future public and industrial demand for power and energy; data on existing transmission systems, including transmission voltage and capacity.
- Data on flora and fauna in the project and on the fish in the rivers and lakes, including data on their migratory and breeding habits.
- Data on tourism and recreational use of rivers and lakes and how this may be encouraged on completion of the proposed reservoir.

As may be noted, some of the data mentioned above would be needed to design and construct the dam and its appurtenant structures which would help to store water behind the reservoir. However, there are other data that decides the following:

- How large the reservoir should be and, consequently, what should be the dam height?
- What should be the size of the spillway and at what elevation the crest level of the spillway be located?
- How many and at what levels sluices be provided and they should be of what sizes?

Two important aspects of reservoirs planning: Sedimentation Studies and Geological Explorations are described in detail in the following section.

4.5.3 Effect of sedimentation in planning of reservoirs

It is important to note that storage reservoirs built across rivers and streams loose their capacity on account of deposition of sediment. This deposition which takes place progressively in time reduces the active capacity of the reservoir to provide the outputs of water through passage of time. Accumulation of sediment at or near the dam may interfere with the future functioning of water intakes and hence affects decisions regarding location and height of various outlets. It may also result in greater inflow of

into canals / water conveyance systems drawing water from the reservoir. Problems of rise in flood levels in the head reaches and unsightly deposition of sediment from recreation point of may also crop up in course of time.

In this regard, the Bureau of Indian Standard code IS: 12182 - 1987 "Guidelines for determination of effects of sedimentation in planning and performance of reservoir" is an important document which discusses some of the aspects of sedimentation that have to be considered while planning reservoirs. Some of the important points from the code are as follows:

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

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 reservoir s 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.

4.5.4 Procedure for planning a new reservoir

The standard procedure that needs to be carried out for planned storages requires an assessment of the importance of the problem to classify the reservoir sedimentation problem as insignificant, significant, or serious. Assessment of reservoir sedimentation problem, in a particular case may be made by comparing the expected average annual volume of sediment deposition with the gross capacity of the reservoir planned. If the

ratio is more than 0.5 percent per year, the problem is usually said to be serious and special care is required in estimating the sediment yields from the catchment. If it is less than 0.1 percent per year, the problem of siltation may be insignificant and changes in reservoir performance. For cases falling between these two limits, the sedimentation problem is considered significant and requires further studies.

The following studies are required if the problem is insignificant:

1. No simulation studies with sediment correlation is necessary**.**
2. The feasible service time for the project may be decided. Sediment distribution studies to ensure that the new zero-elevation does not exceed the dead storage level may be made.

In the above, the following terms have been used, which are explained below:

- **Feasible Service Time**: For a special purpose, the period or notional period for which a reservoir is expected to provide a part of the planned benefit in respect of storage in the reservoirs being impaired by sedimentation. Customarily, it is estimated as the time after which the new zero elevation of the reservoir would equal the sill of the outlet relevant for the purpose.

- **New Zero Elevation**: The level up to which all the available capacity of the reservoir is expected to be lost due to progressive sedimentation of the reservoir up to the specified time. The specified time should be any length of time such as Full Service Time, Feasible Service time, etc.

- **Full Service Time**: For a specified purpose, the period or notional period for which the reservoir provided is expected to provide, a part of the full planned benefit inspite of sedimentation.

The following studies are required if the problem of sedimentation in the reservoir is assessed to be significant, but not serious.

1. Both the full service time and feasible service time for the reservoir may be decided.
2. Simulation studies for conditions expected at the end of full service time may be made to ensure that firm outputs with required depend ability are obtained. The studies used also assess non-dependable secondary outputs, if relevant, available at the end of this period. Studies without sedimentation, with the same firm outputs should bring out the additional potential secondary outputs which may be used, if required in economic analysis, using a linear decrease of these additional benefits over the full service time.
3. No simulation studies beyond full service time, is required.
4. Sediment distribution studies required for feasible service time are essential.

The following studies are required if the problem of sedimentation is serious.

1. All studies described for the 'Significant' case have to be made.
2. The secondary benefits available in the initial years should be more in such cases. If they are being utilized, for a proper assessment of the change of these, a simulation at half of full service time should be required.
3. In these cases, the drop of benefits after the full service time may be sharper. To bring out these effects, a simulation of the project at the end of the feasible service time is required to be done.

4.5.5 Life of reservoir and design criteria

A reservoir exists for a long time and the period of its operation should normally check large technological and socio-economic changes. The planning assumptions about the exact socio-economic outputs are, therefore, likely to be changed during operation, and similarly, the implication of socio-economic differences in the output due to sedimentation are difficult to access. The ever increasing demands due to both increase of population and increases in per capita needs are of a larger magnitude than the reductions in outputs, if any, of existing reservoirs. Thus effects of sedimentation, obsolescence, structural deterioration, etc. of reservoirs may require adjustments in future developmental plans and not simply replacement projects to bring back the lost potential. On a regional or national scale, it is the sufficiency of the total economic outputs, and not outputs of a particular project which is relevant. However, from local considerations, the reduction of outputs of reservoir like irrigation and flood control may cause a much greater degree of distress to the population which has got used to better socio-economic conditions because of the reservoir.

'Life' strictly is a term which may be used for system having two functional states 'ON' and 'OFF'. Systems showing gradual degradation of performance and not showing any sudden non-functional stage have no specific life period. Reservoirs fall in the later category.

The term 'life of reservoir' as loosely used denotes the period during which whole or a specified fraction of its total or active capacity is lost. In calculating this life, the progressive changes in trap efficiency towards the end of the period are commonly not considered. In some of the earlier projects, it has been assumed that all the sedimentation would occur only in the dead storage pocket and the number of years in which the pocket should be filled under this assumption was also sometimes termed as the life of reservoir. This concept was in fact used to decide the minimum size of the pocket. Under this concept, no effect of sedimentation should be felt within the live storage of the reservoir. It has subsequently been established that the silt occupies the space in the live storage of reservoir as well as the dead storage.

If the operation of the reservoir becomes impossible due to any structural defects, foundation defects, accidental damages, etc., this situation should also signify the end of the feasible service time. Before the expiry of this feasible service time, it may be possible to make large changes in the reservoir (for example, new higher level outlets,

structural strengthening, etc.) or other measures, if it is economically feasible to do so. If these studies are done, the feasible service time may be extended.

4.5.6 Geological explorations for reservoir sites

In Lesson 4.4, geological exploration procedures for constructions of dams were discussed in detail. Though a dam is constructed to build a reservoir, a reservoir has a large area of spread and contained in a big chunk of the river valley upstream of the dam. Hence, while identifying a suitable site for a proposed dam, it is of paramount importance that the proposed reservoir site is also thoroughly investigated and explored. The basis of planning for such explorations is to have a rapid economical and dependable pre-investment evaluation of subsurface conditions. It is also necessary that a degree of uniformity be followed while carrying out subsurface explorations so that the frame of reference of the investigation covers all requisite aspects. In view of above, the Bureau of Indian Standards has brought out a code IS: 13216 - 1991 "Code of practice for geological exploration for reservoir sites", that discusses the relevant aspects. According to the code since reservoir projects in river valleys are meant to hold water; therefore, the following aspects of the reservoirs have to be properly investigated

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

These aspects are determined through investigations carried out by surface and sub-surface exploration of proposed basin during the reconnaissance, preliminary investigation, detailed investigation, construction and post-construction stages of the project. The two basic stages of investigation: reconnaissance and preliminary investigations are explained below:

Reconnaissance

In the reconnaissance stage, the objective of investigation is to bring out the overall geological features of the reservoir and the adjacent area to enable the designers, construction engineers and geologists to pinpoint the geotechnical and ecological problems which have to be tackled. The scale of geological mapping for this stage of work need not be very large and the available geological maps on 1:50,000 or 1: 250,000 scales may be made use of. It is advantageous to carry out photo geological interpretation of aerial photographs of the area, if available. If a geological map of the area is not available, a traverse geological map should be prepared at this stage preferably using the aerial photos as base maps on which the engineering evaluation of the various geotechnical features exposed in the area should be depicted.

A topographical index map on 1: 50 000 scales should be used at this stage to delineate the areas which would require detailed study, subsequently.

To prevent an undesirable amount of leakage from the reservoir, the likely zones of such leakage, such as major dislocations and pervious or cavernous formations running across the divide of the reservoir should be identified at this stage of investigation for further detailed investigations.

Major unstable zones, particularly in the vicinity of the dam in tight gorges, should be identified at this stage for carrying out detailed investigations for the stability of the reservoir rim.

The locations for suitable construction material available in the reservoir area should be pin pointed at this stage so that after detailed surveys such materials can be exploited for proper utilisation during the construction stage prior to impounding of reservoir.

The rate of silting of the reservoir is vital for planning the height of the dam and working out the economic life of the project. Since the rate of silting, in addition to other factors, is dependent on the type of terrain in the catchment area of the reservoir, the major geological formations and the ecological set up should be recognized at this stage to enable a more accurate estimation of the rate of silting of the reservoir. For example, it should be possible to estimate at this stage that forty percent of the catchment of a storage dam project is covered by Quaternary sediment and that this is a condition which is likely to a yield a high silt rate or that ninety percent of the catchment of another storage dam project is composed of igneous and metamorphic rocks and is likely to yield a relatively low sediment rate. This information will also be useful in examining whether or not tributaries flowing for long distances through soft or unconsolidated formations, prior to forming the proposed reservoir, can be avoided and if not, what remedial measures can be taken to control the silt load brought by these tributaries.

The impounding of a reservoir may submerge economic/strategic mineral deposits occurring within the reservoir area or the resultant rise in the water table around the reservoir may cause flooding, increased seepage in quarries and mines located in the area and water logging in other areas. It is, therefore, necessary that the economic mineral deposits, which are likely to be adversely affected by the reservoir area, are identified at this stage of the investigation. For example, if an underground working is located close to a proposed storage reservoir area, it should be identified for regular systematic geo-hydrological studies subsequently. These studies would establish whether the impoundment of the water in the reservoir had adversely affected the underground working or not. References should also be made to various agencies dealing with the economic minerals likely to be affected by the impoundment in the reservoir for proper evaluation of the problem and suitable necessary action.

A dam and its reservoir are affected by the environment in which they are located and in turn they also change the environment. Impoundment of a reservoir sometimes results in an increase of seismic activity at, or near the reservoir. The seismic activity may lead to microtremors and in some cases lead to earthquakes of high magnitude. It is, therefore, necessary to undertake the regional seismotechtonic study of the project area. The faults having active seismic status should be delineated at this stage.

Simultaneous action to plan and install a network of seismological observatories encompassing the reservoir area should also be taken.

Preliminary Investigation

The object of preliminary investigation of the reservoir area is to collect further details of the surface and subsurface geological conditions, with reference to the likely problems identified during the reconnaissance stage of investigation by means of surface mapping supplemented by photo geological interpretation of aerial photographs, hydro geological investigations, geophysical investigations, preliminary subsurface exploration and by conducting geo-seismological studies of the area.

On the basis of studies carried out during the reconnaissance stage it should be possible to estimate the extent of exploration that may be required during the preliminary stage of investigation including the total number of holes required to be drilled and the total number and depth of pits, trenches and drifts as also the extent of geophysical surveys which may be necessary. For exploration by pits, trenches, drifts and shafts guidelines laid down in IS 4453: 1980 Name of IS code should be followed.

The potential zones of leakage from the reservoir and the lateral extent of various features, such as extent of aeolian sand deposits, glacial till, land slides, major dislocations or pervious and cavernous formations running across the divide, should be delineated on a scale of 1: 50000.

The geo-hydrological conditions of the reservoir rim should be established by surface and sub-surface investigation as well as inventory, as a free ground water divide rising above the proposed level of the reservoir is a favourable condition against leakage from the reservoir. The level of water in a bore hole should be determined as given in IS 6935: 1973.

The extension of various features at depth, wherever necessary, is investigated by geophysical exploration and by means of pits, trenches, drifts and drill holes. For example, the resistivity survey should be able to identify water saturated zones. The nature of the material is investigated by means of laboratory and in situ tests, to determine permeability and assess the quantum of leakage which may take place through these zones on impoundment of the reservoir. Moreover, permeability of rocks/overburden in the reservoir area is determined from water table fluctuations and pumping tests in wells. For determining in situ permeability in overburden and rock, reference should be made to IS 5529 (Part I): 1985 and IS: 5529 (Part II): 1985 respectively. The information about permeability would enable the designers to estimate the treatment cost for controlling leakage/seepage from the reservoir and to decide whether it would be desirable to change the location of height of the dam to avoid these zones.

Major unstable zones along the reservoir identified during the reconnaissance stage and which are of consequence to the storage scheme should be investigated in detail at this stage by means of surface and sub-surface exploration.

The areas should be geologically mapped in detail on a scale of 1: 2000. The suspect planes/zones of failure should be identified and explored by means of drifts, trenches

and pits. Disturbed and undisturbed samples of the plastic material should be tested for cohesion (c) and angle of internal friction (ϕ) as well as for other relevant properties. The stability of slopes should also be evaluated considering the reservoirs operational conditions. These studies should provide the designers with an idea of the magnitude of the problems that may be encountered, so that they may be able to take remedial measures to stabilize zones or to abandon the site altogether, if the situation demands.

The areas having potential economic mineral wealth and which are likely to be adversely affected by the impoundment of the reservoir should be explored by means of surface and sub-surface investigation to establish their importance both in terms of their value as well as strategic importance. This information would be necessary for arriving at a decision regarding the submergence, or otherwise, of the mineral deposit. The nature and amount of the existing seepage, if any, in the existing mines and quarries in the adjacent areas of the reservoir should be recorded and monitored regularly. This data is necessary, to ascertain whether or not there has been any change in the quantum of seepage in the mines and quarries due to the impoundment of water in the reservoir, directly or indirectly.

Large scale geological mapping and terrace matching across the faults with seismically active status, delineated during the reconnaissance stage, should be carried out on a scale of 1 : 2000 and the trend, and behaviour of the fault plane should be investigated in detail by means of surface studies and sub-surface exploration by pits, trenches and drifts etc. A network of geodetic survey points should be established on either side of the suspected faults to study micro-movements along these suspected faults, if any, both prior to and after impoundment of the reservoir. Micro earthquake studies should be carried out using portable 3-station or 4-station networks in areas with proven seismically active fault features.

On the basis of the studies carried out during the preliminary stage it should be possible to estimate the quantum of exploration which may be required during the detailed stage of investigation including the total number of holes required to be drilled and the total number and depth of pits, trenches and drifts as also the extent of geophysical survey which may be necessary.

Detailed surface and sub-surface investigation of all features connected with the reservoir should be carried out to provide information on leakage of water through the periphery and/or basin of the reservoir area.

Based on these investigations and analysis of data it should be possible to decide as to whether the reservoir area in question would hold water without undue leakage. If, not, the dam site may have to be abandoned in favour of suitable alternative site.

The zones, which on preliminary investigation are found to be potential zones of leakage/seepage from the reservoir, and which due to other considerations cannot be avoided are geologically mapped on a scale of 1 : 2 000 and investigated in detail at this stage by means of a close spaced sub-surface exploration programme. The purpose of this stage of investigation is to provide the designers sufficient data to enable them to plan the programme of remedial treatment. The sub-surface explorations are carried out by means of pits and trenches, if the depth to be explored is shallow, say up to 5 meters, and by drill holes and drifts, if the depth to be explored is greater than 5 meters.

The unstable zones around the reservoir rim, specially those close to the dam sites in tight gorges, should be explored in detail by means of drifts, pits and trenches so that the likely planes of failures are located with precision. The physical properties including angle of internal friction and cohesion of representative samples of the material along which movement is anticipated should be determined. The above information would enable the designers to work out details for preventive measures, for example, it may be possible to unload the top of the slide area or to load the toe of the slide with well drained material, within economic limits.

Sub-surface explorations by drill holes, drifts, pits and trenches should be carried out at possible locations of check dams and at the locations of other preventive structures proposed to restrict the flow of silt into the reservoir. These studies would enable the designers to assess the feasibility of such proposals.

Detailed plans, regarding the economic mineral deposits within the zones of influence of the reservoir should be finalized during this stage by the concerned agencies. The seepage investigations in the quarries and mines within the zone of influence of the reservoir should be continued

4.5.7 Fixing the capacity of the reservoirs

Once it is decided to build a reservoir on a river by constructing a dam across it, it is necessary to arrive at a suitable design capacity of the reservoir. As has been discussed in section 4.5.1, the reservoir storage generally consists of there main parts which may be broadly classified as:
1. Inactive storage including dead storage
2. Active or conservation storage, and
3. Flood and surcharge storage.

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

IS: 5477 Fixing the capacities of reservoirs- Methods
(Part 1): 1999 General requirements
(Part 2): 1994 Dead storage
(Part 3): 1969 Line storage
(Part 4): 1911 Flood storage
The data and information required for fixing the various components of the design capacity of a reservoir are as follows:

a) Precipitation, run-off and silt records available in the region;
b) Erodibility of catchment upstream of reservoir for estimating sediment yield;
c) Area capacity curves at the proposed location;
d) Trap efficiency;
e) Losses in the reservoir;
f) Water demand from the reservoir for different uses;

g) Committed and future upstream uses;
h) Criteria for assessing the success of the project;
i) Density current aspects and location of outlets;
j) Data required for economic analysis; and
k) Data on engineering and geological aspects.

These aspects are explained in detail in the following sections.

4.5.7.1 *Precipitation, Run-Off and Silt Record*

The network of precipitation and discharge measuring stations in the catchment upstream and near the project needs to be considered to assess the capacity of the same to adequately sample both spatially and temporally the precipitation and the stream flows.

The measurement procedures and gap filling procedures in respect of missing data as also any rating tables or curves need to be critically examined so that they are according to guidelines of World Meteorological Organization (WMO). Long-term data has to be checked for internal consistency between rainfall and discharges, as also between data sets by double mass analysis to highlight any changes in the test data for detection of any long term trends as also for stationarity. It is only after such testing that the data should be used for generating the long term inflows of water (volumes in 10 days, 15 days, monthly or yearly inflow series) into the reservoir.

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

If long term run-off records are not available, concurrent rainfall and run-off data may be used to convert long term rainfall data (which is generally available in many cases) into long-term run-off series adopting appropriate statistical/conceptual models. In some cases regression analysis may also be resorted to for data extension.

4.5.7.2 *Estimation of average Sediment Yield from the catchment area above the reservoir*

It is usually attempted using river sediment observation data or more commonly from the experience of sedimentation of existing reservoirs with similar characteristics. Where observations of stage/flow data is available for only short periods, these have to be suitably extended with the help of longer data on rainfall to estimate as far as possible sampling errors due to scanty records. Sediment discharge rating curve may also be prepared from hydraulic considerations using any of the standard sediment load formulae, such as, Modified Einstein's procedure, Young's stream power, etc. It is also necessary to account for the bed load which may not have been measured. Bed load measurement is preferable and when it is not possible, it is often estimated as a percentage generally ranging from 5 to 20 percent of the suspended sediment load. However, actual measurement of bed load needs to be undertaken particularly in cases where high bed loads are anticipated. To assess the volume of sediment that would

deposit in the reservoir, it is further necessary to make estimates of average trap efficiency of the reservoir and the likely unit weight of sediment deposits, along with time average over the period selected. The trap efficiency would depend on the capacity inflow ratio but would also vary with the locations of controlling outlets and reservoir operating procedures. Computations of reservoir trap efficiency may be made using the trap efficiency curves such as those developed by Brune and by Churchill (see IS: 12182-1987).

4.5.7.3 *Elevation Area Capacity Curves*

Topographic survey of the reservoir area should form the basis for obtaining these curves, which are respectively the plots of elevation of the reservoir versus surface area and elevation of the reservoir versus volume. For preliminary studies, in case suitable topographic map with contours, say at intervals less than 2.5 m is not available, stream profile and valley cross sections taken at suitable intervals may form the basis for computing the volume. Aerial survey may also be adopted when facilities are available.

4.5.7.4 *Trap Efficiency*

Trap efficiency of reservoir, over a period, is the ratio of total deposited sediment to the total sediment inflow. Figures 1 and 2 given in Annex A of IS 12182 cover relationship between sedimentation index of the reservoir and percentage of incoming sediment and these curves may be used for calculation of trap efficiency.

4.5.7.5 *Losses in Reservoir*

Water losses mainly of evaporation and seepage occur under pre-project conditions and are reflected in the stream flow records used for estimating water yield. The construction of new reservoirs and canals is often accompanied by additional evaporation and infiltration. Estimation of these losses may be based on measurements at existing reservoirs and canals. The measured inflows and outflows and the rate of change of storage are balanced by computed total loss rate.

The depth of water evaporated per year from the reservoir surface may vary from about 400 mm in cool and humid climate to more than 2500 mm in hot and arid regions. Therefore, evaporation is an important consideration in many projects and deserves careful attention. Various methods like water budget method, energy budget method, etc may be applied for estimating the evaporation from reservoir. However, to be more accurate, evaporation from reservoir is estimated by using data from pan-evaporimeters or pans exposed to atmosphere with or without meshing in or near the reservoir site and suitably adjusted.

Seepage losses from reservoirs and irrigation canals may be significant if these facilities are located in an area underlain by permeable strata. Avoidance in full or in part of seepage losses may be very expensive and technical difficulties involved may render a project unfeasible. These are generally covered under the conveyance losses in canals projected on the demand side of simulation studies.

4.5.7.6 *Demand, Supply and Storage*

The demand should be compared with supplies available year by year. If the demand is limited and less than the available run-off, storage may be fixed to cater to that particular demand which is in excess of the run-off. The rough and ready method is the mass curve method for initial sizing.

Even while doing the above exercise, water use data are needed to assess the impact of human activities on the natural hydrological cycle. Sufficient water use information would assist in implementing water supply projects, namely, evaluating the effectiveness of options for demand management and in resolving problems inherent in competing uses of water, shortages caused by excessive withdrawal, etc. Water demands existing prior to construction of a water resource project should be considered in the design of project as failure to do so may result in losses apart from legal and social problems at the operation stage.

4.5.7.7 *Committed and future upstream uses*

The reservoir to be planned should serve not only the present day requirements but also the anticipated future needs. The social, economic and technological developments may bring in considerable difference in the future needs/growth rate as compared to the present day need/growth rate. Committed and upstream future uses should also be assessed in the same perspective.

4.5.7.8 *Criteria for assessing the success of the project*

Water Resources Projects are to be designed for achieving specified success. Irrigation projects are to be successful for 75 percent period of simulation. Likewise power projects and water supply projects are to be successful for 90 percent and nearly 100 percent period of simulation respectively.

4.5.7.9 *Density Current aspects and location of outlets*

Density current is defined as the gravitational flow of one fluid under another having slightly different density. The water stored in reservoir is generally free from silt but the inflow during floods is generally muddy. There are, thus two layers having different densities resulting in the formation of density currents. The density currents separate the water from the clearer water and make the turbid water flow along the river bottom. The reservoir silting rate can be reduced by venting the density currents by properly locating and operating the outlets and sluice ways.

4.5.7.10 *Data Required for Economic Analysis*

Economic Analysis is carried out to indicate the economic desirability of the project. Benefit cost ratio, Net benefit, Internal Rate of Return are the parameters in this direction. It is desirable to have the benefit cost ratio in the case of irrigation projects and flood mitigation projects to be above 1.5 and 1.1 respectively. Benefit functions for reservoir and water utilisation for irrigation, power, water supply etc., are also to be determined judiciously. Cost benefit functions are obtained as continuous functions using variable cost/benefit against reservoir storage/net utilisation of water and from

benefit functions the benefit from unit utilisation of water can be determined. The spillway capacity has to be adequate to pass the inflow design flood using moderation possible with surcharge storage or any other unobstructed capacity in the reservoir without endangering the structural safety as provided elsewhere in the standard. In the event of the inflow design flood passing the reservoir, the design needs to ensure that dam break situation does not develop or induce incremental damage downstream.

4.5.7.11 *Data on Engineering and Geological Aspects*

Under engineering and geological aspects the following items of work shall invariably be carried out:

a) Engineering
1) Preliminary surveys to assess the catchment and reservoir,
2) Control surveys like topographical surveys,
3) Location of nearest Railway lines/Roads and possible access, and
4) Detailed survey for making area capacity curves for use in reservoir flood routing.

b) Geology
1) General formations and foundation suitability;
2) Factors relating to reservoir particularly with reference to water tightness;
3) Contributory springs;
4) Deleterious mineral and salt deposits; and
5) Location of quarry sites, etc.

Important aspects of the methods are briefly described in the subsequent sections.

4.5.8 Fixing of Inactive Storage including Dead Storage

Inactive storage including dead storage pertains to storage at the lowest level up to which the reservoir can be depleted. This part of the storage is set apart at the design stage for anticipated filling, partly or fully, by sediment accumulations during the economic life of the reservoir and with sluices/outlets so located that it is not susceptible to full depletion. In case power facility is provided, it is also the storage below the minimum draw down level (MDDL).

Sill level of lowest outlets for any reservoir is fixed from command considerations in case of irrigation purposes and minimum draw down level on considerations of efficient turbine operation in the case of power generation purpose. The lowest sill level should be kept above the new zero elevation expected after the feasible service period according to IS 12182 which is generally taken as 100 years for irrigation projects and 70 years for power projects supplying power to a grid.

By providing extra storage volume in the reservoir for sediment accumulation, in

addition to live storage, it is ensured that the live storage although it contains sediment, will function at full efficiency for an assigned number of years. The distribution pattern of sediments in the entire depth of a reservoir depends upon many factors, such as slope of the valley, length of reservoir, constriction in the reservoir, particle size of the suspended sediment and capacity inflow ratio, but the reservoir operation has an important control over the factors. However, the knowledge of the pattern is essential, especially, in developing areas, in order to have an idea about the formation of delta and recreational spots.

The dead storage of a reservoir depends upon the sediment yield of the catchment. The measurement of sediment yield is done as follows:

4.5.8.1 *Measurement of sediment yields*

The sediment yield in a reservoir may be estimated by any one of the following two methods:
a) Sedimentation surveys of reservoirs with similar catchment characteristics, or
b) Sediment load measurements of the stream.

4.5.8.2 *Reservoir Sedimentation Survey*

The sediment yield from the catchment is determined by measuring the accumulated sediment in a reservoir for a known period, by means of echo sounders and other electronic devices since the normal sounding operations give erroneous results in large depths. The volume of sediment accumulated in a reservoir is computed as the difference between the present reservoir capacity and the original capacity after the completion of the dam. The unit weight of deposit is determined in the laboratory front the representative undisturbed samples or by field determination using a calibrated density probe developed for this purpose. The total sediment volume is then converted to dry- weight of sediment on the basis of average unit weight of deposits. The total sediment yield for the period of record covered by the survey will then be equal to the total weight of the sediment deposited in the reservoir plus that which has passed out of the reservoir based on the trap efficiency. In this way, reliable records may be readily and economically obtained on long-term basis.

The density of deposited sediment varies with the composition of the deposits, location of the deposit within the reservoir, the flocculation characteristics of clay content and water, the age of deposit, etc. For coarse material (0.0625 mm and above) variation of density with location and age may be unimportant.

Normally a time and space average density of deposited materials applicable for the period under study is required for finding the overall volume of deposits. For this purpose the trapped sediment for the period under study would have to be classified in different fractions. Most of the sediment escape front getting deposited into the reservoir should be front the silt and clay fractions. In some special cases local estimates of densities at points in the reservoir may be required instead of average density over the whole reservoir.

The trap efficiency mainly depends upon the capacity-in-flow ratio but may vary with location of outlets and reservoir operating procedure. Computation of reservoir trap

efficiency may be made using trap efficiency curves, such as those developed by Brune and by Churchill (see IS: 12182-1987).

4.5.8.3 *Sediment Load Measurements*

Periodic samples front the stream should be taken at various discharges along with the stream gauging observations and the suspended sediment concentration should be measured as detailed in IS 4890: 1968. A sediment rating curve which is a plot of sediment concentration against the discharge is then prepared and is used in conjunction with stage duration curve (or flow duration) based on uniformly spaced daily or shorter time units data in case of smaller river basins to assess sediment load. For convenience, the correlation between sediment concentration against discharge, may be altered to the relation of sediment load against run-off for calculating sediment yield. Where observed stage/flow data is available for only shorter periods, these have to be suitably extended with the help of longer data on rainfall. The sediment discharge rating curves may also be prepared from hydraulic considerations using sediment load formula, that is, modified Einstein's procedure.

The bed load measurement is preferable. How- ever, where it is not possible, it may be estimated using analytical methods based on sampled data or as a percentage of suspended load (generally ranging from 10 to 20 percent). This should be added to the suspended load to get the total sediment load.

4.5.9 Fixing of Live Storage

The storage of reservoir includes the Active Storage (or Conservation Storage) and the Buffer Storage.

Active or conservation storage assures the supply of water from the reservoir to meet the actual demand of the project whether it is for power, irrigation, or any other demand water supply.

The active or conservation storage in a project should be sufficient to ensure success in demand satisfaction, say 75 percent of the simulation period for irrigation projects, whereas for power and water supply projects success rates should be 90 percent and 100 percent respectively. These percentages may be relaxed in case of projects in drought prone areas. The simulation period is the feasible service period, but in no case be less than 40 years. Storage is also provided to satisfy demands for maintaining draft for navigation and also maintaining water quality for recreation purpose as envisaged in design.

Live storage capacity of a reservoir is provided to impound excess waters during periods of high flow, for use during periods of low flow. It helps the usage of water at uniform or nearly uniform rate which is greater than the minimum flow live storage has to guarantee a certain quantity of water usually called safe (or firm) yield with a predetermined reliability. Though sediment is distributed to some extent in the space for live storage, the capacity of live storage is generally taken as the useful storage

between the full reservoir level and the minimum draw-down level in the case of power projects and dead storage in the case of irrigation projects.

The design of the line storage include certain factors, of which the most important in the availability of flow, since, without an adequate flow, it is not possible to cope up with the demand at all periods and seasons throughout the year. When adequate flow is available, there may still be certain problems like the possible maximum reservoir capacity from physical considerations may be limited and then this becomes the governing criteria. Even if an adequate reservoir capacity may be possible to be built, the governing factor may have to be based on the demand.

For fixing the live storage capacity, the following data should be made use of:

a) Stream flow data for a sufficiently long period at the site;
b) Evaporation losses from the water-spread area of the reservoir and seepage losses and also recharge into reservoir when the reservoir is depleting;
c) The contemplated irrigation, power or water supply demand;
d) The storage capacity curve at the site.

Stream flow records are required at proposed reservoir site. In the absence of such records the records from a station located upstream or downstream of the site on the stream or .on a nearby stream should be adjusted to the reservoir site. The run off records are often too short to include a critical drought period. In such a case the records should be extended by comparison with longer stream flow records in the vicinity or by the use of rainfall run off relationship.

The total evaporation losses during a period are generally worked out roughly as the reduction in the depth of storage multiplied by the mean water-spread area between the full reservoir level and the minimum draw-down level. For accurate estimation, monthly working tables should be prepared and the mean exposed area during the month is found out and the losses should be then worked out on the basis of this mean exposed area, and the evaporation data from pan evaporimeter at the reservoir site. The details are expected to be covered in the draft 'Indian Standard criteria for determination of seepage and evaporation losses including the code for minimizing them. In the absence of' actual data these may be estimated from the records of an existing reservoir with similar characteristics, like elevation, size, etc, in the neighbourhood.

Of the various methods available for fixing the live storage capacity, the Working Table method may be used which is prepared on the basis of preceding long term data on discharge observation at the site of the proposed reservoir, inclusive of at least one drought period. A typical format for carrying out the working table computation, is given in the following table:

Working Table

Mon hs	Beginning of period			Inflow in M-Ha-m	Total M-Ha-m	Demand during period				End of period			Spilled Water	Tail Race Level	Effec-tive Head in m	Dis-charge in m³/s	Re-gen e-ration	Power Pote n-tial P=7. 4QH
	Reser voir level	Capa city in M-Ha-m	Wat er Spre ad area			For irri-gati on	For Pow er	Evap o-ratio n	Total	Reser -voir Level	Capa city M-Ha-m	Wat er Spre ad area						
(1)	(2)	(3)	(4)	(5)	(6) = (3) +(5)	(7)	(8)	(9)	(10) = (7)+(8)+(9)	(11)	(12) = (6)- (10)	(13)	(14)	(15)	(16)	(17)	(18)	(19)

The working table calculations may be represented graphically by plotting the cumulative net reservoir inflow exclusive of upstream abstraction as ordinate against time as abscissa. This procedure is commonly called the Mass Curve Technique, where the ordinate may be denoted by depth in centimeters or in hectare meters or in any other unit of volume. Discharge, with units of 10 days or a month may be used culmination in the mass curve. A segment of the mass curve is shown in Figure 3.
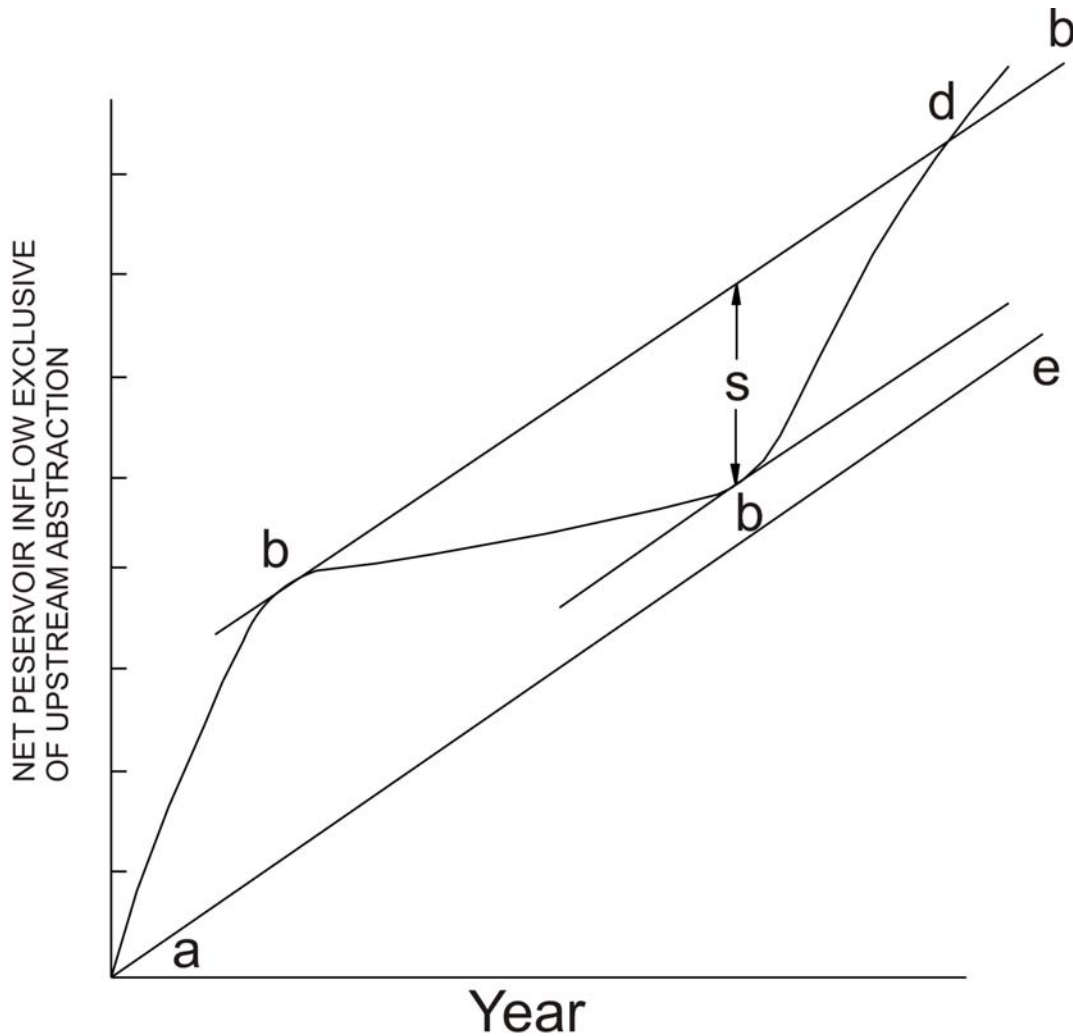

FIGURE3.SEGMENT OF NET INFLOW MASS CURVE

The difference in the ordinate at the end of a segment of the mass curve gives the inflow volume during that time interval. Lines parallel to the lines of uniform rate of demand are drawn at the points **b** and **c** of the mass curve. At **d**, the following inferences can be made:

- The inflow rate between *a* to *b* is more than the demand rate and the reservoir is full.
- Reservoir is just full as the inflow rate is equal to the demand rate.
- Reservoir storage is being drawn down between *b* and *c* since the demand rate exceeds the inflow rate.
- Draw down, S, is maximum at *c* due to demand rate being equal to inflow rate.
- Reservoir is filling or in other words draw down is decreasing from *c* to *d* as the inflow rate is more than the demand rate.
- Reservoir is full at *d* and from *d* to *b* again the reservoir is over flowing because the inflow rate exceeds the demand rate. The greatest vertical distance, S at *c* is the storage required to make up the proposed demand.

The withdrawals from the reservoir to meet the irrigation demand are generally variable and in such cases the demand line becomes a curve instead of a straight line. The demand mass curve should be super-imposed on the inflow mass curve on the same time scale. When the inflow and demand mass curves intersect, the reservoir may be assumed to be full. For emptying conditions of the reservoir the demand curve would be above the inflow curve and the maximum ordinate between the two would indicate the live storage capacity required.

4.5.9.1 *Fixation of Live Storage Capacity for a Given Demand*

Lines parallel to the demand lines are drawn at all the peak points of the mass inflow curve exclusive of upstream abstraction obtained from a long run off record on 10-day (or monthly) basis as shown in Figure 4. When the demand line cuts the mass curve the reservoir may be assumed to be full. The maximum ordinate between the demand line and the mass curve will give the live storage to meet the required demand. The vertical distance between the successive lines parallel to the demand line represents the surplus water from the reservoir.
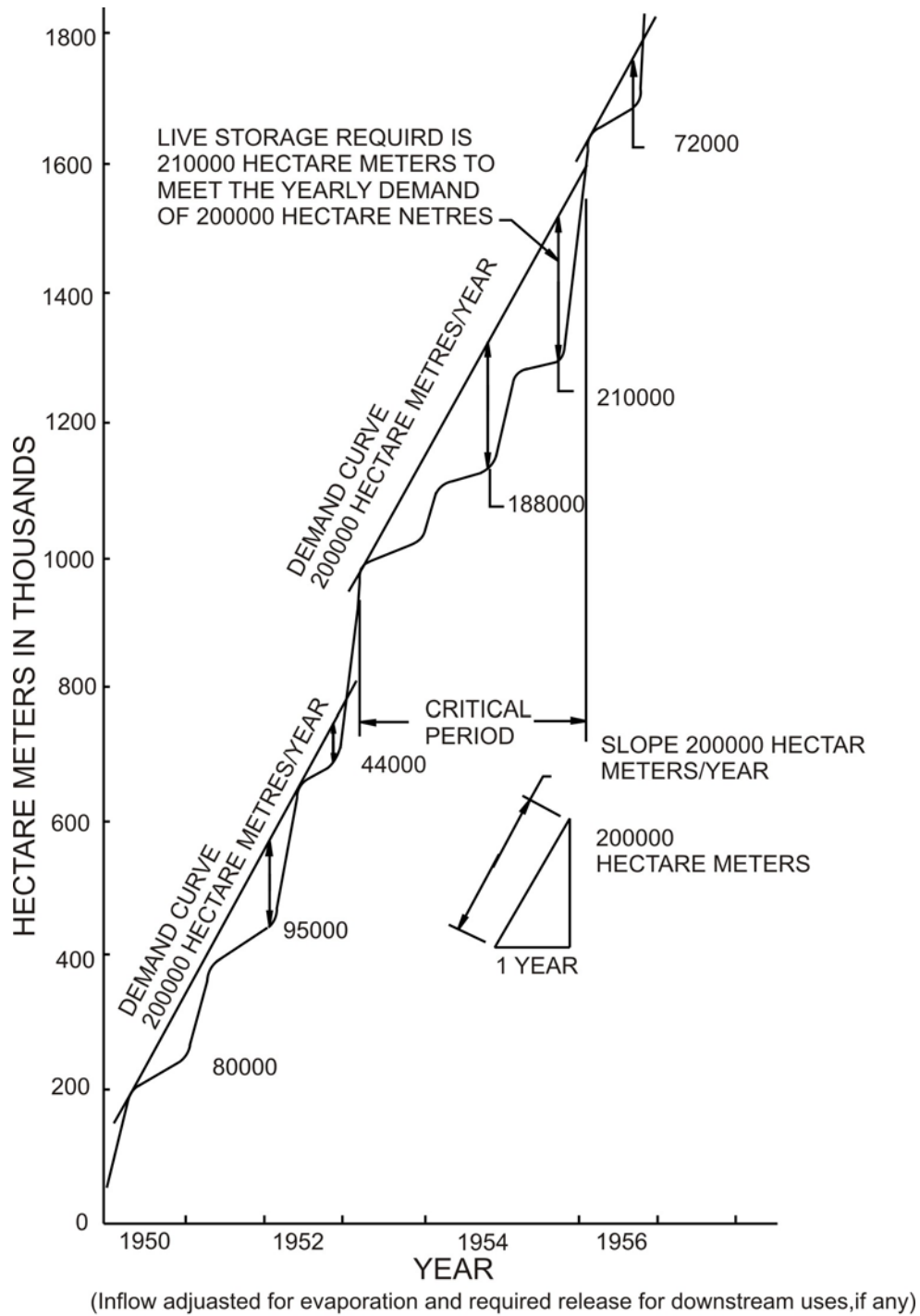
FIGURE 4. A TYPICAL MASS CURVE

4.5.9.2 *Estimation of a Demand from a Given Live Storage Capacity*

The net inflow mass curve is plotted from the available records. The demand lines arc, drawn at peak points of the mass curve in such a way that the maximum ordinate between the demand line and the mass curve is equal to the specified live storage. The demand lines shall intersect the mass curve when extended forward. The slop of the

flattest line indicates the film demand that could he met by the given live storage rapacity.

Before fixing the reservoir capacity, it would be desirable to plot a curve between the net annual drafts and the required live storage capacities for these drafts. This curve will give an indication of the required live storage capacity. However, the economics of the capacity will have to be considered before deciding final capacity.

4.5.10 Fixing of flood and surcharge storage

In case of reservoirs having flood control as one of the purposes, a separate flood control storage is to be set apart above the storage meant for power, irrigation and water supply. Flood control storage is meant for storing flood waters above a particular return period temporarily and to attenuate discharges up to that flood magnitude to minimise effects on downstream areas from flooding. Flood and surcharge storage between the full reservoir level (FRL), and maximum water level (MWL) attainable even with full surplussing by the spillway takes care of high floods and moderates them.

4.5.10.1 *Flood Control Storage*

Storage space is provided in the reservoir for storing flood water temporarily in order to reduce peak discharge of a specified return period flood and to minimize flooding of downstream areas for all floods IS: 5477 (Part 1) : 1999 equal to or lower than the return period flood considered. In the case of reservoirs envisaging flood moderation as a purpose and having separate flood control storage, the flood storage is provided above the top of conservation pool.

4.5.10.2 *Surcharge Storage*

Surcharge storage is the storage between the full reservoir level (FRL) and the maximum water level (MWL) of a reservoir which may be attained with capacity exceeding the reservoir at FRL to start with. The spillway capacity has to be adequate to pass the inflow design flood making moderation possible with surcharge storage.

The methods that are generally used for estimate of the Design Flood for computing the Flood Storage are broadly classified as under:
1. Application of a suitable factor of safety to maximum observed flood or maximum historical flood.
2. Empirical flood formulae.
3. Envelope curves.
4. Frequency analysis.
5. Rating method of derivation of design flood from storm studies and application of the Unit Hydrograph principle.

The important methods amongst the above have been explained in module 2. Nevertheless, these methods are briefly reiterated below:

4.5.10.3 *Application of a Suitable Factor of Safety to Maximum Observed Flood or Maximum Historical Flood*

The design flood is obtained by applying a safety factor which depends upon the judgement of the designer to the observed or estimated maximum historical flood at the project site or nearby site on the same stream. This method is limited by the highly subjective selection of a safety factor and the length of available stream flow record which may give an inadequate sample of flood magnitudes likely to occur over a long period of time.

Empirical Flood Formulae : The empirical formulae commonly used in the country are the Dicken's formula, Ryve's formula and Inglis' formula in which the peak flow is given as a function of the catchment area and a coefficient. The values of the coefficient vary within rather wide, limits and have to be selected on the basis of judgement. They have limited regional application, should be used with caution and only, when a more accurate method cannot be applied for lack of data.

Envelope Curves: In the envelope curve method maximum flood is obtained from the envelope curve of all the observed maximum floods for a number of catchments in a homogeneous meteorological region plotted against drainage area. This method, although useful for generalizing the limits of floods actually experienced in the region under consideration, cannot be relied upon for estimating maximum probable floods for the determination of spillway capacity except as an aid to judgement.

Frequency Analysis: The frequency method involves the statistical analysis of observed data of a fairly long (at least 25 years) period. It is a purely statistical approach and when applied to derive design floods for long recurrence intervals, several times larger than the data, has many limitations. Hence this method has to be used with caution.

4.5.10.4 Rational Method of Derivation of Design Flood from Storm Studies and Application of Unit Hydrograph Principle

The steps involved, in brief, are:

    a. Analysis of rainfall and run-off data for derivation of loss rates under critical conditions;
    b. Derivation of unit hydrograph by analysis (or by synthesis, in cases where data are not available);
    c. Derivation of the design storm; and
    d. Derivation of design flood from the design storm by the application of the rainfall excess increments to the unit hydrograph.

The Maximum Water Level of a reservoir is obtained by routing the design flood through the reservoir and the spillway. This process of computing the reservoir storages, storage volumes and outflow rates corresponding to a particular hydrograph of inflow is commonly referred to as flood routing. The routing is carried out with the help of the

following data,
1. Initial reservoir stage
2. The design flood hydrograph
3. Rate of outflow including the flow over the crest, through sluices or outlets and through power units, and
4. Incremental storage capacity of the reservoir.

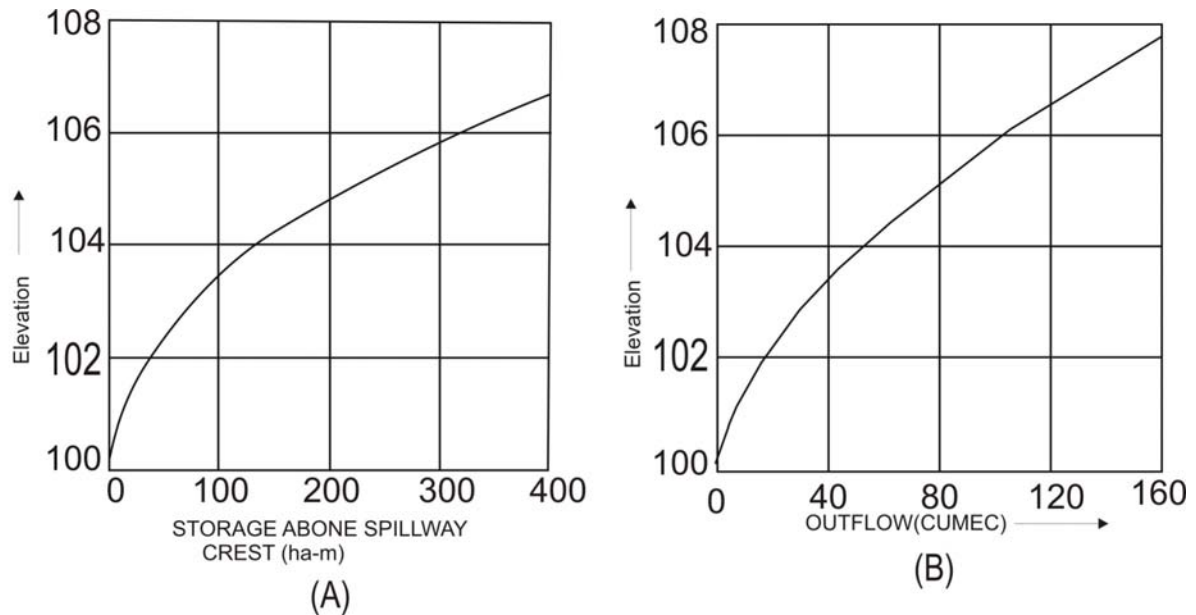Typical values of the last two types of data, is shown in Figure 5.

FIGURE 5. TYPICAL CURVES FOR (A) STORAGE Vs ELEVATION
(B) OUTFLOW Vs ELEVATION

The routing of flood through the reservoir and the spillway is done by solving the continuity of flow within reservoir, which may simply be stated as:
Inflow to reservoir - Outflow to reservoir = Rise is water surface of the reservoir, that is an increase in the storage of the reservoir. That is,

$$(I - O) * \Delta t = \Delta S \qquad (1)$$

Where, I is the inflow discharge (m³/s), O is the Outflow discharge (m³/s), Δs is the in storage volume (m³/s) in time interval Δt (h).
If the inflow hydrograph is known, then we may read out the inflow ordinates at every time interval (t. Suppose, the following values are known:
    I1 = Inflow (m3/s) at the beginning of a time interval
    I2 = Inflow (m3/s) at the end of the time interval

O1= Outflow (m3/s) at the beginning of the time interval
S1= Total storage volume of the reservoir (m3/s) at the beginning of the time interval

And the unknown values are

S2= Total storage volume of the reservoir (m3/s) at the end of the interval
O2= Outflow (m3/s) at the end of the time interval

Then, we rewrite the continuity equation as,

$$\Delta t \left(\frac{I_1 + I_2}{2} \right) - \Delta t \left(\frac{O_1 + O_2}{2} \right) = S_2 - S_1 = \Delta S \qquad (2)$$

Taking the known values to the left side of the equation, one obtains,

$$\left(\frac{I_1 + I_2}{2} \right) + \left(\frac{S_1}{\Delta t} - \frac{O_1}{2} \right) = \left(\frac{S_2}{\Delta t} + \frac{O_2}{2} \right) \qquad (3)$$

Now, for solving the above equation, a table of $\left(\dfrac{S}{\Delta t} - \dfrac{O}{2} \right)$ and $\left(\dfrac{S}{\Delta t} + \dfrac{O}{2} \right)$ versus Reservoir Level, are prepared with the help of the Spillway Capacity (Outflow) curve and the Reservoir Storage Capacity Curve, which were shown in Figure 5. From the table, two graphs are prepared which typically looks as shown in Figure 6.

The graph plots OUTFLOW 0 (CUMEC) on the vertical axis (0 to 140) against $(\frac{2s}{t} \pm 0)$ (CUMEC) on the horizontal axis (0 to 1400). Two curves are shown: the $(\frac{2s}{t} - 0)$ V/S 0 CURVE and the $(\frac{2s}{t} + 0)$ curve.
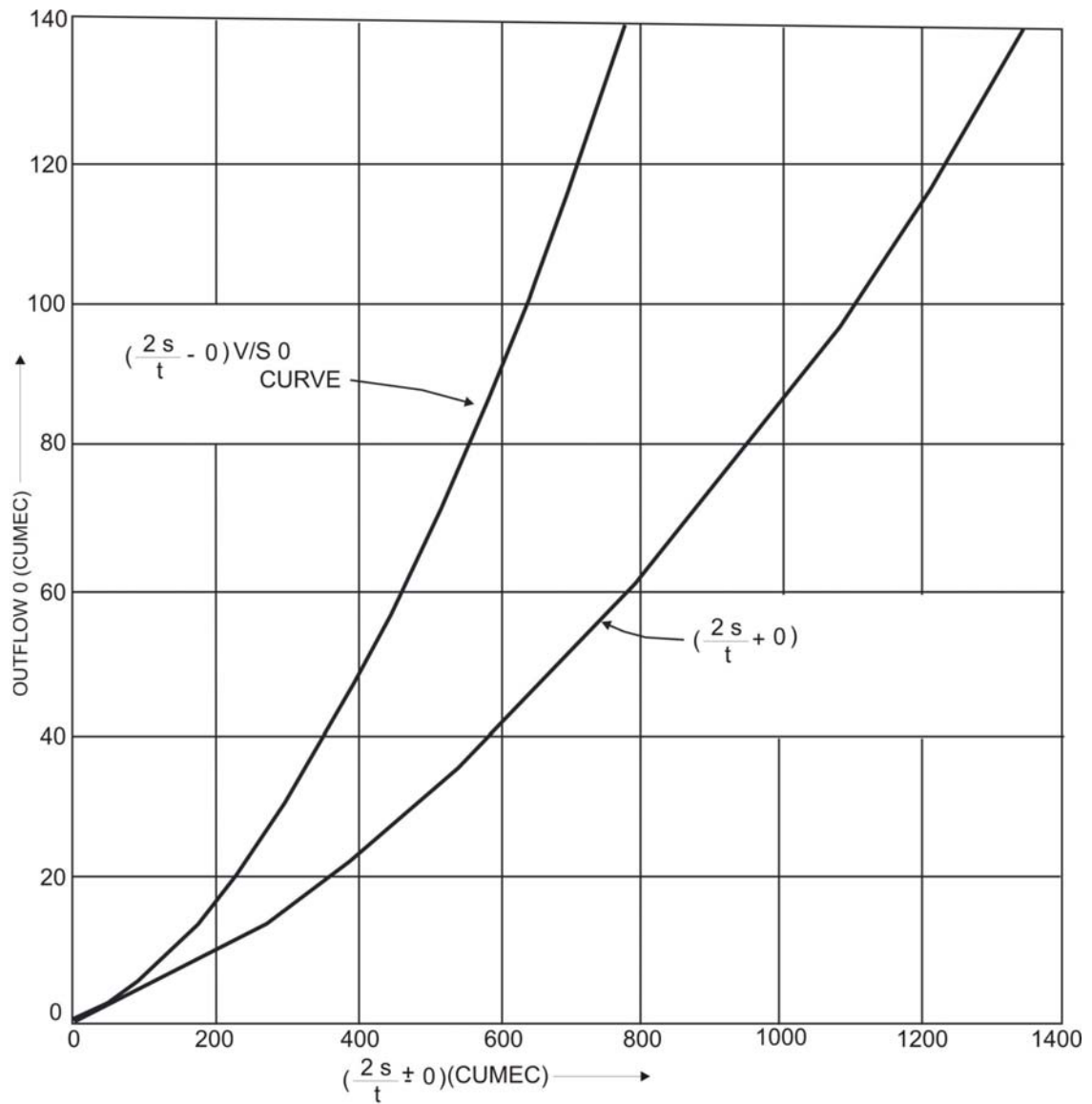
FIGURE 6. TYPICAL COMPUTATION CURVES

At the start of the inflow or the beginning of the first interval of time, to account for the worst condition, the water surface in the reservoir is normally taken to be at the maximum conservation level or the full reservoir level and hence, both the storage S_1 and outflow O_1 at the beginning are equal to zero. Thus, one obtains from equation (3), the following at the beginning of the flood routing procedure:

$$\left(\frac{I_1+I_2}{2}\right)=\frac{S_2}{\Delta t}+\frac{O_2}{2} \tag{4}$$

where, the suffix 1 stands for the time at the beginning of routing and 2 for the time at the end of the routing after a time interval Δt.

For the first interval of time, the inflow rates I_1 and I_2 at the beginning and end of the interval are known (in fact, they are known at all times), and introducing these values in equation (4), $\left(\frac{S_2}{\Delta t}+\frac{O_2}{2}\right)$ becomes known. From Figure 5, corresponding to this value of $\left(\frac{S_2}{\Delta t}+O_2\right)$, one obtain the value of outflow O_2 at the end of the time interval. Corresponding to this value of O_2, one may also find $\left(\frac{S_2}{\Delta t}-O_2\right)$ from Figure 6, which may be used for the second time interval from the following expression:

$$\left(\frac{I_2+I_3}{2}\right)+\left(\frac{S_2}{\Delta t}-\frac{O_2}{2}\right)=\left(\frac{S_3}{\Delta t}+\frac{O_3}{2}\right) \tag{5}$$

In the equation (5), I_2 and I_3 are the inflow rates at the beginning and end of the second interval of time which are known from the given inflow hydrograph. Knowing $\left(\frac{S_2}{\Delta t}-O_2\right)$ from the calculation of the previous step, one may calculate $\left(\frac{S_3}{\Delta t}+\frac{O_3}{2}\right)$ from equation (5) and obtain O_3 and $\left(\frac{S_3}{\Delta t}-O_3\right)$ both from Figure 6. This procedure goes on till the inflow hydrograph gets fully routed through the reservoir.

4.5.11 Reservoir losses and their minimization

Loss of reservoir water would mainly take place due to evaporation and a number of methods have been suggest for controlling such loss. The Bureau of Indian Standard code IS: 14654 - 1999 "Minimizing evaporation losses from reservoirs- guidelines" describes the cause of evaporation reduction methods in detail, some important aspects of which are described in the subsequent paragraphs. As such, percolation or seepage loss is small for most of the reservoirs and progressively gets lowered with the passage of time since the sediment getting deposited at the reservoir bottom helps to reduce percolation losses. Of course, in some hills and valleys forming the reservoir, there may

be continuous seams of porous rock strata or limestone caverns which cause huge amount of water to get drained out of the reservoirs. The reservoir of the Kopili Hydroelectric Project in Assam-Meghalaya border had faced similar problems due to the presence of large caverns which had to be sealed later at quite large cost at a later stage.

A number of factors affect the evaporation from open water surface, of which, the major factors are water spread area and frequent change of speed and direction of wind over the water body. Other meteorological factors like.

   a) Vapour pressure difference_ between water surface and the layer of air above;
   b) Temperature of water and air;
   c) Atmospheric pressure;
   d) Radiation;
   e) Heat storage in water body; and
    f) Quality of water,
have direct influence on the rate of evaporation.

Since the meteorological factors affecting evaporation cannot be controlled under normal conditions, efforts are made for inhibition of evaporation by control of flow of wind over water surface or by protection of the water surface area by physical or chemical methods. The methods generally used are as follows:

   a) Wind breakers,
   b) Covering the water surface,
   c) Reduction of exposed water surface,
   d) Integrated operation of reservoirs, and
   e) Treatment with chemical water evaporetardants (WERs).

4.5.11.1 *Wind Breakers*

Wind is one of the most important factors which affect rate of evaporation loss from water surface. The greater the movement of air over the water surface, greater is the evaporation loss. Planting of trees normal to windward direction is found to be an effective measure for checking of evaporation loss. Plants (trees, shrubs or grass) should be grown around the rim of tanks in a row or rows to act as wind breaker.
These wind breakers are found to influence the temperature, atmospheric humidity, soil moisture, evaporation and transpiration of the area protected.

Plants to act as wind breakers are usually arranged in rows, with tallest plants in the middle and the smallest along the end rows, so that more or less conical formation is formed.

4.5.11.2 *Covering the Water Surface*

Covering the surface of water bodies with fixed or floating covers considerably retards evaporation loss. These covers reflect energy inputs from atmosphere, as a result of

which evaporation loss is reduced. The covers literally trap the air and prevent transfer of water vapour to outer atmosphere.

Fixed covers are suitable only for relatively small storages. For large storages, floating covers or mat or spheres may be useful and effective. However, for large water surfaces the cost of covering the surface with floats is prohibitive, Further in case of reservoirs with flood outlets, there is also the danger of floats being lost over spillway or through outlets. The floating covers are thus of limited utility to larger water bodies.

4.5.11.3 *Reduction of Exposed Water Surface*

In this method shallow portions of the reservoirs are isolated or curtailed by construction of dykes or bunds at suitable locations. Water accumulated during the monsoon season in such shallow portions IS diverted or pumped to appropriate deeper pockets in summer months, so that the shallow water surface area exposed to evaporation is effectively reduced.

4.5.12 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.

Each of these methods is briefly described as follows:

4.5.12.1 *Design of reservoirs*

The capacity of reservoirs is governed by a number of factors which are covered in IS: 5477 (Parts 1 to 4). From the point of view of sediment deposition, the following points may be given due consideration:

      a) The sediment yield which depends on the topographical, geological and geo-morphological set up,meteorological factors, land use/land cover, intercepting tanks, etc;
      b) Sediment delivery characteristics of the channel system;
      c) The efficiency of the reservoir as sediment trap;
      d) The ratio of capacity of reservoir to the inflow;
      e) Configuration of reservoir;
      f) Method of operation of reservoir;
      g) Provisions for silt exclusion.

The rate of sediment delivery increases with the volume of discharge. The percentage of sediment trapped by a reservoir with a given drainage area increases with the capacity. In some cases an increased capacity will however, result in greater loss of water due to evaporation. However, with the progress of sedimentation, there is decrease of storage capacity which in turn lowers the trap efficiency of the reservoir.

The capacity of the reservoir and the size and characteristics of the reservoir and its drainage area are the most important factors governing the annual rate of accumulation of sediment. Periodical reservoir sedimentation surveys provide guidance on the rate of sedimentation. In the absence of observed data for the reservoir concerned, data from other reservoirs of similar capacity and catchment characteristics may be adopted.

Silting takes place not only in the dead storage but also in the live storage space in the reservoir. The practice for design of reservoir is to use the observed suspended sediment data available from key hydrologica1 networks and also the data available from hydrographic surveys of other reservoirs in the same region. This data be used to simulate sedimentation status over a period of reservoir life as mentioned in IS 12182: 1987.

4.5.12.2 *Control of sediment inflow*

There are many methods for controlling sediment inflows and they can be divided as under:
      a) Watershed management/soil conservation measures to check production and transport of sediment in the catchment area.
      b) Preventive measures to check inflow of sediment into the reservoir.

The soil conservation measures are further sub-divided as:

      a) Engineering,

b) Agronomy, and
c) Forestry.

The engineering methods include:

a) Use of check dams formed by building small barriers or dykes across stream channels.

b) Contour bounding and trenching;

c) Gully plugging;

d) Bank protection.

The agronomic measures include establishment of vegetative screen, contour farming, strip cropping and crop rotation.

Forestry measures include forest conservancy, control on grazing, lumbering, operations and forest fires along with management and protection of forest plantations.

Preventive measures to check inflow of sediment into the reservoir include construction of by-pass channels or conduits.

Check Dams

Check dams are helpful for the following reasons:

a) They help arrest degradation of stream bed thereby arresting the slope failure;

b) They reduce the velocity of stream flow, thereby causing the deposition of the sediment load.

Check dams become necessary, where the channel gradients are steep and there is a heavy inflow of sediment from the watershed. They are constructed of local material like earth, rock, timber, etc. These are suitable for small catchment varying in size from 40 to 400 hectares. It is necessary to provide small check dams on the subsidary streams flowing into the main streams besides the check dams in the main stream. Proper consideration should be given to the number and location of check dams required. It is preferable to minimize the height of the check dams. If the stream ha, a very-steep slope, it is desirable to start with a smaller height for the check dams than may ultimately be necessary.

Check dams may generally cost more per unit of storage than the reservoirs they protect. Therefore, it may not always be possible to adopt them as a primary method of sediment control in new reservoirs. However, feasibility of providing check dams at a later date should not be overlooked while planning the protection of-a new reservoir.

Contour Bunding and Trenching

These are important methods of controlling soil erosion on the hills and sloping lands, where gradients of cultivated fields or terraces are flatter, say up to 10 percent. By these methods the hill side is split up into small compartments on which the rain is retained and surface run-off is modified with prevention of soil erosion. In addition to contour bunding, side trenching is also provided sometimes.

Gully Plugging

This is done by small rock fill dams. These dams will be effective in filling up the gullies with sediment coming from the upstream of the catchment and also prevent further widening of the gully.

4.5.12.3 *Control of sediment deposition*

The deposition of sediment in a reservoir may be controlled to a certain extent by designing and operating gates or other outlets in the dam in such a manner as to permit selective withdrawals of water having a higher than average sediment content. The suspended sediment content of the water in reservoirs is higher during and just after flood flow. Thus, more the water wasted at such times, the smaller will be the percentage of the total sediment load to settle into permanent deposits. There are generally two methods: (a) density currents, and (b) waste-water release, for controlling the deposition and both will necessarily result in loss of water.

Density Current

Water at various levels of a reservoir often contains radically different concentrations of suspended sediment particularly during and after flood flows and if all waste-water could be withdrawn at those levels where the concentration is highest, a significant amount of sediment might be removed from the reservoir. Because a submerged outlet draws water towards it from all directions, the vertical dimension of the opening should be small with respect to the thickness of the layer and the rate of withdrawal also should be low. With a view to passing the density current by sluices that might be existed, it is necessary to trace the movement of density currents and observation stations (consisting of permanently anchored rafts from which measurements could be made of temperature and conductivity gradient from the surface of the lake to the bottom, besides collecting water samples at various depths) at least one just above the dam and two or more additional stations in the upstream (one in the inlet and one in the middle) should be located.

Waste-Water Release

Controlling the sedimentation by controlling waste-water release is obviously possible only when water can be or should be wasted. This method is applicable only when a reservoir is of such size that a small part of large flood flows will fill it.

In the design of the dam, sediment may be passed through or over it as an effective method of silt control by placing a series of outlets at various elevations. The percentage of total sediment load that might be ejected from the reservoir through proper gate control will differ greatly with different locations. It is probable that as much as 20 percent of the sediment inflow could be passed through many reservoirs by venting through outlets designed and con- trolled.

Scouring Sluicing

This method is somewhat similar to both the control of waste-water release and the draining and flushing methods. The distinction amongst them care the following:

1)   The waste-water release method ejects sediment laden flood flows through deep spillway gates or large
        under sluices at the rate of discharge that prevents sedimentation.
2)   Drainage and flushing method involves the slow release of stored water from the reservoir through small gates or valves making use of normal or low flow to entrain and carry the sediment, and
3)   Scouring sluicing depends for its efficiency on either the scouring action exerted by the sudden rush of impounded water under a high head through under sluices or on the scouring action of high flood discharge coming into the reservoir.

Scouring sluicing method can be used in the following:

        a) Small power dams that depend to a great extent on pondage but not on storage;
        b) Small irrigation reservoirs, where only a small fraction of the total annual flow can be stored;
        c) Any reservoir in narrow channels, gorges, etc, where water wastage can be afforded; and
        d) When the particular reservoir under treatment is a unit in an interconnected system so that the other
        reservoirs can supply the water needed.

4.5.12.4 *Removal of deposited sediment*

The most practical means of maintaining the storage capacity are those designed to prevent accumulation of permanent deposits as the removal operations are extremely expensive, unless the material removed is usable. Therefore, the redemption of lost storage by removal should be adopted as a last resort. The removal of sediment deposit implies in general, that the deposits are sufficiently compacted or consolidated to act as a solid and, therefore, are unable to flow along with the water. The removal of sediment deposits may be accomplished by a variety of mechanical and hydraulic or methods, such as excavation, dredging, siphoning, draining, flushing, flood sluicing, and sluicing aided by such measures as hydraulic or mechanical agitation or blasting of the sediment. The excavated sediments may be suitably disposed off so that, these do not find the way again in the reservoir.

Excavation

The method involves draining most of or all the water in the basin and removing the sediment by hand or power operated shovel, dragline scraper or other mechanical means. The excavation of silt and clay which constitute most of the material in larger reservoirs is more difficult than the excavation of sand and gravel. Fine-textured sediment cannot be excavated easily from larger reservoirs unless it is relatively fluid or relatively compact.

Dredging

This involves the removal of deposits from the bottom of a reservoir and their conveyance to some other point by mechanical or hydraulic means, while water storage is being maintained.

   Dredging practices are grouped as:
   a) Mechanical dredging by bucket, ladder, etc;
   b) Suction dredging with floating pipeline and a pump usually mounted on a barrage; and
   c) Siphon dredging with a floating pipe extending over the dam or connected to an opening in the dam and
      usually with a pump on a barrage.

Draining and Flushing

The method involves relatively slow release of all stored water in a reservoir through gates or valves located near bottom of the dam and the maintenance thereafter of open outlets for a shorter or longer period during which normal stream flow cuts into or directed against the sediment deposits. Therefore, this method may be adopted in flood control reservoirs.

Sluicing with Controlled Water

This method differs from the flood sluicing in that the controlled water supply permits choosing the time of sluicing more advantageously and that the water may be directed more effectively against the sediment deposits. While the flood sluicing depends either on the occurrence of flood or on being able to release rapidly all of a full or nearly full supply of water in the main reservoir is empty. The advantage of this method is that generally more sediment can be removed per unit of water used than in flood scouring or draining and flushing.

Sluicing with Hydraulics and Mechanical Agitation

Methods that stir up, break up or move deposits of a sediment into a stream current moving through a drained reservoir basin or into a full reservoir will tend to make the removal of sediment from the reservoir more complete. Wherever draining, flushing or sluicing appear to be warranted, the additional use of hydraulic means for stirring up the sediment deposits, or sloughing them off, into a stream flowing through the reservoir basin should be considered. It has, however, limited application.

4.5.13 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.

4.5.13.1 *Operation of Single Purpose Reservoirs*

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

   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 down stream 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 spac*e-* 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.

4.5.13.2 *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 Damodar 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.
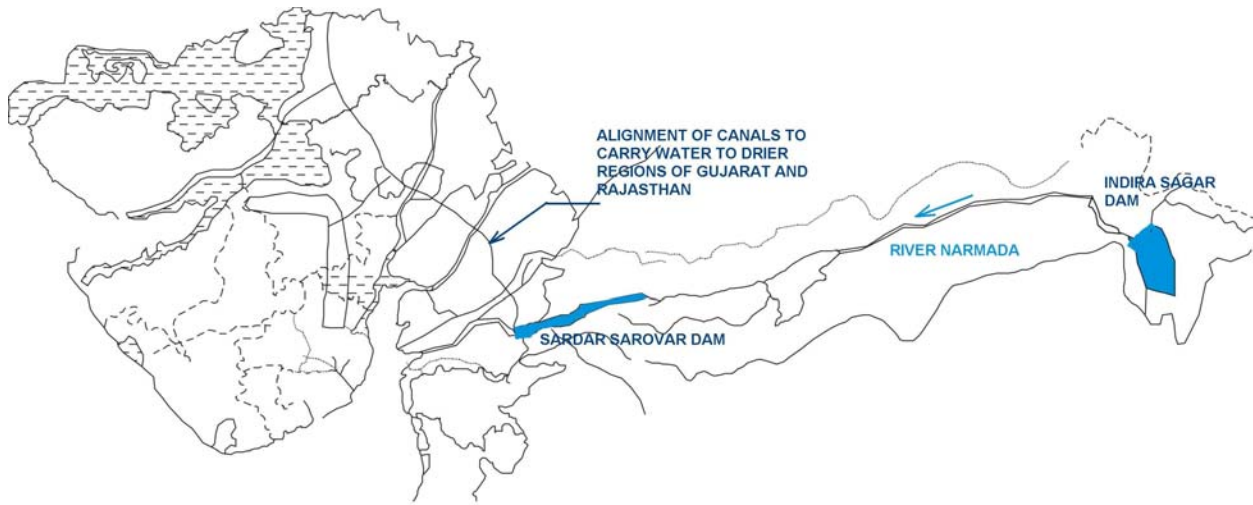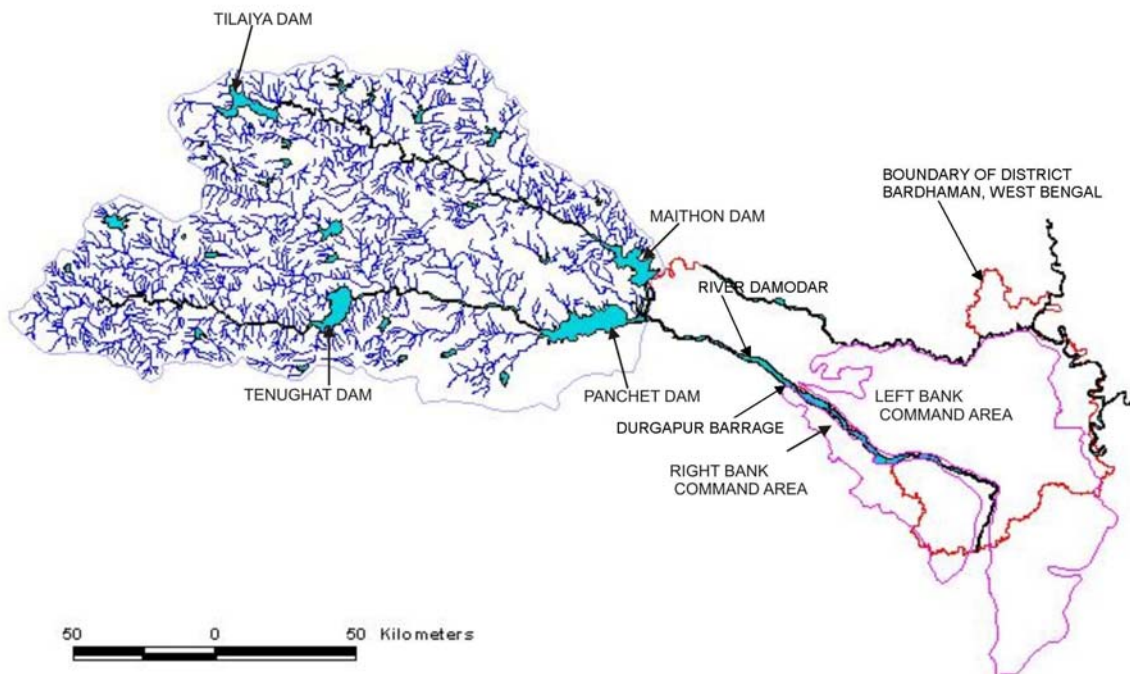

FIGURE 7. NARMADA VALLEY DEVELOPMENT PROJECT

FIGURE.8 DAMODAR VALLEY DEVELOPMENT PROJECTS