CE 15015

WATER RESOURCES ENGINEERING

LECTURE NOTES

MODULE-III

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Course Contents

Module – III

Reservoir management: Fixation of reservoir capacity, Ripple’s mass curve, sequent peak algorithm, allocation of storage space for various uses, reservoir sedimentation and its control, determination of sediment yield at a reservoir site.

Lecture Note 1

Reservoir management

1.1 Introduction

A reservoir is a storage structure that stores water in periods of excess flow (over demand) in order to enable a regulation of the storage to best meet the specified demands. Modelling a reservoir system, in general, is specific to the system, and the assumptions one may use to make the model formulation simple enough for problem-solving through known techniques in systems analysis. This lecture illustrates how a reservoir may be modelled using deterministic inputs. Model formulations for two important aspects of reservoir modeling are discussed: reservoir sizing and reservoir operation.

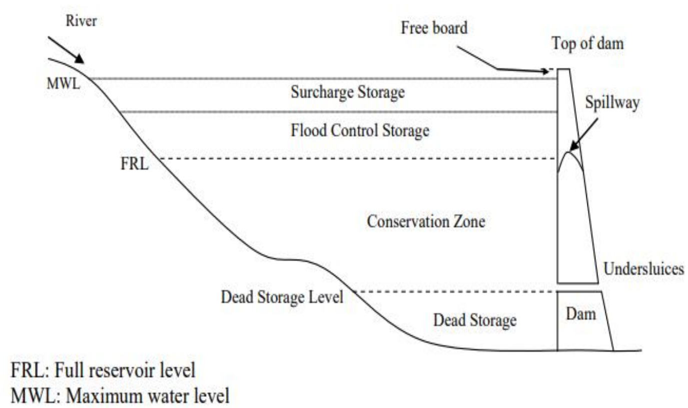

Fig (1) Schematic diagram of a reservoir showing the various storage zones

1.2 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. 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

1.3 Reservoir Sizing

The annual demand for water at a particular site may be less than the total inflow there, but the time distribution of the demand may not match the time distribution of inflow, resulting in surplus in some periods and deficit in some other periods of the year. A reservoir serves the purpose of temporarily storing water in periods of excess inflow and releasing it in periods of low flow so that the demands may be met in all periods. The problem of reservoir sizing involves determination of the required storage capacity of the reservoir when inflows and demands in a sequence of periods are given. The total storage can be divided into three components: dead storage (for accumulation of sediments), active storage (for conservation purpose such as water supply and hydropower production), and flood storage (for reducing flood peak). While each of these components may be determined by separate modelling studies, we confine ourselves in this section only to the determination of the active storage capacity of the reservoir. The inflow to the reservoir is in fact a random variable. The problem gets complicated if the randomness of the inflow has to be taken into account.

One common method, extensively used in practice, is to determine the active storage capacity using the **Rippl diagram or the mass diagram** by plotting cumulative inflow with time. The method involves finding the maximum positive cumulative difference between a sequence of reservoir releases (equal to demands) and historical inflows over a sequence of time periods in which the demand is constant. For details of this method, the reader may refer any standard textbook on hydrology.

If the demand is constant in each time period, the method is quite simple to apply. When the demand varies across time periods, the procedure requires a plot of the cumulative deficits in time from the period in which a deficit sets in, for the duration of the deficit, and finding the maximum deficit among all such durations. The total deficit duration containing this maximum deficit is known as the critical period.

This method is still cumbersome compared to a simple analytical technique, known as **sequent peak method**, which is described next. If we ignore the evaporation losses in the reservoir, the sequent peak method is quite simple. We shall first assume this situation and look at the algorithm to determine the reservoir capacity by the sequent peak method. Later, we shall see how the reservoir losses can be incorporated into the method to determine the active storage capacity of the reservoir.

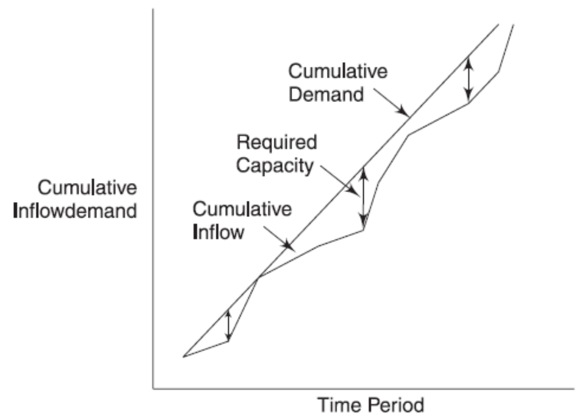

Fig. 5.1 *Mass Diagram Approach to Determine Reservoir Capacity*

Fig(1) Mass Diagram Approach to Determine Reservoir Capacity

1.4 The Mass Curve Method

This method is also known as the Rippl mass curve method after the developer of this method. This is a simple method which is commonly used to estimate the required storage capacity of a reservoir in project planning stage. The method uses the most critical period of recorded flow to compute storage. The critical period is defined as the duration in which initially full reservoir depletes and passing through various states empties without spilling. In the methods based on critical period concept, a sequence of streamflows containing a critical period is routed through an initially full reservoir in presence of specified demands. The reservoir capacity is obtained by finding the maximum difference between cumulative inflows and cumulative demand curves. Let x(t) be the inflows to a reservoir in volumetric units. We define a function X(t):

$$\mathbf{X(t) = \Sigma t\ x(t)\ dt}$$

then the graph of X(t) versus time is known as the mass curve. The mass curve technique, proposed by Rippl in 1883 to determine storage capacity of a reservoir, is a graphical technique.

Although the mass curve technique is very simple and straight forward, it has a few shortcomings. This method is suitable when the draft is constant. It is not possible to consider evaporation losses. One drawback is the implicit assumption that the storage which would have been adequate in past will also be adequate in future. Although this is not clearly true, the error caused is not really serious particularly if sufficiently long flow series has been considered. However, this problem will arise in any other method since true future is not known. Some methods try to address this problem by explicitly considering the stochasticity of the inflows. One more drawback of the mass curve is that no economic analysis can be done in this technique. The storage size cannot be related to the economic life of the project and usually estimate of the storage increase with the increase in the length of record used. Further, storage size cannot be computed for a particular level of reliability. Mass curve method has a number of strengths. The main of these is that the method is simple and very intuitive. Perhaps these are the reasons of its popularity and wide use.

1.5 Sequent Peak Algorithm

Sequent Peak Algorithm overcomes some shortcomings associated with the mass curve method. This method is particularly suited for the analysis of large data with the help of a computer. It was proposed as a method which circumvents the need to choose the correct starting storage which is required in the mass curve procedure. The computations are quite simple and can be carried out as follows. Let I_t be the inflow to the reservoir in the period t, R_t be the release from the reservoir, and St the storage at the beginning of the period t. The reservoir is assumed to be empty in the beginning. The mass curve of cumulative net flow volume (Inflow - Outflow) against chronological time is used. This curve will have peaks (local maximums) and troughs (local minimums). For any peak Pi the next following peak of magnitude greater than Pi is called a sequent peak. The computations are performed for twice the length of the inflow record by assuming that the inflows repeat after the end of first cycle. This assumption is made to take care of the case when the critical period falls at the end of the record.

The variable St is calculated by the following equation:

$S_t = |\ S_{t-1} + R_t - I_t$ if positive

$|\ 0$ if negative or zero .

The required storage capacity is equal to the maximum of S_t values.

In the sequent peak algorithm, it is very easy to consider the variable release from the reservoir. The reliability of the reservoir can be obtained indirectly. Since the reservoir would be able to meet the worst drought from the record, the implied probability of failure would be 1/(N+1). Sequent peak algorithm is very fast and easy to program. A single historical record is used to compute the storage and hence the method is limited in that sense. It is also not possible to exactly consider the losses, these can be approximately included in the releases.

1.6 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.

1.7 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.

1.8 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 geomorphological 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 hydroIogica1 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.

1.9 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.

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