TOPICS

1. Water quality modeling

2. Multipurpose reservoir system

3. Simulation

1. **WATER QUALITY MODELING INTRODUCTION**

Water quality maintaining and monitoring has become an important part of sustainable development. The quality problems in water arise mainly due to its molecular structure itself which makes it a universal dissolvent. Usually water quality is expressed as a function of space and time. The quality of water body shows rapid variations. Variations are more in a river, less in lakes and much less in aquifers. In this lecture we will discuss about the concepts of water quality and river water quality modeling.

WATER QUALITY MONITORING:- Monitoring indicates the long term, standardized measurement and observation of the environment. The location of sampling station depends on the purpose of study. These can be divided into

(i) basic stations which are located usually at the mouth of main streams, major tributaries, downstream of river development projects, at hydrometric stations, gauge discharge sites, industrial and urban centers and at points of water use

(ii) auxiliary stations which are meant to analyse the effect of pollutants discharged into a stream, determination of assimilation capacity of stream etc. Stream quality is assessed by interpolating the data collected at these stations. The samples for water quality should be taken at places where composition is uniform across the cross-section. Hence, sampling points in rivers should be away from any disturbing influences. Sampling frequency depends on the purpose and relative importance of the station, variability of data and accessibility of station. Basic stations usually collect at a sampling frequency of 3 - 4 months per year. At least one sample should be taken in one season. Stations located downstream of a waste outlet, should take samples weekly or biweekly. If the purpose is recreational, sampling can be restricted to the season of use.

Water quality parameters :-Many organic constituents may present in water and measurement of all of them may be practically difficult. Organic pollution is therefore indicated by the non-parametric tests such as Chemical Oxygen Demand (COD) or Total Organic Carbon (TOC). The parameters to be measured are the following: total organic carbon, biochemical oxygen demand (BOD), cyanide, pesticides, suspended solids, nitrogen, fluoride, cadmium, chromium, copper, lead,

nickel, zinc, mercury, boron, dissolved oxygen (DO), pH value, and coliform bacteria. Additional information such as total hardness, alkalinity, calcium hardness, sulphate, phosphate, sodium, potassium etc may be also needed if the objective is to evaluate the influence of pollution control measures on the cost of water treatment. Water quality standards The usage of water depends on its quality. The permissible limits depend on the intended use. For example, water from a particular source may be good for irrigation, but may not be advisable for drinking. Guidelines for drinking water quality were issued by WHO in 1996.

Table 1. Bacteriological quality of drinking water

Organisms	Guideline
All water intended for drinking	
E. coli or thermotolerant coliform bacteria	Must not be detectable in any 100 ml sample
Treated water entering the distribution system	
E. coli or thermotolerant coliform bacteria	Must not be detectable in any 100 ml sample
Total coliform bacteria	Must not be detectable in any 100 ml sample
Treated water in the distribution system	
E. coli or thermotolerant coliform bacteria	Must not be detectable in any 100 ml sample
Total coliform bacteria	Must not be detectable in any 100 ml sample

RIVER WATER QUALITY MODELING

Water quality can be divided into five categories based on the colour of discharge:

Category	Colour	Amount of pollution
I	Blue	No/ Slight
II	Green	Moderate
III	Yellow	Heavy
IV	Red	Excessive
V	Black	Zone of devastation

There are two components for river water quality modeling:

(i) forecasting the developments in the basin and subsequent effects in the water quality and

(ii) forecasting of pollution concentration changes within the stream which includes prediction of solute concentration at various points at various times taking solute concentration at specified point as input and finding the dominant processes controlling the solute concentration. Forecasting of concentration is a simple task if the contaminants are stable i.e., if the concentration changes only through dilution and evaporation. However, precipitation, sedimentation, adsorption etc also act as forcing factors to change the concentrations of many organic and inorganic substances. Such processes are influenced by factors such as pH, temperature, bed characteristics etc, which need to be treated separately. Pollutants may enter the river through a point source or a non-point source. If the source is a well-defined outlet such as industrial outlet or municipal sewers, then it is termed as a point source. If the source is distributed along the water course such as runoff from land, it is termed as non-point source. The source of pollutants can also be classified as continuous and instantaneous source. While continuous sources dump pollutants over a long period of time (e.g. municipal waste water plant), instantaneous sources dump pollutants for a very short interval of time (e.g. spill from a tanker). A plot of pollute concentration with respect to time is known as pollutograph. The graph of the product of pollutant concentration and flow rate/time is known as loadograph.

Components of a river water quality model :-The governing dynamic equations of a river water quality model consider various hydrologic, thermal and biochemical processes that take place within the system. These equations are basically conservation of mass, momentum and energy. The biochemical and chemical processes in a river are influenced by hydraulic and thermal conditions. The main influencing hydraulic variables are flow velocity, depth and discharge. An increase in flow velocity decreases the self-purification. However, it also results in increased turbulence, which aids in proper mixing of oxygen and hence increases reaeration. Greater depths block penetration of sunlight, hence slowing down the photosynthetic process. Pollutant concentration is inversely proportional to discharge since an increased discharge increases the dilution rate. River water quality model therefore can be divided into three components: hydraulic, thermal and biochemical sub models

Hydraulic and thermal models: Considering one-dimensional unsteady flow, the influencing variables are flow depth and cross-section of flow. The influencing equations are conservation of mass and momentum. Thermal model has only one variable i.e., temperature. This sub model can be skipped by directly inputting the variable to the biochemical model. **Biochemical model**: The real life interactions may lead to a large number of variables, making the model complex. One may reduce the number of variables by substitution or grouping of similar variables. A pertinent indicator of water quality is the dissolved oxygen (DO). BOD represents the amount of oxygen needed for biochemical oxidation of matter in a unit volume of water. Most of the biochemical models are simplified versions of the real processes taking place in the water body. **Geochemical processes** :-In addition to the physical processes, chemical and biological processes also influence the solute transport. These geochemical reactions can either be homogenous wherein the dissolved species interact with species of same phase (e.g. Hydrolysis) or heterogenous wherein species from different phases are involved (e.g. reaction between dissolved oxygen and atmospheric oxygen).

OPTIMUM OPERATION MODEL FOR RESERVIOR SYSTEM

Multipurpose Reservoir Operation Introduction Reservoir operation is an important element in the field of water resources planning and management. Different objectives, such as flood control, hydropower generation and water allocation to different users are satisfied by utilizing several control variables in order to define the operation strategies for guiding a sequence of releases to meet the demands. Often, these objectives are conflicting and unequal, which makes reservoir operation a difficult task. Therefore, balanced solutions between the conflicting objectives are needed to optimise reservoir operation. In this lecture, we will introduce the common purposes of reservoirs, planning of multipurpose reservoirs and formulation of multipurpose single and multiple reservoir systems. Combinations of multipurpose reservoir For effective utilization of water, some of the purposes are combined often. The preferred combinations are: (i) Irrigation and power (ii) Irrigation, power and navigation (iii) Irrigation, power and water supply (iv) Recreation, fisheries and wild life (v) Flood control and water supply (vi) Power and water supply (vii) Flood control, irrigation, power and water supply – most common combination.

Multi-objective Optimization – The various purposes of a reservoir may not be compatible to one another. Hence, the unique feature of multipurpose design is an operation plan which effectively compromises the various purposes. There are two possible extremes in reservoir storage allocation: (i) No storage is jointly used (ii) All storage is jointly used In the first case, the total storage requirement is the sum of storage requirements from all purposes. This can be economically obtained when the unit cost of storage is constant or the unit cost decreases as the total storage increases.

The second case gives maximum economy since the storage required is not greater than that necessary for any one of the many purposes. Usually a multipurpose reservoir is designed in between these extremes. Reservoir operating policies typically divide the storage capacity into several pools according to the intended purposes. A typical reservoir pooling for multipurpose is shown in figure 1. Water in the inactive pool or dead storage is not utilized for any purpose. It serves as a head for hydropower generation, recreation, fish habitat or sediment reserve. Conservation storage purposes include municipal and industrial water supply, irrigation, hydroelectric power, navigation etc. Flood control pool remains empty, except during and immediately after a flood event. The operation procedures include emptying the flood control pools as quickly as possible after a flood event, so as to be prepared for accommodating next flood. The releases should be made by ensuring not to cause downstream flooding. Surcharge pool is the uncontrolled storage capacity above the flood control pool

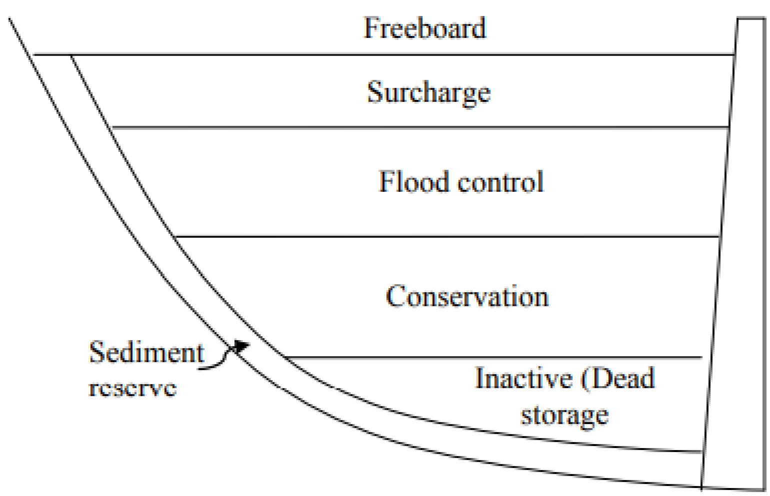

Fig.1 Pooling of reservoir storage

Three aspects of formulation of Multi-purpose Reservoir system

Formulation of Multi-purpose Reservoir System

(i) Optimal sizing and Operation of a single multipurpose reservoir

Consider a multipurpose reservoir designed for water supply, irrigation and power generation and recreation as shown in figure 2. The optimization problem here is to determine both the capacity and operation of the reservoir that maximizes the annual net benefit. The primary decision variables are the reservoir storage and the releases at particular periods to various needs.

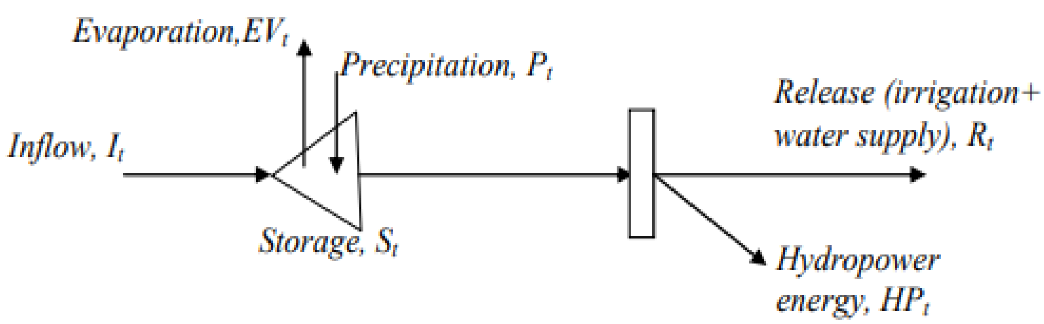

Fig. 2 Multipurpose reservoir

(ii) Optimal sizing and Operation of a multiple reservoir systems

Consider a three reservoir system in figure 3 which all reservoirs are multipurpose. The purposes are same as those of the previous problem. The hydropower generation is done by taking advantage of the head drop. No additional release is made for generating hydropower. The objective is to maximize the net benefit by determining the optimal capacity and release policy of each reservoir.

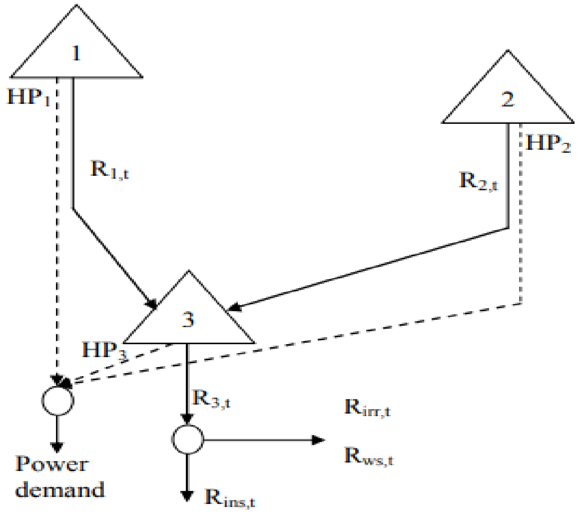

Fig. 3 Three reservoir system

(iii) Operation of multi-objective multipurpose reservoir

In cases where operation objectives have trade-offs, single-objective optimization cannot provide a unique optimum solution. Some objectives can be improved by sacrificing the others. Here the concept of "non-inferiority" as explained in the previous lecture replaces the single-objective optimization problem (either maximization or minimization). The most suitable solution is chosen by the operator according to the preferences. In general, a multi-objective reservoir operation problem can be formulated as follows

$$\text{Maximize } Z(X) = [Z_1(X), Z_2(X), \ldots, Z_n(X)]$$

Subject to

$$g_i(X) \geq 0 \text{ for } i = 1, 2, \ldots, m.$$

where X is a vector of decision variables; $Z_j(X)$, $j=1,\ldots, n$ are the objective functions and $g_i(X)$), $i=1,\ldots,m$ are the constraints that define the feasible solutions.

SIMULATION

RESERVOIR OPERATION SIMULATION

INTRODUCTION :- Reservoir simulation deals with the mathematical simulation of river network with reservoirs. The simulation models include the mass balance of reservoir inflows, outflows and storage fluctuations. These models provide an economic evaluation of damages due to floods, benefits from irrigation, hydropower generation or other such activities. Simulation models provide a realistic and detailed representation of reservoir operations. One of the most popularly used reservoir system simulation models is the HEC–5 model developed by Hydrologic Engineering Center. HEC–ResSim is the Next Generation (NexGen) model which eventually replaces HEC–5. In this lecture we will discuss the simulation of reservoir operation and the simulation models. **Components of a Reservoir simulation model** :-The main components of a reservoir simulation model are: Inputs, physical relationships and constraints, operating rules and outputs. In reservoir simulation, the inputs required are reservoir inflow, evaporation rate and irrigation water demand etc. Physical relationships and constraints defining the relationships among the physical variables of the system involve reservoir storage-elevation-area relationships, storage continuity relationships, and soil moisture balance etc. Operating rules such as release policies and rule curves define the operation of the system. The outputs are a measure of system response resulting from operating the system following known or specified rules and constraints (e.g. Quantum of reservoir release for irrigation, hydropower etc).

STEPS FOR SIMULATION OF RESERVOIR SYSTEM :-The steps to perform a simulation study are: (i) Prepare the diagram of the reservoir system indicating their names, locations, diversions, length and directions of rivers and various tributaries (ii) Collect operational details such as control locations (reservoir, diversion weir, barrage etc) and time details. (iii) Assign numbers to all control points starting from upstream node. (iv) Collect details about each location such as maximum reservoir level, initial storage, elevation – area relationship, demands, evaporation rates etc for all the periods (v) Calculate the flows from the catchment (local flow) to each control location for all periods. Identify the parameters of routing, if required. (vi) Simulate the operation of the system. Examine the performance statistics (like time and volume reliabilities, frequency of spill, largest spill, maximum storage, continuous periods of shortage etc) and plots of different variables such as release, storage and demand for various reservoirs and analyze the possible scope of improvement that can be made on the operation policy. (vii) Modify the input operation policy and simulate the model again. Repeat the model to get desired results.

RESERVOIR OPERATION FOR CONSERVATION PURPOSES

The general procedure for simulation of a reservoir for conservation purposes (such as hydropower, irrigation etc) involves: (i) Identifying the system (ii) Determining the objectives and the criteria for measuring the objectives (iii) The availability of data (iv) Formulation of model by mathematically and quantitatively representing the system's components, hydrology and operating criteria (v) Validation of model (vi) Organizing and solving the model (vii) Analyze and evaluate the results to check how much the objectives are achieved

Simulation of Reservoir Operation for Hydropower Generation

Preliminary Concepts

An average flow of q_t m^3/s, falling through a height of H_t meters continuously in a period (e.g. a week or a month), will yield a power of 9.81 q_t H_t kilowatts (kw). Power expressed i kwh will be

$$P = 9.81 \times 10^6 R_t H_t / 3600 = 2725 R_t H_t \text{ Kwh}$$

where R_t is the total volume of flow in Mm^3 in period t.

Considering a overall efficiency, η, power generated

$$P = 2725 \eta R_t H_t \text{ Kwh}$$

Therefore, hydropower produced in MW for one month (approx. 30 days)

$$P = 2725 \eta R_t H_t / (1000 \times 30 \times 24) = 0.003785 \eta R_t H_t \text{ Mw}$$

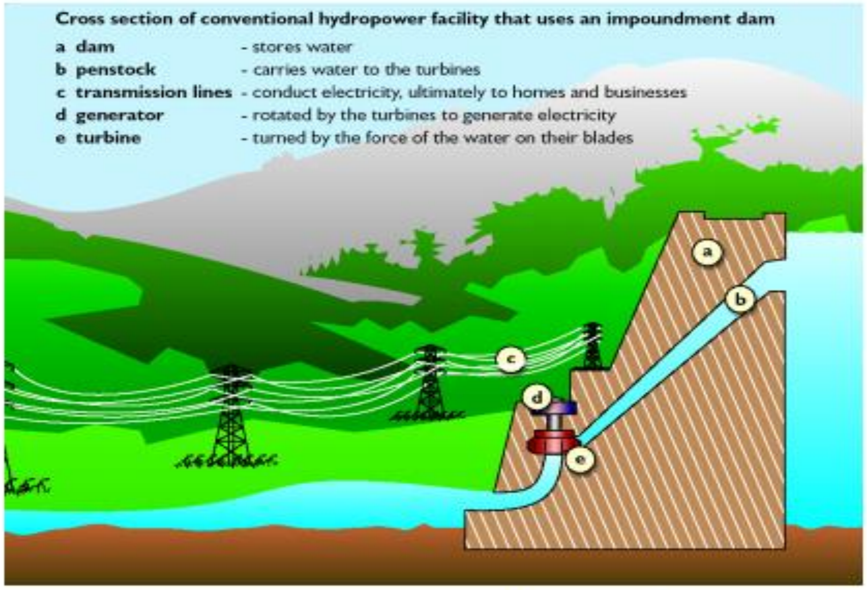

Fig. 1 Components of a hydropower system

Firm Power and Secondary Power

The amount of power that can be generated with certainty without interruption at a site, is called the firm power. i.e., at no time the power produced will be less than the firm power. The power that can be generated more than 50% of time is called the secondary power.

Example:

Consider a river with a minimum monthly flow of 40 Mm^3. If a drop of 50 m is available at a site on the river, the firm power that can be produced at the site in a month, with an efficiency of 0.7, is

$$2725\ \eta\ R_t\ H_t = 2725 \times 0.7 \times 40 \times 50 = 3815000\ Kwh\ = 3.815\ Gwh$$

If the flow with 50% reliability i.e., the flow which will be equalled or exceeded 50% of the time is 70 Mm^3, then the secondary power is

$$2725\ \eta\ R_t\ H_t = 2725 \times 0.7 \times 70 \times 50 = 6676250\ Kwh\ = 6.676\ Gwh$$