Chapter VI

CHAPTER VI

HYDROLOGIC DESIGN CRITERIA

R.K.SHARMA

Director, Hydrology (Central) Dte.,

Central Water Commission

HYDROLOGIC DESIGN CRITERIA

INTRODUCTION

Water Resources have always played a major role in human activities. Rapid industrialization, urbanization and increasing needs of agriculture for growing population have resulted in considerable demand for more water. At the present rate of increase, the demand for water may far exceed the available supplies in near future. For meeting the increasing requirements of water, it is necessary that intensive and extensive investigations and studies on various aspects of Hydrology are carried out in a systematic manner.

Hydrology constitutes a basic tool for the effective utilization of water resources in National Planning, development and coordination as well as mitigation of natural disasters caused by Hydrologic phenomenon like floods and droughts. Hydrology, in as much as it deals with water on earth, is a part of geography. Since the movement of water is controlled by the physical laws of thermodynamics and fluid mechanics, physics plays an important part in hydrology, thus hydrology becomes a part of geophysics. Man's interest in water goes much beyond a scientific enquiry. Water is an important parameter of the environment to sustain life and hence the human interest has been there in understanding hydrology in order to depict a life style which allows either a safe co-existence with water or beneficial modification of the water environment to meet increasing human requirements of food, fibre and energy etc.

As hydrology is not an exact science, application of its knowledge to practical problems requires a great deal of experience and sound judgement on the part of Hydrologist and this is attempted in Applied Hydrology (Project Hydrology).

Proper hydrologic design of the projects results in better overall utilization of available resources in general and more reliable estimates of available yield, spillway capacity, and sedimentation etc. for better management and safety of structures. Since, a great deal of experience is required in solving practical problems the need for a proper hydrologic design criteria/guidelines has always been felt by practicing engineers the world over. Obviously the criteria of designs have evolved alongwith man's experience, understanding of the principles of hydrology and the practices being followed in different parts of the world. Centuries old local water resources systems exist in the world and also in India, to meet the basic needs for drinking water and irrigation. These works were not designed on any hydrologic design criteria. As the science and man's understanding progressed the practices for the hydrological design of water resources projects improved and today the use of untested empiricism has disappeared and has given way to rational hydrologic analysis, modelling techniques, systems technology etc. With the developments in computer technology the techniques of hydrologic analysis have further improved and as such the procedures/guidelines/criteria have also suitably improved and updated.

In India, water related projects are investigated, formulated and implemented by concerned State Govts., Central Water Commission has been entrusted with the responsibility of examination of technical and economic feasibility of projects and has issued Guidelines/Criteria for Investigations and preparation of project estimates. Apart from these guidelines, Bureau of Indian Standards has also prepared a number of standards and codes of practices for carrying out investigations of projects and preparation of detailed project reports. Further, there are many other agencies which are working in the field of hydrology and their efforts are also helping in understanding the science of hydrology and evolution of specific guidelines and design criteria for project hydrology problems. The main organisations in India dealing with hydrology are :

1. Central Water Commission

   Apex Central Organisation in the field of water resources development.

2. Indian National Committee on Hydrology (INCOH)

   To guide hydrological activities and research in India.

3. National Institute of Hydrology (NIH)

   To undertake, aid, promote and coordinate systematic and scientific work in all aspects of hydrology and cooperate with national and international organisations.

4. India Meteorological Department(IMD)

   Apex Indian Government Department for Hydrometeorological measurements and studies.

5. Central/State Ground Water Board

   Apex Govt. organisations dealing with hydrological aspects of ground water.

6. Central Board of Irrigation & Power (CBIP)

   Coordinate National research in Hydrology like other disciplines in water & power.

7. Bureau of Indian Standard (BIS)

   Standardisation of parameters/terminologies in the field of hydrology is coordinated by the BIS.

8. State Irrigation Departments

   Hydrological studies and collection of data for formulation of water resources projects in the state.

9. Central/State Boards for Prevention & Control of Water Pollution

   Govt. organisations dealing with hydrological aspects of water quality.

Ministry of Water Resources, Govt. of India has brought out "Guidelines for preparation of detailed project reports of irrigation multipurpose projects" which include the guidelines/criteria which should be followed for preparation of Hydrology Volume of Detailed Project Report. The following notes have been prepared keeping in view these guidelines and other relevant Bureau of Indian Standard Codes and practices as also other criteria stipulated by various agencies working in the field of hydrology in India.

HYDROLOGICAL STUDIES FOR BARRAGE AND RESERVOIR PLANNING

Water resources development consists of changing the space and time availability of waters or their quality to suit human needs. Thus small local changes in the hydrologic cycle are involved in all water development projects and therefore requires understanding of hydrology of the catchment area. For a small storage based water development project, the main aspects of hydrology which require study would be (1) water availability study to understand the time series of inflows which can be expected in the reservoir, (ii) Flood studies to understand the floods which could be entering the reservoir. The reservoir would have to be safe in appropriately discharging the flood without endangering the dam. Some-times the reservoir would have to impart the floods to lower level in order to break floods in the downstream areas. Sometimes the reservoir would have to be operated in a way which avoids transient temporary flooding of the upstream areas due to floods; (iii) Study to determine evaporation losses from the reservoir, from water conductor systems and from irrigated areas for sustaining the plants. (iv) Sedimentation studies to determine the sequences and volume of sediment inflow into the reservoir and to study their effect in reducing the reservoir capacity. The reservoirs are to be planned in such a way that the sedimentation does not affect its performance in an unreasonable way. (v) Simulation studies to study the performance of the reservoir under a given water inflow and a given [illegible] pattern to decide its performance through a series of successes and failures.

The various hydrological inputs (studies) required for simulation and others are indicated in table-1.

Water Availability Studies

For planning of any project, the first step requires a correct assessment of water availability at the site of interest. This requires a sufficiently long sequence of data at the specific location. The length of the data depends upon the type of storage, type of development and variability of inputs.

In general, a longer period of simulation will give more confidence about the overall performance of the project. However, comparatively shorter length will suffice for within the year storage where the spill occurs almost every year and the critical period is of the duration of few months. A longer period would be required for over the year storages.

TABLE-1

(A) Types of Hydrological inputs required for Simulation

Use	Inputs
Irrigation	Water Inflows, lake Evaporation, P.E. and Rainfall.
Hydropower Water Supply	Water inflows, lake evaporation.
Navigation, salinity control, water quality control, fish & wild life.	Water inflows, lake evaporation low flow inputs.
Flood control, drainage	Flood Inputs
Surface to ground water recharge	Water Inflows, surface to ground water recharge
Multipurpose	Depending on use

Note: If the project involves large storage, sediment inflows will also be required.

(B)Hydrological inputs required for studies other than simulation

Storage	Use	Inputs
Diversion without pondage	All	- Design flood for safety of structure. - Design flood for diversion - Energy dissipation design - Sitting of riverine structure of reservoir outlets. - Tail water rating curves.
Within the year/over the year storage or any complex	All except drainage	- Same as above plus design flood for flood control works.
Any	Drainage	- Design flood for design of drainage works.

Brief Guidelines for fixing the minimum length of data required is as under.

Type of Project	Minimum length of data for use in simulation
Diversion projects	10 years
Within the year storage projects	25 years
Over the year storage projects	40 years
Complex Systems involving combination of above	Depending upon the predominant element.

The flow sequences required for planning of projects need to be prepared for an appropriate time unit so that the simulation studies are accurate and have desired resolution. As the time unit becomes shorter, resolution becomes more but this increases the computational work. Thus a time unit, as large as possible, which still gives a good resolution and accuracy is required. The general criteria/guidelines in this regard are given in table-2.

The type and extent of hydrological and meteorological investigations are planned depending upon nature and purpose of development i.e. the use to which these data would be put to, availability of data in the general region from existing networks/sites and constraints of time and money.

Broad guidelines regarding the length and frequency of hydrological observations are indicated in the table below. However, in situations where long term data of any hydrological phenomenon which is likely to be correlated with the relevant phenomenon are not available in the general region, substantially longer data would be required. Conversely, where

TABLE-2

TIME UNITS REQUIRED FOR SIMULATION
(CLASSIFIED AS PER STORAGE TYPE AND USE)

Type of Storage	Type of use	Time unit required for simulation studies (except for studies of sediment inflow and deposition)
A 1	B 2 to B 7 & B 10	Instantaneous discharges every day, or at smaller units.
A 2	B 2 to B 7	1 day to 10 days depending on the extent of pondage.
A 2	B 1	3 days for upland crops, 10 days for paddies. If extra pondage at headworks in addition to natural storage on field is provided, larger units can be used.
A 3/A 2	B 8	1 hour to 24 hours depending on the damping provided by the drainage basin to the storage.
A 2	B 10	1 day to 10 days depending on the pondage.
A 2	B 11	Minimum of individual time units required by each type of use. If flood control is involved much shorter interval (1 hr. to 24 hrs.) operation is required only for critical flood periods.
A 3	B 1 to B 3	Monthly. However, it may be sufficient to divide the year in 4 to 8 blocks by grouping together periods of definite storage accumulation and storage depletion type, and the periods which can not be classified as such being kept as separate blocks.
A 3	B 4 to B 7	Same as above, but during critical low flows, shorter time unit of about 10 days to 1 month may be required to simulate droughts and extra releases for control of water quality, salinity etc.

TABLE-2 (Cont.)

Type of Storage	Type of use	Time unit required for simulation studies (except for studies of sediment inflow and deposition)
A 3	B 10	Same as A 3 - B1 to B3 discussed above, in dry season, but in rainy season where extra recharge will be affected by rainfall, 1 day to 10 day working will be necessary.
A 3	B 11	Minimum of individual time units for

CLASSIFICATION BY STORAGE BEHIND THE STRUCTURES	CLASSIFICATION BY USE OF PROJECT
A-1 Diversion projects without pondage	B-1 Irrigation
A-2 Diversion projects with pondage	B-2 Hydropower
A-3 Within the year storage projects	B-3 Water supply and industrial use
A-4 'Over the year' storage projects	B-4 Navigation
A-5 Complex systems involving combination of 1 to 4 above mentioned	B-5 Salinity Control
	B-6 Water Quality Control
	B-7 Recreation, fish and wild life
	B-8 Flood Control
	B-9 Drainage
	B-10 Surface to ground water recharge
	B-11 Multipurpose

there is sufficiently long term data available in the vicinity of the desired location, a smaller length than indicated in table-3 may be adequate.

All locations of sites and observations should follow IMD/BIS Standards.

Discharge measurement shall be done by area velocity method using current meter.

Hydraulic structures across the rivers can also be used for flow measurement provided the structures has been properly calibrated preferably by model tests.

In case of storage reservoirs, lake levels reasonably-accurate area capacity tables and withdrawal and lake evaporation data would be required for indirect computation of flow volumes.

Number of ordinary raingauge stations will be so decided as to bring the density to about one station per 600 sq. km in non-orographic regions (less than 1000 m elevation) and about one station per 150 sq. km in orographic regions. One station out of every four ordinary raingauge station shall preferably be equipped with a self recording raingauge, with a minimum of two such stations in the drainage area and other areas of interest. Where no flood studies or water balance studies, are required, rainfall data requirements would be much less.

Pan evaporation and other meteorological data measurement stations shall be set up at major storage reservoir sites and in the irrigation command areas keeping in view the availability of such stations.

While deciding the location of additional hydrological and meteorological stations, future requirements for operational stage of the project shall be kept in view.

TABLE-3

Type of Information	Minimum Length	Frequency
1. River Gauge Data	10 years	Daily at 0800 hrs. during low flows seasons - Thrice daily at 0800, 1300 and 1800 hrs during high flow season. Continuous with an automatic water level record with back up arrangements for hourly quarter hourly observations manually for flood periods and peak(s) respectively.
2. River Flows Discharge	10 years	Weekly during low flow season daily during higher flow season. For rivers with stable beds 20 to 30 observations during high flows covering rising and falling stages shall be sufficient after a few years.
3. Sediment flow and grain size composition.	3 years	- do - alongwith discharge observations.
4. Water Quality	3 years	About once a month with more frequent observation during low flows and concurrent with discharge observations.
5. Water Salinity	3 years	Same as above but additional observations in tidal reach of the river twice a month and at closer interval (3 hours during spring and neep tides).

TABLE-3 (Cont.)

6. River Profiles cross sections showing flow levels	–	The surveys may have to be repeated occasionally for moveable bed rivers. Information to cover all major floods and all critical low flows in recent years.	
7. Pan evaporation concurrent with ordinary raingauge and observation measuring temperature(maximum and minimum dry and wet bulb) wind velocity, sunshine etc.	3 yrs.	Daily	
8. Rainfall (ordinary raingauge) as necessary for strengthening existing network	10 years concurrent with flow observations for rainfall-runoff corelation and as available for hind casting	Daily	longer period
9. Self Recording Raingauges	10 years concurrent with observation	Continuous to be tabulated as hourly/quarter hourly	

Having decided the specifications of the information required, and having assessed the basic data availability, the hydrologist has to use various techniques to extend/generate long term flow sequence for proper evaluation of water availability and project planning. This important task of the hydrologist has been covered in other lectures, however the methodologies and models used in general are indicated below for sake of completion.

METHODOLOGIES

1. Data extension or gap filling.
2. Information transfer from one catchment to another.
3. Transfer of model coupled with data extension.
4. Synthetic generation of data.

MODELS

* Statistical empirical models
* Conceptual models
* Time Series models

In India since rainfall data is normally available for a longer period than runoff data, it is very common to extend runoff data by correlation with rainfall data.

Sedimentation of Reservoirs

Due to impact of rain and water flowing over land surfaces, in gullies and stream channels, large quantities of top soil is eroded from the catchment, and rivers carry huge quantities of silt. When the water surface slope in a stream in equilibrium is reduced by rise in water level e.g. by building a dam, the sediment transport capacity of the stream is reduced at every section in the backwater region and hence sediment in excess of the transport capacity is deposited upstream of dam. As a result there is progressive loss of capacity of the reservoir. Percent loss of capacity per year for some of the Indian reservoir is given below to indicate the magnitude of the problem.

LOSS OF CAPACITY OF SOME INDIAN RESERVOIRS

Name of Resersvoir	River	Period of Observation Years	% Loss of Capacity Per Year
Gobindasagar	Sutlej	17	0.35
Panchet Hill	Damodar	18	0.65
Matatila	Betwa	13	0.78
Maithon	Barakar	16	0.50
Hirakund	Mahanadi	11	0.36
Mayurakshi	Mayurakshi	19	0.49
Gandhisagar	Chambal	5	0.05
Lower Bhavani	Bhavani	12	0.20
Tungabhadra	Tungabhadra	10	0.97

PROBLEMS DUE TO SEDIMENTATION

The deposition of sediment which takes place progressively in time reduces the active capacity of the reservoir which in turn affects the regulating capability 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 sediment into the canals/water problems of rise in flood levels in the head reaches and unsightly deposition of sediment from recreation point of view may also crop up in course of time.

Water resources systems operate over a long period of time and are subject to ever increasing demand for water for various purposes. Besides, long term changes in terms of technology and production functions are also encountered. Man-made changes taking place in the river basin and consequent changes in hydrologic regime controlling the water inputs over-long term periods are also encountered and have to be provided for (All these factors are to be considered and taken into account while assessing performance of any reservoir project). In this context, sedimentation of reservoirs is to be viewed as an additional factor which has to be considered and its effects studied and evaluated on the reservoir performance.

SEDIMENTATION ASSESSMENT

The sediment yield in a reservoir can be measured by using river sediment observation data or more commonly from the experience of sedimentation of existing reservoirs with similar characteristics. Sediment yield at a station can be measured by making suspended and bed load measurements on the river using sediment samplers. It has been found that suspended load Q_s of the bed material is related to the water discharge Q by the equation

$$Q_s = a\ Q^b$$

where 'a' depends on channel, flow and sediment characteristics, and 'b' varies between 1.5 to 2.5. For a given stream such a relation can be developed for each season in order to get more accurate results. It is necessary to evolve proper sediment water discharge rating curve and combine it with flow duration curve based on uniformly spaced daily or shorter time units in case of smaller river basins. When observed flow data is available for shorter periods, these are suitably extended with longer data on rainfall to eliminate, as far as possible, the sampling errors due to shortness of records.

The sediment discharge rating curves can also be prepared from hydraulic considerations using sediment load formulae, but this has not yet become popular. To the suspended load must be added 'Q_b'. the bed load discharge at that station. Measurement of bed load in large stations is very difficult. In the absence of detailed measurements, Q_b is taken as a certain percentage of Q_s depending on concentration of suspended load and size of bed material and suspended sediment. Following table gives general guidance about this.

BED LOAD CORRECTION TABLE

Suspended Load Concentration	Stream Bed Material	Texture of Suspended Material	% of Bed Load in Terms of Measured Suspended Load
1	2	3	4
Less than 1000	Sand	Similar to bed of stream	25 to 150
Less than 1000	Compacted clay gravel cobbles, boulders	Small amount of sand	5 to 12
1000-7500	Sand	similar to bed stream	10 to 35
1000-7500	Compacted clay, gravel cobbles, boulders	25% of sand or less	5 to 12
Greater than 7500	Sand	Similar to bed stream	2 to 8
Greater than 7500	Compacted clay, gravel cobbles, boulders	25% sand or less	5 to 15
Any concentration	Clay & silt unconsolidated	Silt & Clay	Less than 2

The present Indian Code recommends that bed load be estimated as a percentage generally ranging from 5 to 20 percent of the suspended load. However, practical means of measuring bed load of sediment need to be undertaken particularly in cases where high bed loads are anticipated.

In India, presently, Central Water Commission is carrying out sediment observations at 318 stations and State Govts. are also operating some stations. Standard procedures in entire CWC network are being followed and the sampling device is a point integrating sampler like Punjab Bottle sampler or L-80 Turbidi-Sonde sampler. Bed load measurement is not being carried out as a matter of routine. Bed load survey using Russian bed load sampler has however been carried out on few rivers in Ganga Basin under a research project. This data is being published by CWC as annual sediment year Books and is usually used for assessing the silt rates for different catchments while planning water development projects.

The volume of sediment that deposits in the reservoir is estimated using average trap efficiency for the reservoir and expected unit weights of sediment deposits, time averaged over period selected. The trap efficiency depends on capacity inflow ratio but also varies with location of outlets and reservoir operating procedures. In India, trap efficiency is computed using trap efficiency curves developed by Brune and by Churchill.

Reservoir reserves available for projects in the vicinity can also be used in deciding annual sediment inflow. Sediment rates assessed from past data are analysed for trends and likely future changes to decide the rates that would apply in future. When upstream future development is expected, the projects under construction or which have the same priority of being taken up and completed as the project in question are considered for assessing the total sediment yield (IS-12182-1987). However, the MOWR guidelines indicate that allowance shall be made for existing projects or projects under construction. No allowance shall be made for future projects.

DISTRIBUTION OF SEDIMENT VOLUME

Once an assessment of expected volume of total sediment deposition for the required time period has been made, the revised elevation area capacity curves of the reservoir are prepared by using Empirical Area Reduction Method. This method is based on the analysis of data of sediment distribution obtained from resurvey of reservoirs. In this method, reservoirs are classified into four types, namely (a) gorge, (b) hill, (c) flood plain-foot hill, and (d) lake, based on the ratio of the reservoir capacity to the reservoir depth plot on a log-log scale. The empirical sediment distribution-area design curves for each of the four types of reservoir are used to distribute the sediment throughout its depth. The equation for the design curves is of the type.

$$A_p = C^m \quad (1-p)^n$$

Where A_p = a non-dimensional relative area at relative distance 'p' above the stream bed, and

C, m and n = non-dimensional constants which have been fixed depending on the type of reservoir.

First step in empirical area reduction method requires determination of type of reservoir which is obtained by plotting reservoir depth as ordinate against reservoir capacity as abscissa at different elevations on a log-log paper. A line is drawn through the plotted points. Reciprocal of slope of the line determines the reservoir type as per standard groupings. Next using the appropriate design curve and assuming a value of

New Zero Elevation (level upto which reservoir is fully silted up) the sediment area and thus volume at different levels are worked out. The total volume of silt thus worked out should be close to the sediment volume which is to be distributed in the reservoir. If the two are different, a new value to NZE is assumed and computations redone, till the desired accuracy (+1%) is achieved. The revised area capacity curves so worked out are used for reservoir simulation while planning the projects. The Empirical Area reduction method is well documented in literature, thus it has been discussed in these notes very briefly, for details other relevant publications can be referred.

LIFE OF RESERVOIRS

After considerable discussions and deliberations, the water planners in India have agreed that the reservoirs do not have a single well defined life. According to the Compendium on silting of reservoirs in India (1991), reservoirs do not have, strictly speaking, a defined life which denotes two functional states 'ON' and 'OFF'. They show a gradual degradation of performance without any sudden non-functional stage. Sedimentation and consequent reduction of capacity is a gradual process, which can be classified in following phases:

Phase-I The reservoir shows no adverse effects and is able to deliver the full planned benefits.

Phase-II The reservoir delivers progressively smaller benefits, but its continued operation for the reduced benefits is economically beneficial.

Phase-III The sedimentation causes difficulties in operation such as jamming the passage of flow in canals or through turbines.

Phase-IV The Phase-III difficulties become so serious that the operation becomes impossible.

Phase-V The benefits reduce to such an extent that it is no longer beneficial to operate the reservoir.

A similar approach has been incorporated in the Indian Standard IS : 12182 (1987). In this approach the end of Phase-I will depict the end of the period in which the reservoir is capable of yielding the full planned benefits. The Phase-II would depict a period when the operation of the reservoir is also trouble free, in regard to sedimentation, although the efficiency of the reservoir is gradually reducing, and management measures to adjust to the reduction are required. The Phase-III would be a period of troubled operation, and unless some new engineering solutions are implemented, the project may have to be given up in phase-IV or phase-V.

PLANNING PRACTICES FOR RESERVOIR SEDIMENTATION IN INDIA

Dr. A.N. Khosla, the then Chairman, Central Water Commission (CWC) had in the fifties reviewed the work of reservoir sedimentation based on data available for 200 reservoirs all over the world including U.S.A., China and Africa and developed enveloping curves for annual sedimentation rate for major and minor catchments above and below 1000 Sq. miles (2600 sq. kms.) respectively. He concluded that the sediment rate for measure catchments varies from 0.357 to 0.476 mm/year (3.57 to 4.76 ha.m./100 sq.km./yr.) and for minor catchments from 0.38 to 1.28

mm./year(3.80 to 12.8 ha.m/100 sq.km./yr). Upto 1965, the above recommendations were adopted in the design of reservoirs and the sediment was assumed to get deposited at the lowest level and 'life' was taken as the period required for complete sedimentation of the dead storage. Thus, in this old practices;

Life in years = Dead storage capacity/average annual sediment yield.

The normal planning practice is to have this 'life' of at least 100 years.

The assumption that sediment would settle within the dead storage was not supported by the experience in other countries or India. The experience of USA was that sedimentation takes place throughout the reservoir and the development of methods for sediment distribution were published around early fifties. It was also realised that the sediment inflow rates need to be checked up through reservoir resurveys. Hence resurveys in a number of projects were taken up through research schemes. The results, indicating a considerable difference from the initial assumption, started becoming available by 1965. After 1965, CWC started insisting that the sediment inflow rates be based on the basis of reservoir survey data. It also brought out the need for distributing the sediment throughout the reservoir. For this purpose, the empirical area reduction method was preferred in general. Atleast the more important major projects had to adopt this new approach. However, no guidance was given until then about which stage of sedimentation should be used for the working table studies.

Around 1974, it was decided that the 50 year sedimented position of the reservoir should be used in the simulation or working table studies for the project. Also by this time the observed suspended sediment data from the key hydrologic network of CWC had become available in considerable volume. CWC therefore started insisting on the use of this measured sediment transport data also to firm up the assumption of the inflow rates of sediment, in addition to the reservoir re-survey information. In 1980, the report of the working group on the guidelines for the preparation of detailed project report of major and medium irrigation projects was published. In this report, CWC had incorporated the above mentioned practices to make these mandatory on the State Governments. Also in this report the detailing of the sediment studies was linked with the expected seriousness of the sediment problem. For very serious cases, redistribution and reestimation of trapping efficiency in 10 year block was indicated.

In 1987, CWC got this practice incorporated in the IS: 12182(1987) "Guidelines for Determination of Effects of Sedimentation in Planning and Performance of Reservoirs" to make this the national practices. In these guidelines the general philosophy and the concept of multiple life related terms was also spelt out. Also these guidelines indicated that the full services time for hydroelectric projects can be reduced to 25 years against 50 years of irrigation projects. The IS guidelines also include notes on the need for periodic resurveys and give guidance to determine their frequency.

The present practice as incorporated in IS: 12182(1987) has following main features:

1. The sedimentation rate is to be decided on the basis of observations of river sediment flow and reservoir surveys.

2. Methodologies for trapping efficiency and sediment distribution have been specified. For trapping efficiency determination, both the Brune's Curves or the Churchills method

are advocated. For distribution of sediment within the resersvoir depths, empirical area reduction method is preferred.

3. The live storage is to be so planned that the benefits do not reduce for a period of 50 years (full service time) for irrigation or 25 years for hydropower projects connected to a grid on account of sedimentation.

4. The live storage is to be planned that sedimentation beyond the outlet, causing operational problems, would not occur for 100 years for irrigation projects and 75 years for hydropower projects in a grid.

5. For simulation, if sedimentation is not serious, the conditions obtained at the end of full service period are to be used throughout the simulation period. If the problem is serious, studies are to be done by redistributing sediment and recomputing trap efficiency in 10 year blocks.

The extent of studies to be done themselves are linked to the seriousness of the problem, as assessed in a preliminary study. For this purpose, the problem is categorised in three classes:

Insignificant - If the annual loss of capacity is less then 0.1 percent, the problem is taken as insignificant. "No check on Full Service Time" needs to be made. The availability of adequate Feasible Service Time however have to be ensured.

Significant - If the annual loss of capacity is between 0.1 percent to 0.5 percent , the simulation or working table studies may be done for the reservoir geometry as obtained at the end of the "Full Service Time". This would simplify the simulation study, and would also ensure that the planned benefits are available for this period.

The availability of adequate "Feasible Service Time" is also to be checked.

Serious - If the annual loss of capacity is beyond 0.5 percent, the recompilation of trapping efficiency and reservoir geometry for every 10 in the simulation studies is preferred.

While deciding this practice, a thought had to be given to various issues, some of which are discussed below:

The projects, in India, are subject to economic analysis and a benefit cost ratio of more than 1.5 is generally required to prove the interest rate of 10 percent is assumed. At this rate of interest, the present value of the benefit stream hardly reduces. If the benefits reduce fast say after 30 years. (For example the present value of perpetual benefit stream of Rs.1/yr. would be Rs.10, whereas that of stream of Rs.1/yr. for next 30 years alone would be about Rs.9.50. Thus, economic analysis, would favour projects with relativity small "full" and "feasible" service times. There were however two strong extra economic considerations explained below:

1. The availability of "good" reservoir sites constitutes a significant natural resources. Unlike water resource, this resource is not renewable, since dredging is, in general, impracticable. Any policy requiring a "short run" use of this important resource could jeopardise the future of mankind.

2. The irrigation benefits are site specific. To reap these benefits, the farmers have to be organised to change their lifestyle to shift from the traditional rainfed agriculture to irrigated agriculture. Such adoption is not free from social stress and problems. If, soon after such a change, the farmers are to face inadequate availability or non availability of water, there could be even more serious social and economic problems in the region. Atleast a couple of generation of farmers should not face endemic water shortages in the post project conditions.

Against these two strong extra economic considerations which would favour long full and feasible service times, the planners had to weigh the economic considerations, and the practicability of looking up capital sums for additional storages without planned use. The current decisions explained above are somewhat adhoc decisions reached in these circumstances.

Indian practice as incorporated in the guidelines of 1987 has been evolved from 1974 onwards. Some of the difficulties experienced as per this practice are described below:

(a) For many Himalayan Streams which carry very heavy loads of sediments, planning of the project with a feasible service time of 75 or 100 years becomes difficult. For hydroelectric projects in particular, it is possible to repay the development costs in a few years, and a project can be planned effectively for a shorter period. In Pakistan, for example, the Tarbela project has perhaps been planned to use most of its capacity in about 50 years. This brings us to the extra-economic considerations discussed earlier. A periodical thinking of this aspect is perhaps necessary.

(b) A large number of hydro-electric and even irrigation Projects are planned as pondages where the capacity: inflow ratio or the detention period can be of the order of a few days to a month. For many such projects, most of the capacity is against crest gates. There is a belief amongst planning engineers that for such structures, where the gates would inflow period, no sedimentation would occur above the crest of the gates. Although there is enough empirical evidence to indicate that sedimentation does occur above crest level, simple methods to indicate the new regime of the river upstream of the dam, and the 'ultimate' pondage available for re-regulation in spite of sedimentation, are not available.

Reservoir Capacity-Simulation Studies

The normal sequence of planning of water resource systems involves testing of the trial designs of water resource systems under various inputs to see if they produce the desired level of output as planned. For a single storage, the problem is one of matching the size of interdependent parameter such as reservoir design and operating rules, target demand and its seasonal variation and reliability required in obtaining the target demand. 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, sequential routinng, performance assessment studies etc. In this method, the water balance of the reservoirs 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.

DECISION ABOUT TIME UNIT AND LENGTH OF DATA

The recommendations regarding the choice of time unit and length of data have already been discussed under para 2.1 - Water Availability Studies. In general, smaller time unit gives better resolution and longer period gives more confidence about the performance of system.

PHYSICAL CONSIDERATION IN MODELLING

While modelling the water resource system for simulation, various physical considerations have to be modelled. Some of these are as follows.

(i) The maximum and minimum limits of storages are to be modelled while simulating the change of storages under inflows and outflows.

(ii) The maximum diversion capacities of various diversion structures and the maximum hydraulic capacities (elevation-outflow curves) for the outlets & spillways are to be modelled.

(iii) The elevation area capacity data of the resevoir is to be modelled. This will be required both for computing evaporation losses and for deciding the operating head on turbines. The elevation area capacity curve of a reservoir would change in time as sedimentation occurs. However, unless sedimentation is extremely serious, it is not worthwhile trying to model this change in time. It is sufficient to fix a time (normally 50 years for storages having the expected elevation area capacity curve at the end of this period. This sedimented elevation area capacity data can be modelled and used throughout the period of simulation.

(iv) In addition to these, other parameters like water quality may have to be modelled by the appropriate physical processes in some cases. Return flows from irrigation areas, industrial uses etc. are to be modelled and brought back in the computations at appropriate place.

(v) If any transfers between surface and ground water (either gains or losses) are expected in a long river reach, these have to be modelled.

(vi) The passage of flood flows through the reservoir and through reaches of the river would be of interest in projects involving flood control. Appropriate techniques are to be included in the model. Also, stage discharge relations at salient flood damage points will have to be modelled so that water levels can be estimated & monitored.

MODELLING OF DEMANDS

Demand for irrigation or industrial and water supply can be modelled as fixed annual quantities having a fixed cyclic variation within the year. However, for areas or for seasons where the rainfall contributes considerably to the total crop water requirement, the irrigation water requirements are likely to be different from year to year depending upon the rainfall pattern. In such cases, a separate model for deciding the water demand in that particular year and season would be required. The slow growth of demand can also be modelled.

Power demand is normally modelled as firm target output. Although the firm power would normally be at the same level throughout the year, a seasonal fluctuation in the load may require or allow firm power level itself to have seasonal fluctuations. The water required for power generation would have to be calculated to meet the firm power demand depending upon the average water level during the time period. This procedure is iterative.

Evaporation can be considered as an automatic demand since the quantum depends upon the average surface area of the lake, the volume is found by iterative procedure.

OPERATION POLICIES

For complicated water resource systems, an appropriate decision on operation policies forms the crux of simulation. The policy at a multipurpose single reservoir would involve :

(i) Considerations to separate the firm and secondary demand and for deciding the priorities of uses;

(ii) Rules for deciding outflows to meet non-compatible requirements for different uses in case of shortages;

(iii) Rules for distributing shortages or anticipated shortages for different time periods;

(iv) Rules deciding the distribution of irrigation shortages over different crops;

(v) Rules regarding operation to suit flood control, i.e.

(a) Rule curves for slow filling of conservation shortages so that the reservoir is kept empty as far as possible without causing a large risk of the conservation storage not getting filled up.

(b) Rules deciding flood releases during the flood.

These rules will also incorporate emergency procedures where the flood is so much that the safety of the structure is involved.

(vi) Rules incorporating forecasts of inflows

One important consideration is that the operation rules should be based only on the data available and the study of the system at the time of operation. Thus it is not permissible to reduce the release from a reservoir in a particular year because from the historical data it is known that the "next" year is going to be a drought year. Similarly the simulation will not reflect reality if, because of the 'foresight' available in using the past data as the future data, the reservoir is kept empty to negotiate a particular future flood beyond the forecasting possibilities.

(vii)External Constraints

The system may have to consider constraints outside the system boundary. These may be in the form of minimum or maximum permissible release downstream, reservation for upstream use etc. These would have to be modelled. However, it may many times be unrealistic to consider these external constraints as inflexible under some unusual hydrologic situations. Such situations have to be foreseen and the relaxation of the constraints in different situation would also have to be modelled.

After the systems model is ready the performance of the reservoir can be simulated from one time period to another. This working can be presented as a working table showing the initial state inflows, demands, outflows, meeting the demands, unused compulsory outflows, shortages etc. at each reservoir/ points of interest etc.

ABSTRACTING THE PERFORMANCE OF SIMULATION STUDIES

Since the purpose of the simulation studies is to know the acceptability or otherwise of the performance of the particular design under the given hydrologic inputs, this performance is to be abstractlevels. It may not be necessary to give the complete tabulation of the simulation studies.

The different performance indices, for a particular use can be:

(i) Number of failure years compared with total years for which simulation is done. Here even a small failure for any one month will qualify the whole year as a failure year.

(ii) Number of censored failure years compared with the total years. Here the failures below a threshold level, in quantum or in time, would be neglected.

(iii) Number of crop seasons for which failure of irrigation occurs compared with total crop seasons considered in simulation. Again the failure may be either censored or uncensored.

(iv) The total time units for which the failure occurs compared to the total time units used in the simulation. A variation of this index is the reliability which is number of time units in which the demand is met divided by the total number of time units.

(v) The average annual quantum of shortage i.e. the sum of all shortages divided by the total period of simulation including the years of success. Another variation of this index is the 'Volumetric Reliability' which is equivalent to Fiering (1967) performance index. This is defined as the actual average supply over the study period divided by the demand.

Each performance index has some advantages, the volumetric reliability in general takes into consideration the overall performance but does not bring out the severity of the failures. The timings of the failure would also be of importance for irrigation.

In case an economic model (loss function) which can convert the failure at any period into the equivalent 'shortrun' loss is available, the average annual cost of failure would provide a powerful performance index. But even in such a case, the extra economic factors like social acceptability of an unreliable supply will have to be considered while comparing alternatives.

The acceptability of performance as seen in the simulation is decided by checking if the firm demands have been met with the desired reliability: that is, whether these meet the acceptability criteria. In case, these are not met or the performance is better than required, it is customary to change the assumptions and conduct simulation study again in the planning phase of the project. In general, for irrigation and hydropower projects, it is customary to adopt the following acceptability criteria:

a) Any year or water year in which the firm demands are labelled as a failure year.

b) The ratio of failure years to the total years of simulation is determined. For irrigation and hydro-power, the ratio shall not exceed 0.25 and 0.1 respectively. The evaluation of performance may also be made through economic analysis considering the series of benefits from year to year, during the period of simulation.

DESIGN CRITERIA FOR PREPARATION OF HYDROLOGIC INPUTS FOR DESIGN

A design flood is a hypothetical flood (peak discharge or hydrograph) adopted in the traditional methods of engineering design as the basis for the design of one or more project components or purposes. Some of the common purposes are:

(i) Design floods adopted for the safety of structures against failure by overtopping etc. during floods, such as design flood adopted for dams to decide their spillway capacities/spillway surcharge storage and ;free board requirements, design floods for barrages/weirs to decide their water ways and free board requirements, design floods for deciding the height of coffer dams and capacities of river diversion works during construction, design floods for cross drainage structures, bridges etc. to decide their water ways.

(ii) Design floods adopted for flood control and drainage works to provide safety to down stream/local areas against flooding.

(iii) Design flood (levels) for siting the structures on river banks for safety against flooding.

Since design floods adopted often mark the difference between safety and disaster, utmost attention has been given the world over to select and estimate the design flood that is most appropriate for a given case. Economic, social and other non-hydrologic considerations influence the philosophy of protection, and hence the selection. Policy criteria have been laid down by most organisations for several applications and are followed unless there are compelling local factors for deviation in the particular case. For instance, according to Central Water Commission criteria for major hydraulic structures, spillways of all major and medium dams with storage larger than 50,000 ac. ft. (61 Mm3) are to be designed for the probable maximum flood. Where such floods cannot be estimated for any reason these provide a design flood of atleast 1000-year return period. Dams having smaller storages than above are to be designed to negotiate the standard project flood or the 100 year return period flood at the site, whichever is higher.

For small structures and also for uses at (ii) and (iii) above, and for temporary river diversion works during construction used; the selection of return period being governed by policy decisions wherever these exist or by economic and technical consideration of particular case.

Criteria for fixing spillway capacity

The hydrologic design criteria for fixing spillway capacity as prevalent in India are indicated in IS 11223-1985, "Guidelines for fixing Spillway Capacity" According to these guidelines various inflow design floods that need to be considered for various functions of spillways are:

(a) Inflow design flood for the safety of the dams:

It is the flood for which the performance of the dam should be safe against overtopping, structural failure and its energy dissipation arrangements, if provided for a lower flood, should function reasonably well.

(b) Inflow design flood for efficient operation of energy dissipation works:

This flood could be lower than the flood for safety of dam and for this the dissipation arrangements, are expected to work most efficiently.

(c) Inflow design flood for checking extent of upstream submergence.

(d) Inflow design flood for extent of downstream damage in the valley.

The criteria for classification of dams is based on size of the dam and the hydraulic head (MWL - average flood level on downstream). The classification for the dam is greater of the two indicated by the two parameters:

classification	Cross Storage	Hydraulic Head
Small	Between 0.5 and 10 million m^3	Between 7.5m & 12m.
Intermediate	Between 10 & 60 million m^3	Between 12m & 30 m.
Large	Greater than 60 million m^3	Greater than 30 m.

The inflow design flood for safety of the dam would be as follows :

Size as Determined above	Inflow design Flood for Safety of Dam
Small	100 year flood
Intermediate	SPF
Large	PMF

Floods of larger or smaller magnitude may be used if the hazard invohigh or low. The relevant parameters to be considered in judging the hazard in addition to the size would be :

i) distance to and location of the human habitations on the downstream after considering the likely future developments.

ii) maximum hydraulic capacity of the downstream channel at a level at which catastrophic damage is not expected.

For more important projects dam break studies may be done as an aid to the judgment in deciding whether PMF needs to be used. Where the studies or judgment indicate an imminent danger to present or future human settlements, the PMF should be used. Any departure from the general criteria as above on account of larger or smaller hazard should be clearly brought out and recorded.

Although criteria and guidelines as above are available to assist in the choice of a particular type of flood, for any structure location specific factors etc. are also to be considered in this important decision. In this background a high level technical committee under the Chairmanship of Member (WP), CWC also exists to which the State Govts. refer various projects to deçide upon the type of design flood to be adopted for working out "inflow design flood".

The Committee advises about the type of inflow design flood to be adopted for a particular structure, to ensure an acceptable level of the hydrologic safety, after considering the general guidelines/criteria of the BIS/CWC and other bodies, the importance of the project, the affects of its likely failure, the availability of data etc. The Committee also advises about the ambient conditions like initial reservoir level, type of preceding & succeeding flood, type of mechanical failure etc. to be considered for the cases, again after reviewing the general guidelines & the specific considerations involved. For the storage structure referred to it, the Committee also advises whether a lower flood can be adopted as 'the design flood for the most efficient operation of the energy dissipation arrangements', and if so the type of this flood.

All the storage dams involved in irrigation/hydropower/water supply/multipurpose which are to receive external assistance are referred to the Committee. Other dams, not receiving such an aid may also be referred to the Committee by the State Govts. concerned at their discretion. Similarly, other hydraulic structures like barrages, weirs, cross drainage structures but not including road and railway bridges may also be referred to the Committee at the discretion of the concerned organisation.

While the committee normally limits its work to a high level technical opinion about the type of design flood to be adopted, where required by complications of the case, the committee also goes into the procedures and methods and gives a decision on the design storm/design flood to be adopted.

In cases where inflow design flood for safety of the dam may not undermine the dam foundation and endanger its safety the energy dissipation arrangements for the spillway may be designed for the best efficiency for a smaller inflow flood than the inflow design flood for the safety of the dam.

The inflow design floods for safety or for energy dissipation for intermediate and large dams the design situation is required to consist of the flood followed or preceded by a 25 year flood, if two large floods have occured in close succession in the region in past. The period between the two is decided after analysis of past data.

Where a 'T' year flood is to be used through probability analysis, any value between and including the expected value of the flood, as indicated by the analysis to be 95 percent upper confidence ban value, may be used depending on the importance of the structure, length of data, etc.

Inflow design flood for checking the extent of upstream submergence depends on local condition, type of property and effects of its submergence. Except for very important structures in the upstream like power houses, mines, etc. for which levels corresponding to SPF or PMF may be used: smaller design floods and levels attained under these may suffice. In general a 25 year return period flood for land acquisition and 50 year return period flood for built up property acquisition may be adopted.

Inflow design flood for checking extent of downstream damage depends on local conditions, type of property and effects of its submergence. For important facilities like power houses, the outflows under inflow design flood for safety of dams and all gates operative condition are relevant. Normally, the discharge relevant to check acceptability of downstream submergence may be smaller than those for power houses at or near the toe of the dam.

Design Criteria for Barrages and Cross Drainage Structures

Selection of suitable hydrologic design criteria for river structures is a problem faced by the engineers all over the world. Apart from safety the economic considerations are also important. An optimum design criteria can be reached by compromising the cost and the risk factors. Design floods for these structures are decided on the basis of a 'T' year return period with a calculated risk of the flood being exceeded. A flood of specific frequency , is adopted depending on the functional importance, with judicious combination of safety and economy.

CRITERIA FOR DESIGN FLOOD ESTIMATION FOR BARRAGES

For barrages, the CWC 1968 criteria applies. Diversion dams or weirs and barrages have usually small storage capacities, and the risk of loss of life and property down stream would rarely be enhanced by failure of the structure. Apart from the loss of the structures by its failure, this would bring about disruption of irrigation and communications that are dependent on the barrage. In consideration of these risks involved the CWC criteria redesigned for floods of frequency 50 to 100 years. For barrages, it requires the use of a 100 year return period flood or standard project flood whichever is higher.

CRITERIA FOR DESIGN FLOOD ESTIMATION FOR WEIRS (UNGATED HEADWORKS)

In the case of small reservoirs where the release of stored water due to the failure of the dam would not appreciably enhance the flood hazard downstream, the spillway capacity may be designed for a design flood of specified frequency, say 50 to 100 years as recommended by the Central Water Commission.

CRITERIA FOR DESIGN FLOOD ESTIMATION OF ROAD AND RAILWAY BRIDGES

For road bridges, the Indian Road Congress IRC: 5-1970, Section-I General Features of Design applies. According to this, the design discharge for which the waterway of a bridge is to be designed shall be the maximum flood observed for a period of not less than 50 years; shall be discharge from an another recognised method applicable for that area; shall be the discharge found by the area velocity method; by unit-hydrograph method; and the maximum discharge fixed by the judgment of the engineers responsible for the design with comparison of above mentioned method is to be adop-ted. For railway bridges, a 50-year flood is to be used for smaller bridges carrying railways of lesser importance like minor lines and branch lines. In the case of larger bridges i.e. those carrying main lines and very important rail lines, a 100-year return period flood is to be adopted as per the railway codes (Indian Railway Standards - 1963).

CRITERIA FOR DESIGN FLOOD ESTIMATION FOR CROSS DRAINAGE STRUCTURES ON IRRIGATION NETWORKS

The cross drainage works can be classified under three broad categories viz. (i) Structure for a carrier channel over a natural drainage (ii) Structure for a carrier channel underneath a natural drainage and (iii) Structure for a carrier channel crossing a natural drainage at the same level. The design flood to be adopted for minor cross drainage works depend upon the size of drainage channels, the canals, the cost and importance of the structure. The BIS Code of practice for design of cross drainage works [IS:7784(part-I)1975] recommends that the design (of waterway) in such cases may be based on 10 to 25-year frequency flood with increased afflux. However, the foundations and free-board etc., should be checked to be safe for the increased afflux and velocities due to a 50-yr or 100-yr return period flood.

For very large cross drainage works, damage to which is likely to affect the canal supplies over a long period the design should be based on maximum probable flood. It is quite probable that a flood of higher magnitude than the design flood may pass through the structure posing great danger to the stability of foundation and the structure. Return period to take care of this unprecedented and unforseen nature of flood intensities in cases of important structures, an adequate margin of safety is envisaged in the estimation of design discharge. For this purpose, the design discharge may be increased by the percentages given below for obtaining the foundation and free-board design.

Sl.NO.	Catchment Area	Increase in Design Discharge
1.	Up to 500 Km 2	30% to 25% decreasing with increase in area
2.	500 to 5000 Km 2	25% to 20% decreasing with increase in area
3.	5000 to 25000 Km 2	20% to 10% decreasing with increase in area
4.	Above 25000 Km 2	Up to 10 percent

As per Central Water Commission criteria, waterways for canal aqueducts should be provided to pass a 50-100 year return period flood, but their foundations and free boards should be for a flood of not less than 100-year return period.

Each site is individual in its local conditions, and evaluation of causes, and effects. While, therefore, the above mentioned norms, may be taken as the general guidelines, the hydrologist, and, the designer would have the discretion to vary the norms, and the criteria in special cases, where the same are justifiable on account of assessable and acceptable local conditions; these should be recorded, and, have the acceptance of the competent authority.

Govt. of Gujarat has adopted a still severer criteria for cross drainage works of Sardar Sarovar Narmada Canal, which is given below.

Range of Catchment Area	Design flood to be adopted	
	For designs	For checking
0 - 10 Sq. miles	100-yr R.P. flood	100-yr R.P.flood +30%
10 - 50 "	-do-	-do-
50 - 200 "	-do-	P.M.F.
200 Sq. miles & above	-do- (or S.P. Flood)	P.M.F.

Design Criteria for Flood Control Schemes

The design criteria for flood control schemes has also evolved in India over the years, pooling the experiences and practices followed by various State Govts. and Central Organisations.

During the fifties, CWC has recommended that for flood embankments the highest flood level which the embankment should withstand may be assessed based on the data situation. Where G-D data was available for 40 to 50 years a 100-year flood was recommended, when shorter data was available, the flood could be assessed based on certain relations developed between flood value and storm rainfall and choosing a design storm rainfall intensity from past rainfall data. However, when no data was available, local empirical formulae like Dicken's or Ryves could be used. The high flood levels so obtained were increased for other unaccounted factors by an amount which was taken as certain percentage of the depth of inundation over natural ground.

Later, the following broad criteria was recommended and followed in the country.

(1) Predominantly agricultural areas	25 years flood frequency on small tributaries and 50 years flood frequency on major rivers
(2) Town protection works	100 years flood frequency
(3) Important industrial complexes, assets and lines of communications	100 years flood frequency

Since enough long range hydrological data is not available and since the results of frequency analysis on the basis of short term data can be misleading, the general practice followed is to adopt the above frequencies or the observed maximum flood in the recent past, which ever is higher." The CWC have further stated that "...where the frequency studies have been carried out on the basis of a long-term data, works for agricultural areas should be designed only on the basis of frequency specified and not on the basis of observed data even if it is higher. However, in the case of towns, each case will have to be considered on its merits depending upon the damage potential, further growth of the town after the original construction of works etc."

According to Ganga Flood Control Commission "Subject to availability of observed hydrological data, the design HFL may be fixed on the basis of flood frequency analysis. In no case, the design HFL should be lower than the maximum on record. For small rivers carrying discharge upto 3000 cumecs, the design HFL shall correspond to 25 years return period flood. For the river carrying peak flood above 3000 cumecs, the design HFL shall correspond to 50 years return period. However, if the embankments concerned are to protect big township, industrial area or other places of strategic importance the design HFL shall generally correspond to 100 year return period flood.

In the case of double embankments, the design HFL shall be determined keeping in view the anticipated rise in the HFLs on account of jacketting of the river."

The Rashtriya Barh Ayog recommends that benefit-cost criterion should be properly adopted. But since the relevant data for such an analysis may not be available the Ayog recommends" (i) for predominantly agricultural areas: 25-year flood frequency (in special cases, where the damage potential justifies, adopted). (ii) for town protection works, important industrial complexes etc: 100-year flood frequency (for large cities like Delhi, the maximum observed flood, or even the maximum probable flood should be considered for adoption).

CONCLUSIONS

Design criteria refers to standards and practices laid down for judging whether a project has been properly designed to deliver the anticipated outputs. If different criteria are adopted, different engineering decisions may result and which criteria should be adopted depends on decision maker. The need for criteria and standardisation arises whenever choices between alternatives are to be made in a systematic and scientific manner. Further, the areas of activity which address the problems involved with complexities of nature, have to necessarily depend on experience and judgment, and thus need adequate standards and criteria to guide the practicing engineers and decision makers.

The above notes are based on Indian experience and practices in the field of project hydrology and do not compare the same with standards and criteria followed elsewhere. However, the standards may be similar to those that are followed in other countries in as much as the guidance taken from the experiences of other countries while framing Indian Standards.

REFERENCES

1. Refresher Course for Inservice Engineers on "Hydrology for Senior Engineers": (1981) Central Water Commission, New Delhi.
2. Embankment Manual, CW&PC, No.:73, Nov. 1960, Flood Wing, Central Water & Power Commission, Ministry of Irrigation & Power, New Delhi.
3. Sedimentation Study of Narmada Sagar, HYD 315, Jan. 1990, Hydrology (Central)Directorate, Central Water Commission, New Delhi.
4. Systems Engineering Workshop for Water Resources Development and Reservoir Operation. Lecture Notes, Jan. 1985, Systems Engineering Unit.
5. Working Group Report "Guidelines for Preparation of Detailed Project Reports of Irrigation and Multipurpose Projects" 1980, Govt. of India, Ministry of Irrigation, New Delhi.
6. Report of Rashtriya Barh Ayog (National Commission on Floods) Mar. 1990, Govt. of India, Ministry of Energy and Irrigation (Deptt. of Irrigation), New Delhi.
7. Lecture Notes of "Regional Training Course on Reservoir Sedimentation and Control, Dec. 1991, Central Water Commission, New Delhi. .p135
8. National Seminar on Use of Computers in Hydrology and Water Resources, 1991, Central Water Commission, New Delhi.
9. Workshop on Design Flood Estimation for small and medium catchments in Gujarat, 1991, Hydrology Study Organisation, Central Water Commission, New Delhi.
10. Design Criteria for Flood Protection Embankment Sections; 1978, Ganga Flood Control Commission, Patna.

11. IS:12182-1987 "Guidelines for Determination of Effects of Sedimentation in Planning and Performance of Reservoirs", Feb. 1988, Bureau of Indian Standards, Manak Bhawan, New Delhi.

12. IS:11223-1985 "Guidelines for fixing spillway capacity", Nov. 1985, Indian Standards Institution, Manak Bhawan, New Delhi.

13. IS:5477 (Part I-IV_-1969 "Methods for Fixing the Capacities of Reservoirs" July 1970, Indian Standards Institution, Manak Bhawan, New ?Delhi.

14. IS:7784 (Part_I)-1975, IS Code of Practice for Design of Cross drainage works, 1975, Indian Standards Institution, Manak Bhawan, New Delhi.

15. IRC: 5-1970, General Features of Design-Section-I, 1970, Indian Road Congress, Jam Nagar House, New Delhi.