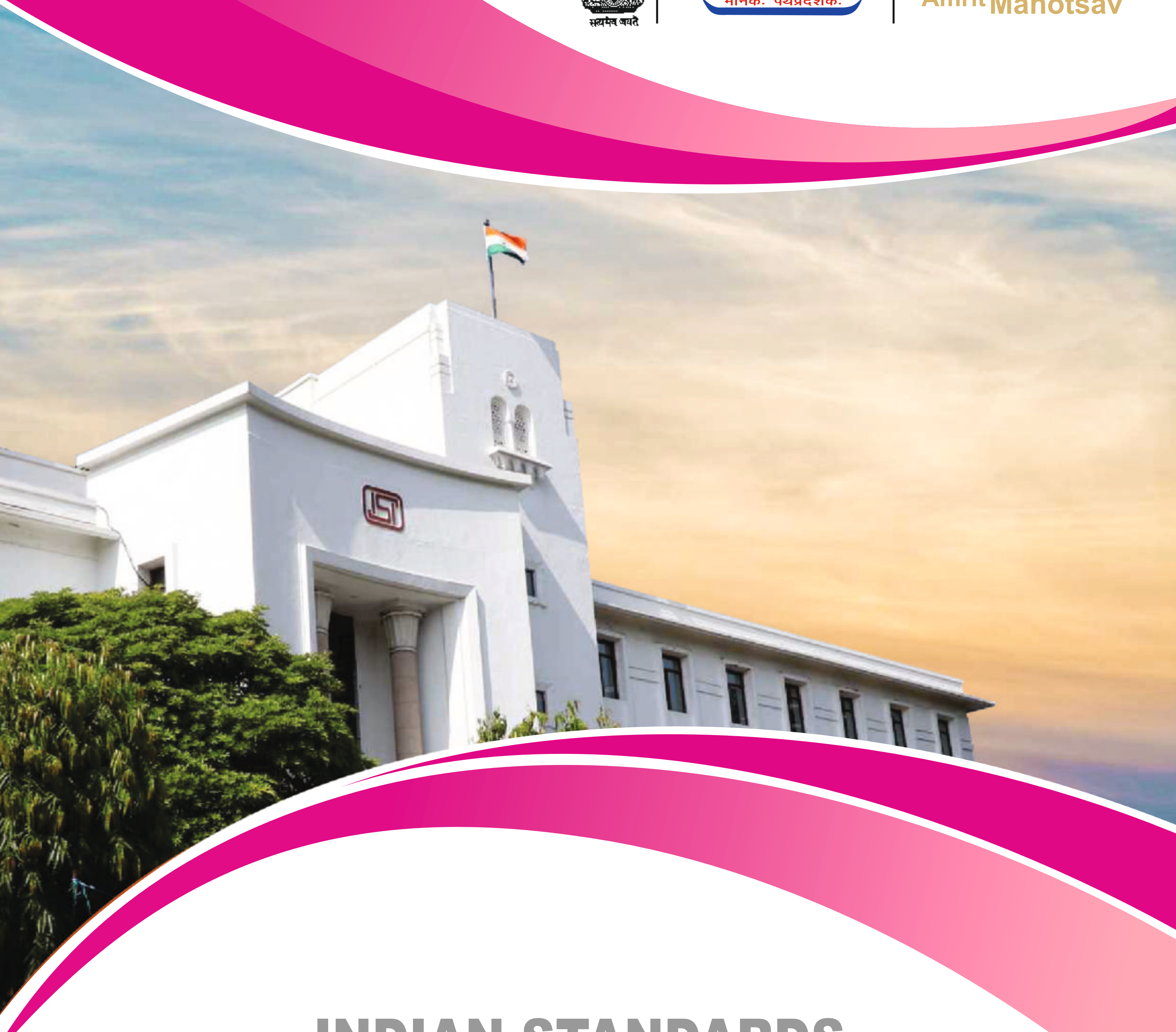


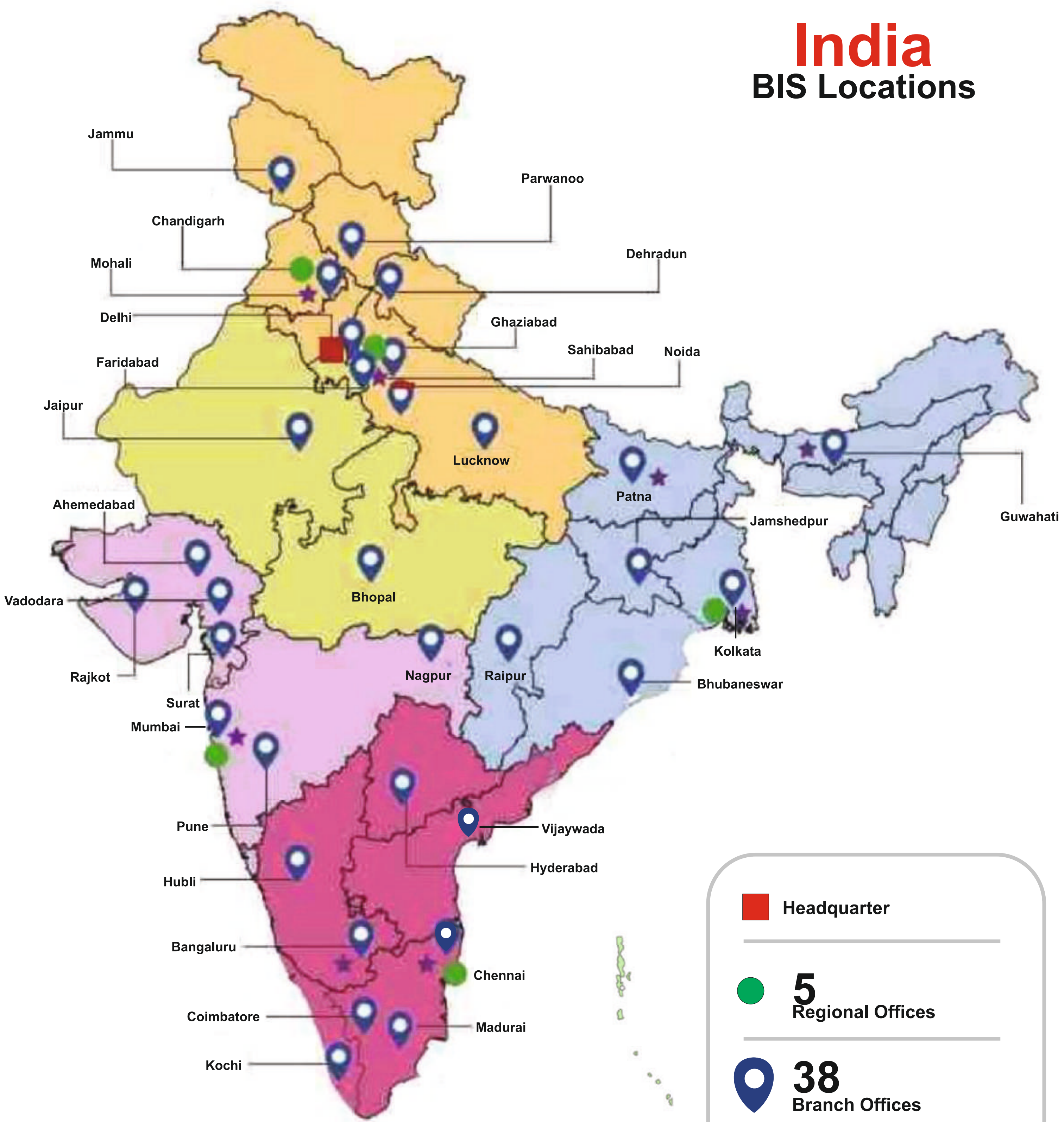
# INDIAN STANDARDS
# ON
# LAKES & RESERVOIRS - FIXING OF CAPACITIES OF RESERVOIRS


**BUREAU OF INDIAN STANDARDS**
Ministry of Consumer Affairs
Food and Public Distribution
Government of India

**भारतीय मानक ब्यूरो**
उपभोक्ता मामले, खाद्य और
सार्वजनिक वितरण मंत्रालय
भारत सरकार

NORTHERN CENTRAL EASTERN WESTERN SOUTHERN

# India
## BIS Locations




Headquarter

**5** Regional Offices

**38** Branch Offices

**8** Laboratories

Training Institute (NITS)

# ABOUT BIS

Bureau of Indian Standards (BIS), the National Standards Body (NSB) of India was established under the *BIS Act*, 1986 and came into existence on 1 April 1987 assuming the functions of the erstwhile Indian Standards Institution (ISI). The ISI was established on 6 January 1947. *The BIS Act*, 2016 came into force on 12 October 2017 superseding BIS Act 1986. *The BIS Act*, 2016 provides for the establishment of a national standards body for the harmonious development of the activities of standardization, conformity assessment and quality assurance of goods, articles, processes, systems and services and for matters connected therewith or incidental thereto.

BIS through its core activities of standardization and conformity assessment, has been benefiting the national economy by providing safe, reliable and quality goods; minimizing health hazards to consumers; protecting the environment; controlling over proliferation of varieties; promoting exports and imports substitutes, etc. The standardization and conformity assessment schemes of BIS apart from benefitting the consumers and industry also support various public policies especially in areas of product safety, consumer protection, food safety, environment protection, building and infrastructure development, etc.

BIS also represents India in international standards bodies like International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) and participates actively in the international standardization work undertaken by these bodies. BIS presents the national viewpoints on new areas taken up for international standardization and on various draft international standards during the process of development of these standards so that the country's interest is protected and reflected in these standards. This also enables the BIS technical committees to consider adoption of the international standards as Indian Standards, with or without modifications, in order to enable our products and services to integrate with global trade and commerce.

### What are Standards?

Standard is a document, established by consensus and approved by a recognized body, that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context.

### Importance of Standardization

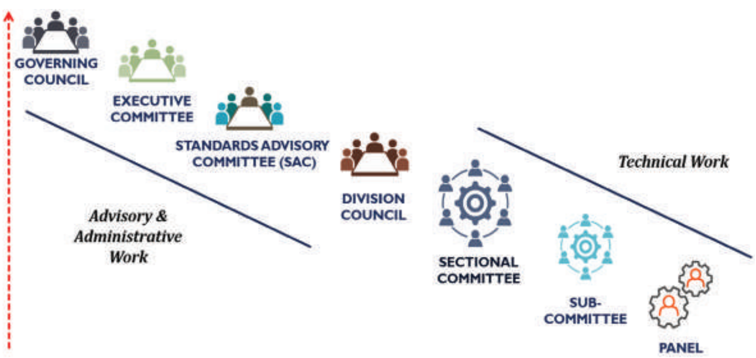
Standardization is the process of developing technical standards through consensus of different parties.This standardization aims to address one or all of compatibility, interchangeability, variety control, safety, environment protection, product protection and fitness for purpose. Standards provide numerable benefits to the technologists, producers, consumers and traders besides defining purpose for each of these entities.

Standards can be formulated at various levels ranging from an individual through National (IS) to International level (ISO). Also, depending on the subject in hand, standards can be made on various aspects such as terminology, specification, sampling, testing, code of good practice, systemes and services.

## STANDARDIZATION ACTIVITY OF BIS

### Standardization Structure

There are 16 Technical Departments formulating standards in various subject areas. Corresponding to these departments, 16 division councils exist. Each division council has several sectional committees working under it. The standards cover important segments of economy and help the industry in upgrading the quality of their goods and services.

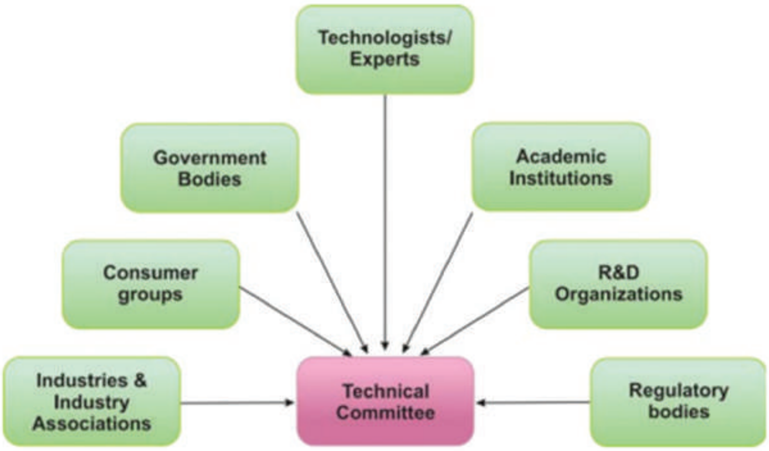


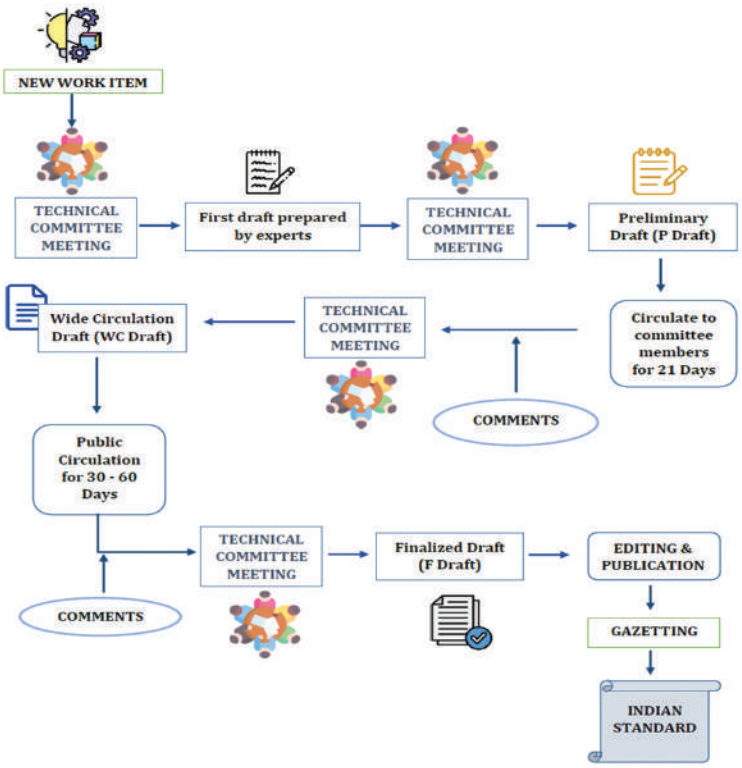
| | | | |
|---|---|---|---|
| Ayush Division Council (AYDC) | Chemical Division Council (CHDC) | Civil Engineering Division Council (CEDC) | Electro-Technical Division Council (ETDC) |
| Electronics & Telecommunication Division Council (LITDC) | Food and Agriculture Division Council (FADC) | Mechanical Engineering Division Council (MEDC) | Management and Systems Division Council (MSDC) |
| Metallurgical Engineering Division Council (MTDC) | Medical Equipment & Hospital Planning Division Council (MHDC) | Petroleum, Coal & Related Products Division Council (PCDC) | Production and General Engineering Division Council (PGDC) |
| Transport Engineering Division Council (TEDC) | Textile Division Council (TXDC) | Water Resources Division Council (WRDC) | Service Sector Division Council (SSDC) |

## Standards Formulation Process

The Indian Standards are developed by technical committees that are representative of various stakeholders having interest in the relevant subject of standardization under the scope of such committees through a process of consultation so that views of all are given due consideration and a consensus is evolved in formulating a standard. The stakeholders involved in national standardization can broadly be categorized as industry, consumers/ users, technologists (R&D and scientific institutions, academia, individual subject experts, etc) and government departments/regulators.

The process of standards development of BIS is aligned with accepted international best practices that are based on the core principles of openness, transparency, impartiality and consensus. The process begins with the identification of the standardization needs of the given sector or subject following which the development of the standard is taken up and planned bythe relevant technical committee. Apart from consultation within the technical committees, draft standards are also open for public views/comments.




Standards Development Process Flow

**WATER RESOURCES DEPARTMENT (WRD)**

WRD is one of the 16 technical departments of BIS with the scope "Standardization in the field of water resources development and management; to include activities covering utilization of water resources for all uses. In regard to drinking and industrial water supply, the work shall be confined to making the raw water available for treatment and distribution. However, special publications for water management shall include all facets of technology and engineering covering the entire hydrologic cycle. In regard to water for hydroelectric uses, the work shall include planning and design of hydroelectric development and powerhouse structures but may not include generation, transmission, and distribution equipment.".

WRDC is the division council of the WRD department.

The aspect-wise breakup of the standards formulated by WRDC is given below:

| Aspect | No. of Standards |
|---|---|
| Product Standards | 11 |
| Methods of Test | Nil |
| Codes of Practice | 368 |
| Terminology | 37 |
| Dimensions | Nil |
| Others | 45 |
| Total | **461** |

WRD, BIS is a 'P' member in 7 committees and an 'O' Member in 6 committees of ISO. It also holds the Secretariat for 3 ISO Committees, viz

1. ISO TC 113
2. ISO TC 113/SC–1
3. ISO TC 113/SC–6

## List of Sectional Committees under WRD

Under WRD, there are 17 Sectional Committees working in various subject areas. The list of committees with their scope is as follows:

| Sectional Committee Number | Sectional Committee Name | Scope |
|---|---|---|
| **WRD 01** | Hydrometry | Standardization of methods, procedures, instruments, and equipment relating to techniques for hydrometric determination of water level, velocity, discharge, and sediment transport in open channels and fluid flow in closed conduits, hydrological and meteorological investigations. |

| | | |
|---|---|---|
| | | Co-ordination with the work of:<br>i) ISO/TC 113 Hydrometry and its subcommittees SC 1 and SC 6 –Secretariat<br>ii) ISO/TC 113/SC 1, SC 2, SC 5 & SC 6 – P member<br>iii) ISO/TC 30 measurement of fluid flow in closed conduits and its subcommittees SC 2, SC 5, and SC 7 – O member |
| **WRD 03** | Ground Water and Related Investigation | Standardization of all aspects of groundwater resources, related investigations, water harvesting, and recharge for groundwater Coordination with work of:<br>i) ISO/TC 113/SC 8 – P member<br>ii) ISO/TC 319 – O member |
| **WRD 05** | Geological Investigation and Subsurface Exploration | Standardization of criteria for choice of methods, investigations, and testing of subsurfacestrata and recommendations for the collection and presentation of data. |
| **WRD 06** | Water Resources Planning, Management and Evaluation | Standardization for water resources planning, development and management. |
| **WRD 08** | Foundation and Foundation Treatment | Standardization of criteria for design and construction of foundations on rocks, impermeable and permeable strata for water resource projects, including methods of foundation treatment. |
| **WRD 09** | Dams and Spillways | Standardization of criteria for planning, design, construction, maintenance and related aspects of various types of dams and spillways. |
| **WRD 10** | Reservoirs and Lakes | Standardization of criteria for planning, design, operation, maintenance and other related aspects of reservoirs/lakes. |
| **WRD 12** | Hydraulic Gates and Valves | Standardization of criteria for selection, design, construction, maintenance, operation and testing of gates and valves. |
| **WRD 13** | Canals and Cross Drainage Works | Standardization of criteria for planning, location, design, construction, inspection, maintenance and other related aspects for canals and cross drainage works. |
| **WRD 14** | Water Conductor Systems | Standardization of criteria for planning, design, construction, maintenance and related aspects of all components of water conductor systems. |
| **WRD 15** | Hydroelectric Power House Structures | Standardization of criteria for location, design, construction and maintenance of powerhouse structures, including pumped storage. |
| **WRD 16** | Hydraulic Structure Instrumentation | Standardization of criteria for selection, installation, usage and maintenance of instruments used for the measurement of displacement, strain, stress, temperature etc. in hydraulic structures. |
| **WRD 21** | Safety in Construction, Operation and Maintenance of River Valley Projects | Standardization of safety aspects during various stages of construction, operation and maintenance of components and appurtenances of water resource projects. |

| | | |
|---|---|---|
| **WRD 22** | Flood Management, Erosion Management and Diversion Works | Standardization of criteria for planning, design, construction, operation, maintenance and other related aspects of river training works, barrages, weirs and diversion works. |
| **WRD 23** | Measurement and Cost Analysis of Works for River Valley Projects | Standardization in the field of measurement and cost analysis of civil engineering works for water resource projects. |
| **WRD 24** | Environmental Assessment and Management of Water Resources Projects | Standardization in the field of environmental assessment, evaluation and management relevant to water resources projects. |
| **WRD 28** | Coastal Zone Water Management | Standards on planning, design, construction and management of coastal zone water resources. The scope covers the standardization on coastal pollution, coastal erosion, desalination, intake and outfalls, salt water intrusions, remote sensing, estuary hydraulics, back water, islands, coastal hazards, coastal structures and coastal aquifers. |

## RESERVOIRS & LAKES

Reservoirs & Lakes Sectional Committee, WRD 10 is one of the 17 sectional committees working under WRDC with the scope "Standardization of criteria for planning, design, operation, maintenance and other related aspects of reservoirs/lakes".

This committee has formulated a total of **14** standards. The complete list of standards formulated by this committee has been placed below.

| Sl No. | IS No. | Title |
|---|---|---|
| **1** | IS 4410 Part 6 : 1983 | Glossary of Terms Relating to River Valley Projects: Part 6 Reservoirs |
| **2** | IS 5477 Part 1 : 1999 | Fixing the Capacities of Reservoirs Methods: Part 1 General Requirements (First Revision) |
| **3** | IS 5477 Part 2 : 2020 | Methods for Fixing the Capacities of Reservoirs: Part 2 Dead Storage (Second Revision) |
| **4** | IS 5477 Part 3 : 2002 | Fixing the Capacities of Reservoirs – Methods: Part 3 Live Storage (First Revision) |
| **5** | IS 5477 Part 4 : 2019 | Methods for Fixing the Capacities of Reservoirs: Part 4 Surcharge Storage (First Revision) |
| **6** | IS 6518 : 2017 | Guidelines for Control of Sediment in Reservoirs (Second Revision) |
| **7** | IS 6939 : 1992 | Methods for Determination of Evaporation from Reservoirs (First Revision) |
| **8** | IS 7323 : 1994 | Operation of Reservoirs – Guidelines (First Revision) |
| **9** | IS 8237 : 1985 | Code of Practice for Protection of Slope for Reservoir Embankment (First Revision) |
| **10** | IS 12182 : 1987 | Guidelines for Determination of Effects of Sedimentation in Planning and Performance of Reservoirs |

| | | |
|---|---|---|
| **11** | IS 13665 : 2017<br>ISO 6421 : 2012 | Hydrometry – Methods for Assessment of Reservoir Sedimentation (First Revision) |
| **12** | IS 14654 : 1999 | Minimising Evaporation Losses from Reservoirs – Guidelines |
| **13** | IS 15472 : 2004 | Guidelines for Planning and Design of Low Level Outlets for Evacuating Storage Reservoirs |
| **14** | IS 15840 : 2009 | Determination of Volume of Water and Water Level in Lakes and Reservoirs |

The important standards formulated by this committee in regards to fixing of capacities of reservoirs are explained in brief in this handbook.

# IS 4410 Glossary of Terms Relating to River Valley Project : Part 6 Reservoirs

**Scope**

This standard contains definitions of terms relating to the various types of reservoirs, storage and sedimentation in reservoirs, and evaporation losses from reservoirs, but does not contain definitions of terms relating to sub-surface or groundwater reservoirs.

**Reservoir**

A pond, lake, or other space, either natural in its origin or created in whole or in part by building engineering structures used for storage, regulation, and control of water.

**Types of Reservoirs**

- **Distribution Reservoir —** A reservoir connected with the distribution system of a water supply project, used primarily to care for fluctuations in demand that occur over short periods and as local storage in case of emergency.
- **Impounding Reservoir —** A reservoir with gate-controlled outlets wherein surface water can be retained for a considerable period and released for use at a time when the normal flow of the stream is insufficient to satisfy requirements.
- **Balancing Reservoir —** A reservoir downstream of the main reservoir for holding water released from the main reservoir more than that required for irrigation, power generation, or other purposes.
- **Grit Reservoir —** A reservoir used for the storage of turbid water for the purpose of sedimentation.
- **Multipurpose Reservoir —** A reservoir constructed and equipped to provide storage and release of water for two or more purposes such as irrigation, flood control, power generation, navigation, pollution abatement, domestic and industrial water supply, fish culture, and recreation.

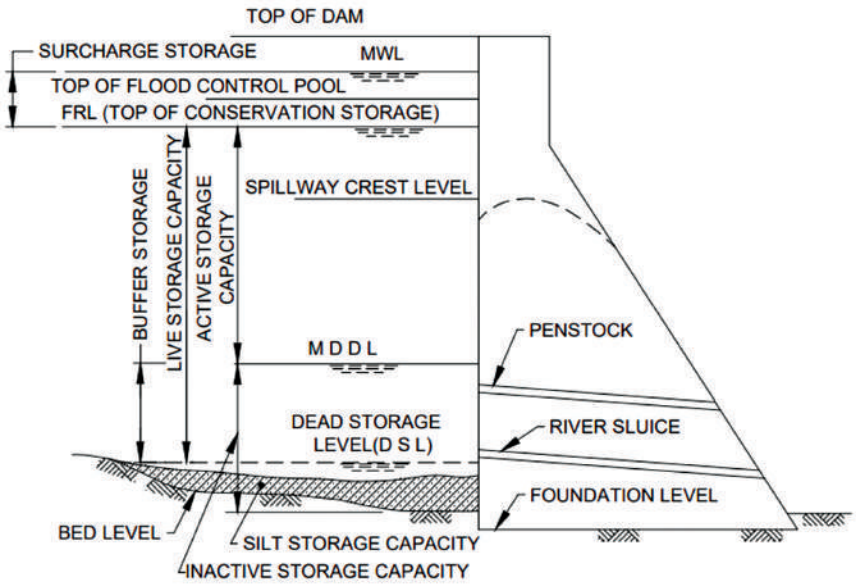
**Terms Relating to Storage in Reservoirs.**

- **Full Reservoir Level (F.R.L) —** The highest reservoir level that can be maintained without spillway discharge or without passing water downstream through sluiceways.
- **Minimum Draw Down Level (M.D.D.L) —** It is the lowest level at which the full release towards meeting the specified purpose is physically possible and allowable under operating instructions.
- **Active Capacity —** The storage available for project purposes, usually the storage between the lowest allowable level of release (M.D.D.L) and the highest controlled water surface (F.R.L).
- **Inactive Capacity —** Storage capacity; exclusive of dead storage, below minimum draw-down level (M.D.D.L).
- **Dead Storage (D.S.L) —** Storage of a reservoir not susceptible to release by the in-built sluices/ outlet means.
- **Buffer Storage —** The space located between the dead storage level (D.S.L) and minimum draw-down level (M.D.D.L).
- **Live Storage Capacity —** Capacity available between dead storage level (D.S.L) and full reservoir level (F.R.L).
- **Maximum Water Level (M.W.L.) —** The maximum water level likely to be attained in the reservoir at the dam face while negotiating the adopted design flood.

- **Controlled Storage Capacity —** Reservoir storage capacity subject to control by the operation of gates or other control devices.

- **Silt Storage —** Storage designed for the accumulation of silt in a reservoir.

- **Surcharge Storage —** Storage capacity between the maximum operating level of a reservoir (or F.R.L) and the maximum water level (M.W.L).



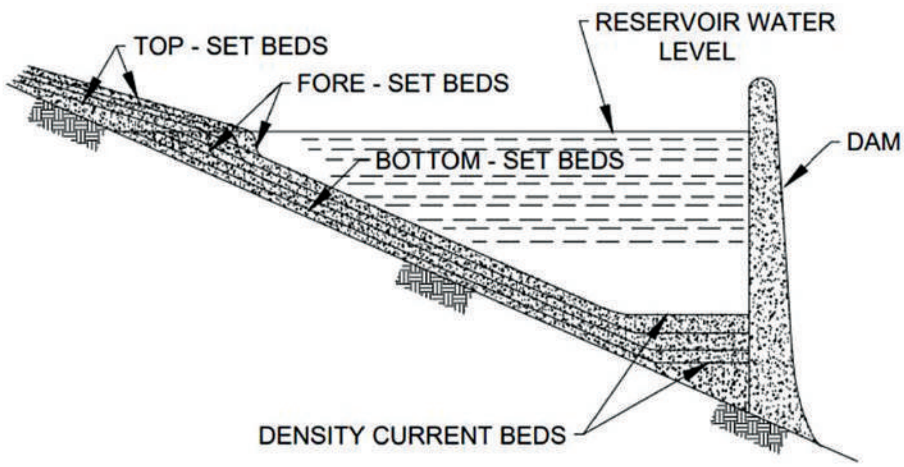

**Terms Relating to Sedimentation in Reservoir.**

- **Bottom - Set Beds —** Beds formed from the finer particles usually of silt and clay carried by the stream water in suspension. The particles settle very slowly in the bottom of the reservoir.

- **Fore - Set Beds —** Beds formed from the coarse sediments carried by the stream usually traveling on or near the stream bottom and deposited where the current retards as it flows into the reservoir.

- **Top - Set Beds —** These are usually composed of rapid-setting coarse.

- **Trap Efficiency —** The trap efficiency of the reservoir is defined as the ratio of the total deposited sediment in the reservoir to the total sediment inflow in a year. It is expressed as a percentage.



**Terms Relating to Evaporation from Reservoir and its Control.**

- **Evaporation —** The process by which the water is changed from a liquid state to a gaseous state below the boiling point through the transfer of heat energy.
- **Evaporation Rate —** Quantity of water evaporated from a given water surface per unit of time, expressed in terms of **mm per day.**
- **Potential Evaporation —** Quantity of water vapour that could be emitted by a surface of pure water, per unit surface area and unit time, in the existing condition.
- **Evaporation Pan —** An experimental tank used to determine the amount of evaporation from the surface of water.
- **Evaporation Retardants —** Methods or measures of evaporation reduction from the water surface, such as windbreaks, shading, and protective films.
- **Dosage —** The quantity of the retardant substance required to form a monolayer on a unit of water surface in the first instance, or for subsequent regular replenishment of the film formed.
- **Wind Breaks —** A barrier composed of planted trees, on the shores of the reservoir, designed to break the velocity of the wind over the water surface to reduce evaporation.

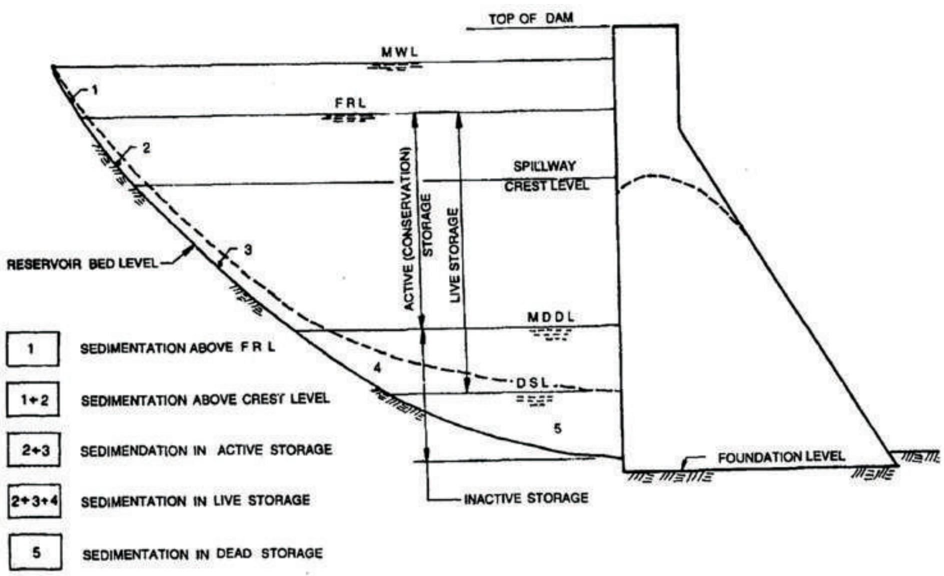
# IS 5477 Fixing the Capacities of Reservoirs – Method : Part 1 General Requirements

**Scope**

This standard deals with data and information required for the location and fixing of the capacity of reservoirs and specifies the post-construction data to be collected during the operation of the reservoirs.

**Some Important Terms**

- **Sediment Yield —** The total quantity of sediment brought in a year to a reservoir because of erosion in the watershed. Expressed in mm per unit area per year.
- **Within-the-year Storage —** Storage of a reservoir meant to meet the demands of a hydrologic year.
- **Carry-over Storage —** The water stored in a reservoir that is not used up in a year and is stored for use in the next year.
- **Flood Control Storage —** Storage capacity provided to attenuate the flood peak depending on its volume and downstream releasing constraints.
- **Field Storage —** The water above full reservoir level (F.R.L) spreading towards the catchment area.
- **Sedimentation Zones —** The space occupied by the sediment in the reservoir. It can be divided into separate zones of reservoirs as shown below.




**In the context of reservoir storage, various critical aspects are considered:**

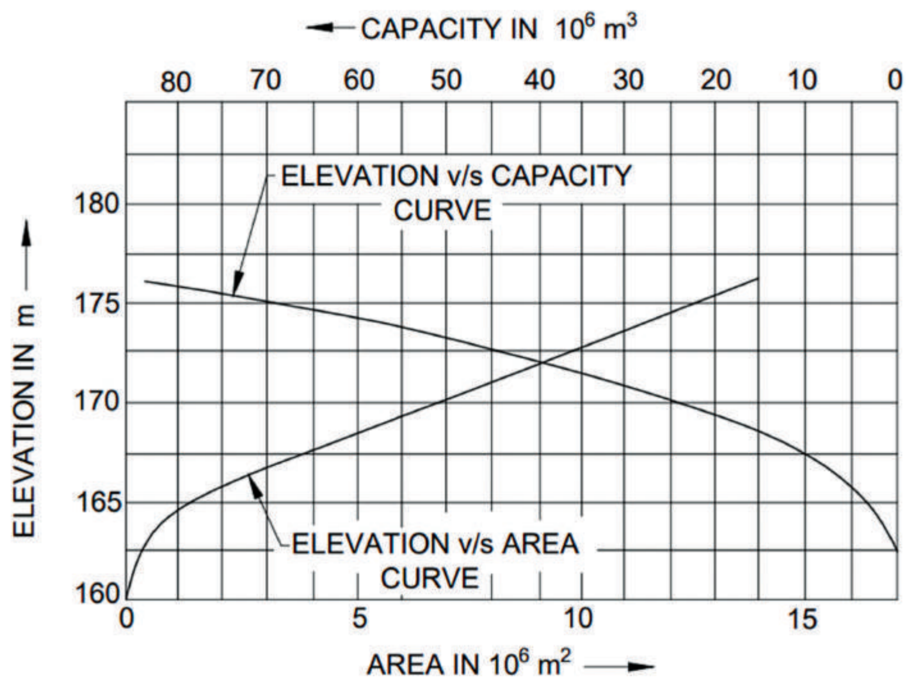
- **Inactive Storage (Including Dead Storage) —** This is the capacity at the reservoir's lowest level, reserved for sediment accumulation during its economic life. It may also include space below the minimum drawdown level (M.D.D.L) in power generation projects. The lowest sill level of outlets is determined to ensure it remains above the expected new zero elevation after the feasible service period.

- **Active or Conservation Storage —** This storage ensures a reliable water supply to meet project demands (e.g., power, irrigation, or water supply). It should guarantee specific success rates, such as 75 percent for irrigation, 90 percent for power, and 100 percent for water supply projects (unless in drought-prone areas). The simulation period should be at least 40 years.

- **Flood and Surcharge Storage —** For reservoirs with flood control purposes, two components are considered:

  a. **Flood Control Storage —** This temporary space stores floodwaters above a specified return period flood, helping reduce peak discharges and downstream flooding.

  b. **Surcharge Storage —** It's the storage between the full reservoir level (F.R.L) and the maximum water level (M.W.L). Adequate spillway capacity is crucial for managing inflow design floods and using surcharge storage for moderation.




In addition to these aspects, several types of data and information are needed for effective reservoir planning and management:

- **Precipitation, Run-Off, and Silt Records —** These data help assess the capacity of precipitation and discharge measuring stations in the catchment area and are used to generate long-term water inflow volumes.

- **Estimation of Average Sediment Yield from the Catchment Area —** This involves using river sediment data, extending short-term stage/flow data, creating sediment discharge rating curves, and accounting for bed load.

- **Elevation Area Capacity Curves —** These curves are essential for reservoir design and are generated through topographic surveys or stream profiles and valley cross-sections.

- **Trap Efficiency —** This parameter is crucial for calculating sediment trap efficiency and is determined based on sedimentation index curves.
- **Losses in Reservoir —** Evaporation and seepage losses are considered, and data on these losses are collected and analysed to mitigate them effectively.
- **Demand, Supply, and Storage —** Water demand, supply, and storage requirements are compared annually to ensure effective water management and meet project objectives.
- **Committed and Future Upstream Uses —** Both existing and anticipated future water requirements and uses are assessed to accommodate them in the reservoir design.
- **Criteria for Assessing Project Success —** Specific success criteria are defined for different types of projects (e.g., irrigation, power, water supply) to evaluate their performance.
- **Density Current Aspects and Location of Outlets —** Considerations are made to manage density currents effectively, including the location and operation of outlets to prevent sedimentation.
- **Data Required for Economic Analysis —** Economic assessments consider various parameters like benefit-cost ratio, net benefit, and internal rate of return. These require detailed data on costs, benefits, and other financial aspects.
- **Data on Engineering and Geological Aspects —** Engineering surveys and geological assessments are carried out to ensure the feasibility and safety of the project.
- **Post-Construction Data —** After a reservoir becomes operational, ongoing data collection on inflow, outflow, sedimentation, capacity, seepage, wave heights, reservoir levels, and evaporation losses is vital for improved reservoir operation and maintenance.

These aspects collectively contribute to effective reservoir planning, construction, and management, ensuring the project's success and sustainability.

## IS 5477 Methods for Fixing the Capacities of Reservoir : Part 2 Dead Storage

### Scope

This standard covers methods for computing the sediment yield and for predicting the probable sediment distribution in the reservoir below the normal reservoir level (F.R.L.).

### Measurement of Sediment Yields:

- **Reservoir Sedimentation Survey:**

  This method estimates the sediment yield from the catchment by measuring the accumulated sediment in a reservoir for a known period. Electronic devices like echo sounders are used for accurate measurements. The volume of sediment is computed by subtracting the present reservoir capacity from the original capacity after dam completion. The unit weight of the sediment is determined in the laboratory from samples or by field measurements. Trap efficiency is considered when calculating the total sediment yield.

- **Sediment Load Measurements:**

  Periodic samples from the stream are collected at various discharges, and suspended sediment concentration is measured. This data is used to create a sediment rating curve, relating sediment concentration to discharge. This curve is then used to assess sediment load based on stage duration curve data or flow duration data. Bed load measurement is preferable but can be estimated as a percentage of suspended load if necessary.

### Predicting Sediment Distribution:

The overall goal of these methods is to assess the sediment distribution in a reservoir over time. This information is crucial for designing reservoirs, fixing dead storage levels, and determining the sill levels of outlets. It ensures that the reservoir's capacity is effectively managed despite sediment accumulation, helping maintain its functionality for various purposes like power generation, irrigation, and water supply.

- **Empirical Area Reduction Method:**

  Reservoirs are classified into four types based on their capacity-to-depth ratio. Design curves are created for each type to predict sediment distribution in the reservoir at different depths. These curves are used to calculate sediment deposition.

- **Area Increment Method:**

  This method approximates sediment deposition by progressively reducing the reservoir's surface area at each elevation by a fixed amount. Successive approximations are made until the total sediment volume below the new zero elevation matches the predetermined capacity after accounting for sediment accumulation over time. The equation used in this method involves various parameters, including sediment volume, area correction factor, and reservoir depth.

- **Moody's Method to Find New Zero Elevation:**

  This method is used to determine the new zero elevation directly without trial and error. It utilizes parameters such as functions of relative depth, relative volume, relative area, sediment storage, total sediment, and reservoir capacity. Graphical plotting of these functions is used to identify the new zero elevation.

# IS 5477 Fixing the Capacities of Reservoirs – Method : Part 3 Live Storage

## Scope

This standard lays down the criteria for fixing the live storage capacities of reservoirs.

## Terminology

These definitions are crucial in reservoir planning and simulation studies to ensure that the reservoir can effectively meet the diverse water demands while considering factors like agriculture, energy generation, navigation, and ecological balance. Proper estimation and management of water demand are essential for the successful operation of reservoir projects.

- **Irrigation Demands —** These are the volumes of water required from the reservoir for irrigation purposes within specific time intervals (e.g., 10 days, 15 days, monthly, or yearly). Irrigation demands are determined based on factors such as crop water needs, field efficiencies, conveyance efficiencies, cropping calendars, and leaching requirements. The total demands for a command area are projected considering various agricultural factors and development plans.

- **Demand for Navigation, Recreation, etc —** This refers to the volume of water required to maintain minimum navigational draft downstream, and the minimum discharge needed to preserve the ecological balance in the downstream reach. These demands are determined to ensure the health of the river and support activities like navigation and recreation. Pre-project water demand is also considered to address economic, social, and legal issues.

- **Power Demand —** Power demand is the volume of water needed from the reservoir to generate electricity using planned power facilities. It involves estimating power output based on factors like net head, discharge, generation unit efficiency, load factor, and load patterns. The duration for which water volume is calculated depends on the relevant simulation study.

- **Water Supply Demand —** This term represents the volume of water required for drinking, domestic use, and potentially industrial use for a projected population that the water supply system aims to serve. It includes accounting for distribution losses and other losses in the supply network.

- **Minimum Drawdown Level —** This is the lowest water level at which it is physically possible and allowed under operational instructions to release water from the reservoir to meet a specified purpose. It defines the minimum reservoir level required for releases.

- **Net Annual Water Demand —** This refers to the total annual water demand for various uses (irrigation, navigation, power generation, water supply, etc.) excluding evaporation losses from the reservoir. It represents the net water demand after accounting for different uses.

## General Factors for the Design of Reservoirs

Consideration of these factors is essential in designing reservoirs that can effectively meet their intended purposes while accounting for variations in streamflow, evaporation, seepage, and reliability requirements. Proper planning and data analysis are crucial for the success of reservoir projects.

### Annual Dependable Flow:

The annual flow of water into the reservoir should be determined by analysing the variability of annual stream flows. This analysis helps identify whether a stream frequently has insufficient water to meet the estimated demand for a specific reservoir project. Reservoir storage can help augment low flows. The effectiveness of a reservoir depends on the rate of withdrawal (called reservoir draft D), reservoir storage capacity (S), and the time series structure of stream flows, which are interrelated in the storage equation S = f (D, R), where R represents reliability.

The storage equation helps establish the relationship between reservoir storage capacity, draft, and reliability. In reservoir design, two of these three variables can be considered independent and assigned specific values, while the third can be computed from the storage equation based on available water data.

**Required Data –** To fix the storage capacities of reservoirs, the following data are required:

- Stream flow data at the project site or from nearby stations for a period of 25 to 40 years.
- Data on evaporation losses from the water surface and seepage losses.
- Sediment data at or near the project site.
- Elevation versus area and capacity curves for the original reservoir.
- Water use demand data.

**Stream Flow Data –** Stream flow data for various durations (e.g., 10 days, 15 days, monthly, yearly) over a period of 25 to 40 years are needed for conducting reservoir simulation exercises. These data can be obtained from historical records, data collected at the project site, or derived from records of nearby stations with suitable adjustments.

**Evaporation Estimation –** Reservoir or lake evaporation cannot be directly measured and must be estimated. Methods such as water budget, energy budget, and pan-evaporation techniques are used for estimation. Pan evaporation data collected locally, with proper exposure and no distortions, are commonly used for reservoir design purposes. If local data are not available, estimates may be derived from records of existing reservoirs with similar characteristics. Generally, reservoir evaporation is a fraction of pan evaporation, typically ranging from 0.67 to 0.81 times.

**Seepage Losses –** Estimations for seepage losses and groundwater recharge should be made until adequate data are obtained. Seepage losses occur when water infiltrates the reservoir bed and surrounding soil, affecting the available storage.

**Project Success –** Planning should aim for the successful operation of the reservoir project for a specified percentage of years, depending on the project type and location. For example, irrigation projects should target a success rate of at least 75% of the years, while hydropower projects aim for 90% success, and domestic and industrial water supply projects aim for 100% success. These percentages may be adjusted for projects located in drought-prone areas.

**Methods for fixing Storage Capacity:**

These procedures help in determining the appropriate storage capacity of reservoirs while considering factors such as inflow, outflow, demand, and storage constraints. Proper capacity planning ensures the reliability and effectiveness of the reservoir for various purposes, including water supply, irrigation, and hydroelectric power generation.

**Graphical Procedure:**

- Reservoir storage capacity is determined by considering the inflow and outflow mass curves.

- Inflow (I) and outflow (O) mass curves are plotted over time, representing cumulative sums of inflow and outflow, respectively.

- The storage capacity (S) is calculated as the difference between the inflow and outflow mass curves: S = (I - O).
- A graphical technique is described to determine the required storage capacity for a constant demand with no failure allowed during the design period.
- The graphical procedure identifies various conditions of the reservoir based on the interaction of inflow and outflow curves.

**Numerical Procedure (Simulation/Working Tables):**

- This procedure is suitable for reservoirs with non-uniform demand.
- It involves setting upper and lower bounds for reservoir capacity.
- A trial value for the reservoir capacity is selected.
- The procedure involves a series of computations based on streamflow data over a specified period.
- During each period, the release of water is made equal to the demand if sufficient storage is available. Otherwise, the release is reduced to prevent violations of storage constraints.
- Constraints include a minimum storage capacity ($S_{min}$) and a maximum storage capacity ($S_{max}$).
- The computations are carried out over the entire period of record.
- Water deficits and spills are calculated based on violations of the storage constraints.
- The reliability (q) of the reservoir is computed based on the water deficits. If the reliability is below the desired value, it indicates that the reservoir capacity must be increased, and the process is repeated. A smaller size is considered if the reliability is too high, indicating an oversized reservoir.
- The process continues iteratively until the required reliability is achieved.

**Considerations:**

- Using revised areas and capacities expected after half the service time in these studies is important.
- Sedimentation studies may be necessary to determine revised areas and capacity after the half-service time and New Zero Elevation (NZE) after the feasible or expected service time depending on sediment flow into the reservoir.

## IS 5477 Methods for Fixing the Capacities of Reservoir : Part 4 Surcharge Storage

### Scope

This standard covers the criteria and procedure to be followed in estimating the surcharge storage capacity of a reservoir.

### Terminology

- **Normal Conservation Level (NCL) –** The normal conservation level is the highest water level at which a reservoir is intended to be held under regular conditions for various uses, excluding flood control. It represents the typical operational level of the reservoir.
- **Probable Maximum Flood (PMF) –** PMF is the flood event that can be expected under the most severe combination of meteorological and hydrological conditions that are reasonably possible in the region. It is calculated based on the probable maximum storm, which is an estimate of the upper limit of storm rainfall over the basin. PMF helps assess the maximum flood risk.
- **Standard Project Flood (SPF) –** SPF is the flood event that can be expected from the most severe combination of meteorological and hydrological factors that are typically characteristic of the region. It is calculated using the standard project storm (SPS). While storms from outside the basin can be considered, extremely rare storms that are not characteristic of the region are excluded when determining the SPS rainfall for the basin.
- **Design Flood –** The design flood is the flood event adopted for designing and engineering purposes. It can be the probable maximum flood (PMF), the standard project flood (SPF), or a flood corresponding to a desired frequency of occurrence, depending on the required level of safety against potential structural failures. The choice of the design flood is influenced by factors outlined in IS 11223.

### General Guidelines

### Standard of Security

- Decisions regarding the level of safety required for the dam's integrity during extreme flood events are essential for dam safety.
- When a dam failure could result in loss of life, widespread property damage, and harm to the dam structure (especially for large reservoir spillways), a very high degree of security must be ensured against failure under the most severe flood conditions reasonably possible.
- In cases where loss of life is not a concern, economic considerations play a significant role in determining the design flood level.

### Assumption of Full Reservoir Level:

- It should be assumed that the reservoir will be filled to its full reservoir level (FRL) at the time the design flood strikes.
- Even if reservoir operation plans suggest that some storage capacity below the FRL might be available at the onset of the design flood, the assumption of a full reservoir is justified due to potential factors like incorrect flood predictions, mechanical issues, or negligent operation of regulating outlets.

- Future developments or changes in reservoir usage could also increase the likelihood of a full reservoir during the design flood event.

**Spillway Capacity Guidelines**

- These general principles underscore the critical importance of ensuring dam safety during extreme flood events. The document emphasizes that safety measures must be commensurate with the potential consequences of dam failure, considering both the safety of human life and property as well as economic factors. Additionally, it stresses the need to consider a full reservoir condition during the design flood, even if initial operational plans suggest otherwise, to account for various uncertainties and future changes. Specific guidelines for spillway capacity determination are addressed in a separate standard.

**Estimation of Design Flood**

This section outlines the process for estimating the design flood for reservoirs using the Hydro-meteorological Method and Frequency Analysis Method.

**Hydro-Meteorological Method:**

This detailed procedure ensures that the design flood is accurately estimated for reservoir design, considering various factors related to the catchment, storm characteristics, and runoff.

**Estimation of Design Storm**

- Design storm depths, such as Probable Maximum Precipitation (PMP), Standard Project Storm (SPS), or storm depths for various return periods, and appropriate durations are determined based on IS 5542.

**Design Storm Duration**

- The duration of the design storm is determined based on factors like catchment size, shape, unit hydrograph (UG) base period, and storm movement direction with reference to river flow.
- For most practical purposes, the UG base period governs the duration of the design storm depth.
- Smaller catchments with UG base periods of less than 12 hours typically use a one-day design storm.
- If the UG base period is between 24 to 48 hours, a two-day design storm is considered.
- Basins with UG base periods exceeding 48 hours generally use a three-day design storm.
- Storms with periods exceeding 72 hours are not typically used in design flood estimation, except for very large catchments where simultaneous rainstorms can be considered.

**Time Adjustment of Design Rainfall**

- Corrections are made to convert the 1-day SPS/PMP rainfall depths into 24-hour rainfall depths.
- This adjustment considers the time distribution pattern of observed storms in the area.
- If no such data is available, a factor of 1.15 is applied to 1-day rainfall depths to convert them into 24-hour rainfall, with a maximum increase of 50 mm.

**Short Interval Distribution**

- The design storm is divided into short time intervals based on observed time distribution of severe storms in the catchment.
- If this information is not available, regional flood estimation reports or PMP atlases can be used.

**Loss Rate**

- Initial loss and infiltration index values are derived based on available hydrologic records.
- Minimum values are selected under the assumption of a saturated basin during the design storm, resulting in low loss rates.
- However, it is recommended to use these values only if they are obtained from records of very severe storms in wet soil conditions.
- In cases where data is insufficient, a loss rate of 1-2 mm/h is applied, depending on catchment characteristics and vegetation.

**Critical Sequencing**

- Effective rainfall intensities are computed by subtracting the loss rate from actual intensities.
- A critical sequence of the effective storm (effective hyetograph) is estimated using two bells of 12 hours each per day.

**Basin Response Function**

- The unit hydrograph (UG) is derived from observed flood events and corresponding rainfall in gauged catchments.
- In ungauged catchments, synthetic unit hydrographs may be developed based on catchment characteristics using established methods.

**Limitations**

- The unit hydrograph principle is suitable for watersheds with catchment areas of less than 5,000 km$^2$. Larger catchments should be divided into sub-catchments.
- The principle is not recommended for catchments smaller than 25 km$^2$, and detailed rainfall-runoff modelling should be used.
- Average catchment rainfall should be estimated from a well-distributed rain gauge network.
- The unit hydrograph principle is not recommended for snow-fed catchment areas.

**Convolution**

- Convolution involves computing the hydrograph of direct surface runoff (DSRO) by multiplying UG ordinates at unit duration intervals by rainfall excess ordinates and adding them by lagging, one unit duration at a time.

**Base Flow**

- The base flow value chosen should match the season of the storm and preferably be based on observed flood hydrographs.
- If observed data is unavailable, base flow data from adjacent basins converted to flow rate per unit area can be used.
- In the absence of such data, a flat rate of 0.05 $m^3/km^2$ may be adopted.

**Frequency Analysis Method:**

This method allows for the estimation of design floods based on the statistical analysis of historical flow data, which can be valuable for assessing flood risks and designing reservoirs with adequate flood protection.

A prerequisite for this method is the availability of annual maximum flow data for a sufficiently long period (typically more than 25 years). It is important to note that a purely statistical approach for deriving design flood for very long recurrence intervals, much larger than the length of the data record, has limitations and should be used cautiously. In cases with limited data, other methods like the partial duration method or regional frequency techniques should be employed as a tentative approach, and results should be verified and cross-checked using hydrological approaches. Various computer programs are available for conducting frequency analysis.

In the frequency analysis method for estimating the design flood, the following steps are followed:

**Data Checking**

- The processed data is checked to ensure that the fundamental assumptions of frequency analysis are met.
- Randomness, trends, jumps, and outliers in the data are examined and appropriate corrections are made.

**Probability Distributions**

- Various probability distributions (such as Log-normal, Pearson Type III, Log-Pearson Type III, and Gumbel) are fitted to the data.
- Parameters of these distributions are estimated using methods like moments, maximum likelihood, least squares, and probability-weighted moments.

**Goodness of Fit Test**

- Statistical tests (e.g., D-index, Chi-square, Komogorov-Smirnov) are applied to identify the distribution that best fits the data.

**Confidence Intervals**

- Confidence intervals are calculated to estimate a range of values likely to include an unknown population parameter.
- These intervals are typically calculated for a significance level of 95 percent but can be computed for other levels as well (e.g., 90, 99, 99.9 percent).
- Wider intervals indicate greater uncertainty about the parameter.

**Estimation of Design Flood**

- The identified probability distribution, based on goodness of fit tests, provides the relationship between probabilities of exceedance/return periods and flood magnitudes.

- Using this distribution, flood magnitudes for different return periods are computed.

**Determination of Maximum Water Level**

In the context of determining the maximum water level in a reservoir during a flood event, the process involves reservoir routing, specifically using the Modified Puls' or Storage Indication method. Here's an overview of the key steps and data requirements:

**Data Requirement for Storage Indication Method**

To perform reservoir routing using the Storage Indication method, the following data is needed:

- Reservoir stage-discharge and stage-storage relationships.
- Inflow hydrograph (typically representing the design flood).
- Full reservoir level.
- Initial outflow (both controlled and uncontrolled).
- Initial reservoir level.

The stage-discharge relationship can be established using the general weir formula, while the stage-storage relationship can be derived from topographic maps. The design flood hydrograph serves as the inflow hydrograph. Controlled outflow refers to estimated outflow through turbines, sluices, etc., while uncontrolled outflow represents discharge through the spillway.

**Reservoir Routing**

Reservoir routing can be computationally intensive, but it's essential for understanding how the reservoir will respond to a design flood event and determining the maximum water level that can be expected.

Reservoir routing is based on the mass balance principle, where the rate of change of storage is equal to the difference between the rate of inflow and outflow. Mathematically, it can be expressed as:

$dS/dt = I - Q$

Here, $dS/dt$ is the rate of change of storage, I is the rate of inflow, and Q is the rate of outflow, including controlled and uncontrolled components.

The step-by-step procedure for reservoir routing involves the following:

- At the beginning of routing, the known inflow and initial reservoir stage are used to calculate storage and initial outflow.

- Compute the change in storage ($\Delta S$) and new outflow rate ($Q_2$) for each time step (e.g., hourly) based on stage-discharge and stage-storage relationships.

- Continue these calculations for subsequent time steps until there is minimal change in the outflow.

- The maximum stage reached during the routing process represents the maximum water level for the reservoir.

The selection of the time step ($\Delta t$) is critical for accurate routing. It should be chosen such that it adequately captures the changes in the inflow hydrograph. Typically, $\Delta t$ should be one-third to half of the time it takes for water to travel through the reservoir. A general rule of thumb is to set $\Delta t$ at 20 to 40 percent of the time to the peak of the inflow hydrograph.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