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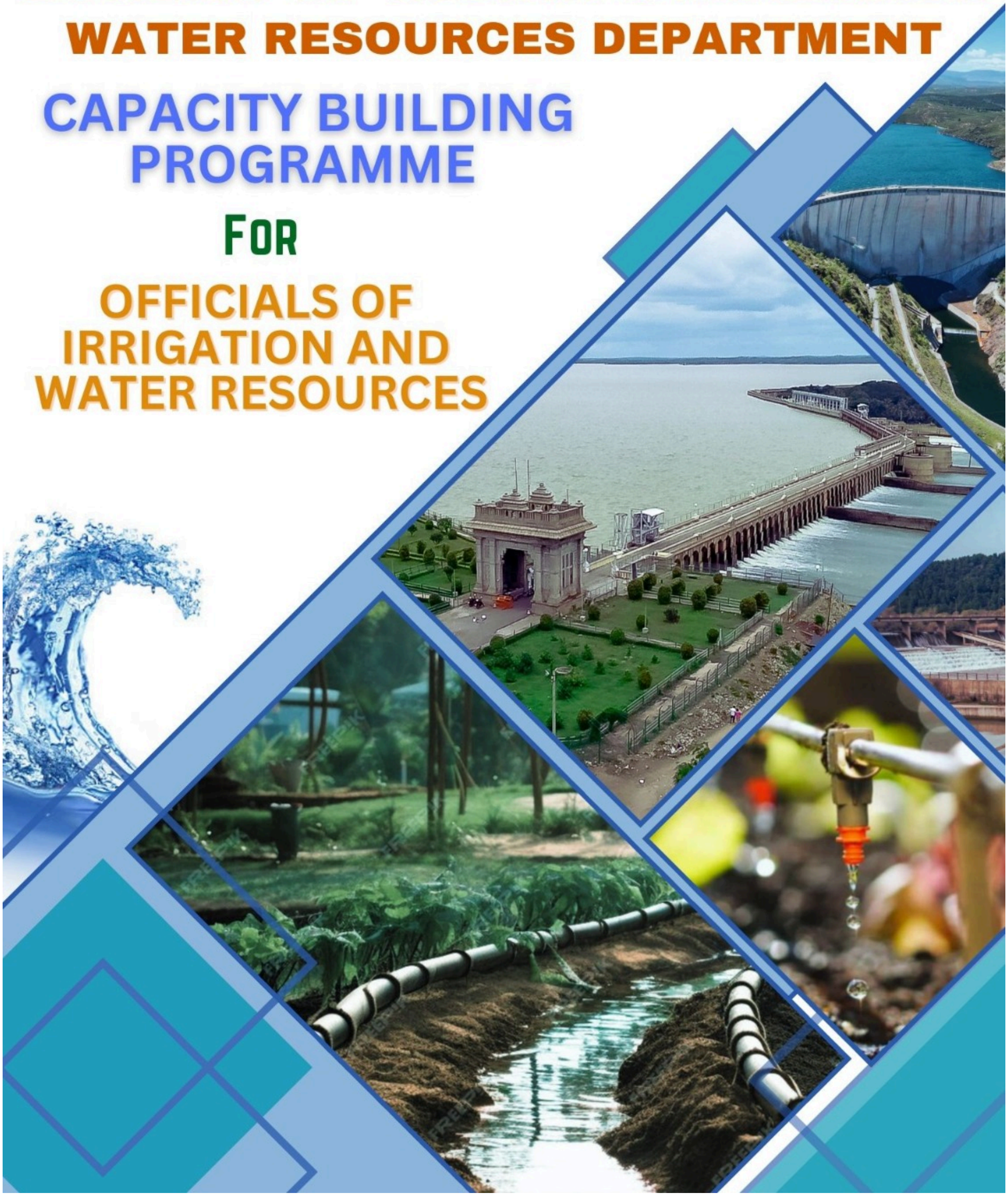
BUREAU OF INDIAN STANDARDS

WATER RESOURCES DEPARTMENT

CAPACITY BUILDING PROGRAMME

For

OFFICIALS OF IRRIGATION AND WATER RESOURCES



REFERENCE MATERIAL

FOR

TWO-DAY CAPACITY BUILDING PROGRAMME FOR OFFICIALS OF

IRRIGATION & WATER RESOURCES DEPARTMENTS

Preface of the book

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CHAPTER 1

Canals

As per **IS 4410 (Part 5): 2023, Canal** is an artificial open channel carrying water including situations passing through tunnels enroute.

Canals are manmade waterways channels, for water conveyance. They help in irrigation, water control and flood prevention. The canal comprises of earth work, concrete, lining, head regulators and expansive joints.

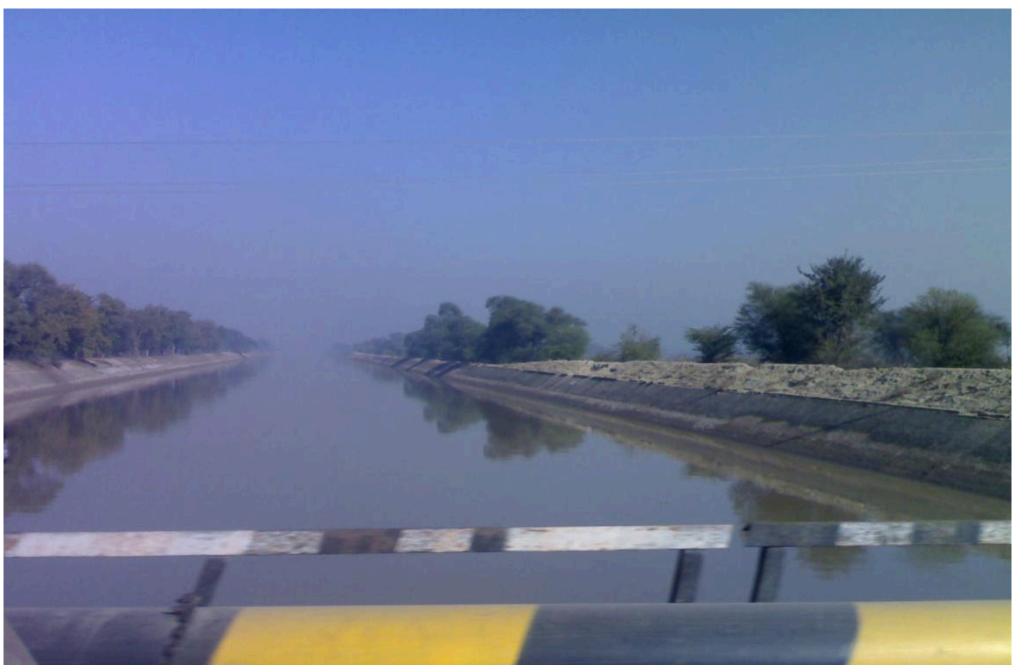


Fig.1 Indira Gandhi Canal

There are various types of canal based on the different criteria as mentioned below:

- Classification based on natural Supply of source
- Classification based on Functions
- Classification based on Type of Boundary of surface soil

- Classification based on Financial Output
- Classification based on Discharge
- Classification based on Canal Alignment

Classification Based on natural Supply sources of water

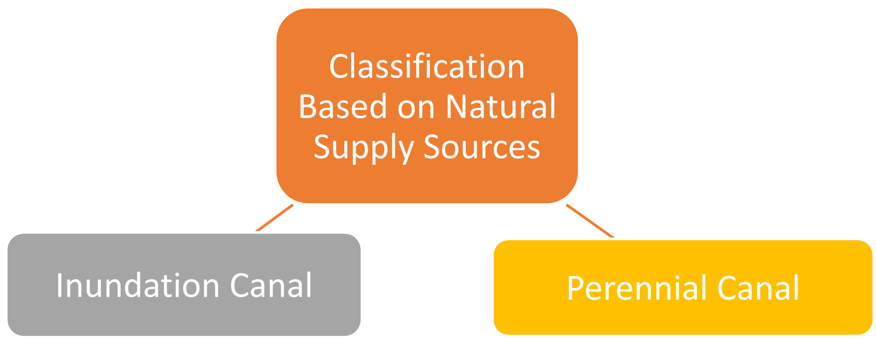


Fig.2 (Classification Based on Natural Supply Sources)

Perennial canals

These canals are connected to dams and barrages, and have water throughout the year. They are a good choice for irrigating large areas of land and all types of areas.

Inundation canals

These canals are long and originate from large rivers, and are only full of water when the river is in flood or during the wet season. They are not useful during the dry months and only irrigate low-lying areas of land.

Perennial canals are more suitable for cultivation and other uses than inundation canals, so many inundation canals are being converted into perennial canals.

Fig.3 (Difference between Perennial & Inundation canal)

Classification based on Functions

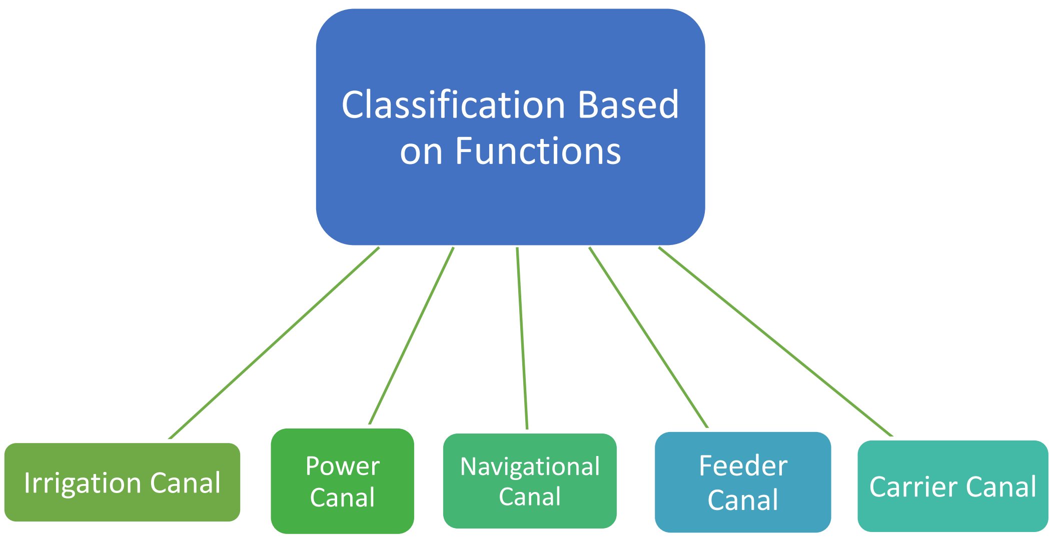


Fig.4 (Classification Based on Functions)

Irrigational Canal: - A canal whose primary function is to irrigate the Gross command area.

Feeder canal: - A canal which is built to feed another canal is known as feeder canal.

Power canal: - A canal used constructed to generate hydraulic power is called Power canal.

Carrier canal: -A multi-purpose canal that serves as both an irrigation canal and a feeder canal.

Navigation canal: A canal which is Used primarily for transportation by water.

All these canal are classified based on function which serves the various purpose discussed briefly.

Classification based on Type of Boundary of surface soil

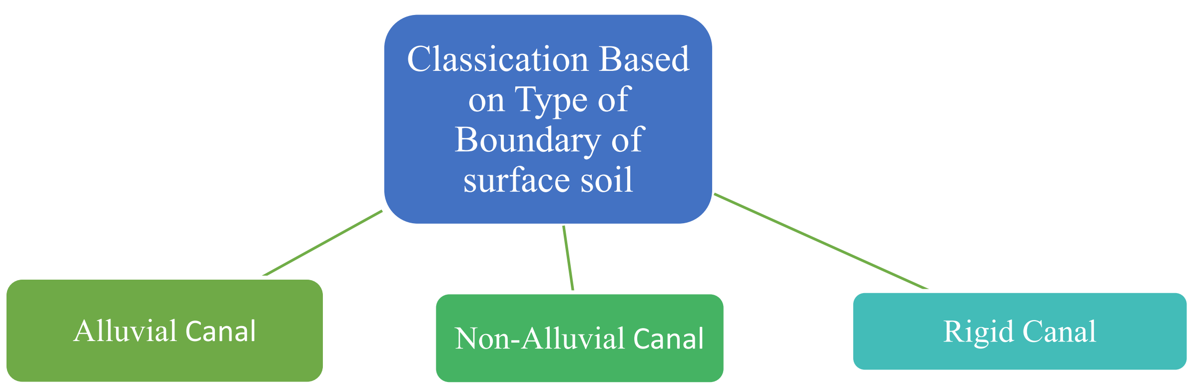


Fig.5(Classification Based on Type of Boundary of surface soil)

Based on the type of boundary, canals are classified as alluvial canals where the boundary is made of loose, sedimentary soil like silt and sand, and non-alluvial canals where the boundary is composed of firmer materials like clay, rock. A rigid surface canal even a hard lining made of concrete or stone.

Alluvial canals: Excavated in naturally occurring alluvial soils. Prone to erosion and siltation due to the loose soil. May require special design considerations to manage sediment transport.

Non-alluvial canals: Constructed in firmer soil types like clay or rock. Generally, experience less erosion and siltation compared to alluvial canals.

Rigid boundary canal: A rigid boundary canal is a channel with fixed banks and a bed made of non-erodible materials, such as concrete or stone. The defining characteristic of a rigid boundary canal is that its boundaries do not deform or erode.

Classification based on Financial Output

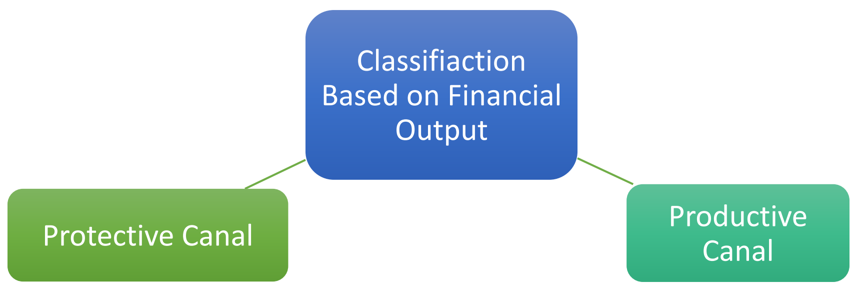


Fig.6 (Classification Based on Financial Output)

Based on financial output, a canal can be classified as either a productive canal which generates enough revenue to cover its maintenance and construction costs, or a protective canal which is primarily built for protection against water scarcity and may not generate significant revenue.

Productive Canal: This type of canal is designed to produce enough income through irrigation activities to cover its operational costs and recoup the initial investment made in its construction.

Protective Canal: A protective canal is primarily built to safeguard an area from water shortages during droughts or famines, and its primary focus is not on generating significant revenue.

Classification based on Canal Alignment

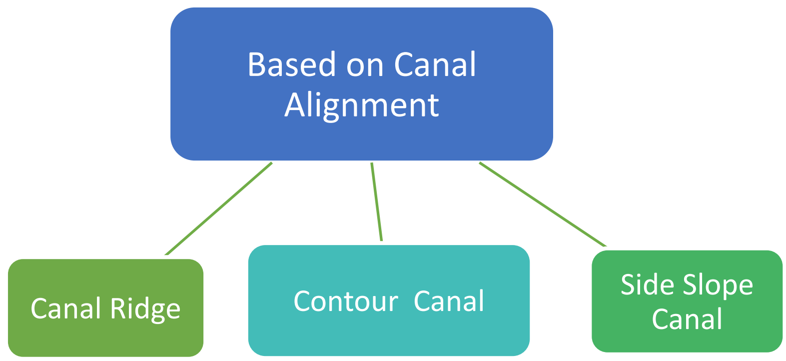


Fig.7(Classification Based on Canal Alignment)

Ridge canal or Watershed Divide: The canal which is aligned along any natural watershed (ridge line) is called a watershed canal, or a ridge canal. Aligning a canal (main canal or branch canal or distributary) on the ridge ensures gravity irrigation on both sides of the canal. The dividing ridge line between the catchment areas of two streams (drains) is called the watershed or ridge canal. Thus between two major streams, there is the main watershed (ridge line), which divides the drainage area of the two streams.

Fig.8(Ridge Canal or Water Shed Divide**)**

Contour Canal: A contour canal irrigates only on one side because the area on the other side is higher. It is also known as a single bank canal; this canal is aligned along the natural contour of the country.

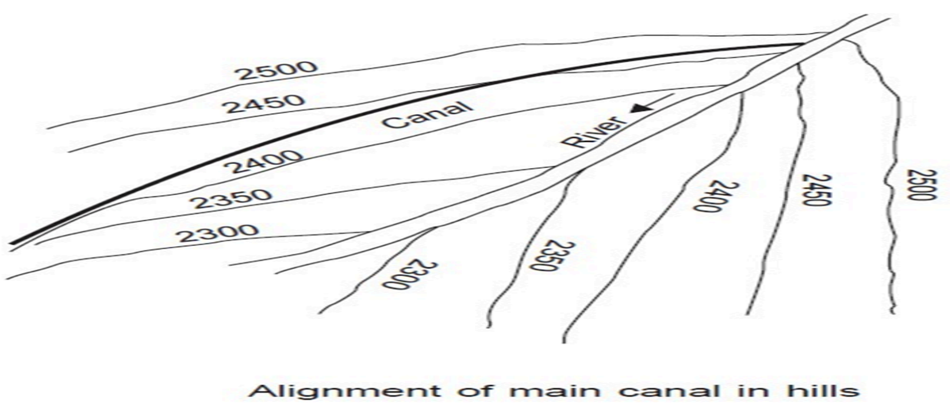


Fig.9(Contour Canal)

Side Slope Canal: A side slope canal is that which is aligned at right angles to the contours. Since such a canal runs parallel to the natural drainage flow, it usually does not intercept drainage channels, thus avoiding the construction of cross-drainage structures.

Classification based on Discharge

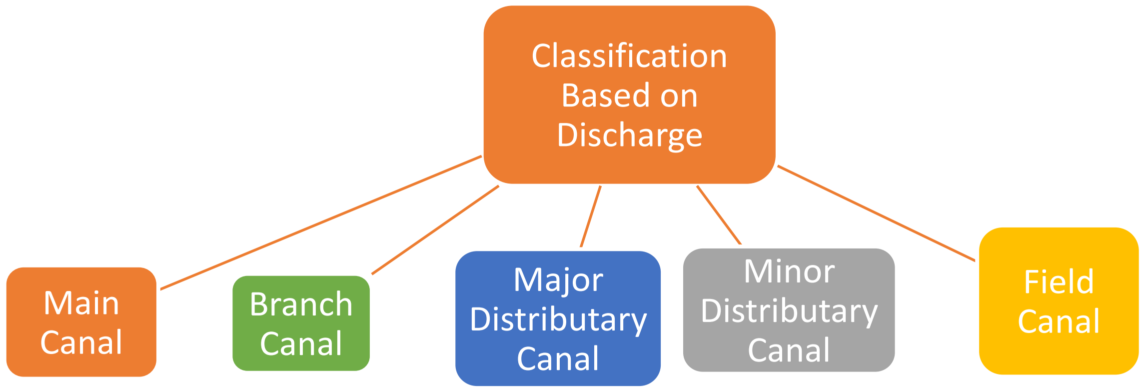


Fig.10(Classification based on Discharge)

Main Canal: The principal channel of a canal system off-taking from a river or a reservoir or a feeder and also called as 'Main Line'.

Branch Canal: A canal receiving its supply from the main canal and acting as feeder for distributaries. It is also called 'Lateral'

Major Distributary Canal: A channel receiving its supply from main or the branch canal. It supplies water to minors and watercourses. It will be called a 'Major Distributary'

Minor Distributary Canal: It supplies water to other distributary called a Minor Distributary.

Field Channel: The channel that conveys water from water courses to the cultivator's fields.

IS 10430 : 2000 Criteria for Design of Lined Canals and Guidance for Selection of Type of Lining (First Revision)

➢ **Seepage Control: -** Canal reaches of sufficient length having permeability of 1x 10-6 (cm/s) or less need not be lined when the velocity in the canal does not exceed the permissible velocity. However, reaches of permeability 1x 10-6 (cm/s) or less may be lined, particularly in power channels, for hydraulic efficiency and erosion resistance. Canal reaches of greater permeability may be lined with suitable material.

➢ **Strength and Durability: -** The canal lining shall be able to withstand the effect of velocity of water, rain, sunshine, frost, freezing and thawing (where applicable), temperature and moisture changes, chemical action of salts, etc. With suitable treatment, lining should be able to withstand the effect of gypsum, black cotton soil/bentonite. It should also be able to withstand the damaging effect caused by abrasions, cattle traffic, rodents and weed growth.

➢ **Side Slopes: -** Lining is usually made to rest on stable slopes of the natural soil; so slopes should be such that no earth pressure or any other external pressure is exerted over the back of the lining. Sudden drawdown of water level in the lined canal should be controlled by strict operation rules and regulations to avoid external pressure on the lining.

➢ **Berm: -** In deep cut reaches of canals with discharge capacity exceeding 10 cumecs, it is desirable to provide berms of 3 to 5 m width on each side for stability, facility of maintenance, silt clearance.

➢ **Dowla: -** To check the ingress of rain water behind the lining of the side slopes of the canals, horizontal cement concrete coping 100 mm to 150 mm thick, depending upon size of canal should be provided at the top of lining. The width of coping at the top shall not be less than 225 mm for discharge up to 3 cumecs, 350 mm for discharge more than 3 cumecs and 550 mm for discharge more than 10 cumecs.

➢ Limiting Velocities of lining are given below:

a) Stone-pitched lining **-1.5 m/sec**

b) Burnt clay tile or brick lining **-1.8 m/sec**

c) Cement concrete lining- **2.7 m/sec**

IS 10646: 1991 Canal linings Cement Concrete Tiles -Specification

- **DIMENSIONS: -**The nominal dimension shall be as below: 500 mm x 500 mm, 500 mm x 250 mm, 400 mm x 400 mm, 300 mm x 300 mm and 250 mm x 250 mm.

- **TOLERANCE: –** Tolerance in Length and breadth shall be of 3 mm and in thickness shall not be less than the specified value.

FLEXURAL STRENGTH OF MANUFACTURED TILES: – When tested according to the method given at Annex A, minimum breaking load per cm length of tile shall not be less than 41 kg for 60 mm, 29 kg for 50 mm and 18 kg for 40 mm tiles thickness.

➢ **Test: -** The specimen shall be immersed in potable water for 24 hours and then taken out and wiped dry. The specimen shall be placed horizontally on roller bearers 1.50 mm apart with their length parallel to bearers. The load shall be applied at mid-stand by means of steel bar parallel to the bearers.

➢ The length of the bearers and that of the loading bar shall be longer than the length of the specimen and their contact shall be rounded to a diameter- of 25 mm. A plywood packing 3 mm thick and 25 mm wide shall be placed between the specimen.

➢ **Loading: -** Starting from zero, the load shall be increased steadily and uniformly at a rate not exceeding 2 kg/cm length per minute up to the load.

IS 11809: 1994 Lining for canals by stone masonry - Code of Practice

•**Dimensions of Stones and Thickness of Lining (Clause 4.1)**

SI. No.	Canal Capacity (Cumec)	Thickness of Lining (mm)	Average Dimension (mm)	Minimum Dimension (mm)
1.	0 to less than 10	150	150	75
2.	10 to less than 100	225	225	110
3.	100 above	300	300	150

Table No.1 Dimension of Stone

- ✓ The stone should be laid on lime mortar (1:2) or cement mortar 1: 3 over a bed of minimum 12 mm thick lime/cement mortar.

- ✓ The lining should be started after at least 35 m length of canal sub-grade is properly dressed to receive lining.

- ✓ The subgrade should be uniformly soaked with water, without making it slushy, to ensure that water penetrates to a depth of about 300 mm in sandy soil and about 150 mm in other soils.

- ✓ Stones should be firmly embedded in mortar. Hollows, if any, should be rectified by relaying the defective portions with fresh mortar.

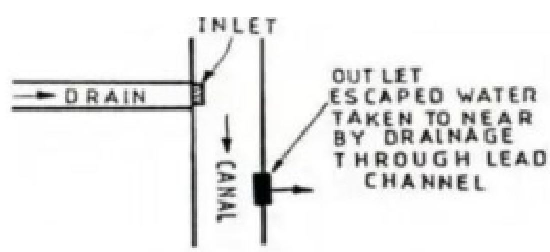
- ✓ If the water table is high, it should be lowered to at least 300 mm below the subgrade.

Cross Drainage Work

In an Irrigation project, when the network of main canals, branch canals, distributaries, etc. are provided, then these canals may have to cross the natural drainages like rivers, streams, nallahs, etc. at different points within the command area of the project.

The crossing of the canals with such obstacle cannot be avoided. So, suitable structures must be constructed at the crossing point for the easy flow of water of the canal and drainage in the respective directions. These structures are known as cross-drainage works.

Works required to construct, to cross the drainage are called Cross Drainage Works (CDWs). At the meeting point of canals and drainages, bed levels may not be same. Depending on their bed levels, different structures are constructed and accordingly they are designated by different names.



Canal Inlet and Outlet Plan

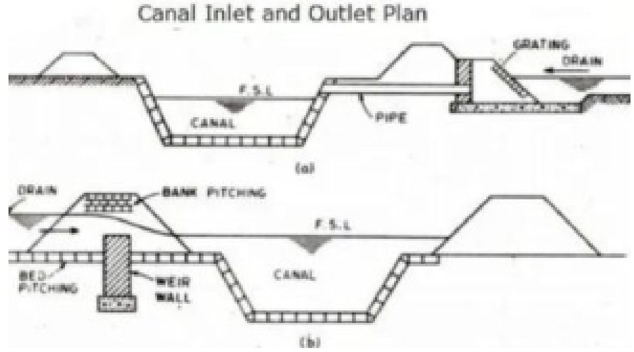


Fig.11(Canal Cross Drainage Work)

Types of Cross Drainage Works

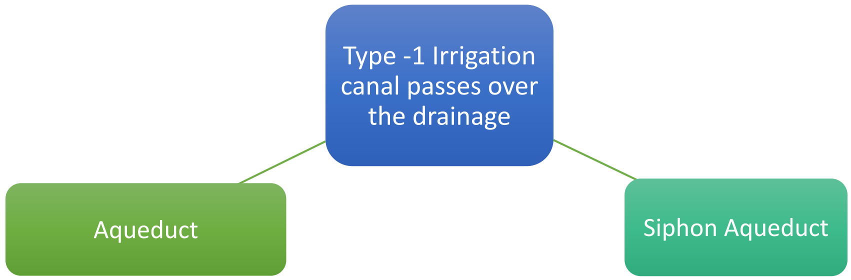


Fig.12(Type -1 Irrigation canal passes over the drainage)

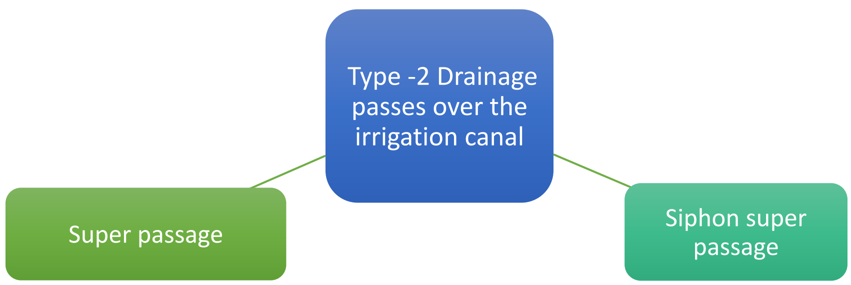


Fig.13(Type -2 Drainage passes over the irrigation canal)

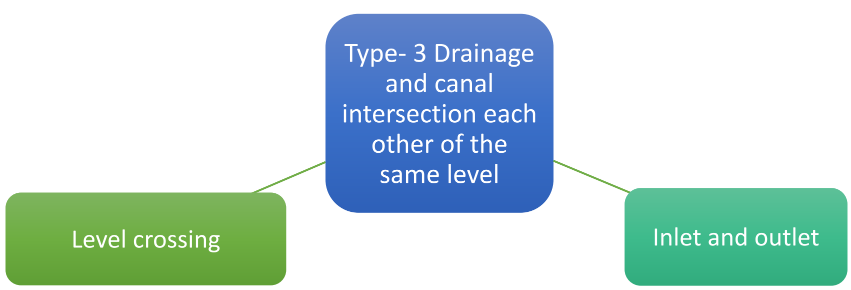


Fig.14(Type- 3 Drainage and canal intersection each other of the same level)

AQUEDUCT

•**Aqueduct** - The hydraulic structure in which the irrigation canal is taken over the drainage (such as river, stream etc.) is known as aqueduct. This structure is suitable when bed level of canal is above the highest flood level of drainage. In this case, the drainage water passes clearly below the canal.

Fig.15(Aqueduct)

SIPHON AQUEDUCT

•**Siphon Aqueduct** - In a hydraulic structure where the canal is taken over the drainage, but the drainage water cannot pass clearly below the canal. It flows under symphonic action. So, it is known as siphon aqueduct. This structure is suitable when the bed level of canal is below the highest flood level.

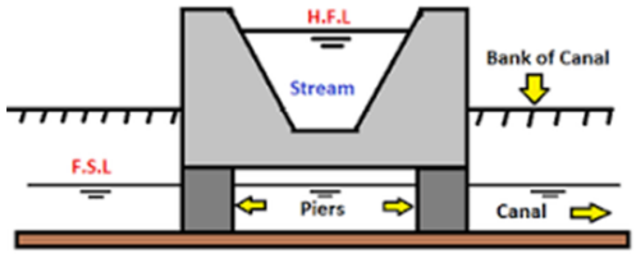


Fig.16(Siphon Aqueduct)

SUPER PASSAGE

• **Super Passage-**The hydraulic structure in which the drainage is taken over the irrigation canal is known as super passage. The structure is suitable when the bed level of drainage is above the full supply level of the canal. The water of the canal passes clearly below the drainage.

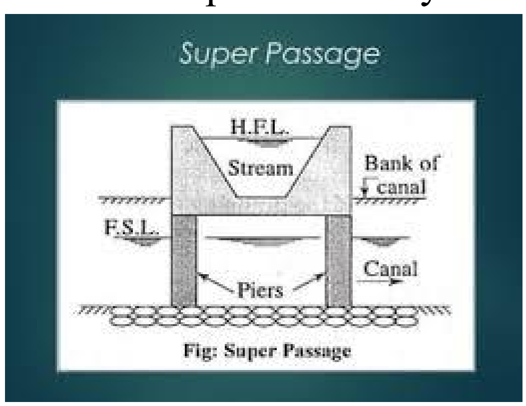


Fig.17(Super Passage)

SIPHON SUPER PASSAGE

• **Siphon Super Passage -** The hydraulic structure in which the drainage is taken over the irrigation canal, but the canal water passes below the drainage under symphonic action is known as siphon super passage. This structure is suitable when the bed level of drainage is below the full supply level of the canal.

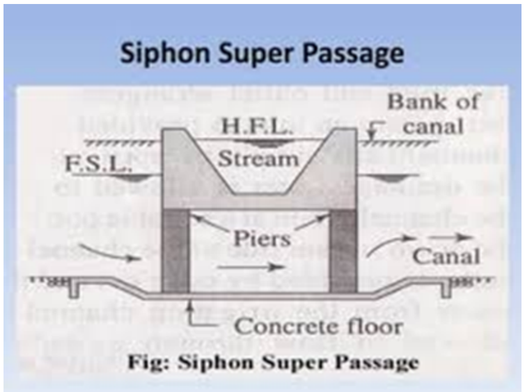


Fig.18(Siphon Super Passage)

LEVEL CROSSING

• **Level Crossing -** When the bed level of canal and the stream are approximately the same and quality of water in canal and stream is not much different, the cross drainage work constructed is called level crossing where water of canal and stream is allowed to mix. With the help of regulators both in canal and stream, water is disposed through canal and stream in required quantity. Level crossing consists of following components

(i) crest wall
(ii) Stream regulator
(iii) Canal regulator.

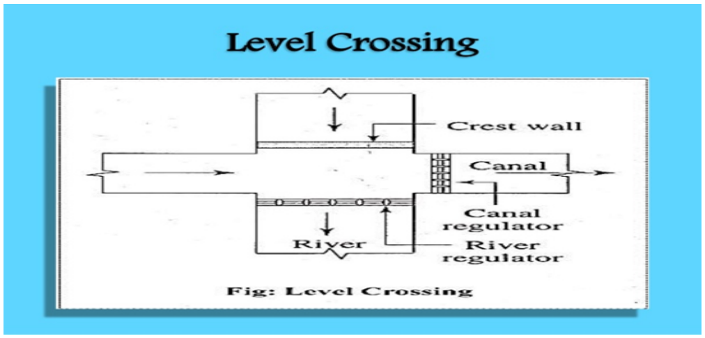


Fig.19(Level Crossing)

INLET & OUTLET

In cross-drainage works, an inlet and outlet are simple openings that allow water to flow in different directions when a small drainage meets a small channel. The inlet allows drainage to enter the canal, and the outlet allows part of the water to drain back into the stream.

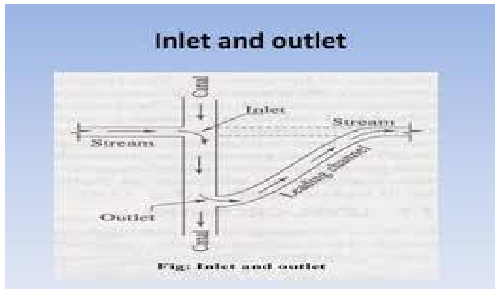


Fig.20(Inlet and Outlet)

Design of Cross Drainage Work (IS 7784 (Part 1): 2013)

Data Requirement of Cross Drainage Work - A location map for the work with results of subsurface exploration conducted at site, cross-sections of the stream, upstream and downstream of the proposed site, should be prepared.
A catchment area map to a suitable scale, with contour markings at suitable intervals showing the main drainage channel from its sources together with all its tributaries.

Design Flood

- Design flood for drainage channel to be adopted for cross drainage works should depend upon the size of the canal, size of the drainage channel and location of the cross drainage. A very long canal, crossing a drainage channel in the initial reach, damage to which is likely to affect the canal supplies over a large area and for a long period, should be given proper weightage.

- A very long canal, crossing a drainage channel in the initial reach, damage to which is likely to affect the canal supplies over a large area and for a long period, should be given proper weightage.

- Cross drainage structures are divided into four categories depending upon the canal discharge and drainage discharge. Design flood to be adopted for these four categories of cross drainage structures would depend upon type of structure and flood frequency.

The discharges determined by different methods mentioned in **IS 5477 (Part 4)** should be compared to see if any large variations are exhibited.

•For working out tilt design of an aqueduct, the specific design data should be available in addition to those laid down by **IS 7784 (Part 1): 1993**.

•Wing walls for drainage may be provided with 2: 1and 3: 1 splays on upstream and downstream side; the splay should not be flatter than 3: 1 and 4: 1 respectively.

•Canal transitions should preferably be provided with 2: 1 and
3: 1 splays on upstream and downstream side, but not flatter than 3: 1 and 5: 1 respectively.

Design of Cross Drainage Work (IS 7784 (Part 2/Sec 1): 1995)

•The **maximum spacing** of joints in either direction should be limited to **20 m**.

•A **gap of 15 mm** with water stops at all the joints across along the barrel should be provided to Accommodate the movements.

•A suitable arrangement for supporting the section of the aqueduct may be decided depending upon the nature of foundation, difference between HFL of the drain and bed of canal and height between bed of canal and bottom of stream/drain and the afflux allowable in the drain.

•Hydraulic design data shall be made available as given in **IS 7784 (Part I)**. In the case of syphon super passage, the following data shall also he made available in addition:

1) **Side slopes**,
2) **Allowable head loss**,
3) **Whether canal is lined and if so the lining maternal**.

•Bottom slab of the drainage bed should also be considered for H.F.L. loading due to water and loading due to surcharge of earth and partial silt load.

Design of Cross Drainage Work IS 7784 (Part-2/Sec 2): 2000

•The section of the trough should permit a scouring velocity at maximum observed flood. A velocity of **2 to 3 m per second** is normally **permissible**.

•Afflux should be such that it does not exceed the limits of submergence and tolerances of the environments. Energy loss should he determined in accordance with **IS 7784 (Part 1)**.

•High flood level (H.F.L) calculated or observed, whichever is more at the center line of the crossing, water surface slope of the stream or drain and the total length of the work being known, the H.F.L at the upstream and downstream of the work can be determined, taking into consideration the parameters at the site.

Construction of Cross Drainage Work (IS 9913: 2000)

•Static penetration tests shall have carried out at all important components of the proposed structure, that is abutment, pier, wing wall.

•Where a ring bund or a coffer dam is to be formed, the top level should be kept well above the normal flood level as per provisions of **IS 9795(Part 1)**.

•Where feasible the foundation concrete shall be laid in a single pour.
•The **outer diameter** shall be large and preferably **not less than 6 m** with the minimum thickness of caisson wall, as one meter.

•**Pile foundations** are generally **not provided in case of aqueducts** Piles, where unavoidable, should not he provided within the flood zone of the river with deep scour.
•Piers and abutments may he solid, or cellular type The **minimum thickness, of wall shall be 600 m** The construction joint splash zone.

Operation of Cross Drainage Work

•The water-shed canals do not cross natural drainages. But in actual orientation of the canal network, this operational condition may not be available and the obstacles like natural drainages may be present across the canal. So, the cross drainage works must be provided for running the irrigation system.

•At the crossing point, the water of the canal and the drainage get inter mixed. So, for the smooth running of the canal with its design discharge the cross drainage works are required.

•The site condition of the crossing point may be such that without any suitable structure, the water of the canal and drainage cannot be diverted to their natural directions. So, the cross drainage works must be provided to maintain their natural direction of flow.

Maintenance of Cross Drainage Work (IS 7331: 1981)

•The approach and exit channels in the vicinity of cross drainage works shall be cleared of silt, debris, stumps, branches of trees, etc. before the onset of monsoon or the reopening of the channel after a closure, to keep the work free from obstructions.

•Any crack and hole in upstream and downstream floors of the cross drainage works shall be duly repaired well before the monsoon sets in. Any potholes or open joints in the masonry/concrete in the floor or side walls shall be properly repaired, any deviation from the original formations on the bed and sides is to be noticed.

•The drainage or, weep holes and pressure release valves in abutments, wings, etc. shall be cleaned of all extraneous matter to prevent building up of hydrostatic pressure, in excess of the designed provision.

•It shall be ensured that the water seals or the asphalt joints are intact, Leakage through water seals whether in canal through, or in the drainage vents, shall be corrected as far as possible by the use of appropriate filler material.

Safety code for operation and maintenance of river valley projects IS 10386 (Part 9): 1998

Cross drainage works, or CD works, are important for road safety and flood prevention. The safety of cross drainage works can be improved by:

- **Using local materials:** Use materials that are available locally and design the shape and size of the cross drainage work to take advantage of their properties.
- **Inspecting on-site**: Before deciding on the location of a cross drainage work, inspect the site to assess all relevant factors.
- **Designing for a flood return cycle:** For rural roads, it's often better to design a cross drainage work for a flood return cycle of five to ten years. This can be considered a temporary structure, and data collected during its life can help design a more adequate structure in the future.
- **Considering protection works:** Depending on the site conditions, protection works like retaining walls and stone pitching may be required.
- **Designing the waterway:** The waterway should be designed so that the velocity generated during a dominant flood is enough to scour material, but not so excessive that it damages the work.

Annexure

Indian Standards Used in Canal & Canal Linings

SI. No.	IS Number	IS Title
1	IS 10430 : 2000	Criteria for design of lined canals and guidance for selection of type of lining (First Revision)
2	IS 10646 : 1991	Canal linings – Cement concrete tiles - Specification (First Revision)
3	IS 11809 : 1994	Lining for canals by stone masonry - Code of practice (First Revision)
4	IS 12379 : 1988	Code of practice for lining of water - Courses and field channels
5	IS 13143 : 1991	Joints in concrete lining of canals - Sealing compound - Specification
6	IS 3872 : 2002	Lining of canals with burnt clay tiles - Code of practice (First Revision)
7	IS 3873 : 1993	Laying .cement concrete/stone slab lining on canals - Code of practice (Second Revision)
8	IS 4515 : 2002	Stone pitched lining for canals - Code of practice (Second Revision)
9	IS 4558 : 1995	Under - Drainage of lined canals - Code of practice (Second Revision)

10	IS 4701 : 1982	Code of practice for earthwork on canals (First Revision
11	IS 4839 (Part 1) : 1992	Maintenance of canals code of practice: Part 1 unlined canals (Second Revision)
12	IS 4839 (Part 2) : 1992	Maintenance of canals – Code of practice: Part 2 lined canals (Second Revision)
13	IS 4839 (Part 3) : 1992	Code of practice for maintenance of canals: Part 3 canal structures, drains, outlets, jungle, clearance, plantation and regulation second revision)
14	IS 5256 : 1992	Sealing expansion joints in concrete lining of canals - Code of practice (First Revision)
15	IS 5690 : 1982	Guide for laying combination lining for existing unlined canals (First Revision)
16	IS 5968 : 1987	Guide for planning and layout of canal system for irrigation (First Revision)
17	IS 6936 : 1992	Guide for location, selection and hydraulic design of canal escapes (First Revision)
18	IS 7112 : 2002	Criteria for design of cross - section for unlined canals in alluvial soil (First Revision)
19	IS 7113 : 2003	Soil - Cement lining for canals - Code of practice (First Revision)

20	IS 9698 : 1995	Lining of canals with polyethylene film - Code of practice (First Revision)
21	IS 9447 : 2023	Assessment of Seepage Losses in Canals by Analytical method- Guidelines (first revision)
22	IS 11385 : 2008	Subsurface exploration for canals and cross drainage works - Code of practice (First Revision)
23	IS 9097 : 1979	Guide for laying lining of canals with hot bitumen or bituminous felts
24	IS 9452 (Part 1) : 1993	Measurement of seepage losses from canals - Code of practice: Part 1 Ponding method
25	IS 9452 (Part 2) : 1980	Code of practice for measurement of seepage losses from canals: Part 2 inflow and outflow method

Indian Standard used in Canal Cross Drainage Works

SI. No.	IS Number	IS Title
1	IS 11570 : 1985	Criteria for hydraulic design of irrigation intake structures
2	IS 7784 (Part 1) : 2013	Design of cross drainage works - Code of practice: Part 1 general features (Second Revision)
3	IS 12331 : 1988	General requirements for canal outlets

4	IS 6004 : 1980	Criteria for hydraulic design of sediment ejector for irrigation and power channels (First Revision)
5	IS 6522 : 1972	Criteria for design of silt vanes for sediment control in off taking canals
6	IS 6936 : 1992	Guide for location, selection and hydraulic design of canal escapes (First Revision)
7	IS 7112 : 2002	Criteria for design of cross -: Sec for unlined canals in alluvial soil (First Revision)
8	IS 7113 : 2003	Soil - Cement lining for canals - Code of practice (First Revision)
9	IS 7114 : 1973	Criteria for hydraulic design of cross regulators for canals
10	IS 7331 : 1981	Code of practice for inspection and maintenance of cross drainage works (First Revision)
11	IS 7495 : 1974	Criteria for hydraulic design of silt selective head regulator for sediment control in off taking canals
12	IS 7784 (Part 2/Sec 1) : 1995	Design of cross drainage works code of practice: Part 2 specific requirements: Sec 1 aqueducts (First Revision J
13	IS 7784 (Part 2/Sec 2) : 2000	Code of practice for design of cross drainage works: Part 2 specific requirements: Sec 2 super passages (First Revision)

14	IS 7784 (Part 2/Sec 3) : 1996	Code of practice for design of cross drainage works: Part 2 specific requirements: Sec 3 canal siphon(First Revision)
15	IS 7784 (Part 2/Sec 4) : 1999	Design of cross drainage works - Code of practice: Part 2 specific requirements: Sec 4 level crossings (First Revision)
16	IS 7784 (Part 2/Sec 5) : 2000	Code of practice for design of cross drainage works part2 specific requirements: Sec 5 syphon aqueducts (First Revision)
17	IS 7871 : 1975	Criteria for hydraulic design of groynes walls (Curved Wing) for sediment distribution at offtake points in a canal
18	IS 7880 : 1975	Criteria for hydraulic design of skimming platform for sediment control in off taking canal
19	IS 7986 : 1976	Code of practice for canal outlets
20	IS 8835 : 1978	Guidelines for planning and design of surface drains
21	IS 9452 (Part 3) : 1988	Code of practice for measurement of seepage losses from canals: Part 3 seepage meter method
22	IS 9913 : 2000	Code of practice for construction of cross drainage works (First Revision)
23	IS 6531 : 2021	Canal head regulators criteria for design Second Revision

24	IS 4410 (Part 15/Sec 5) : 2023	Glossary Of Terms Relating To River Valley Projects Part 15 Canal Structures Section 5 Cross-Drainage Works

CHAPTER 2

Geological Investigations and Engineering Applications

Introduction

The Bureau of Indian Standards (BIS), established under the BIS Act, 2016, is India's national standards body responsible for developing, implementing, and maintaining standards across diverse sectors. Its primary objective is to ensure quality, safety, and reliability in products, services, and systems while fostering sustainable practices. BIS plays a vital role in facilitating trade, protecting consumer interests, and promoting innovation. Through standardization, conformity assessments, and certification services, it supports critical areas such as infrastructure, engineering, and resource management, contributing to India's economic growth and sustainable development.

Geological investigations and engineering applications are integral to infrastructure planning and development. By examining the earth's subsurface composition and resources, these fields provide essential data for designing safe structures, optimizing resource utilization, and mitigating natural hazards. BIS contributes significantly by establishing standardized guidelines for practices such as soil and rock testing, groundwater exploration, and geotechnical assessments. These standards ensure accuracy, uniformity, and safety, enabling the seamless integration of geological insights into engineering solutions and strengthening the resilience of India's infrastructure.

Section 1: Geological Structure of Dams

Importance of Geological Alignment in Dam Construction

Geological alignment plays a critical role in the stability, safety, and functionality of dams. Proper alignment ensures that the dam's structure integrates seamlessly with the geological features of the area, maximizing stability and minimizing risks such as seepage, foundation failure, or structural deformation.

Stability of the Foundation

The dam must rest on stable geological formations to resist the pressures exerted by the impounded water.

Minimization of Seepage

Proper alignment helps identify and mitigate zones prone to seepage, reducing water loss and the risk of piping.

Earthquake Resistance

Alignment considers seismic activity to position the dam away from active faults and maximize stability.

Construction Feasibility

Alignment with natural geological features can reduce excavation costs and optimize material use.

Factors Affecting Dam Foundation

Rock Type and Strength

Strong, non-weathered rocks such as granites or basalts are ideal. Weak or porous rocks like shale or sandstone may require extensive treatment.

Seepage Characteristics

Permeable formations need grouting or cutoff walls to prevent water loss.

Structural Discontinuities

Faults, joints, and folds can act as zones of weakness, increasing susceptibility to failure.

Weathering and Erosion

Highly weathered rocks reduce the bearing capacity of foundations.

Tectonic Activity

Proximity to faults or seismic zones influences the choice of location and design considerations.

Favourable and Unfavourable Geological Conditions

Favourable Conditions

Competent and massive igneous rocks (e.g., granite, basalt).

Low-permeability sedimentary rocks (e.g., well-cemented sandstone).

Gentle dips or horizontal bedding planes.

Unfavourable Conditions

Weak, porous, or highly weathered rocks.

Fault zones, shear zones, or areas with extensive fracturing.

Karstic formations with voids or sinkholes.

Absence of active faults and minimal jointing	Steeply dipping bedding planes that increase the risk of sliding.

Geological Structure Considerations

Dam Axis and Geological Strike

The dam axis should ideally align perpendicular to the geological strike of the underlying rock strata. This minimizes the risk of sliding along bedding planes and ensures uniform load distribution. Special considerations include:

Anticline Structures	**Syncline Structures**
Avoid placing the axis along the crest of anticlines, as these zones are prone to fracturing and instability	Synclines may offer better stability if they consist of compact and impermeable rock types

Fault Zones

Dams should be located away from active fault zones to prevent displacement during seismic events

Jointed Rocks

Joint patterns must be studied in detail to ensure proper orientation of the dam axis, minimizing the likelihood of structural failure

Foundation Recommendations for Different Geological Conditions

Anticlines

Avoid construction along anticline crests.

Use extensive grouting to address fractures and reduce permeability.

Synclines

Suitable for dam foundations if the trough consists of impermeable and compact rocks.

Ensure adequate drainage to avoid water accumulation within the syncline.

Fault Zones	**Jointed Rocks**
Conduct thorough investigations to avoid locating dams on active faults.	Treat joints using grouting or concrete filling to reduce seepage and increase stability.
Implement seismic-resistant designs and consider using flexible materials to accommodate movement.	Optimize the dam axis orientation to minimize stress along joint planes

Case Study: Example of a Dam Project with Favourable Geological Structure

Bhakra Dam, Himachal Pradesh, India

Geological Setting: Built on the Sutlej River, the Bhakra Dam rests on compact and massive granitic rocks, which provide excellent stability and low permeability.

Key Features: The dam's alignment is perpendicular to the geological strike, ensuring minimal seepage and robust support.

Construction Challenges: Minor jointing and weathering in the granitic foundation were treated using extensive grouting, ensuring durability.

Outcome: The dam has successfully served as a critical hydropower and irrigation resource for decades, showcasing the importance of favourable geological conditions in dam construction.

Identify the Correct Geological Conditions for a Dam Foundation

1. Which of the following rock types is most favourable for a dam foundation?

(a) Shale (b) Granite (c) Limestone (d) Sandstone

2. What should be avoided when selecting the site for a dam?

(a) Compact granitic rocks (b) Fault zones

(c) Low-permeability sedimentary rocks (d) Horizontal bedding planes

3. Which geological structure is more stable for dam construction?

(a) Anticline with fractures (b) Syncline with impermeable rocks

(c) Fault with active displacement (d) Karstic formation with sinkholes

4. What is the primary consideration when aligning the dam axis?

(a) Perpendicular to the river flow

(b) Parallel to fault lines

(c) Perpendicular to the geological strike

(d) Along the axis of anticlines

5. Which treatment is commonly used for jointed rocks in dam foundations?

(a) Sealing joints with grouting

(b) Increasing joint width

(c) Realigning the joint planes

(d) Allowing natural seepage

6. Why are karstic formations generally unsuitable for dams?

(a) They have high permeability

(b) They are composed of impermeable rocks.

(c) They have horizontal bedding planes

(d) They are resistant to erosion

Answer: 1. (b) Granite 2. (b) Fault zones 3. (b) Syncline with impermeable rocks 4. (c) Perpendicular to the geological strike 5. (a) Sealing joints with grouting 6. (a) They have high permeability.

Section 2: Treatment of Dam Foundation

Improving Foundation Conditions

The treatment of dam foundations is crucial to ensure the stability and integrity of the dam structure. A strong and stable foundation reduces the risk of settlement, seepage, or even failure due to inadequate support.

Methods of improving foundation conditions include grouting, grout curtains, and soil treatments.

Grouting

Grouting involves injecting a fluid mixture (grout) into the ground or rock beneath the dam foundation. This fluid can fill voids, joints, or cracks and solidify to form a stable, impermeable barrier.

It is commonly used to treat jointed rocks, fractured soils, or areas with groundwater flow.

Grouting Process in Jointed Rocks

Grouting involves injecting a liquid mixture (cement-based or chemical grout) into the rock mass, typically through boreholes drilled into the rock. The grout fills the joints and cracks, solidifying the rock mass and reducing the permeability of the foundation. In areas with jointed rocks, grouting is used to create an impermeable barrier to water seepage, thus improving the foundation's stability.

Step 1: Drill holes into the jointed rock at specific intervals.

Step 2: Inject grout under pressure into these holes, filling fractures and voids.

Step 3: Allow grout to solidify, forming a tight, impermeable seal.

Case Study:

In the **Three Gorges Dam** project in China, extensive grouting was used to treat the jointed rock foundations. Due to the complexity of the geological conditions, the grout curtains extended up to 300 meters in depth, ensuring stability and preventing seepage into the dam's foundation. **(China Three Gorges Project Corporation, 2005)**

Indian Standards on Grouting:

IS 6066 : 1994 Pressure grouting of rock foundations in river valley projects - Recommendations (Second Revision)

IS 4999 : 1991 Recommendations for grouting of pervious soils (First Revision)

IS 14343 : 1996 Choice of grouting, materials for alluvial grouting – Guidelines

IS 12584 : 1989 Bentonite for grouting in civil engineering works – Specification

Grout Curtains

A **grout curtain** is a vertical or inclined barrier created by injecting grout into the rock or soil at various depths. It is designed to reduce the permeability of the foundation, controlling water seepage into or underneath the dam.

This method is particularly effective in porous or fractured rock formations.

Grout Curtain Installation Process

Step 1: Identify the geological layers requiring treatment.

Step 2: Drill vertical holes through these layers to a specified depth.

Step 3: Inject grout into these holes, creating a continuous impermeable barrier between the dam foundation and the surrounding area.

A grout curtain is created by drilling a series of closely spaced holes along the dam's foundation and injecting grout to create a continuous barrier. This method is particularly effective in porous or fractured rock formations where seepage is a concern. The grout used forms a solid, impermeable mass that prevents the flow of water underneath the dam.

In the **Bhakra-Nangal Dam** in India, a grout curtain was used extensively beneath the dam to prevent water seepage through the fractured rocks of the region. The curtain was created using high-pressure grouting techniques, ensuring that water could not compromise the foundation integrity. (*Central Water Commission (CWC), India, 2007)*

Indian Standards on Grout Curtain:

IS 11293 : 2018 Guidelines for the design of grout curtains for earth and rock fill dams, masonry dams and concrete gravity dams

Soil Treatments

Various soil treatments, such as **compaction grouting** and **chemical grouting**, are used to stabilize loose or weak soils beneath dam foundations. These treatments increase the load-bearing capacity of the soil and reduce its permeability.

Case Study: Dam Foundation Treatment in Jointed Rocks

Example: The Narmada Valley Dam, India

In areas where rock formations are highly jointed, such as in the **Narmada Valley** of India, the foundation treatments have included extensive grouting and grout curtain installations. The project engineers identified highly fractured basalt rock that required treatment for water seepage prevention.

Approach:

Multiple boreholes were drilled at strategic intervals along the foundation.

A cement-based grout mixture was injected under pressure to fill the joints and cracks in the basalt formation.

The grout curtain was installed around the entire dam base to prevent groundwater flow beneath the structure.

Lessons Learned:

The success of the grouting operation in the Narmada Valley Dam project significantly increased the water retention capacity of the reservoir and prevented seepage from compromising dam stability.

Source: "Dam Foundation Treatment in Jointed Rocks," Journal of Geotechnical Engineering, 2018

Interactive Element:

Puzzle: Match the Geological Condition with the Treatment Method

Geological Condition	**Treatment Method**
1. Jointed or fractured rock	A. Grouting

2. High permeability soil	B. Grout Curtains
3. Soft, unstable clay	C. Soil Stabilization

Answer Key:

1 → A (Grouting fills cracks in jointed rock).

2 → B (Grout curtains prevent seepage through permeable soils).

3 → C (Soil stabilization methods improve the strength of unstable clay)

Dam foundation treatment is a critical part of ensuring the longevity and safety of dam structures. By applying proven methods such as grouting, grout curtains, and soil treatments, engineers can significantly improve the stability of dams. Adhering to established standards, including **BIS**, and learning from successful national and international projects provides a framework for effective foundation treatment strategies.

Section 3: Geological Investigation of Tunnels

Geological investigation plays a crucial role in the design and construction of tunnels. Tunnels, whether for transportation, utilities, or other infrastructure, pass through varying geological formations that can significantly impact the safety, stability, and durability of the tunnel. A comprehensive geological investigation helps identify the type of rock and soil, groundwater conditions, fault lines, and other geological features that may affect the tunnel's construction and long-term performance. By assessing these conditions, engineers can design appropriate tunnelling methods, select suitable materials, and plan for any potential challenges such as water seepage, ground movement, or rock instability. Proper geological surveys and investigations are essential to mitigate risks, optimize construction techniques, and ensure the successful completion of tunnel projects.

Types of Tunnels and Excavation Methods

Tunnels can serve a variety of purposes, such as transportation, water supply, sewer systems, and utilities. Understanding the geological conditions along the tunnel's route is essential for selecting the appropriate excavation method. Below are some common types of tunnels and the methods used for excavation:

Types of Tunnels

Transportation Tunnels: Used for roads, railways, and subways.

Utility Tunnels: For water supply, sewage, and electricity cables.

Hydropower Tunnels: For water diversion or hydropower generation.

Excavation Methods

Drill and Blast Method

Used for hard rock tunnelling, where explosives break the rock.

Tunnel Boring Machine (TBM)

A machine that bores through rock or soil to create circular tunnels

Cut-and-Cover Method

Typically used for shallow tunnels, involving excavation and then covering the tunnel with a structure.

Immersed Tube Tunnel

Used for underwater tunnelling by sinking prefabricated tunnel sections into a waterway.

Geological Investigation Techniques for Tunnels

Geological investigations are essential to assess the conditions of the ground through which the tunnel will pass. The primary techniques used in tunnel investigations include:

Borehole Drilling:

Borehole drilling involves drilling into the ground to collect samples of soil, rock, and groundwater. This method helps determine the type of rock, groundwater levels, and soil characteristics at different depths, which is crucial for selecting the tunnelling method and designing tunnel support systems.

Geophysical Surveys:

Geophysical techniques, such as seismic refraction and resistivity surveys, are non-invasive methods used to map subsurface conditions. These surveys can detect variations in rock types, fractures, and fault zones, which are critical for tunnelling projects.

Geotechnical Analysis:

Once samples are collected, geotechnical testing is performed to evaluate the strength, permeability, and other properties of the materials. This analysis helps in the selection of appropriate tunnel linings and support structures.

Relevant Indian Standards:

IS 13216 : 1991 Code of practice for geological exploration for reservoir sites

IS 15681 : 2006 Geological exploration by geophysical method (Seismic Refraction) - Code of practice

IS 15736 : 2007 Geological exploration by geophysical method (Electrical Resistivity) - Code of practice

IS 15755 : 2007 Hydrometry - Geophysical logging of boreholes for hydrogeological purposes - Considerations and guidelines for making measurements

IS 15897 : 2011 Surface geophysical surveys for hydro geological studies

IS 17883 : 2022 Geological Exploration for Tunnels Guidelines

Geological Information for Tunnelling

Influence of Rock Type and Alignment on Excavation Methods

The type of rock encountered during tunnelling significantly impacts the choice of excavation method. Below are the effects of different rock types:

Hard Rock (e.g., Granite, Basalt)	Soft Rock (e.g., Claystone, Shale)
Harder rocks are typically excavated using the drill and blast method or Tunnel Boring Machines (TBM). These rocks require high energy for excavation and may cause tunnelling to be slow and costly.	Soft rocks are easier to excavate and may require less sophisticated methods, such as a slurry TBM or even a simple cut-and-cover method.

Mixed Ground (hard and soft layers)

In mixed ground, varying excavation methods may be needed in different sections. A combination of TBMs and drill-and-blast techniques is often employed to deal with the varying conditions.

Example: The **Narmada Canal Tunnel Project**, part of India’s Narmada Valley Development, involved tunnelling through fractured and water-rich rock. The tunnel was lined with reinforced concrete to withstand the groundwater pressure and prevent seepage, ensuring the water conveyance system's longevity and efficiency.

Impact of Geological Conditions on Tunnel Design

Geological conditions, including the presence of groundwater, fractures, faults, and the type of rock, affect tunnel design in several ways:

Groundwater Control

In areas with high groundwater, such as aquifers or riverbeds, it is necessary to design tunnel linings and waterproofing systems to prevent water ingress.

Tunnel Lining

The type of material for tunnel linings (concrete, steel, etc.) is influenced by the geological conditions. In unstable or fractured rock, stronger and

Grouting or drainage systems may also be required.

more flexible linings are used to withstand deformation.

Support Systems

In soft or unconsolidated soils, tunnel excavation often requires immediate support, such as shotcrete or steel ribs, to prevent tunnel collapse. In hard rock conditions, less immediate support may be needed, but the risk of explosive hazards may require careful monitoring.

Interactive Element: Quiz - Best Tunnelling Methods for Different Geological Conditions

Instructions: Choose the most appropriate tunnelling method based on the given geological conditions. After completing the quiz, refer to the explanations for more details.

Question 1: You are tasked with tunnelling through a mountainous region with **hard granite rock**. What excavation method should you use?

a) Tunnel Boring Machine (TBM)

b) Drill and Blast Method

c) Cut-and-Cover Method

d) Immersed Tube Tunnel

Question 2: You are working on a tunnel under a river, where you encounter **soft clay and silt** layers. Which method is most suitable for excavation?

a) Tunnel Boring Machine (TBM)

b) Cut-and-Cover Method

c) Drill and Blast Method

d) Slurry TBM

Question 3: In a city with high **groundwater levels** and soft rock layers (shale), which additional step is required during tunnelling?

a) Use of a Tunnel Boring Machine

b) Grouting to control seepage

c) Shotcrete for support

d) All of the above

Question 4: In a region with a mix of **soft and hard rock layers** (e.g., limestone overlaid by sandstone), which method is most appropriate?

a) Tunnel Boring Machine (TBM)

b) Drill and Blast Method for soft rock and TBM for hard rock

c) Cut-and-Cover Method

d) Immersed Tube Tunnel

Answers & Explanations

1. **Answer: b) Drill and Blast Method**
   Hard granite rock requires the drill and blast method, as this

technique is highly effective in breaking through hard rock formations.

2. **Answer: d) Slurry TBM**
   Slurry TBM is ideal for tunneling through soft, water-bearing soils like clay and silt, as it can manage water pressure and prevent ground settlement.
3. **Answer: b) Grouting to control seepage**
   Groundwater control is essential in areas with high water levels, and grouting is a common method used to prevent water ingress and stabilize the tunnel.
4. **Answer: b) Drill and Blast Method for soft rock and TBM for hard rock**
   Mixed ground conditions require the use of different techniques, where drill and blast may be needed for soft rock layers and TBM for harder layers.

Examples from International and National Water Resources Projects

The Kariba Dam Tunnel (Zambia-Zimbabwe) The Kariba Dam project involved tunnelling through fractured rock formations. To handle groundwater pressures and prevent water ingress, the project utilized a combination of drill and blast methods and slurry TBM in areas where the rock was fractured. Grouting was also performed to stabilize the rock and prevent seepage.

Source: "Kariba Dam Hydropower Tunnel Project," World Bank Report, 2010.

The Tehri Dam Tunnelling Project (India) The Tehri Dam, one of India's largest hydropower projects, required tunnelling through both hard granite rock and fractured zones. The project used Tunnel Boring Machines (TBM) for the granite sections and drill-and-blast techniques in fractured zones. The tunnels were designed with reinforced concrete linings to withstand water pressure and prevent seepage.

Source: "Tehri Hydropower Tunnel Construction," THDC India Ltd., 2009.

Geological investigations are integral to the successful design and execution of tunnelling projects. The type of rock and soil, along with groundwater conditions, dictate the choice of excavation method. International and national tunnelling projects showcase the importance of adapting excavation techniques to varying geological conditions. The use of comprehensive geological surveys, including borehole drilling and geophysical methods, enables engineers to make informed decisions for the safety and efficiency of tunnel construction.

Section 4: Geological Investigation of Canals

Geological investigations play a crucial role in the design, construction, and maintenance of canals, particularly those used for water resources projects such as irrigation, water supply, and flood management. Understanding the subsurface conditions along the proposed canal route is essential for determining its stability, efficiency, and longevity.

Canal Alignment and Geological Considerations

Canal alignment plays a crucial role in its stability, performance, and longevity. Geological conditions, such as soil type, rock formations, groundwater levels, and seismic activity, significantly influence the alignment of canals.

Factors Affecting Canal Alignment:

- **Topography:** Elevation differences along the canal's route.
- **Soil Conditions:** Permeability and strength of soils along the proposed alignment.
- **Hydrology:** Impact of groundwater flow and surface water levels on canal design.

    - **Seismic Zones:** Areas with seismic activity may require additional reinforcement or alternative alignment.

Geological Considerations:

- **Permeable Soils and Rocks:** Areas with high permeability require more attention to seepage control methods, such as lining.
- **Fault Zones:** Fault zones may cause shifting and require special construction techniques to stabilize the canal route.

Lining Methods for Canals Based on Geological Factors

Canal linings are essential to control water seepage, prevent erosion, and ensure the efficient conveyance of water. The choice of lining material depends on various geological factors:

- **Concrete Lining:** Commonly used in areas with highly permeable soils and soft rocks.
- **Clay Lining:** Suitable for areas where the soil is less permeable and stable.
- **Geomembrane Lining:** Used in areas with high seepage or adverse soil conditions, offering a cost-effective solution.
- **Stone Pitching or Masonry Lining:** Ideal for rocky or mountainous areas to prevent erosion and control seepage.

Importance of Subsurface Investigations for Canal Construction

Subsurface investigations, such as borehole drilling and geophysical surveys, are vital in determining the geological conditions along the canal's route. These investigations help identify:

- **Soil and Rock Types:** Whether the soil is clayey, sandy, or rocky, affecting the choice of lining and construction method.
- **Groundwater Flow:** Determines seepage rates and the need for a more durable lining method.

- **Seismic Activity:** Identifies areas of potential instability requiring special construction techniques or alignment adjustments.

Construction of The Indira Gandhi Canal, India

The Indira Gandhi Canal, also known as the Rajasthan Canal, is one of India's largest irrigation projects. The canal spans 650 kilometres across the arid regions of Rajasthan. During its construction, extensive geological investigations were carried out to determine the most suitable alignment and lining methods.

Geological Investigations:

- Boreholes were drilled along the canal's route to assess soil permeability, groundwater levels, and the type of rock formations.
- Seismic activity was considered for areas in the Aravalli range, where fault lines were identified.
- A combination of **concrete and geomembrane linings** was chosen for areas with high seepage, while **clay linings** were used in less permeable soil zones.

Outcome:
The geological survey ensured that water seepage was controlled effectively, and the canal system has provided irrigation to the region for over four decades, with minimal maintenance issues.

Table 1: Different Types of Canal Linings and Their Suitability for Varying Geological Conditions

Geological Condition	Suitable Lining Type	Reasons for Suitability

High permeability (sandy soils, fractured rock)	Concrete Lining, Geomembrane	Controls seepage and water loss effectively.
Low permeability (clay or loam)	Clay Lining	Natural material that enhances soil cohesion and reduces seepage.
Rocky or mountainous terrain	Stone Pitching, Masonry Lining	Provides stability against erosion and weathering in uneven surfaces.
Areas with heavy rainfall or floods	Reinforced Concrete, Asphalt	Prevents erosion and manages water flow in fluctuating conditions.
Areas with high seepage risk	Geomembrane Lining, Bentonite Clay	Ensures minimal seepage and prevents water loss due to permeability.

Relevant Indian Standards

IS 11385 : 2008 Subsurface exploration for canals and cross drainage works - Code of practice (First Revision)

Interactive Element:

1. **Which type of canal lining is most suitable for high seepage areas, such as sandy soils or fractured rocks?**

A) Clay Lining B) Concrete Lining

C) Stone Pitching D) Geomembrane Lining

2. **For canals passing through rocky or mountainous terrain, which lining method is preferred to prevent erosion and manage seepage?**

A) Geomembrane Lining B) Reinforced Concrete

C) Stone Pitching or Masonry Lining D) Clay Lining

3. **Which geological condition would make the use of geomembrane lining most effective?**

A) High permeability soils B) Low permeability soils

C) Rocky terrains D) Shallow groundwater presence

4. **In areas with high rainfall and flood risk, which lining method helps manage water flow and prevent erosion?**

A) Stone Pitching	B) Geomembrane Lining
C) Reinforced Concrete Lining	D) Clay Lining

Answer Key:

1. **D) Geomembrane Lining** (Prevents water loss in highly permeable areas).
2. **C) Stone Pitching or Masonry Lining** (Stable in uneven, rocky terrains).
3. **A) High permeability soils** (Geomembrane lining is effective for controlling seepage).
4. **C) Reinforced Concrete Lining** (Durable for managing floodwater and preventing erosion).

This section outlines the critical role geological investigations play in the construction and design of canals. By thoroughly understanding the geological conditions of a region, engineers and geologists can select the most suitable alignment and lining methods for canals, ensuring they are both cost-effective and sustainable. Through case studies, data, and standards, this content has been designed to provide geologists with a comprehensive understanding of canal construction processes while integrating important national and international standards, making it a valuable resource for practical applications in the field.

Section 5: Hydrological and Meteorological Investigations

Hydrological and meteorological data are crucial for effective infrastructure planning, particularly in regions prone to extreme weather conditions, such as droughts, floods, or varying seasonal patterns. Accurate data on precipitation, temperature, streamflow, and groundwater levels are essential to make informed decisions regarding water management, infrastructure resilience, and sustainable development.

This section delves into the key concepts of hydrology and meteorology, exploring their significance in infrastructure planning, key parameters to consider, and their role in decision-making processes. Additionally, case studies will be examined to showcase how these parameters directly impact infrastructure projects.

Importance of Hydrological and Meteorological Data in Infrastructure Planning

The role of hydrological and meteorological investigations in infrastructure planning cannot be overstated. With the increasing impact of climate change, understanding rainfall patterns, temperature variations, groundwater levels, and streamflow is pivotal for:

- **Flood and drought management**: Infrastructure such as roads, dams, bridges, and buildings must be designed with anticipated environmental conditions in mind.
- **Water resource management**: Data helps in planning for reservoirs, irrigation systems, and wastewater treatment.
- **Urban planning**: Effective drainage systems, stormwater management, and floodplain protection rely on meteorological data.

These factors ensure that infrastructure is not only resilient to extreme weather but also sustainable in the long term.

Key Parameters in Hydrological and Meteorological Investigations

Precipitation

Precipitation data is fundamental in understanding water availability in a region. The frequency, intensity, and distribution of rainfall play a key role in water resource management. For example, data on annual precipitation trends can guide the construction of reservoirs or irrigation channels.

In the **Indian subcontinent**, regions like Rajasthan and Gujarat face severe water scarcity. Precipitation data is essential to plan for water storage systems in these drought-prone areas.

Temperature

Temperature affects evaporation rates, which in turn influence groundwater recharge and streamflow. Increased temperatures can lead to more rapid evaporation, especially in arid regions, impacting water availability for infrastructure projects.

In **California**, the temperature rise due to climate change has significantly altered the seasonal snowmelt patterns, which has major implications for water storage and hydroelectric power plants.

3. Streamflow

Streamflow data helps to understand the movement of surface water, which is crucial for river-based infrastructure such as dams and bridges. Fluctuations in streamflow can indicate risks of flooding or drought, which in turn affect infrastructure safety and planning.

Kosi River in Bihar, India, has a history of shifting its course and causing large-scale flooding. Hydrological studies of streamflow have been used to construct embankments and plan flood management strategies.

4. Groundwater Levels

Groundwater levels are key to determining the long-term sustainability of water supplies. Rising or falling groundwater levels can indicate the efficiency of recharge mechanisms and can inform the development of sustainable water systems.

In **China**, excessive groundwater extraction for irrigation in the North China Plain has led to a significant decline in groundwater levels, affecting both agriculture and urban water supply.

Graph: Rainfall Trends in a Particular Region

Table: Drought Indices and Their Significance in Water Resource Management

Drought Index	Description	Application in Infrastructure
Standardized Precipitation Index (SPI)	Measures precipitation deficit over time	Helps plan water storage systems
Palmer Drought Severity Index (PDSI)	Indicates long-term drought severity	Aids in designing irrigation infrastructure
Crop Moisture Index (CMI)	Tracks short-term drought conditions	Guides crop irrigation and groundwater management

Case Study: Hydrological Investigation in Drought-Affected Region

Drought in Marathwada Region, Maharashtra (India)

In 2016, the Marathwada region of Maharashtra, India, faced severe drought conditions. Hydrological investigations, including precipitation, groundwater level monitoring, and streamflow analysis, were essential in:

- Identifying critical water shortages.
- Planning infrastructure projects, including water conservation measures such as check dams and reservoirs.
- Implementing emergency water supply systems.

These investigations directly impacted the region's infrastructure by ensuring that the design of water systems could handle water scarcity during extreme conditions.

Interactive Element: Multiple-Choice Question

Que. How does temperature affect groundwater levels?

a) Higher temperatures lead to an increase in groundwater levels.
b) Higher temperatures lead to a decrease in groundwater levels due to increased evaporation.
c) Temperature has no effect on groundwater levels.
d) Groundwater levels fluctuate randomly regardless of temperature changes.

Correct Answer: b) Higher temperatures lead to a decrease in groundwater levels due to increased evaporation.

The **Bureau of Indian Standards (BIS)** plays a crucial role in setting standards for hydrological and meteorological investigations, particularly in the context of infrastructure planning. BIS standards for hydrometry (Hydrometry Sectional Committee, WRD 01), flood management (Flood Management, Erosion Management and Diversion Works Sectional Committee, WRD 22), and groundwater investigations (Groundwater and related Investigations Sectional Committee, WRD 03) ensure that data collection and analysis follow internationally recognized methodologies. The Indian standards developed by various Sectional Committees of BIS contribute to:

- **Consistency in data**: Ensuring accurate and comparable hydrological data across regions.
- **Sustainability**: Helping in the design of infrastructure that can withstand the impacts of changing climatic conditions.

Hydrological and meteorological investigations provide the foundational data required for effective infrastructure planning. By understanding key parameters such as precipitation, temperature, streamflow, and groundwater levels, engineers and planners can design resilient, sustainable infrastructure projects that can withstand the challenges posed by extreme weather events.

Through case studies, data analysis, and BIS standards, this section has highlighted the importance of integrating hydrological and meteorological data into infrastructure development. This will guide the future efforts of geologists, urban planners, and engineers in ensuring the success and longevity of infrastructure projects across the globe.

Section 6: Selection of Tunnel Site

Tunnels are critical components of modern infrastructure, serving as the backbone for transportation systems like metro lines, highways, railways, and water supply systems. The selection of the tunnel site is one of the most challenging and crucial stages of tunnel engineering, involving complex geological investigations. This section covers the key criteria and considerations involved in selecting tunnel routes, the influence of geological conditions on tunnel alignment, and the excavation methods used in tunnel construction. It also highlights relevant standards from the Bureau of Indian Standards (BIS), and includes interactive elements for a comprehensive understanding of tunnel site selection.

The selection of a tunnel site and the alignment for excavation requires a careful study of the geological conditions, project requirements, and available technology. The primary goal is to ensure that the tunnel can be constructed efficiently, safely, and sustainably.

Criteria for Selecting Tunnel Routes

Several factors influence the selection of tunnel routes, which include:

Geological Conditions

The type of rocks and soil encountered, including their stability and ability to support tunnelling operations.

Hydrological Conditions

Groundwater presence can pose challenges, especially if tunnels need to be excavated below the water table.

Environmental Impact

The potential for disruption to the surrounding environment, including soil stability, flora, fauna, and human settlements.

Cost and Accessibility

Route selection also considers project cost, construction feasibility, and availability of construction materials.

Geological Factors Affecting Tunnel Alignment

Rock Types and Strength:

The type of rock through which a tunnel will pass (e.g., hard rock, soft rock, or mixed rock) significantly influences both excavation methods and tunnel design.

- **Hard Rocks:** Typically, tunnels through hard rocks (e.g., granite, basalt) are more stable and easier to tunnel through, but require heavy-duty machinery.
- **Soft Rocks:** Soft rock (e.g., clay, silt) can be more challenging, as it may collapse more easily and require more robust support systems.

Faults and Fractures:

The presence of faults, fractures, and other geological discontinuities can compromise the integrity of the tunnel and pose risks during construction.

Groundwater Conditions:

Tunnels in areas with high groundwater levels require specific precautions to prevent flooding and water ingress. In such areas, engineers use dewatering techniques and install water-tight linings.

In the realm of civil engineering, geological investigations are fundamental to the successful design, construction, and maintenance of critical infrastructure such as dams, tunnels, and canals. By understanding the geological conditions of a project site, engineers can make informed decisions that ensure the stability, safety, and longevity of these structures. The insights provided by geological surveys help mitigate risks associated with poor foundation conditions, groundwater issues, and seismic activity, thus preventing costly failures and enhancing the sustainability of infrastructure projects.

The application of advanced methods such as grouting, soil stabilization, and tunnel boring technology, alongside adherence to internationally recognized standards, plays a crucial role in overcoming challenges posed by complex geological environments. Case studies of major projects such as the Narmada Dam, Gotthard Base Tunnel, and the Mahi Bajaj Canal exemplify how effective geological investigations lead to successful project outcomes.

The Bureau of Indian Standards (BIS), through its development and dissemination of relevant standards, plays a pivotal role in ensuring that geological investigations align with national and global best practices. By setting clear guidelines, BIS ensures that infrastructure projects meet high safety standards while maintaining environmental sustainability.

In conclusion, the integration of geological investigation processes with engineering practices, underpinned by BIS standards, is key to the development of safe and efficient infrastructure. This booklet provides a detailed exploration of these processes and their applications, serving as a valuable resource for engineers, geologists, and policymakers involved in the planning and execution of large-scale infrastructure projects. By leveraging the knowledge and techniques outlined here, professionals can contribute to the creation of resilient and sustainable infrastructure that benefits society for generations to come.

CHAPTER 3

Dam Instrumentation

A. Introduction

Instrumentation in dams forms the backbone of their safety and operational reliability. It provides engineers with the tools to monitor critical parameters, detect anomalies, and make informed decisions to prevent failures. The role of instrumentation extends beyond mere observation—it is an active mechanism for ensuring the structural and functional health of dams under diverse environmental and operational conditions.

This handbook serves as a guide for field engineers. It presents a structured roadmap for planning, implementing, and managing dam instrumentation systems, focusing on standardization as a pivotal element for accuracy, uniformity, and effectiveness.

Readers will explore key aspects of instrumentation, from selecting appropriate technologies to the integration of advanced monitoring systems like IoT and AI.

The aim is to cultivate a deeper understanding of the technical and operational nuances of dam instrumentation, emphasizing the importance of adopting standardized practices to safeguard water resource infrastructure and foster resilience against evolving challenges.

B. What is Instrumentation?

Instrumentation refers to the use of specialized devices to monitor and measure key physical parameters that impact the safety and performance of dams. These parameters include water pressure, seepage, movement, stress, strain, and temperature. By collecting and analyzing data, instrumentation enables engineers to assess dam behaviour and make informed decisions to ensure structural safety and functionality.

B.1 Components of an Instrumentation System

1. **Sensors**: Devices that detect and measure physical parameters (e.g., piezometers for water pressure).
2. **Signal Transmission Media**: Mechanisms for transmitting data from sensors to monitoring systems (e.g., cables, wireless systems).
3. **Data Acquisition Systems**: Tools for recording, storing, and processing data.
4. **Visualization and Reporting Tools**: Software or equipment for presenting data in a usable format.

B.2 Types of Instrumentation

Instrumentation can be classified based on its purpose and operating principles:

- **Mechanical Instruments**: Operate based on mechanical principles (e.g., standpipe piezometers).
- **Electrical Instruments**: Use electrical signals to measure parameters (e.g., vibrating wire strain gauges).
- **Automated Systems**: Include data loggers and remote monitoring technologies for real-time data collection.

C. Purpose of Instrumentation

The primary purpose of instrumentation is to monitor and evaluate the safety and performance of dams. It serves the following objectives:

1. **Proving Behaviour is as Expected** Instrumentation helps confirm that the dam is performing as designed. It verifies design assumptions by showing that no abnormalities exist, which provides reassurance about the dam's stability and functionality.
2. **Warning of a Problem** Instruments can detect unusual changes or trends in dam behaviour that are not visibly apparent. This early

detection can warn of potential issues, allowing for timely intervention before problems become severe.

3. **Defining and Analyzing a Problem** Data from instruments assist in defining and analyzing the extent and specifics of a dam issue. This includes understanding whether issues like movements or leaks are localized or widespread, worsening or stable, thus guiding the necessary corrective actions.
4. **Evaluating Remedial Actions** After implementing remedial measures to correct identified issues, instrumentation continues to monitor the dam. This ongoing data collection is crucial to evaluate the effectiveness of the interventions and ensure the dam's continued safe operation.

D. Need for Instrumentation

Instrumentation in dams is crucial for reducing risks and preventing failures by continuously inspecting, monitoring, and analyzing a dam's behaviour. Key focus areas include monitoring structural displacements, deformations, settlements, seepages, and piezometric pressures, as well as detecting seismic activities that could damage the dam. Despite the variability in instrumentation needs for each dam, the presence or absence of existing instrumentation is not the sole reason for new installations. Effective instrumentation is vital for assessing dam performance, enhancing safety, and refining future dam designs.

E. Parameters to be Monitored

Instrumentation in dams revolves around monitoring key parameters that directly impact structural integrity, operational efficiency, and safety. These parameters provide critical insights into the dam's performance and potential vulnerabilities.

E.1 Key Parameters

1. **Water Pressure**
   - **Definition**: Measures the pore pressure and uplift forces within the dam body and its foundation.

- **Importance**: High water pressure can lead to instability or failure by reducing effective stress.
- **Instruments Used**: Piezometers (open standpipe, closed hydraulic, and electrical).

2. **Seepage and Leakage**
   - **Definition**: Tracks water movement through or around the dam.
   - **Importance**: Excessive seepage can lead to erosion, piping, or foundation instability.
   - **Instruments Used**: Weirs, Parshall flumes, velocity meters, calibrated containers.
3. **Structural Movement**
   - **Definition**: Observe displacements, deformation, and vibrations of the dam structure.
   - **Importance**: Detects abnormal structural behaviour caused by internal or external stresses.
   - **Instruments Used**: Inclinometers, extensometers, crack meters, and plumb lines.
4. **Stress and Strain**
   - **Definition**: Measures forces and deformation within the dam material.
   - **Importance**: Identifies overstressed areas that may lead to cracks or failure.
   - **Instruments Used**: Stress meters, strain gauges.
5. **Temperature**
   - **Definition**: Monitors temperature changes within the dam body and foundation.
   - **Importance**: Temperature variations affect material properties and expansion, impacting structural behaviour.
   - **Instruments Used**: Thermometers, thermographs.
6. **Seismic Activity**
   - **Definition**: Records ground motion and dam response during seismic events.
   - **Importance**: Evaluates the structural resilience and identifies potential vulnerabilities.

- **Instruments Used**: Accelerometers, seismographs.

7. **Reservoir and Tailwater Levels**
   - **Definition**: Monitors water levels upstream and downstream of the dam.
   - **Importance**: Helps in flood management and evaluating hydraulic forces acting on the dam.
   - **Instruments Used**: Staff gauges, ultrasonic sensors.
8. **Weather Conditions**
   - **Definition**: Observes hydrometeorological parameters such as rainfall, evaporation, and wind.
   - **Importance**: Provides context for analyzing dam behaviour under varying climatic conditions.
   - **Instruments Used**: Rain gauges, evaporation pans, anemometers.

Structure Type	Feature	Visual observation	Movements	Uplift and pore pressure	Water levels and flow	Seepage flows	Water quality	Temperature measurement	Crack and joint measurement	Seismic measurement	Stress-strain measurement
Embankment Dams	Upstream slope	●	●	●	●	–	–	–	–	●	–
	Downstream slope	●	●	●	–	●	●	●	●	●	–
	Abutments	●	●	●	–	●	●	●	–	●	–
	Crest	●	●	●	–	–	–	–	●	●	–
	Internal drainage system	–	–	●	–	●	●	●	–	–	–
	Relief Drain	●	–	●	–	●	●	–	–	–	–
	Riprap and other slope protection	●	–	–	–	–	–	–	–	–	–
Concrete and Masonry Dams	Upstream slope	●	●	–	●	–	–	●	●	●	●
	Downstream slope	●	●	●	–	–	–	●	●	●	●
	Abutments	●	●	●	–	●	●	–	–	●	●
	Crest	●	●	●	–	–	–	●	●	●	●
	Internal drainage system	–	–	●	–	●	–	–	●	–	–
	Relief drains	●	–	●	–	●	–	–	–	–	–
	Galleries	●	●	–	–	–	–	–	●	●	●
	Sluiceways/controls	●	–	–	●	–	–	–	–	–	–
Spillways	Approach channel	●	●	–	●	–	–	–	–	–	–
	Inlet/outlet	●	●	●	●	●	–	–	●	●	–

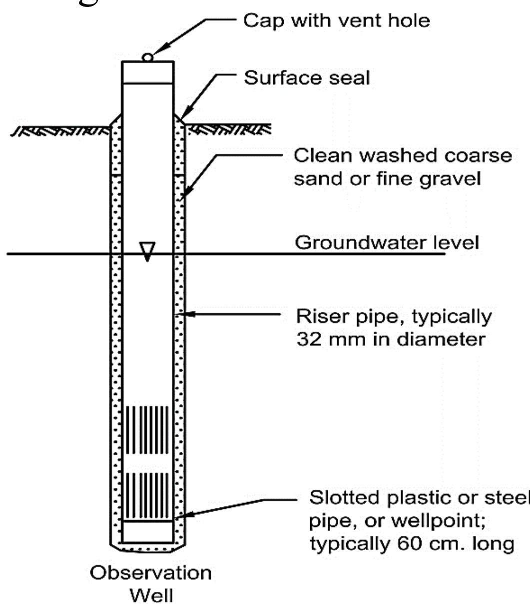
Parameters to be Monitored at Dams and the Suggested Instruments or Observation Techniques to be Used

Structure Type	Feature	Visual observation	Movements	Uplift and pore pressure	Water levels and flow	Seepage flows	Water quality	Temperature measurement	Crack and joint measurement	Seismic measurement	Stress-strain measurement
	structure										
	Stilling basin	●	–	–	●	–	–	–	●	–	–
	Discharge conduit/channel	●	–	●	●	–	–	–	–	–	–
	Gate controls	●	–	–	–	–	–	–	–	–	–
	Erosion protection	●	–	–	–	–	–	–	–	–	–
	Side slopes	●	●	●	–	●	–	–	–	–	–
Outlets & Drains	Inlet/outlet structure	●	●	●	●	–	–	–	●	●	–
	Stilling basin	●	–	–	–	–	–	–	–	–	–
	Discharge conduit/channel	●	●	●	●	–	–	–	●	–	–
	Trash rack/debris controls	●	–	–	–	–	–	–	–	–	–
	Emergency systems	●	–	–	–	–	–	–	–	–	–
General Areas	Reservoir surface	●	–	–	–	–	●	–	–	–	–
	Mechanical/electrical systems	●	–	–	●	–		–	–	–	–
	Shoreline	●	–	–	–	–	●	–	–	–	–
	Upstream watershed	●	–	–	–	–	●	–	–	–	–
	Downstream channel	●	–	–	–	●	●	–	–	–	–

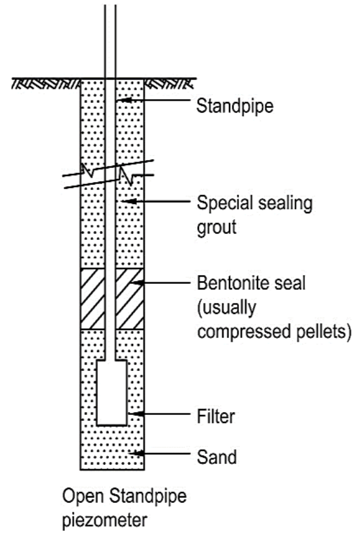
Parameters to be Monitored at Dams and the Suggested Instruments or Observation Techniques to be Used

F. Instrument Types and Their Uses

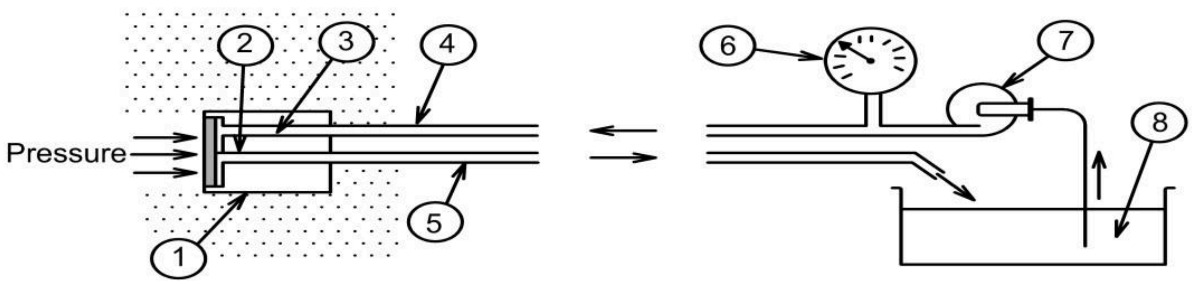
F.1 Water Pressure:
Measures the pressure of water within a dam structure to detect abnormalities and assess dam stability.
F.1.1 Open-type Hydraulic Piezometers: Instruments used for direct measurement of water level elevations in a dam, crucial for assessing hydrostatic pressures.
F.1.1.1 Observation Wells: Basic open-type piezometers with a slotted or porous bottom used to measure water levels across different zones, which may provide ambiguous data due to interconnected strata.



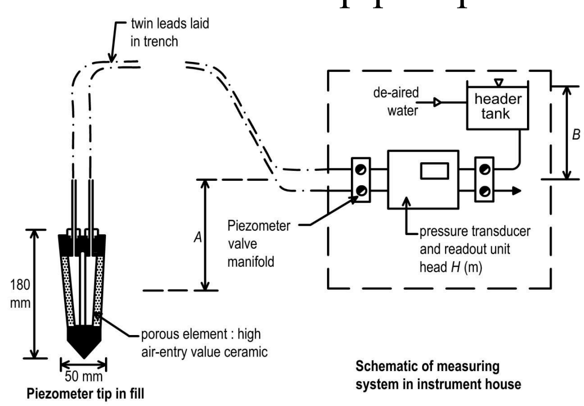
F.1.1.2 Open Standpipe Piezometers: Enhanced open-type piezometers with subsurface seals to isolate specific measurement strata for more accurate hydrostatic pressure readings.



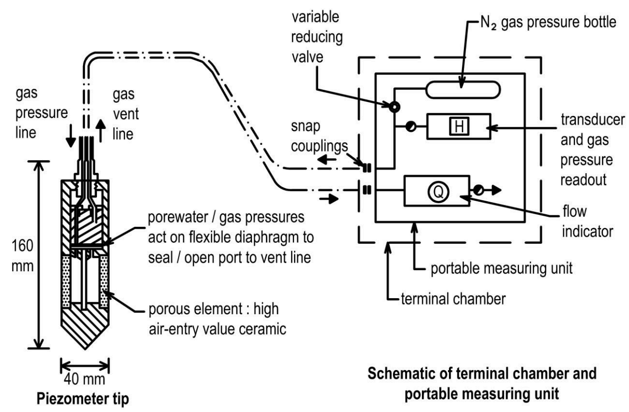
F.1.2 Closed-type Hydraulic Piezometers: Utilize a sealed system to measure water pressure across a diaphragm without direct atmospheric exposure, enhancing measurement reliability.



F.1.2.1 Closed Standpipe Piezometers: Measure water levels under artesian conditions using a pressure gauge, providing accurate readings even when the water level is above the pipe top.



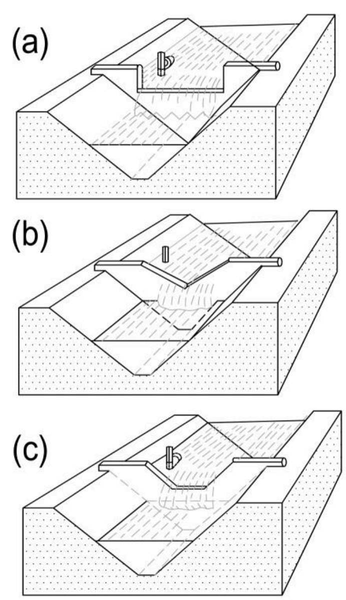
F.1.3 Electric Piezometers: Offer rapid responses to water level changes but are typically more expensive and less flexible compared to hydraulic models.



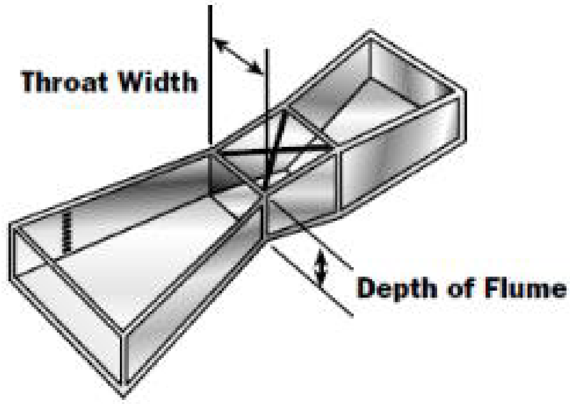
F.1.4 Monitoring Frequency: The appropriate frequency for checking piezometers varies based on operational and environmental conditions to ensure timely detection of potential issues.

F.2 Seepage and Leakage:
Indicators of a dam’s water-retention effectiveness and potential internal erosion problems, critical for maintaining dam safety.

F.2.1 Measurement Using Weirs: Weirs are used to measure water flow rates, helping in the management and diagnosis of water flow-related issues in dams.



F.2.2 Measurement Using Parshall Flumes: Parshall flumes measure water flows in open channels, providing essential data for operational management and safety analysis.



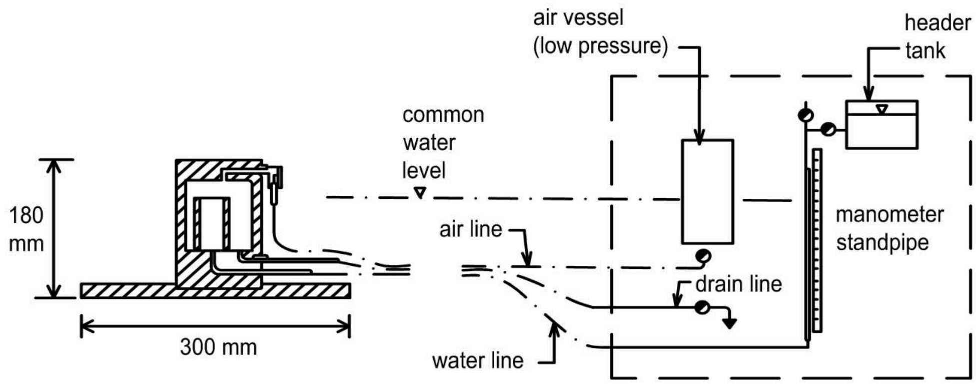
F.2.3 Measurement Using Velocity Meters: Velocity meters are used to measure water flow rates, important for assessing the condition and efficiency of water flow management systems.

F.2.4 Measurement Using Calibrated Containers: These are used to measure specific volumes of water, aiding in precise water management and safety assessments.

F.2.5 Detection by Visual Inspection: Regular physical inspections are vital for assessing and identifying potential issues in dam infrastructure.

F.2.6 Detection Using Fibre Optic Cable: Advanced technology used to monitor conditions within the dam structure, providing real-time data on potential problem areas.

F.3 Movement:
Monitoring physical movements within the dam structure is essential for assessing its stability and integrity.



Settlement cell in fill

Schematic of standpipe system in instrument house

F.3.1 Types of Movement: Identifies different forms of physical movements observed in dams, each indicating different potential issues and structural behaviours.

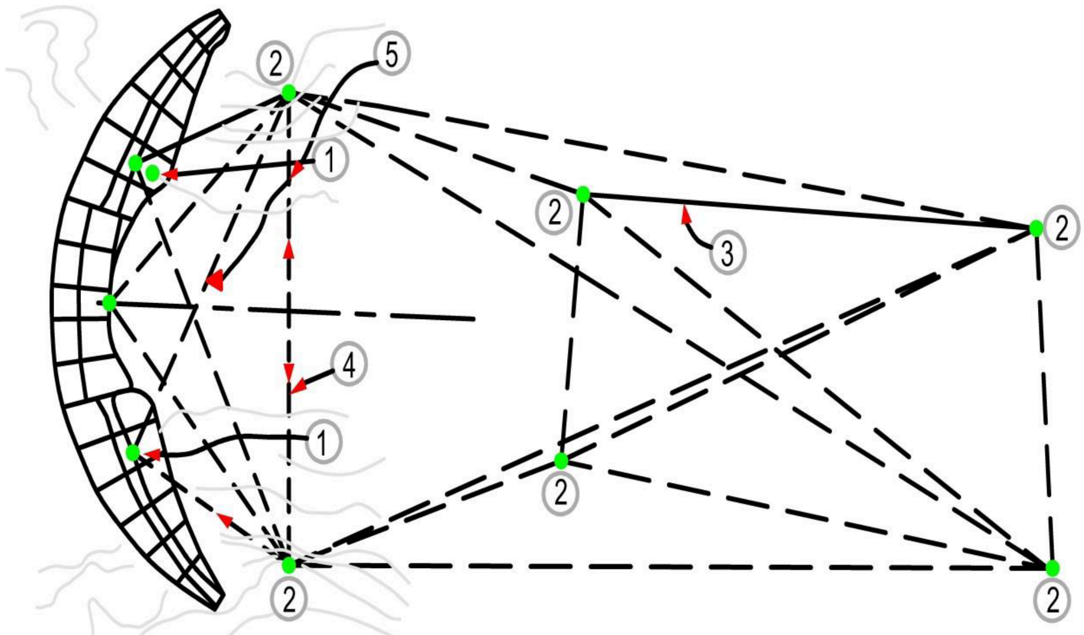
F.3.2 Surface Movement: Monitoring surface movements is crucial to detect shifts or deformations that could affect dam safety.

F.3.2.1 Level Surveys: Conducted to monitor vertical movements and ensure the dam remains level and stable.

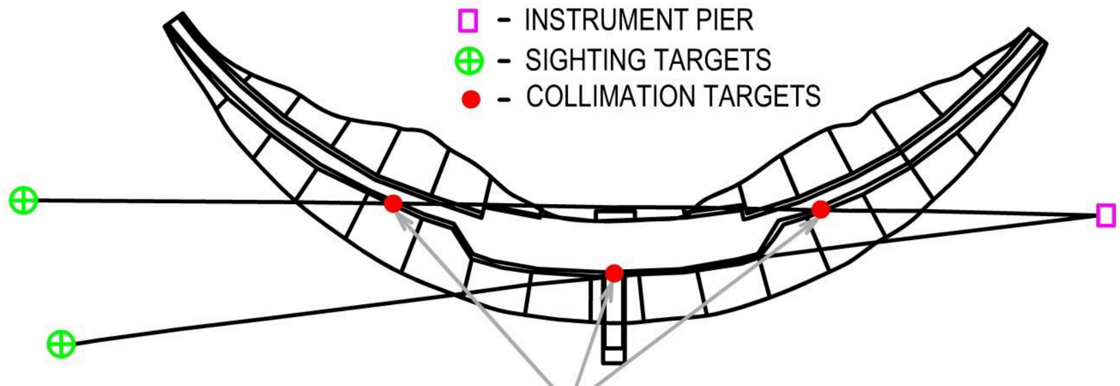
F.3.2.2 Alignment Surveys: Used to measure and ensure the correct positioning of dam components relative to each other.

F.3.2.3 Triangulation: A method for measuring distances and angles to ascertain the geometric positions of points on the dam.

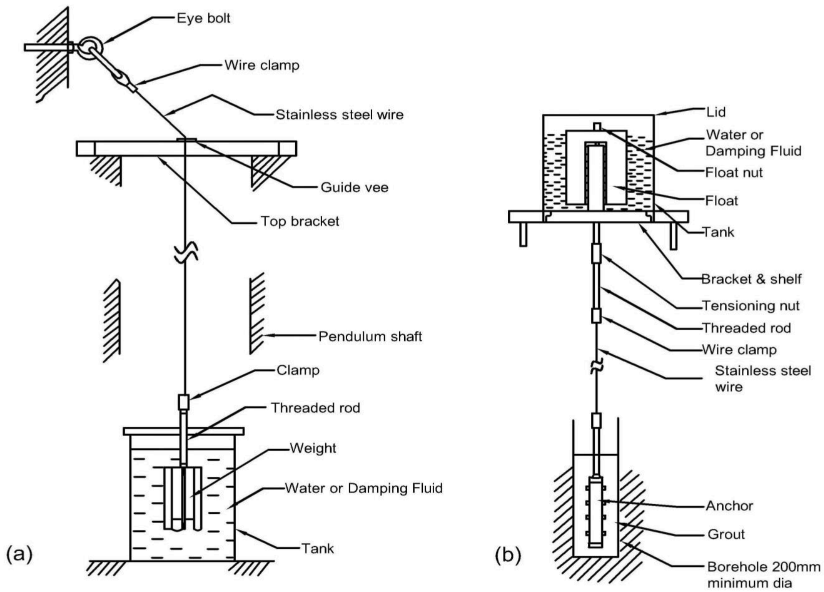
F.3.2.4 Triangulation and Trilateration: Techniques combined to provide precise measurements of the dam's structural elements.



F.3.2.5 Collimation: Used to check for alignment errors in the structure, helping to maintain the dam's structural integrity.

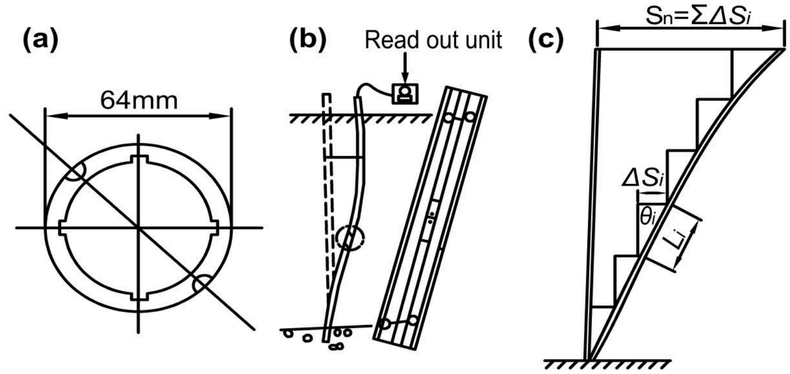


F.3.2.6 Plumblines: Employed for vertical alignment measurements, crucial for assessing the gravitational stability of dam structures.

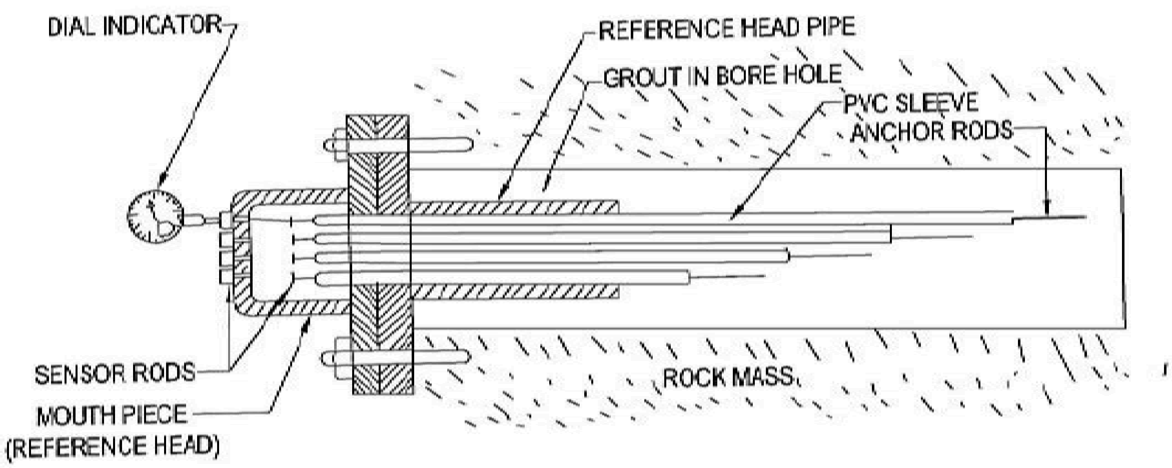


F.3.2.7 Tiltmeters: Used to detect angular movements, providing early warnings of potential structural shifts.

F.3.2.8 Inclinometers: Measure slope or incline variations, indicating potential stability issues.

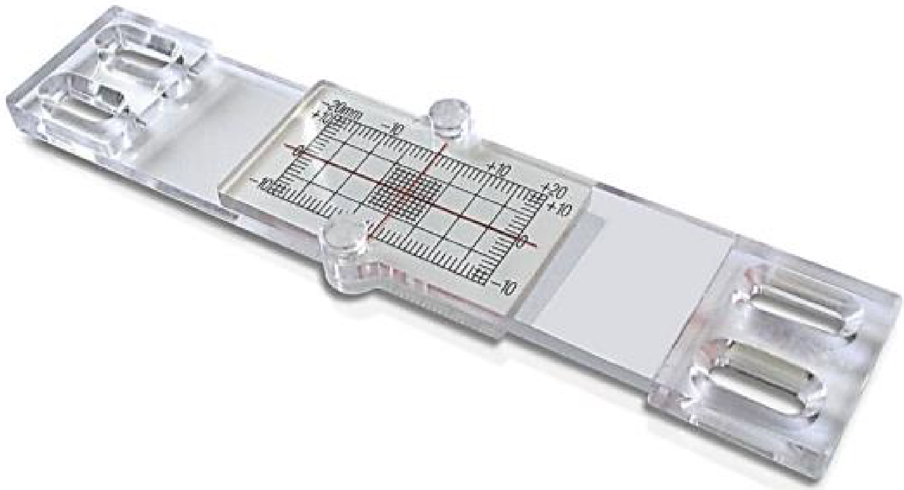


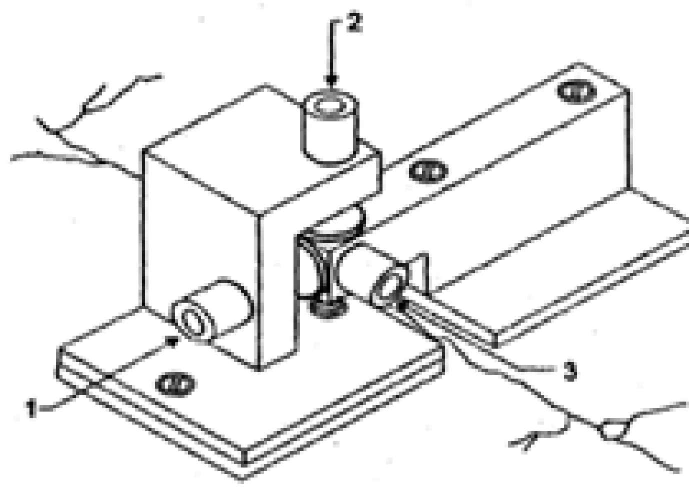
F.3.2.9 Extensometers: Measure the deformation or extension of materials within the dam, helping to monitor stress and strain responses.



F.3.3 Joint or Crack Movement: Focuses on movements at joints or cracks, which can be early indicators of structural failure.

F.3.3.1 Crack Movement: Tracks the expansion or contraction of cracks within the dam structure, a critical aspect of maintenance and safety protocols.

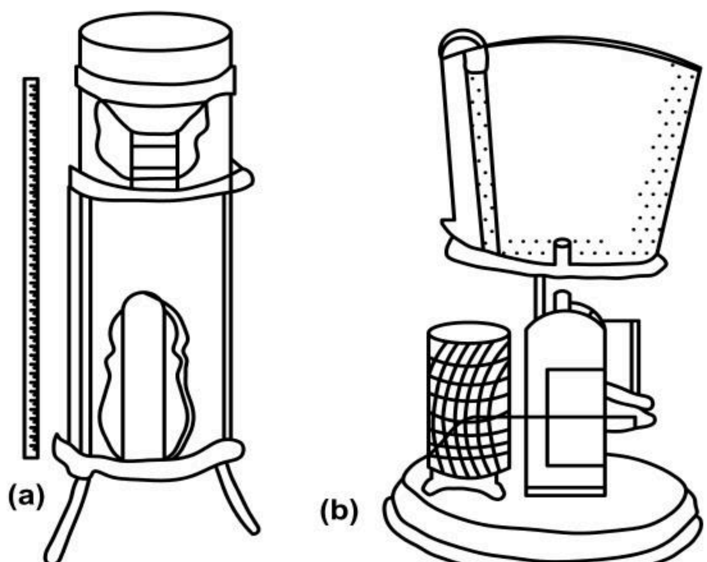




F.4 Reservoir/Tail Water Elevations:
Monitoring of water levels in the reservoir and downstream to manage hydrostatic pressures and operational safety.

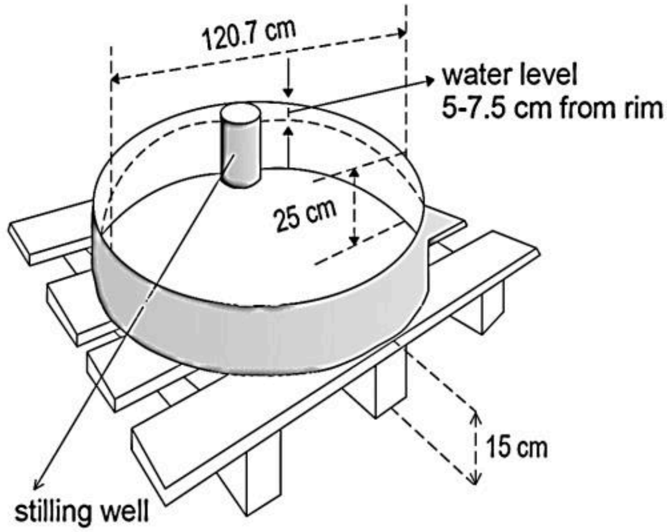
F.4.1 Staff Gauge: Used to manually measure water levels, providing essential data for daily operations and safety checks.

F.4.2 Precipitation: Measurement of rainfall and other forms of precipitation influencing reservoir levels and dam safety management.
F.4.2.1 Rainfall: Tracking rainfall amounts as part of environmental monitoring to assess potential impacts on reservoir levels and dam safety.



F.4.2.2 Snowfall: Measuring snowfall, especially in regions where snowmelt significantly impacts reservoir levels and structural safety.

F.4.2.3 Evaporation: Measures water evaporation rates, crucial for managing water resources and understanding environmental conditions.



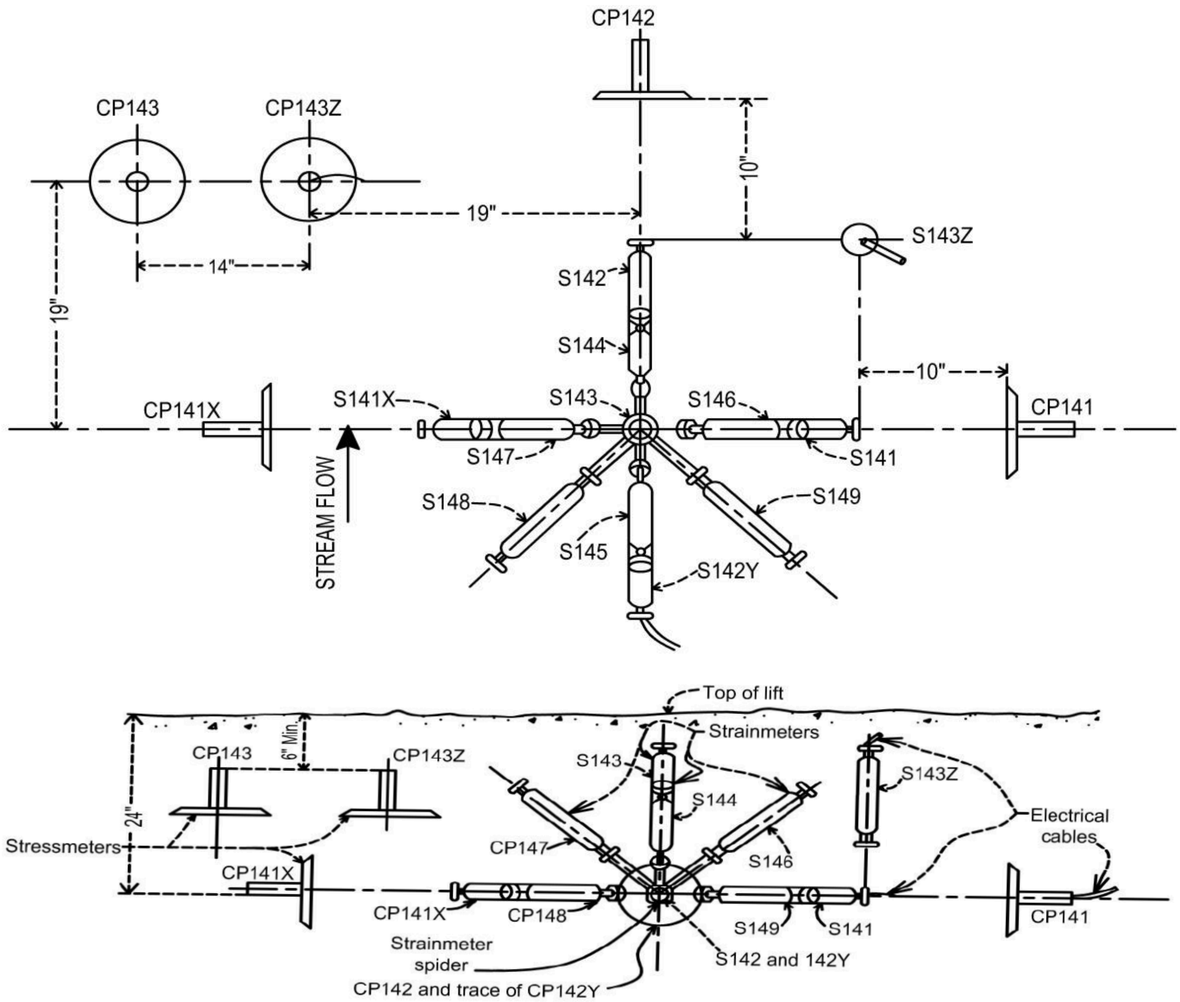
F.5 Local Seismic Activity:
Monitoring of seismic events that could affect dam stability, using instruments like accelerographs and seismographs.
F.5.1 Accelerographs: Used to measure the acceleration of ground motion, providing data critical for seismic safety analysis.

F.5.2 Seismographs: Detect and record seismic waves, essential for assessing the impact of earthquakes on dam integrity.

F.6 Stress and Strain:

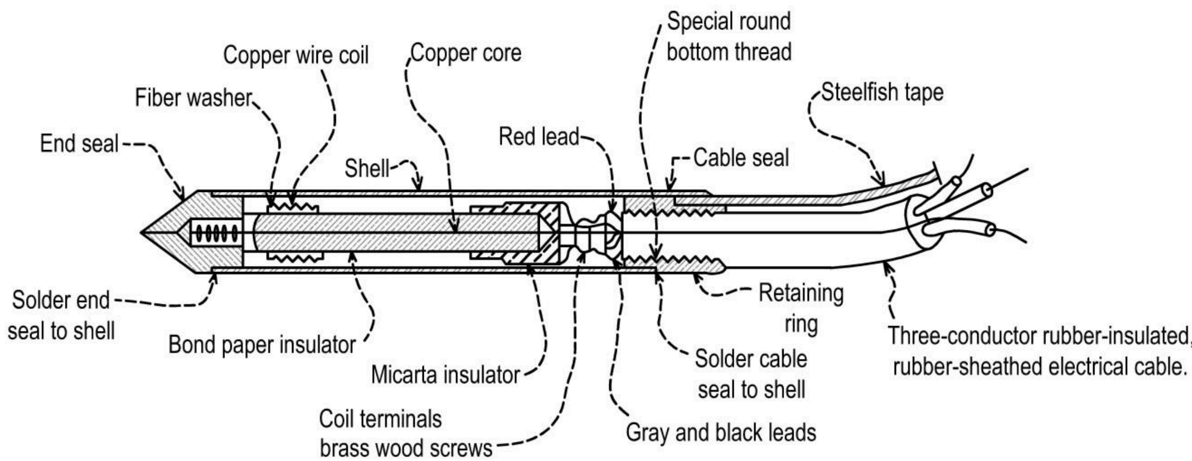
Focus on the internal stresses and strains within the dam, vital for understanding material responses under various loads.

F.6.1 Types of Pressure (Stress) Measuring Devices: Different devices used to measure internal pressures and stresses, helping to ensure the dam's structural health.



F.7 Temperature:

Monitoring temperature variations within the dam structure, which can affect material properties and structural behaviour.



G. Frequency of Monitoring

Determining the frequency of monitoring is essential to ensure that the instrumentation system provides timely and accurate data. The frequency depends on various factors, including the type of dam, its age, and the criticality of the parameters being monitored.

Type of instrument	During Construction		During initial filling	During Period of Operation		
	Construction	Shutdown		Year 1	Years 2 to 3	Regular
Vibrating wire piezometers	W	M	W	BiW	M	M
Hydrostatic uplift pressure pipes	W	M	W	W	BiW	M
Porous-tube piezometers	M	M	W	W	M	M
Slotted-pipe piezometers	M	M	W	W	M	M
Observation wells	W	M	W	W	BiW	M
Seepage measurement (weirs and flumes)	W	M	W	W	M	M
Visual seepage monitoring	W	W	W	W	F	M
Resistance thermometers	W	M	W	W	M	M
Thermocouples	D	M	W	W	M	M
Carlson strain meters	W	W	W	BiW	M	M
Joint meters	W	W	W	BiW	M	M
Stress meters	W	M	W	BiW	M	M
Reinforcement meters	W	M	M	M	M	M
Penstock meters	W	M	M	M	M	M
Deflectometers	W	M	W	W	M	M
Vibrating wire strain gauge	W	M	M	M	M	**M**
Vibrating-wire total pressure cell	W	M	M	M	M	M
Load cell	W	M	W	BiW	M	M
Pore pressure meters	W	W	W	BiW		M
Foundation deformation meters	W	W	W	BiW	M	M
Flat jacks	D	W	W	BiW	M	M
Tape gauges (tunnel)	W	W	W/BiW	BiW	M	M
Whitmore gauges, Avongard crack meter	W	M	W	W	M	M
Wire gauges	W	M	W/M	W/M	M	M/Q
Abutment	W	M	W	W	M	M

Type of instrument	During Construction		During initial filling	During Period of Operation		
	Construction	Shutdown		Year 1	Years 2 to 3	Regular
deformation gauges						
Dial gauges, differential buttress gauges	W	M	W	W	M	M
Plumblines	D	W	D	W	BiW	M
Inclinometer	W	W	W	W	BiW	M
Collimation	Every two days for a month	M	W	BiW	M	M
Embankment settlement points	--[c]	--	M	BiM	Q	SA
Level points	M	Q	M	M/Y	BM/Q	BM
Multipoint extensometers	W	M	W	M	M	Q/SA
Triangulation			M	M	Q	SA
Trilateration (EDM)	--	--	BiW/M	M	Q	Q/A
Reservoir slide monitoring systems	--	--	M	M	M	Q
Power plant movement	--	--	M/W	M	M	M/Q
Rock movement	W	M	W	M	M	M

[a]These are suggested minimums. However, anomalies or unusual occurrences, such as earthquakes or floods, will require additional readings.
[b]D = daily, W = weekly, BiW = bi-weekly, M = monthly, Q = quarterly, SA = semi-annually, A = annually.
[c]Not applicable.

H. Hydro-Meteorological Instrumentation

H.1 Measurement of Rainfall

Rainfall is measured using rain gauges, including ordinary and recording types such as the natural syphon and tipping bucket models.

H.1.1 Ordinary Rain Gauge: This gauge measures rainfall manually with a least count of 0.1 mm, recording daily at 8:30 AM. It features a funnel and a polyethene bottle, varying in capacity to accommodate different rainfall conditions.

H.1.2 Recording (Automatic) Rain Gauges: Typically one-tenth of total gauges, used for detailed and continuous rainfall data, recommended for automatic weather stations.

H.1.3 Installation: Rain gauges are installed on a stable masonry or concrete foundation, ensuring the rim is exactly 300 mm above ground level, particularly in flood-prone areas.

H.1.4 Data Validation for Rainfall: Involves primary validation by comparing observed data against preset limits or statistical ranges and secondary validation by checking spatial consistency with nearby stations.

H.1.5 Number of Rain Gauges Required for a Catchment: The number depends on geographic and meteorological factors, ensuring sufficient coverage for accurate rainfall measurement across different terrain types.

H.2 Measurement of Snowfall

Involves modifications to ordinary rain gauges, like removing funnels and adding windshields, to accurately measure snowfall, especially in areas with substantial solid precipitation.

H.3 Measurement of Evaporation

Utilizes evaporation pans (Class A pan evaporimeters) to measure water evaporation rates, important for understanding water balance in reservoirs and planning water resource management.

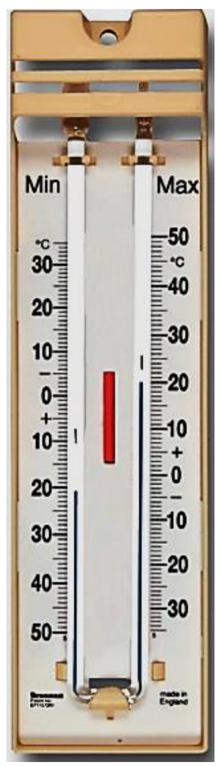
H.3.1 Evaporation Pan: The setup and use of standard evaporation pans, emphasizing the importance of accurate water level maintenance and protection from external factors like wildlife and debris.

H.3.2 Errors in Measurement (Evaporation): Potential errors include observer inaccuracies, instrument issues like leakage, and environmental effects such as wind and evaporation from gauge surfaces.

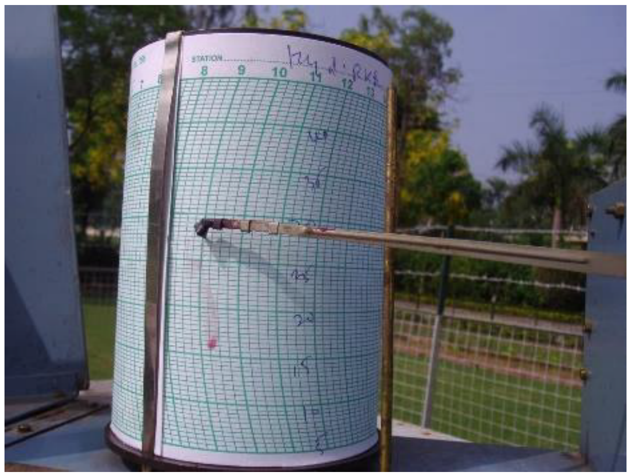
H.4 Measurement of Temperature

Involves using maximum and minimum temperature thermometers and thermographs to record daily temperature variations, critical for environmental monitoring and operational management at dams.

H.4.1 The Maximum and Minimum Temperature Thermometer: Measures the highest and lowest daily temperatures using a U-shaped glass tube with mercury and alcohol, with markers reset daily using a magnet.



H.4.2 Thermograph: A bimetallic strip records temperature changes continuously on a rotating drum, providing a detailed temperature profile over time.

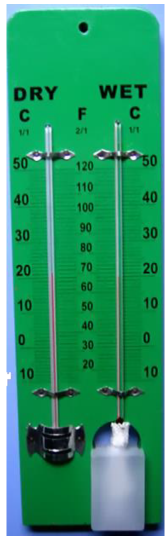


H.4.3 Errors in Measurement (Temperature): Common issues include sensor inaccuracies and environmental influences, necessitating regular calibration and maintenance to ensure reliable data.

H.5 Measurement of Relative Humidity

Uses dry and wet bulb thermometers and hair hygrographs to measure atmospheric humidity, essential for understanding climatic conditions affecting dam operations.

H.5.1 Dry and Wet Bulb Thermometer: Consists of two thermometers, one dry and one covered with a wet cloth, used together to calculate humidity based on temperature differences.

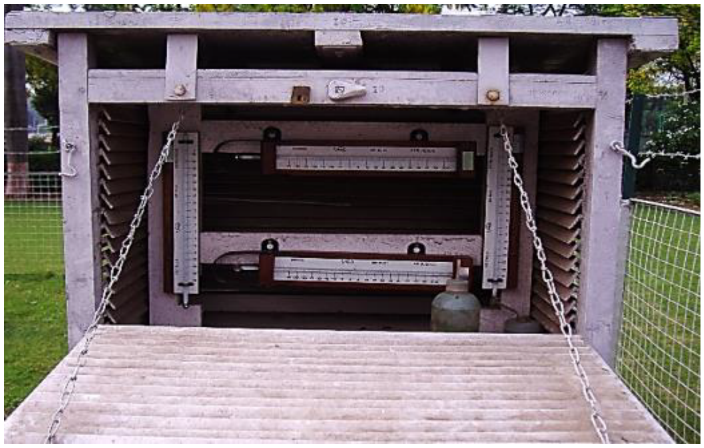


H.5.2 Hair Hygrograph: Utilizes the length changes in a strand of human or horse hair under different humidity conditions to record changes over time, providing a continuous humidity profile.

H.5.3 Errors in Measurement (Humidity): Potential errors include calibration issues, sensor sensitivity to environmental factors, and mechanical problems in hygrographs affecting accuracy.

H.5.4 Data Validation for Temperature: Temperature data is validated through checks against historical records, cross-references with other meteorological data, and calibration against standard instruments.

H.6 Housing for Thermometers:
Thermometers are housed in a Stevenson's screen, which is a shelter made of wood, painted white and designed to provide a uniform temperature environment by allowing air to circulate freely through its double-louvered sides.



H.7 Measurement of Wind Direction:
Wind direction is measured using a wind vane, which is mounted on a vertical axis to freely rotate and indicate the wind direction based on compass points or degrees from true north.

H.8 Measurement of Wind Speed:

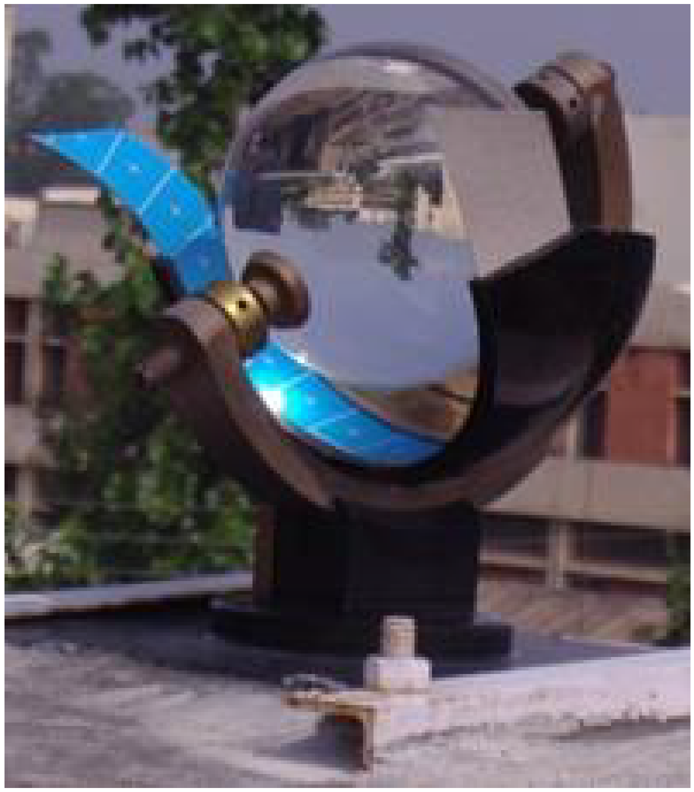
Wind speed is measured using a cup counter type anemometer, which calculates the wind run through a mechanical counter, providing readings of instantaneous and average daily wind speeds.

H.8.1 Errors in Measurement (Wind): Errors may include observer errors in reading the counter, calculation mistakes, and equipment issues such as poor maintenance or damage affecting the anemometer's accuracy.

H.8.2 Data Validation for the Wind: Validation involves ensuring that reported wind speeds are plausible based on known conditions, such as zero readings during calm conditions and not exceeding expected maximums during variable conditions.

H.9 Measurement of Sunshine Hours:

The duration of sunshine is recorded using a Campbell-Stokes Sunshine Recorder, which focuses sunlight onto a specially designed chart to measure sunshine duration.



H.9.1 Errors in Measurement (Sunshine Hours): Common errors include using incorrect charts leading to misinterpretation of the burn marks and observer errors in reading these marks.

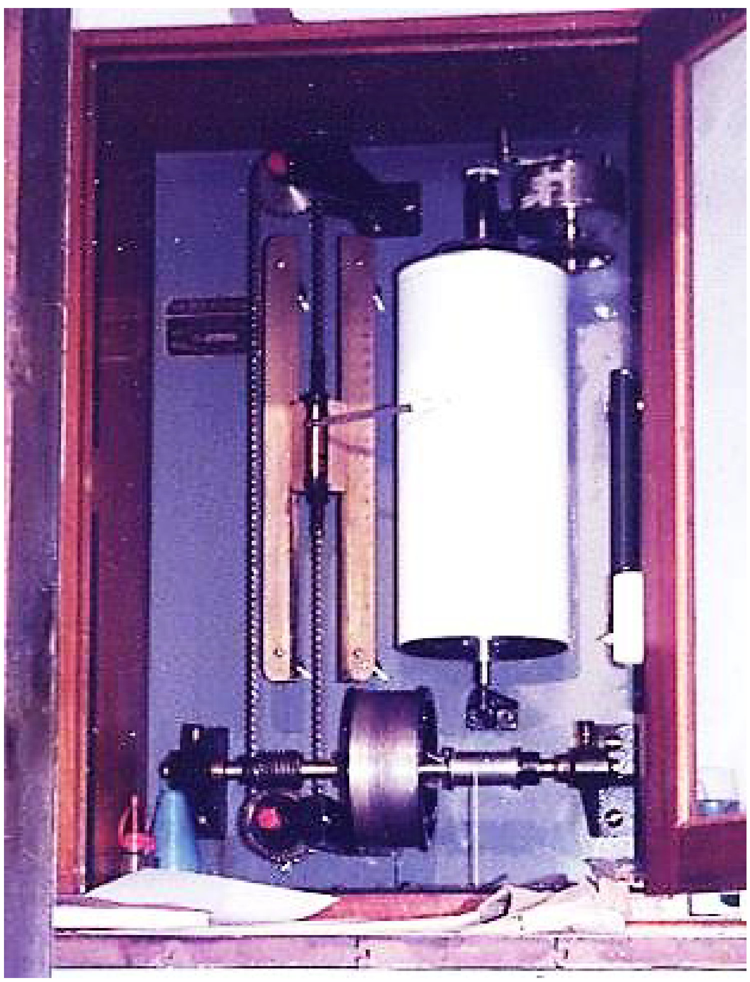
H.9.2 Data Validation for Sunshine Hours: Validation checks include discarding sunshine records outside expected sunrise and sunset times and ensuring daily totals do not exceed the maximum possible sunlight hours.

H.10 Measurement and Recording of Weather Parameters Together: This can be efficiently performed using an Automatic Weather Station, which measures various weather parameters simultaneously with minimal human intervention and stores the data for later retrieval or real-time transmission.

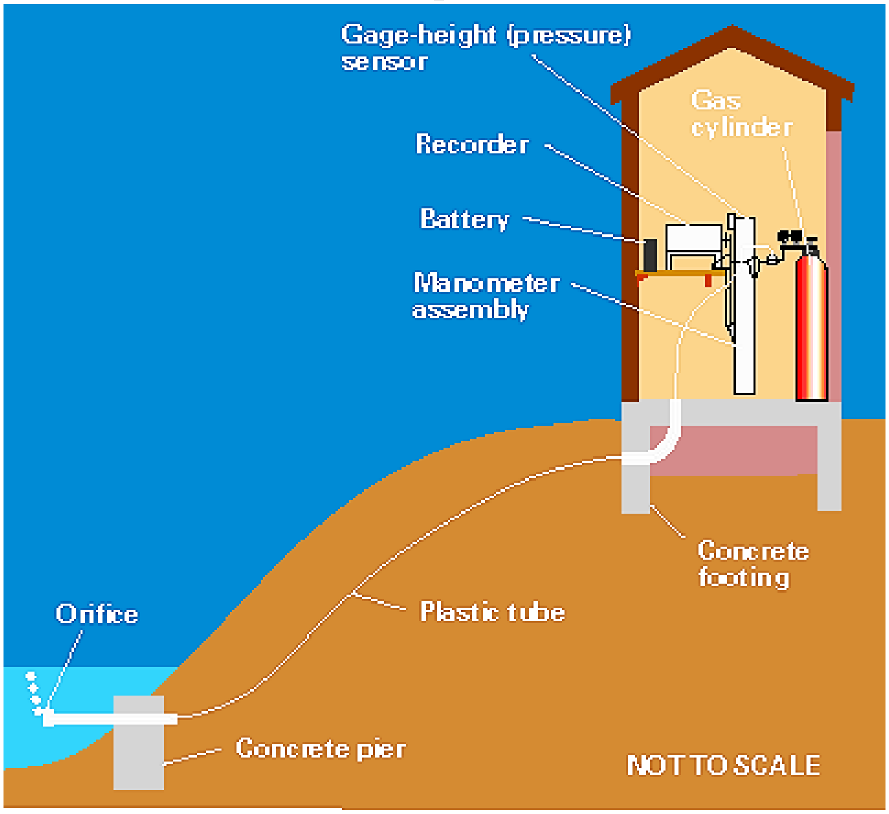
H.11 Measurement of Water Level of the Reservoir:
Water levels are recorded using both manual and automatic methods to accurately monitor reservoir conditions and manage water resources effectively.

H.11.1 Manual Type Water Level Measurement: Involves using staff gauges and wire gauges, where the former is a fixed vertical scale and the latter uses a weight and reel system to measure water depth.

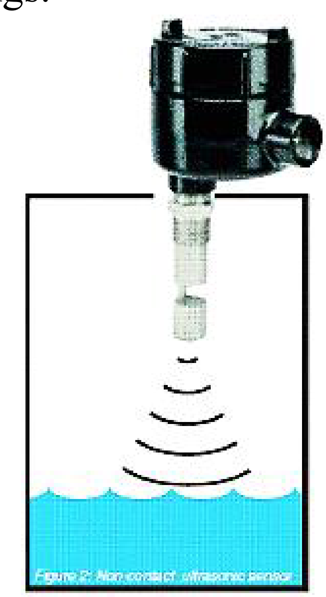
H.11.1.1 Staff Gauge: A simple instrument consisting of a marked gauge fixed to a structure, used for manual reading of water levels in a reservoir or river.
H.11.1.2 Wire Gauge: Uses a weighted wire lowered to the water surface to measure depth, with measurements taken from the length of wire dispensed.
H.11.2 Automatic Water Level Recorders: Include devices like float gauges, bubble gauges, ultrasonic echo sounders, and radar gauges that provide continuous and accurate water level data.
H.11.2.1 Float Gauge: Uses a floating device connected to a scale to measure water levels, translating the vertical movement of the float into level readings.



H.11.2.2 Bubble Gauge: Measures water levels by releasing air into a tube until it reaches the water surface, with the pressure required providing a measure of the water depth.



H.11.2.3 Ultrasonic Echo Sounder: Utilizes sound waves to measure the distance to the water surface from a fixed position above, providing accurate water level readings.



H.11.2.4 Radar Gauge: Employs radar waves to measure the distance to the water surface, offering a non-contact method of water level measurement, suitable for various environmental conditions.

H.12 Measurement of Seepage:

Seepage through dams is measured using weirs or flumes installed in channels, where water levels are monitored to calculate discharge using established relationships.

H.12.1 V-notch Weir: Utilizes a triangular notched plate for measuring low and high flow rates with accuracy. Simple, low-cost, and robust, its discharge calculation depends on the water head at the weir.

H.12.2 Rectangular Notch Weir: Measures water discharge using a rectangular notch that may cover the entire channel width or be contracted, affecting head loss and discharge calculation.

H.12.3 Trapezoidal Notch Weir: A fully contracted weir suitable for large discharges, combining the properties of rectangular and triangular weirs without the need for end corrections.

H.12.4 Broad Crested Weir: Features a wide crest to maintain condition over time, suitable for high discharges, though susceptible to sediment deposition and high head loss.

H.12.5 Parshall Flume: Measures flow with minimal head loss and is suitable for channels with low gradient, allowing for a high degree of submergence without losing accuracy.

H.12.6 Venturi Flume: Measures flow by inducing a critical flow condition through a constricted section, providing high accuracy and efficiency with minimal head loss.

H.13 Measurement of Streamflow:
Includes direct and indirect techniques such as area velocity and dilution methods, essential for managing water resources and ensuring dam safety.

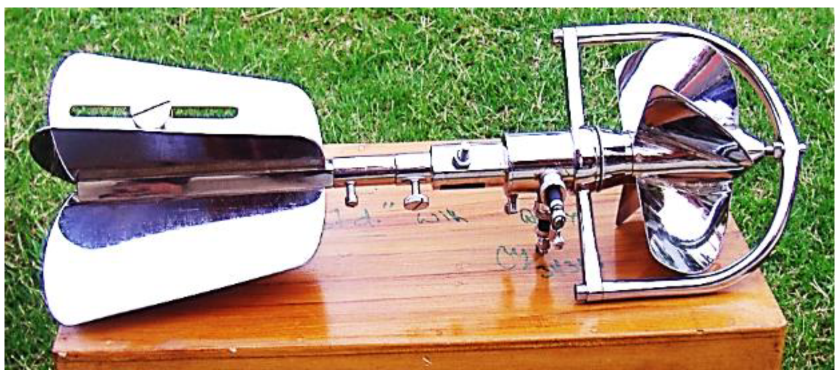
H.13.1 Requirements of a Good Gauge and Discharge Site: Highlights the need for a stable, well-positioned gauge site to provide reliable discharge data over long periods.

H.13.2 Area Velocity Method: Uses the cross-sectional area and flow velocity to calculate streamflow, suitable for varying channel conditions.

H.13.2.1 Measurement of Stream Velocity Using Current Meter: Involves deploying meters like propeller or electromagnetic types to measure water speed directly in the stream.

H.13.2.2 Vertical Axis Meters: Measures flow velocity using a vertically mounted rotor, effective in capturing vertical components of water movement.

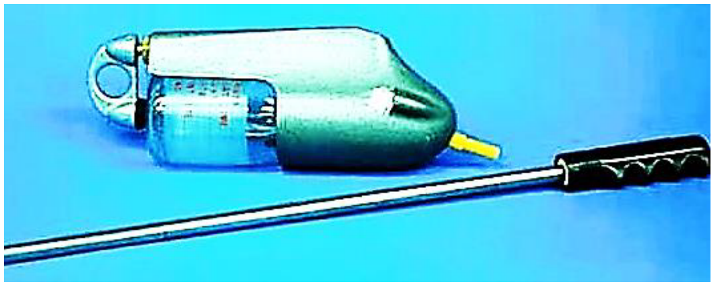
H.13.2.3 Horizontal Axis Meters: Utilizes a horizontally mounted propeller to measure flow velocity, providing reliable measurements under varied flow conditions.



H.13.3 Dilution Techniques: Employs environmentally friendly tracers to determine streamflow by analyzing changes in tracer concentration downstream.

H.13.4 Electromagnetic Method: Uses magnetic fields to measure flow velocity, offering non-intrusive measurements with high accuracy.
H.13.5 Ultrasonic Method: Applies ultrasonic signals to measure water speed and depth, useful for detailed flow analysis in various conditions.

H.14 Measurement of Suspended Sediment Load: Essential for assessing sediment transport through a waterway, impacting reservoir capacity and water quality.



I. Instrumentation Data Collection & Management

Effective data collection and management are central to the success of dam instrumentation systems. Properly organized data provides actionable insights into the dam's performance, enabling timely decisions that enhance safety and efficiency.

Data Collection Method	Advantages	Disadvantages
Manual Readings	• Generally simple to perform and do not require high level of expertise • Personnel are already on site for regular visual observations • Data quality can be evaluated as it is collected	• Labor intensive for data collection and reduction • Not practical to collect frequent data • Potential for errors in transposing data from field sheets into data management/ presentation tools • May be impractical for remote sites where personnel are not frequently on site
Standalone Data loggers	• Frequent and event-driven data collection • Consistent data collection and electronic data handling • Equipment is fairly inexpensive and simple to set up	• Requires some expertise to configure dataloggers • Data quality cannot be evaluated until it is collected from the field • Potential for lightning strikes • Power source needs to be considered

Data Collection Method	Advantages	Disadvantages
Real-time Monitoring Networks	• Frequent and event-driven data collection • Consistent data collection and electronic data handling • Real-time display and notification (24/7) • Reduces labor effort for data collection and processing • Can remotely change the monitoring frequencies and data collection configurations as needed • Allows for rapid evaluation of monitoring results	• Automation may encourage complacency if overall monitoring program is not well defined or understood • Requires a higher level of expertise to install and maintain • Higher cost of installation and periodic maintenance • The importance of frequent routine visual inspections may be overlooked or discounted somewhat due to the real-time presentation of automated instrument readings • Potential for lightning strikes • Power source needs to be considered

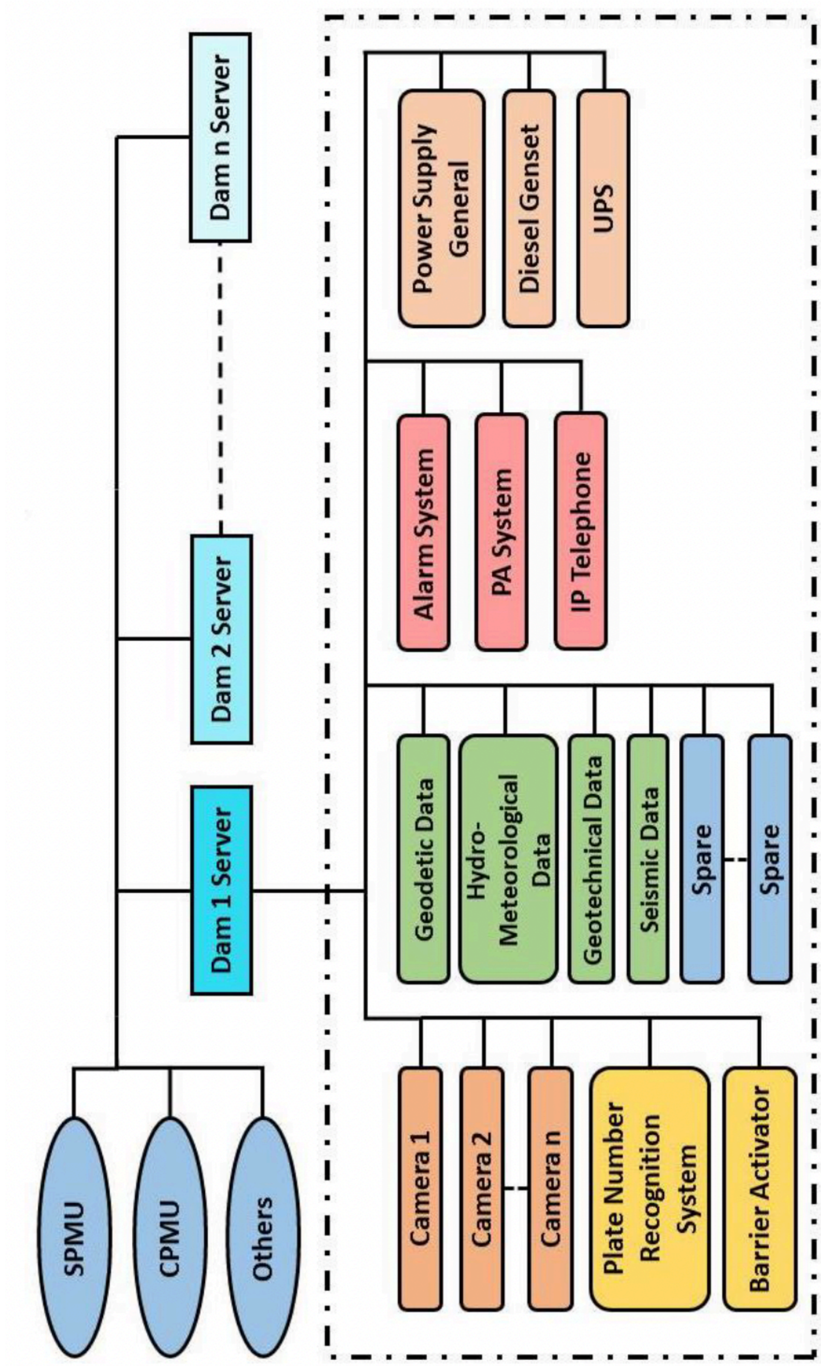
J. Monitoring Data Organization and Analysis

Organizing and analyzing monitoring data is critical for deriving meaningful insights from dam instrumentation systems. Properly structured data facilitates efficient analysis, enabling engineers to detect patterns, identify risks, and make informed decisions.

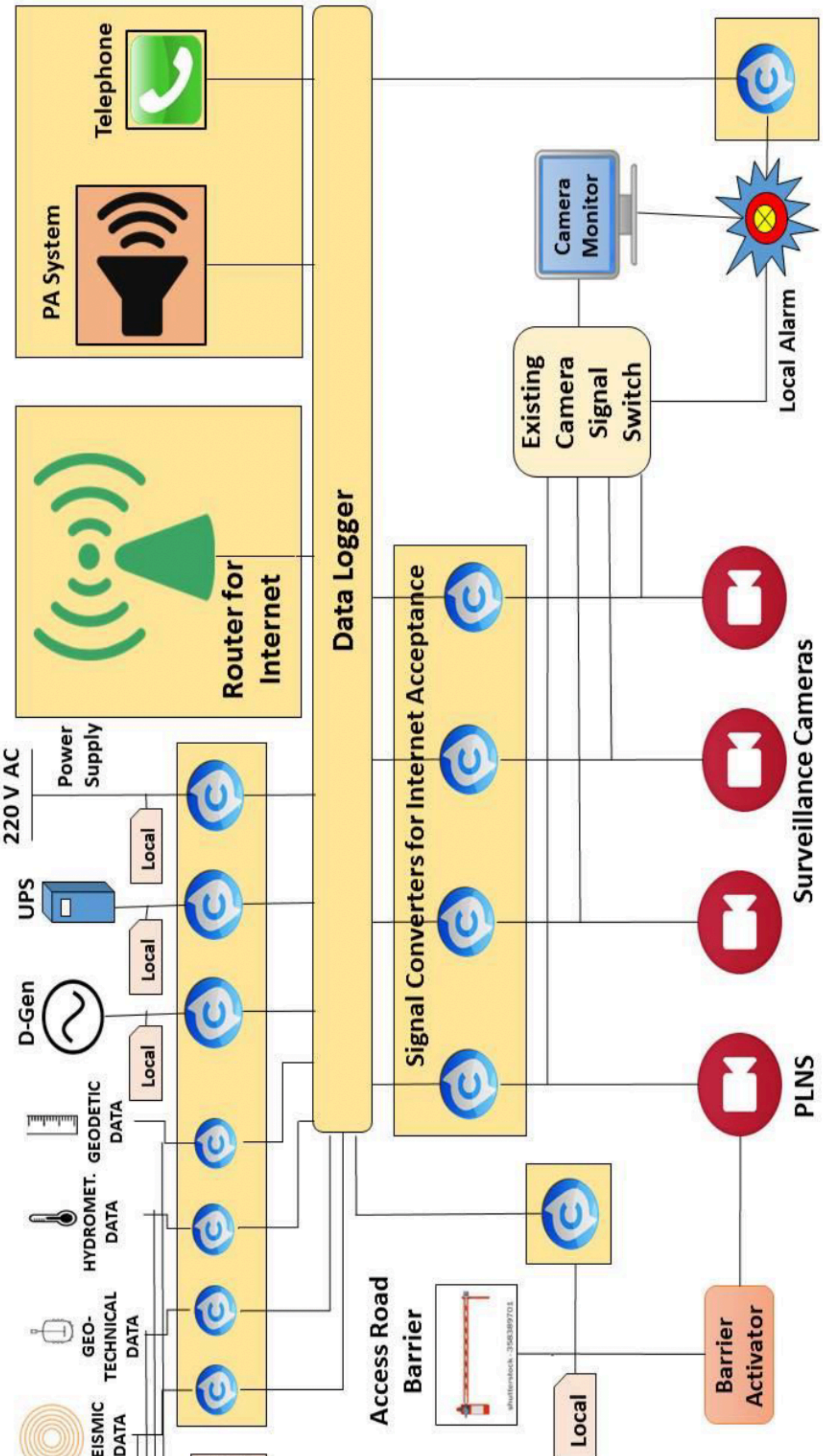
Interrelated Physical Factors	How Their Relationships Affect Data interpretation
Water Pressure/ Reservoir And Tail-water Levels/ Precipitation	• Water pressure in or under an embankment, or under a concrete dam, is related to reservoir and tail-water levels. • Water pressure in the abutments of a dam is related to reservoir and tail-water levels. • Water pressure in the slopes of a dam is directly related to reservoir level. • Precipitation and local ground water may influence water pressure in or under embankments, under concrete dams, in dam abutments, and in the slopes of a dam.
Water Pressure movement	• As water pressure increases within an embankment, or in a dam's foundation or abutments, the effective shear strength available to resist movement is reduced. If this shear strength is reduced to less than driving forces, movement will occur.
Water Pressure/Seepage/ Reservoir Level/ Precipitation	• Seepage normally is directly related to the reservoir level. • Precipitation often results in a temporary increase in the seepage flow. • Decreasing seepage flow and increasing water pressure under the dam or in its abutments indicate that the drainage or exit control systems are losing their effectiveness. • Decreasing seepage flows and decreasing water pressure under the dam or in its abutments indicate that the infiltration of reservoir water into the foundation or abutments is decreasing (possibly due to siltation of the reservoir basin).
Movement/Reservoir Level	• Normally, as the reservoir level increases, a concrete dam will deflect in the downstream direction. • Reservoir-level increases normally will not cause embankment dams to deflect significantly. • For very high earth and rockfill embankment dams, measured movements may be influenced by reservoir-induced settlement. • As a general rule of thumb, post construction settlement of an embankment dam should not exceed 1% of the height of the dam • An acceptable value of lateral deflection after filling is difficult to predict for any size of embankment dam • The key consideration for an embankment dam is that vertical settlement or lateral deflection of the crest should decrease in rate over time for a constant loading condition. A sudden or even gradual increase in the rate of vertical or lateral movement should be cause for further evaluation • The predicted piezometer levels will obviously vary with size and type of dam, height of reservoir, etc., and acceptable ranges cannot be quantified except on an individual basis.

Interrelated Physical Factors	How Their Relationships Affect Data interpretation
Movement/Temperature	• Concrete expands as temperature increases, and contracts as temperature decreases. • In locations with large differences between summer and winter temperatures, concrete monoliths in a dam will move, causing joints and cracks to open in the winter and close in the summer. • In the summer, as the temperature of the downstream face of a dam increases, the concrete near the downstream face will expand. Meanwhile, because the reservoir keeps the upstream face at a more constant temperature, there is little or no expansion of the concrete near the upstream face. This differential expansion of concrete may cause the top of the dam to move or rotate slightly upstream.
Seepage/Temperature	• The seepage or leakage through the cracks and joints of a concrete dam is inversely related to the temperature of the air/concrete/water. • For dams founded on fractured rock that experience seasonal changes in water temperature, there will often be an increase in flow from foundation drains during the winter.
Seepage/ Water Pressure/ Turbidity /Solutioning	• Turbid flow or increasing turbidity levels may indicate changes in seepage flows and water pressure. • Any sudden change in water pressure should be followed by seepage flow inspections. • A steady increase in seepage, with no increase in turbidity, indicates that seepage should be tested for the presence of dissolved solids.
Seismic Activity/Seepage **Movement/Water Pressure**	• Ground motion can cause a dam to move or deform, resulting in damage and/or structural instability and failure. Such movement can also damage seepage control features. • Seepage rate increases, increasing turbidity, or a large increase in water pressure could all indicate that damage has occurred to the structure. • Leakage/ Seepage is sensitive to earthquakes and is an important factor affecting the stability of dam body and its foundation • Case studies show that leakage/seepage and pore pressures often changes as a result of ground shaking. Usually they increase after an earthquake • In most cases, the increase is only temporary and will decrease or become stable over time and it may last from several days to a few years until a stable condition is reached
Construction Activity	• During construction or rehabilitation activities, high water pressures, sudden changes in water pressure or seepage, and/or unexpected movements would indicate the possible development of unsafe conditions.

General Instrumentation and Surveillance System Proposed for DRIP Dams



Integrated Instrumentation and Surveillance System for automated warning system for DRIP Dams


PA System
Telephone
Router for Internet
Data Logger
Camera Monitor
Existing Camera Signal Switch
Local Alarm
Signal Converters for Internet Acceptance
Surveillance Cameras
PLNS
220 V AC
Power Supply
UPS
D-Gen
Local
Local
Local
GEODETIC DATA
HYDROMET. DATA
GEO-TECHNICAL DATA
SEISMIC DATA
Local
Access Road Barrier
Barrier Activator
Local

K. Importance of Standardization

Standardization in dam instrumentation is a cornerstone for ensuring uniformity, reliability, and accuracy across monitoring systems. It establishes a common framework for design, installation, operation, and maintenance, fostering consistency and enabling better decision-making.

K.1 Objectives of Standardization

1. **Enhance Data Comparability**:
   - Uniform standards allow data to be compared across different dams and time periods.
2. **Improve Reliability**:
   - Ensures the quality and performance of instruments and systems.
3. **Facilitate Communication**:
   - Provides a common language among engineers, operators, and policymakers.
4. **Support Regulatory Compliance**:
   - Aligns instrumentation practices with national and international guidelines.
5. **Promote Efficiency**:
   - Streamlines procurement, installation, and maintenance processes.

K.2 Key Areas for Standardization

1. **Instrumentation Design**:
   - Specifies the types of instruments and their configurations for various dam types.
2. **Installation Practices**:
   - Outlines procedures for proper placement and securing of instruments to ensure accuracy.
3. **Data Collection Protocols**:
   - Defines intervals, methods, and formats for data recording.
4. **Calibration and Maintenance**:

   - Standardizes schedules and techniques to maintain instrument accuracy and functionality.
5. **Data Analysis and Reporting**:
   - Establishes uniform criteria for interpreting data and presenting findings.

K.3 Benefits of Standardization

1. **Improved Safety**:
   - Ensures consistent monitoring of critical parameters, reducing the likelihood of undetected issues.
2. **Cost Savings**:
   - Reduces duplication of efforts and ensures efficient resource utilization.
3. **Knowledge Sharing**:
   - Enables easy transfer of practices and findings across projects and regions.
4. **Global Compatibility**:
   - Facilitates collaboration on international projects and adoption of global best practices.
5. **Enhanced Innovation**:
   - Provides a stable foundation for developing and integrating advanced technologies.

L. Consequences of Lack of Standardization

The absence of standardization in dam instrumentation can lead to significant challenges, impacting the safety, reliability, and efficiency of dam operations. Understanding these consequences underscores the importance of adopting uniform practices across all phases of instrumentation.

L.1 Key Consequences

1. **Inconsistent Data**:

- o Variability in data collection methods and instrument specifications leads to non-comparable results.
- o Inconsistent data hampers accurate analysis and decision-making.

2. **Reduced Reliability**:
    - o Non-standardized instruments may lack precision and durability, leading to inaccurate measurements.
    - o Increases the risk of undetected structural or operational issues.
3. **Higher Costs**:
    - o Duplication of efforts in system design, installation, and maintenance due to lack of uniformity.
    - o Additional expenses for troubleshooting and replacing incompatible systems.
4. **Operational Inefficiencies**:
    - o Incompatible systems result in delays and errors in data collection and interpretation.
    - o Manual reconciliation of disparate data formats consumes time and resources.
5. **Increased Safety Risks**:
    - o Failure to detect critical issues due to inaccurate or incomplete data.
    - o Delayed response to emergencies due to a lack of reliable monitoring systems.
6. **Obstacles to Collaboration**:
    - o Difficulty in sharing data and findings among stakeholders due to incompatible formats and practices.
    - o Hinders collaborative efforts in multi-dam or international projects.
7. **Regulatory Non-Compliance**:
    - o Failing to meet safety standards and guidelines exposes dam authorities to legal and reputational risks.
8. **Stifled Innovation**:
    - o Inconsistent practices create barriers to adopting and integrating advanced technologies.

M. Existing Standards

INDIAN STANDARDS RELATED TO METEOROLOGICAL INSTRUMENTATION	
IS NO.	**IS TITLE**
IS 11875 : 1986	Specification For Diffuse Pyranometer
IS 11876 : 1986	Specification For Airmeter
IS 12781 : 1989	Marine Bucket For Sea Surface Temperature Measurement - Specification
IS 13436 : 1992	Sensitive Anemometer - Specification
IS 13448 : 1992	Meteorology - Thermoelectric Pyrheliometer - Specification
IS 13459 : 1992	Angstrom Pyrheliometer - Specification
IS 15216 : 2002	Balloons - Meteorological
IS 15243 : 2002	Velocity Scale Set For Meteorological Purposes
IS 15253 : 2002	Dew Gauge - Specification
IS 16739 : 2018	Meteorology - Sonic Anemometers/Thermometers Acceptance Test Methods For Mean Wind Measurements
IS 16740 (PART 1) : 2018	Meteorology - Wind Measurement Part 1 Wind Tunnel Test Methods For Rotating Anemometer Performance

IS 16741 : 2018	Meteorology - Air Temperature Measurements Test Methods For Comparing The Performance Of Thermometer Shields/Screens And Defining Important Characteristics
IS 18627 : 2024	Tipping Bucket Rain Gauges – Specification
IS 18629 : 2024	Air Quality -- Meteorology – Siting Classifications For Surface Observing Stations On Land
IS 4849 : 1992	Meteorology - Rain Measures - Specification (First Revision)
IS 5225 : 2024	Meteorology – Rain Gauge, Non-Recording -- Specification (Second Revision)
IS 5235 : 1992	Meteorology - Rain gauges Recording - Specification (First Revision)
IS 5793 : 2024	Aneroid Barometers – Specification
IS 5798 : 1970	Specification For Mercury Barometers
IS 5799 : 1970	Specification For Windvane
IS 5900 : 1970	Specification For Hair Hygrograph
IS 5901 : 1970	Specification For Thermograph, Bimetallic
IS 5912 : 1997	Specification For Anemometer, Cup Counter (First Revision)
IS 5924 : 1988	Specification For Clock Mechanisms And Drums For Meteorological Instruments (First Revision)
IS 5945 : 1970	Specification For Barograph, Aneroid
IS 5946 : 1992	Meteorology - Whirling Psychrometer - Specification (First Revision)

IS 5947 : 1970	Charts For Recording Meteorological Instruments
IS 5948 : 1970	Specification For Thermometer Screens
IS 5973 : 1998	Pan Evaporimeter - Specification (First Revision)
SP 61 : 1994	General Guidelines For Automatic Weather Stations
IS 6805 : 1973	Specification For Assmann Psychrometer
IS 6806 : 1973	Specification For Snow gauge
IS 6871 : 1992	Wind Equipment - Distant Indicating - Specification (First Revision)
IS 7243 : 1974	Specification For Sunshine Recorder
IS 7244 : 1974	Specification For Thermometer For Mercury Barometer
IS 8336 : 1977	Specification For Thermoelectric Pyranometer
IS 8693 : 2024	Net Pyrradiometer – Specification (First Revision)
IS 8754 : 1992	Electrical Anemograph - Specification (First Revision)
IS 9085 : 1979	Specification For Correction Slide For Mercury Barometers
IS 1191 : 2016	Hydrometry - Vocabulary And Symbols

INDIAN STANDARDS RELATED TO DAM INSTRUMENTATION	
IS NO.	**IS TITLE**
IS 10334 : 1982	Code Of Practice For Selection, Splicing, Installation And Providing Protection To The Open Ends Of Cables Used For Connecting Resistance Type Measuring Devices In Concrete And Masonry Dams
IS 10434 (PART 1) : 2003	Installation, Maintenance And Observation Of Deformation Measuring Devices In Concrete And Masonry Dams - Guidelines: Part 1 Resistance Type Jointmeters (First Revision)
IS 10434 (PART 2) : 1996	Guidelines For Installation, Maintenance And Observation Of Preformation Measuring Devices In Concrete And Mas - Onry Dams: Part 2 Vibrating, Wire Type Jointmeter
IS 12949 : 2013	Installation, Maintenance And Observation Of Instruments For Pore Pressure Measurements In Earth And Rockfill Dams - Vibrating Wire Type Electrical Pore Pressure Cell - Code Of Practice (First Revision)
IS 13073 (PART 1) : 2002	Installation, Maintenance And Observation Of Displacement Measuring Devices In Concrete And Masonry Dams - Code Of Practice: Part 1 Deflection Measurement Using Plumb Lines (First Revision)
IS 13073 (PART 2) : 2000	Code Of Practice For Installation, Maintenance And Observation Of Displacement Measuring Devices For Concrete And Masonry Dams: Part 2 Geodetic Observation - Crest Collimation
IS 13232 : 1992	Installation, Maintenance And Observations Of Electrical Strain Measuring Devices In Concrete Dams - Code Of Practice

IS 14248 : 1995	Guidelines For Instrumentation Of Barrages And Weirs
IS 14278 : 1995	Stress Measuring Devices in Concrete And Masonry Dams - Installation, Commissioning And Observations - Code Of Practice
IS 14750 : 2014	Code Of Practice For Installation, Maintenance And Observation Of Seepage Measuring Devices For Concrete/Masonry And Earth/ Rockfill Dams (First Revision)
IS 14793 : 2013	Installation, Maintenance And Observation Of The Instruments For Vibration Studies Other Than Earthquakes On Hydraulic Structures And Machines - Code Of Practice (First Revision)
IS 17158 : 2019	Guide For Type Of Measurement, Choice Of Location And Type Of Instruments For Underground Power House
IS 6524 : 1972	Code Of Practice For Installation And Observation Of Instruments For Temperature Measurements Inside Dams : Resistance Type Thermometers
IS 6532 : 1972	Code Of Practice For Design, Installation, Observation And Maintenance Of Uplift Pressure Pipes For Hydraulic Structures On Permeable Foundations
IS 7356 (PART 1) : 2002	Code Of Practice For Installation, Maintenance And Observation Of Instruments For Pore Pressure Measurements In Earth Dams And Rockfill Dams - Part 1 : Porous
IS 7356 (PART 2) : 2003	Installation, Observation And Maintenance Of Instruments For Pore Pressure Measurements In Earth And Rockfill Dams - Code Of Practice: Part 2 Twin Tube Hydraulic Piezometers (Second Revision)

IS 7436 (PART 1) : 1993	Guide Fort Types Of Measurements For Structures In River Valley Projects And Criteria For Choice And Location Of Measuring Instruments: Part 1 For Earth And Rockfill Dams (First Revision)
IS 7436 (PART 2) : 2019	Guide For Types Of Measurements For Structures In River Valley Projects And Criteria For Choice And Location Of Measuring Instrument: Part 2 Concrete And Masonry Dams (Second Revision)
IS 7500 : 2000	Code Of Practice For Installation And Observation Of Cross Arms For Measurement Of Internal Vertical Movement In Earth Dams (First Revision)
IS 8226 : 2017	Installation And Observation Of Base Plate Apparatus For Measurement Of Foundation Settlement In Embankments - Code Of Practice (First Revision)
IS 8282 (PART 1) : 1976	Code Of Practice For Installation, Maintenance And Observations Of Pore Pressure Measuring Devices In Concrete And Masonry Dams: Part 1 Electrical Resistance Type Cell
IS 8282 (PART 2) : 1996	Installation, Maintenance And Observations Of Pore Pressure Measuring Devices In Concrete And Masonry Dams - Code Of Practice: Part 2 Vibrating Wire Type Cell
IS 4967 : 1968	Recommendations For Seismic Instrumentation For River Valley Projects

References:

1. **CWC Guidelines for Instrumentation of Large Dams**

CHAPTER 4

Dam Safety, Repair, and Rehabilitation

A. Introduction

The concept of dam safety is built on three foundational pillars: structural integrity, vigilant surveillance, and effective emergency response strategies. Ensuring the safety of dams involves a relentless commitment to these components, facilitated by ongoing field investigations, adept material selection for repairs, and adherence to robust construction standards. The dynamic landscape of dam safety is further complicated by evolving meteorological patterns and the downstream development, underscoring the necessity for a proactive and well-resourced approach to dam maintenance.

As we delve into this handbook, readers will gain insights into the latest practices for dam rehabilitation, understand the planning aspects crucial for the systematic repair, and appreciate the complexities of maintaining dam safety in a rapidly changing world. Case studies from across India offer practical examples and lessons learned, serving as invaluable references for ongoing and future projects.

The goal is to enhance awareness of the technical, operational, and policy aspects of dam safety and rehabilitation while underscoring the importance of adhering to standardized guidelines to ensure sustainable, safe, and resilient water resources infrastructure.

B. Overview of Dam Safety, Repair, and Rehabilitation in India and its Importance

India ranks third globally in terms of large dams, with over 5,200 completed and approximately 450 under construction. Many of these structures have aged significantly, with around 213 being over 100 years old. The deterioration of dams due to ageing, environmental factors, and evolving safety standards presents challenges that necessitate timely repair and rehabilitation.

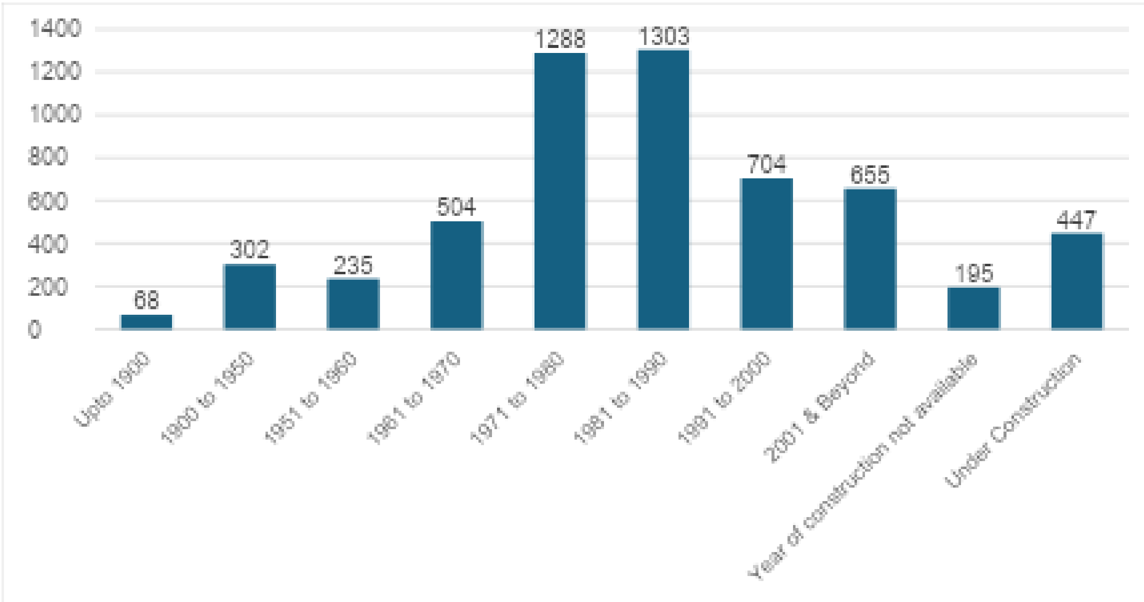


Fig 1 Number of Large Dams in India

B.1 Key reasons for focusing on dam safety include:

- **Mitigating Risks to Life and Property**: Unsafe dams pose significant risks to downstream populations and infrastructure.
- **Ensuring Continuity of Benefits**: Dams play a vital role in water supply, irrigation, hydropower generation, and flood control.
- **Adapting to Climate Change**: Increased intensity and frequency of extreme weather events necessitate that dams are resilient and robust.

B.2 Key Challenges in Dam Safety

- **Ageing Infrastructure**: Many dams do not meet modern design standards for structural and hydrological safety.
- **Inadequate Maintenance**: Insufficient funds and technical expertise often lead to delayed or insufficient repairs.

- **Upstream and Downstream Developments**: These developments may impose additional pressures on dam stability and functionality.

C. Dam Failures

Understanding the causes of dam failures is essential for formulating effective safety and rehabilitation strategies. Failures may result from structural deficiencies, environmental conditions, or operational errors.

C.1 Key Causes of Dam Failures:

- **Overtopping**: Often the primary cause of dam failures, overtopping occurs when water flows over the crest due to inadequate spillway capacity or extreme flood events.
- **Structural Instability**: Issues such as cracking, sliding, or overturning can lead to dam collapse.
- **Foundation Failures**: Weak foundations, excessive seepage, and erosion can compromise the stability of the structure.
- **Seepage and Piping**: Internal erosion caused by uncontrolled seepage can weaken the dam body and lead to failures.
- **Material Deterioration**: Aging materials, weathering, and lack of maintenance contribute significantly to dam vulnerabilities.
- **Operational and Design Deficiencies**: Inadequate design, faulty construction practices, or operational mismanagement can also lead to failures.

C.2 Historical Failures in India

India has experienced 36 documented dam failures, with the majority occurring between 1951 and 1970. These include the Tigra Dam (1917) in Madhya Pradesh, which failed due to overtopping. The analysis of these incidents highlights the importance of proper design, regular inspections, and adherence to safety standards.

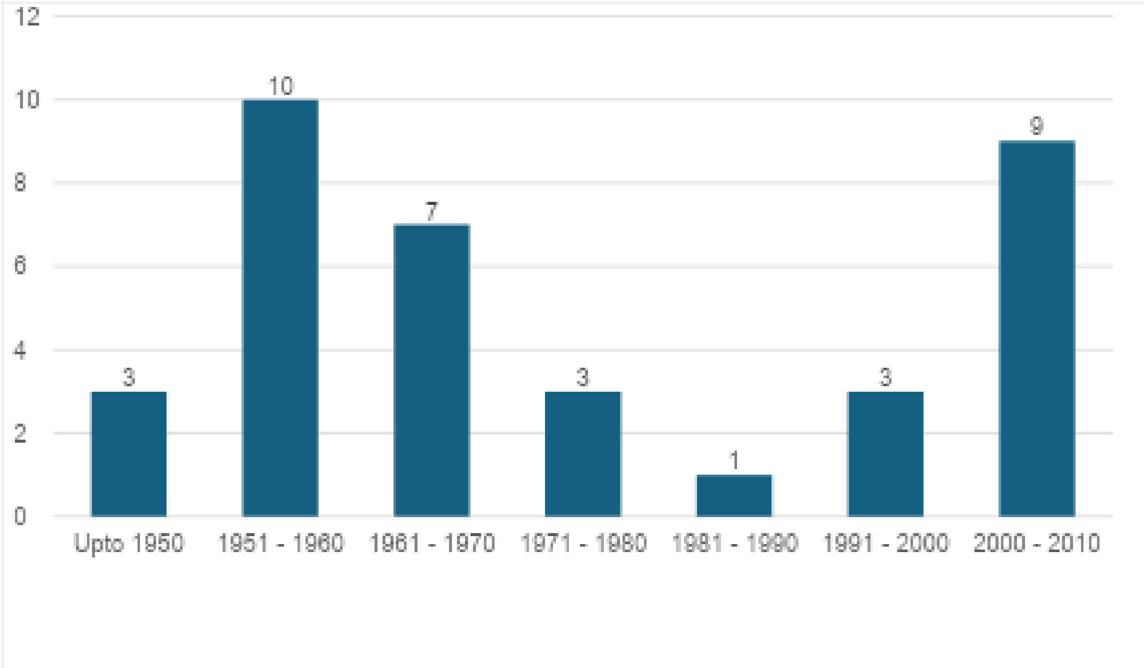


Fig 2 Year-wise Number of Dam Failures in India

C.3 Lessons Learned from Historical Failures

Dam failures provide valuable insights into the need for robust safety mechanisms. Key lessons include:

- **Regular Monitoring**: Continuous monitoring using modern instrumentation is critical for identifying potential issues early.
- **Emergency Preparedness**: Developing and implementing Emergency Action Plans (EAPs) can mitigate risks to downstream communities.
- **Periodic Maintenance**: Timely repairs and maintenance are essential to prevent deterioration.

C.4 Importance of Surveillance and Maintenance

Regular surveillance and maintenance form the backbone of dam safety management. Effective practices include:

- **Periodic Inspections**: Visual and technical inspections should be conducted to assess structural health.
- **Monitoring Instruments**: Seepage measurement, deformation monitoring, and piezometer readings provide essential data for evaluating dam performance.
- **Data Analysis**: Long-term trends from instrumentation data can help predict potential vulnerabilities.

By prioritizing these activities, dam operators can enhance the safety and longevity of the structures, ensuring they continue to deliver their intended benefits without posing risks to downstream populations.

D. Planning for Rehabilitation

D.1 Assessing Rehabilitation Needs

Rehabilitation planning begins with identifying deficiencies and determining the scope of work. The following steps are essential:

- **Preliminary Assessment**:
    - Review historical performance records.
    - Conduct visual inspections and gather data from monitoring instruments.
    - Identify critical areas requiring immediate attention.
- **Detailed Investigations**:
    - Perform geotechnical and structural evaluations.
    - Assess hydrological and seismic safety under updated design standards.
    - Examine the condition of spillways, gates, and appurtenant structures.
- **Risk Assessment**:
    - Prioritize deficiencies based on their impact on dam safety.
    - Conduct probabilistic risk analyses to evaluate potential failure scenarios.

- Develop risk reduction strategies to address identified vulnerabilities.
- **Cost-Benefit Analysis**:
  - Evaluate the financial feasibility of proposed rehabilitation measures.
  - Consider the benefits of extended service life and enhanced safety.
- **Preparation of a Rehabilitation Plan**:
  - Define the scope, objectives, and timeline of the rehabilitation project.
  - Incorporate emergency preparedness and response strategies.
  - Ensure alignment with BIS standards and regulatory requirements.

D.2 Design Aspects to be Considered

The requirement for rehabilitation is generally based on the observations/ recommendations brought out in various inspection reports of the project. Various factors which are taken into account are:

- Reports of earlier comprehensive and other inspections.
- Condition of the dam & appurtenant structures.
- Performance/condition of Hydro-Mechanical equipment.
- Evaluation of instrumentation data.
- Photographs taken at different points of time.
- Original designs & drawings, material properties considered.
- Details of any earlier dam incident including rehabilitation works carried out.
- Risk analysis, if carried out.
- Further investigations, as required.

D.3 Factors to be considered

- Review of design flood studies which may suggest an increase in spillway capacity.
- Revised water availability studies which may suggest an increase/decrease in hydro-electric capacity, irrigation or water supply.
- Impact of any recently constructed projects on the upstream.
- Reservoir operation experience of the operating personnel in respect of Hydro-Mechanical equipment etc.
- Any changes in river morphology.
- Consideration of construction techniques.
- The effect of the methods of rehabilitation which might include grouting, pre-stressing, blasting etc. on the existing structure.
- The effect of using materials that have different properties than the original materials on the structure.
- Mitigation of environmental impact.

D.4 Risk Analysis and Management

Risk management is crucial for prioritizing rehabilitation activities. Key aspects include:

- **Failure Mode Analysis**: Identify potential failure mechanisms and their probabilities.
- **Integration of Monitoring Data**: Use historical data to predict future behaviour.
- **Emergency Action Planning**: Develop actionable strategies to address high-risk scenarios.

D.5 Financing and Operational Challenges

Rehabilitation projects often face financial and operational constraints. Strategies to overcome these challenges include:

- **Securing Funds**:

    - Leverage government schemes like the Dam Rehabilitation and Improvement Project (DRIP).
    - Explore public-private partnership models for funding.
- **Operational Constraints**:
    - Minimize disruption to dam operations by phasing rehabilitation works.
    - Use advanced construction techniques to reduce project timelines.

Effective planning and resource allocation are essential to address these challenges and ensure successful rehabilitation outcomes.

E. Field Investigations and Monitoring Techniques

E.1 Importance of Field Investigations

Field investigations provide critical data for assessing the condition of dams and formulating effective rehabilitation strategies. These investigations focus on understanding the current state of the structure, identifying potential vulnerabilities, and recommending corrective measures. The primary objectives include:

- **Evaluating Structural Integrity**: Assess the condition of the dam body, foundation, and appurtenant works.
- **Identifying Seepage and Leakage Points**: Locate areas of uncontrolled seepage and determine their impact.
- **Material Testing**: Analyze the properties and behaviour of construction materials under current conditions.

E.2 Types of Field Investigations

- **Visual Inspections**:
    - Regularly conducted to identify visible signs of distress, such as cracks, seepage, or deformation.
    - Provide an initial understanding of potential issues that require detailed analysis.
- **Geotechnical Investigations**:
    - Evaluate the foundation and abutment materials.
    - Use techniques like borehole drilling, Standard Penetration Tests (SPT), and Cone Penetration Tests (CPT).
- **Geophysical Investigations**:
    - Use non-invasive techniques like seismic refraction, electrical resistivity, and ground-penetrating radar to assess subsurface conditions.
- **Hydrological and Hydraulic Studies**:
    - Analyze reservoir behaviour under varying conditions.
    - Assess spillway capacity and downstream flood risk.
- **Instrumentation and Monitoring**:
    - Install instruments like piezometers, inclinometers, and strain gauges to monitor real-time data.
    - Regularly analyze instrumentation data to detect anomalies.

E.3 Minimum Design Studies required

- Review and determination of Revised Design flood viz. Probable Maximum Flood (PMF), Standard Project Flood (SPF) or 100-year flood return period flood, on a case-to-case basis.

- Determination of Maximum Water level for the revised design flood by Flood routing studies.
- Check for freeboard in the dam for the MWL condition.
- To check the need for any Structural / non-structural measures in case of any upward revision of design flood.
- Identification of the site in case an additional spillway is required.
- All topographical & geological investigations for the selected possible additional spillway sites.
- Re-checking of freeboard considering the planned structural provisions.
- To carry out a seismic study for determination of seismic design parameters (if necessary) and to obtain approval from NCSDP, if required.
- Review of stability of the dam & spillway based on actual material properties etc.

E.4 Special Investigations

This may be required for specific issues like the determination of permeable locations in the dam for planning directional grouting or for conducting a seismic study to determine the site-specific seismic parameters.

- Geophysical Investigations for masonry/ concrete dams for determination of permeable locations/zones
- Geophysical Investigations for Embankment dams for determination of permeable locations/ zones
- Determination of Site-Specific Seismic Parameters

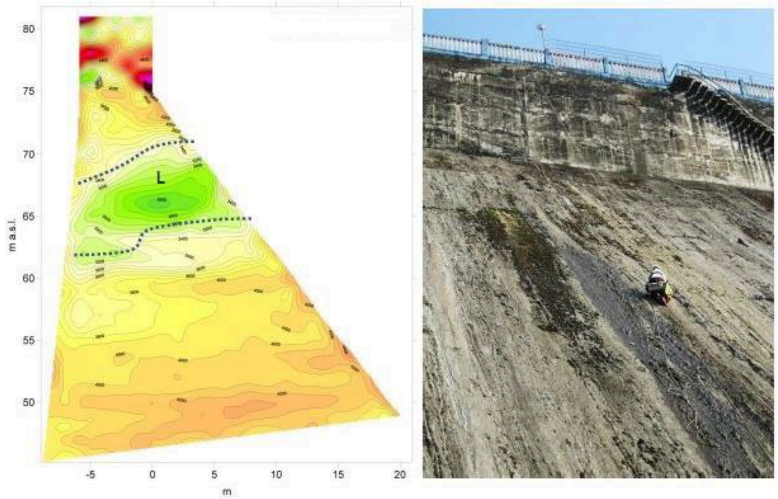


Fig 3 Typical Sonic Tomograms showing Velocity Contours and a view of the receiver points on the downstream side

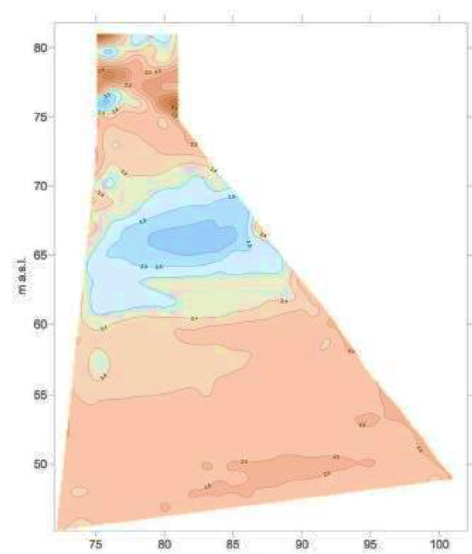


Fig 4 Typical Section showing Density Contours in Dam section

F. Materials for Rehabilitation

Effective repair and rehabilitation of dams require the selection of appropriate materials tailored to the type and extent of the observed deficiencies. Repair materials should provide durability, compatibility with the existing structure, and resistance to environmental factors.

F.1 Causes of Distress in Concrete

Some of the causes are given below:

- Accidental loadings
- Acid attack
- Alkali-Silica reactions
- Sulphate attack on concrete
- Construction errors
- Differential settlement and movement
- Shrinkage
- Temperature changes
- Cavitation, abrasion and impact
- Freezing and thawing

F.2 Symptoms of Distress in Concrete

Some of the symptoms are given below:

- Construction Faults
- Cracking
- Disintegration
- Distortion/Movement
- Erosion
- Joint Failure
- Seepage

- Spalling

F.3 Key materials include:

1. **High-Performance Concrete (HPC)**
    - A durable and high-strength material designed to withstand harsh conditions.
    - Used for spillways, energy dissipators, and other critical structural components requiring enhanced performance.
2. **Bonding Agents**
    - Primarily used to improve adhesion between old and new concrete surfaces.
    - Ensure seamless integration in repair works, preventing delamination.
3. **Cementitious Mortar**
    - Non-shrink mortar used for surface repairs, crack filling, and joint sealing.
    - Offers good durability and compatibility with existing masonry or concrete.
4. **Free Flow Micro-Concrete**
    - Flowable concrete used for precision repairs in inaccessible areas.
    - Ideal for applications requiring strength and compactness in narrow spaces.
5. **Various Types of Grouts**
    - Includes cement, chemical, and epoxy grouts for filling voids and stopping seepage.
    - Commonly applied in foundation treatments and leakage control.
6. **Epoxy Compounds**
    - High-strength materials used for crack repairs, bonding, and surface strengthening.
    - Known for their quick curing and excellent water resistance properties.

7. **Patching Materials**
    - Used for localized repairs of damaged or deteriorated concrete surfaces.
    - Ensures structural integrity and restores aesthetic appearance.
8. **Resurfacing Materials**
    - Applied as overlays to restore or enhance the performance of existing surfaces.
    - Provide abrasion and weather resistance, extending service life.
9. **Steel Liner**
    - Protective lining used in spillways, gates, and pipes to prevent abrasion and corrosion.
    - Offers long-term durability in high-flow and erosive environments.
10. **Fibre-Reinforced Concrete**
    - Concrete mixed with fibers (e.g., steel, glass, or synthetic) for enhanced tensile strength.
    - Reduces crack propagation and improves durability under load.
11. **Polymer Concrete and Coatings**
    - Polymer-modified materials used for waterproofing, crack sealing, and surface protection.
    - Known for their high chemical resistance and flexibility.
12. **Geo-Synthetics & Geo Membrane**
    - Used as sealing systems to control seepage and improve stability in dams.
    - Offer lightweight, durable, and cost-effective solutions for waterproofing and erosion control.

F.4 Laboratory Studies on Epoxy / Cementitious Repair Materials

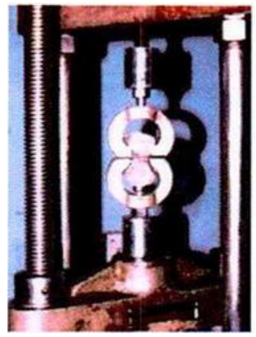
1. **Mix Viscosity and Pot Life (IS 9162)**
    - Determines the flow characteristics and usable time of repair materials after mixing.

- o Essential for assessing the practicality of application under site conditions.

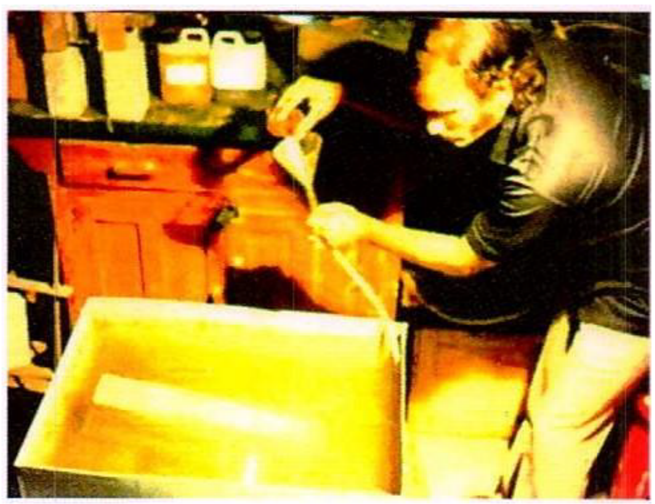
2. **Compressive Strength (IS 9162)**
    - o Measures the material's ability to withstand compressive loads.
    - o A critical parameter for structural repairs and ensuring durability.

3. **Tensile Strength (IS 4456, IS 9162)**
    - o Evaluates resistance to tensile forces, indicating material flexibility and robustness.

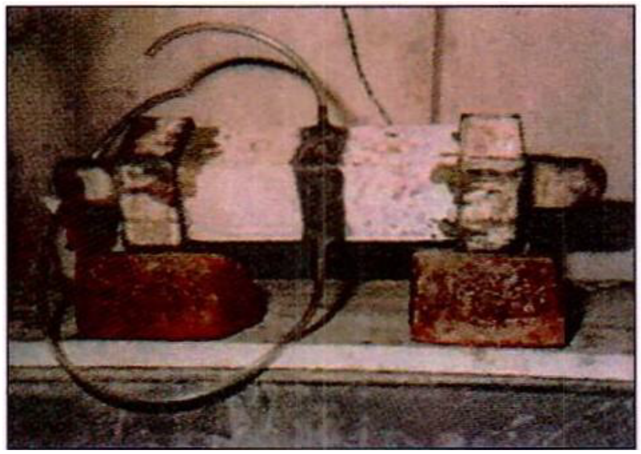
- Important for applications subjected to stretching or pulling forces.



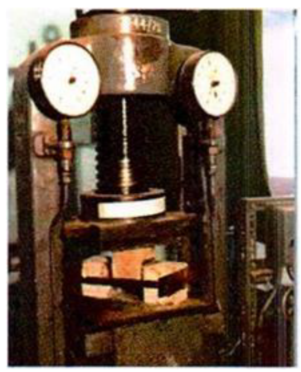
4. **Penetrability**
   - Assesses the ability of repair materials to penetrate fine cracks and voids.
   - Key for effective seepage control and void filling.



5. **Bond Strength Under Tension**
   - Tests adhesion strength when subjected to tensile forces.
   - Ensures the material's integrity under operational stress.

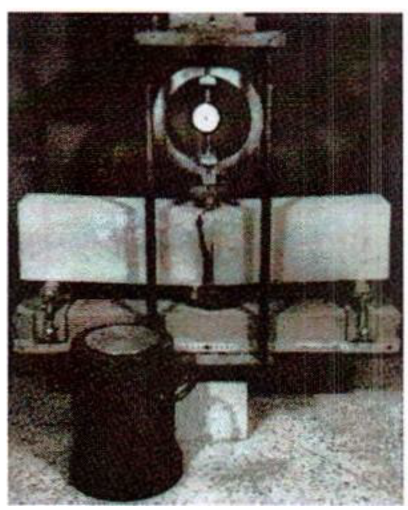


6. **Bond Strength with Concrete Under Shear**
   - Measures shear resistance at the interface between repair material and concrete.
   - Crucial for ensuring cohesive performance in structural repairs.



7. **Slant Cone Test**
   - Determines bond strength at an inclined interface, simulating realistic shear stresses.
   - Evaluates compatibility and strength improvement.

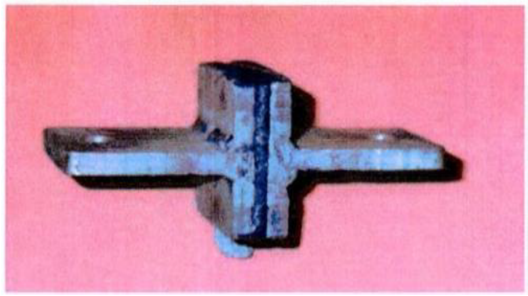
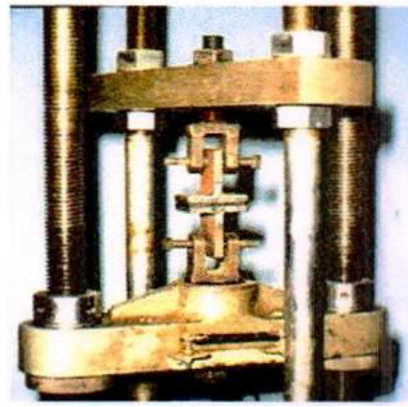
8. **Flexure Test**
    - o Assesses the ability of repair materials to withstand bending or flexural stresses.
    - o Important for repairs in beams and slabs.



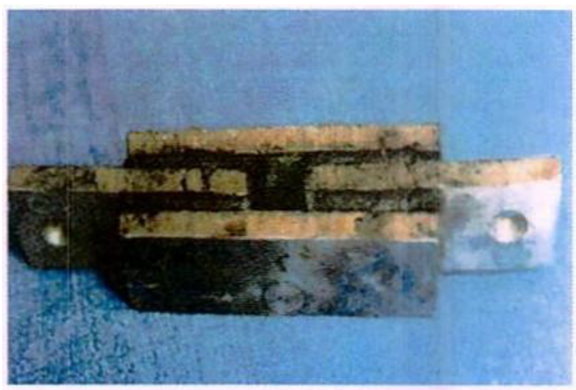
9. **Pressure Bearing Capacity of the Sealing System**
    - o Tests the sealing system's resistance to hydraulic pressures.
    - o Ensures long-term water tightness in seepage-prone areas.

10. **Modulus of Elasticity (IS 9221)**
    - Indicates the stiffness of repair materials under stress.
    - Helps in predicting deformation and compatibility with surrounding structures.

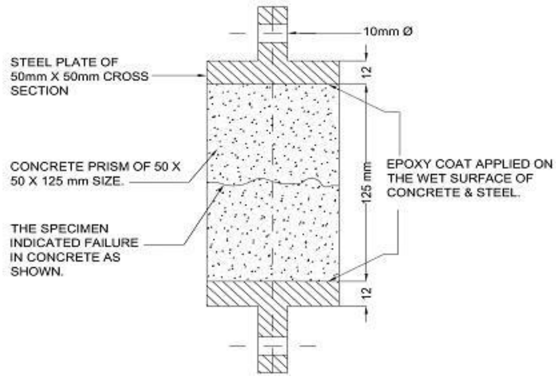
11. **Bond Strength with Steel Under Tension**
    - Evaluates the adhesion between repair material and steel under tensile stress.
    - Essential for reinforced concrete repair applications.

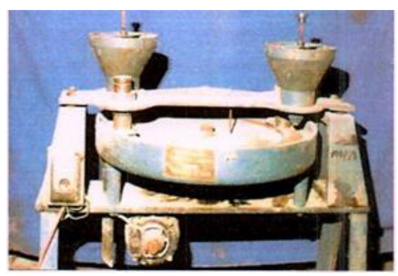
12. **Bond Strength with Steel Under Shear**
    - Measures resistance to shearing forces at the steel-repair material interface.
    - Ensures stability in jointed or composite structures.



13. **Bond Strength with Steel & Concrete Under Tension**
    - Tests the combined tensile performance of steel, concrete, and repair materials.
    - Critical for multi-material structural systems.



14. **Abrasion Resistance of Epoxy Mortar**
    - Assesses durability against wear caused by friction or abrasive forces.
    - Important for repairs in high-traffic or flow areas.



15. **Flowability/Workability (IS 2250)**
    - Evaluates the ease of application and flow of repair materials.
    - Ensures material suitability for various repair scenarios.

16. **Assessment of Strength Improvement**
    - Comprehensive testing to quantify enhancements in structural and material properties post-repair.
    - Demonstrates the effectiveness of selected materials in rehabilitation works.

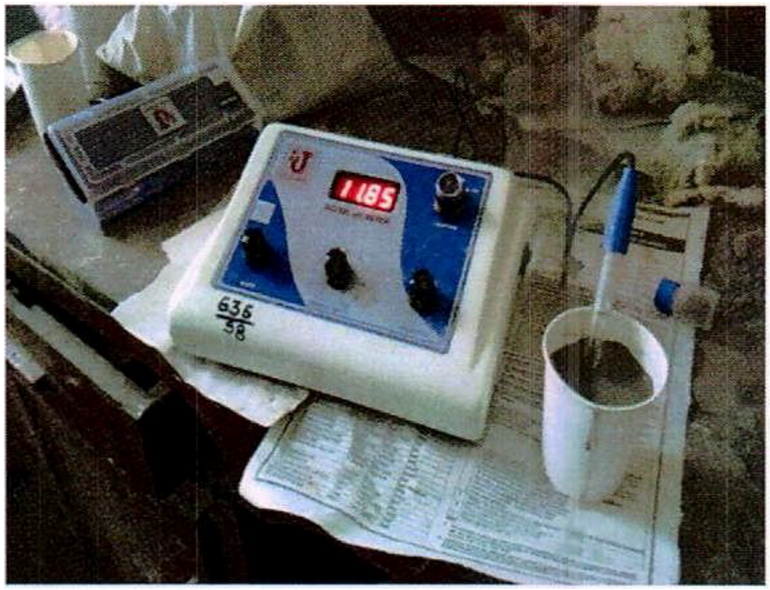
F.5 Laboratory Experimentation for Selection of Ideal Cementitious Grout System

1. **Flowability Test by Marsh Cone Apparatus**
    - Measures the time taken for the grout to flow through the cone.
    - Ensures adequate flowability for penetration into cracks and voids during application.

2. **Settlement/Segregation Test**
    - Assesses the uniformity of the grout mix by checking for material separation.
    - Ensures homogeneity and stability of the grout for consistent performance.

3. **Gelification Test**
    - Determines the time taken for grout to gel or set after mixing.
    - Important for planning application timelines and ensuring efficient usage.

4. **pH Value**
    - Measures the acidity or alkalinity of the grout to ensure compatibility with the surrounding materials.
    - Prevents chemical reactions that could compromise durability or structural integrity.



5. **Compressive Strength**
   - o Tests the grout's ability to withstand compressive forces once set.
   - o Critical for load-bearing applications and structural repairs.

6. **Test on Steel Fibre Reinforced Concrete (SFRC)**
   - o Evaluates the performance of grout when combined with steel fibres for enhanced strength.
   - o Assesses crack resistance and overall structural durability.
7. **Toughness Index**
   - o Measures the energy absorption capacity of the grout, indicating its ability to resist impact and deformation.

- Essential for high-stress or dynamic environments.

G. Rehabilitation of Concrete and Masonry Dams

G.1 Rehabilitation of the Foundation

1. **Loss of Strength under Permanent or Repeated Actions**
   - Repeated loading or environmental factors can lead to foundation weakening.
   - Rehabilitation involves strengthening techniques like grouting and foundation anchoring.
2. **Erosion & Solution**
   - Foundation material erosion or dissolution, particularly in limestone or similar rocks, reduces stability.
   - Measures include sealing surfaces and injecting grouts to fill voids and cracks.
3. **Grout Curtains and Foundation Drains**
   - Used to control seepage and improve stability by injecting grout to create impervious barriers.
   - Foundation drains reduce uplift pressure and improve overall dam performance.

G.2 Rehabilitation of Dam Body

1. **Chemical Reactions Resulting in Swelling**
   - Alkali-silica reactions and sulphate attacks cause swelling and cracking in concrete.
   - Treatment involves replacing affected areas with resistant materials and sealing cracks.

2. **Deficiencies on Account of Increased Seepage**
   - High seepage through cracks or porous zones compromises structural safety.
   - Rehabilitation includes grouting and installing impervious linings or membranes.
3. **Shrinkage and Creep Leading to Contraction**
   - Over time, shrinkage and creep lead to structural deformations and stress concentrations.
   - Corrective measures include joint repairs and the use of flexible sealants.
4. **Degradation of Dam Faces**
   - Weathering, abrasion, and chemical exposure degrade concrete or masonry surfaces.
   - Resurfacing with high-performance materials restores integrity and appearance.
5. **Loss of Strength Because of Repeated Actions**
   - Cyclic loads, such as thermal or hydrological stresses, reduce material strength.
   - Measures include reinforcing weakened sections and applying protective coatings.
6. **Structural Joints**
   - Deterioration of joints causes leakage and movement between concrete sections.
   - Rehabilitated by replacing joint materials and installing modern flexible seals.
7. **Pre-stressed Structures**
   - Loss of pre-stress due to corrosion or aging affects structural integrity.
   - Re-tensioning and replacing corroded tendons restore strength.

G.3 Improvement in Stability

1. **Design Aspects**

    - Stability improvements may involve redesigning critical sections to meet updated safety criteria.
    - Additional measures include buttressing, anchoring, and increasing dam weight to counter instability.

H. Rehabilitation of Embankment Dams

H.1 Deformation

- Settlement, differential movement, or lateral displacement can affect embankment stability.
- Rehabilitation includes re-compaction, slope regrading, and installing monitoring systems for long-term observation.

H.2 Seepage Flows

- Seepage through the dam or foundation can lead to erosion and instability.
- Measures include installing drains, cutoffs, and seepage control systems to maintain stability and prevent water loss.

H.3 Internal Erosion

1. **Filters and Drains**
    - Installed to capture and redirect seepage safely, preventing particle migration and internal erosion.
    - Enhance long-term stability by controlling pore water pressures.
2. **Grouting**
    - Injection of cementitious or chemical grouts to seal seepage paths within the dam or foundation.
    - Effective for filling voids and reducing permeability.
3. **Diaphragm Walls and Cutoffs**
    - Constructed as vertical barriers to block seepage through the dam body or foundation.
    - Commonly made of concrete, plastic, or bentonite clay.

4. **Sheet Piling**
   - Steel or other impermeable materials driven into the foundation to create seepage barriers.
   - Suitable for repairs in limited access areas.
5. **Clay Blanket**
   - A layer of clay applied to the upstream face to reduce seepage.
   - Acts as a natural, low-permeability barrier.
6. **Reconstruction and Replacement of the Core Section**
   - Core material replaced or reconstructed to restore seepage control.
   - Typically involves modern materials and advanced techniques.
7. **New Filters and Drain Provisions**
   - Additional filters and drainage systems installed to manage seepage effectively.
   - Essential for preventing internal erosion in aging embankments.

H.4 External Erosion

1. **Upstream Protection**
   - Repairs to riprap or wave protection systems to prevent erosion caused by wave action or overtopping.
   - Enhances resistance to weathering and water forces.
2. **Crest of the Dam, Parapet Walls, and Downstream Slope**
   - Rehabilitation of damaged parapet walls, crest settlement, and downstream erosion.
   - Includes re-compaction, turfing, and erosion-resistant coverings.

H.5 Loss of Bond Between Concrete Structure and Embankment

- Separation between concrete appurtenant structures (e.g., spillways) and the embankment can cause seepage or instability.

- Repaired by joint sealing, structural strengthening, or installing flexible connections.

H.6 Slope Stability Improvement

- Instability due to steep slopes, poor drainage, or material degradation.
- Improved by regrading slopes, adding berms, or installing geosynthetics for reinforcement.

H.7 Rehabilitation to Enhance Resistance to Seismic Effects

- Seismic upgrades include strengthening foundations, densifying soil, and using reinforced earth techniques.
- Reduces risks of liquefaction or deformation during earthquakes.

H.8 Rehabilitation of Upstream Faces

1. **Asphaltic Concrete Faces**
    - Used to repair upstream faces with asphalt layers for waterproofing and erosion control.
    - Provides flexibility and durability against wave action.
2. **Concrete Faces**
    - Replacement or repair of concrete slabs on upstream faces to restore impermeability and stability.
    - Includes sealing cracks and resurfacing with durable materials.

I. Rehabilitation of Appurtenant Works

I.1 Principal Causes of Deterioration

1. **Local Scour**
    - **Detection and Monitoring**: Regular bathymetric surveys and visual inspections identify scour zones.

- **Rehabilitation Measures**: Scour holes are filled with concrete or riprap, and protective measures like aprons and cutoff walls are added.

2. **Erosion by Abrasion**
   - **Detection and Monitoring**: Inspections reveal surface wear caused by sediment-laden water flow.
   - **Effect on Safety and Performance**: Surface damage can compromise structural safety and efficiency.
   - **Repair of Damaged Surfaces**: Damaged areas are resurfaced with abrasion-resistant materials or protective linings.
3. **Erosion by Cavitation**
   - **Detection and Monitoring**: High-velocity flow conditions are analyzed for cavitation risks.
   - **Effect on Safety and Performance**: Cavitation causes pitting and structural weakening.
   - **Rehabilitation Measures**: Damaged zones are repaired with high-strength materials, and flow profiles are redesigned to reduce cavitation.
4. **Obstruction by Floating Debris in the Flow**
   - **Detection and Monitoring**: Debris accumulation is observed using surface inspections and flow monitoring.
   - **Effect on Safety and Performance**: Debris can block spillways, gates, and other flow paths, reducing operational efficiency.
   - **Rehabilitation Measures**: Removal of debris and installation of trash racks or debris booms.

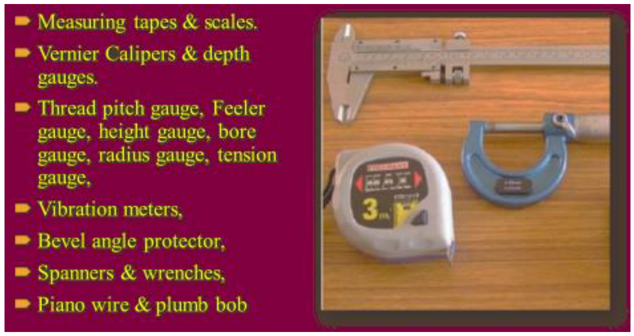
I.2 Rehabilitation of Outlet Works

1. **Outlet Tunnels and Conduits**
   - Repairs address leaks, cracks, and blockages in tunnels and conduits, ensuring flow efficiency.

    - Structural linings or relining with reinforced materials are often used.
2. **Bottom Outlets**
    - **Operation and Maintenance**: Regular cleaning and inspection prevent blockages and wear.
3. **Rehabilitation of Spillways and Energy Dissipators**
    - Surface restoration, structural strengthening, and reconfiguration of energy dissipators improve flood handling.
4. **Protection of Abutments**
    - Stabilization through rock bolting, grouting, and erosion protection measures like riprap or concrete cladding.

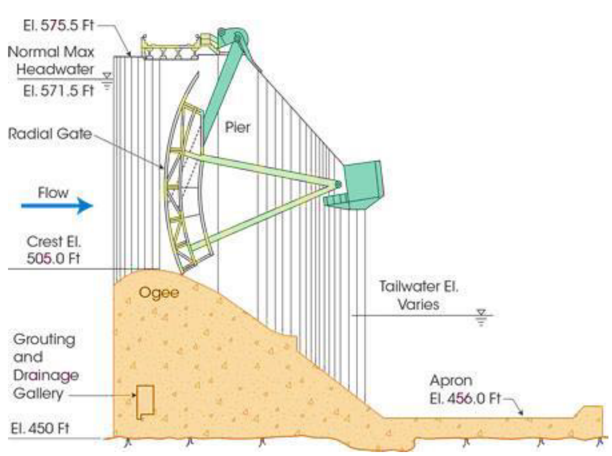
I.3 Rehabilitation of Gates and Other Discharge Equipment

1. **General**
    - **Basic Concerns**: Aging and corrosion reduce gate functionality and safety.
    - **Priorities in Rehabilitation Works**: Address critical components like seals, hoists, and bearings.
    - **Upstream Closure Facility**: Temporary barriers are installed during gate repairs.
2. **Rehabilitation Works Including Inspections/Monitoring**
    - **Old and Aged Gate Installations**: Focus on corrosion and mechanical wear.
    - **Underwater Inspections**: Embedded parts and seals are inspected for integrity.
3. **Investigations/Testing Before Rehabilitation**
    - **Integrity Review Protocol Requirements**: Detailed inspections using ultrasonic, magnetic particle, and radiographic methods identify defects.
    - **Visual Inspection and Measurement**: Dimensions and surface conditions of critical components are assessed.

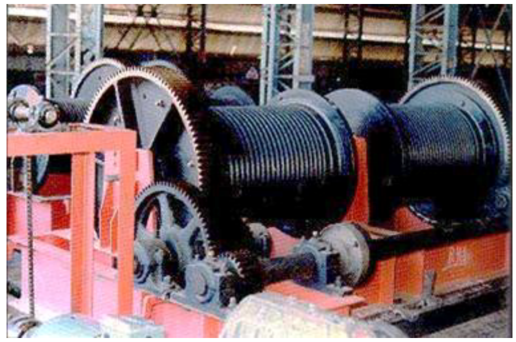


- **Surface Hardness Testing**: Ensures material durability and compatibility with repairs.

4. **Protection Measures**
   - **General/P.P.E Requirements**: Adherence to safety standards and proper equipment use during rehabilitation.
5. **Checks Before and After Rehabilitation**
   - **Vertical Lift Wheeled Gates and Radial Gates**: Testing for smooth operation and alignment.



- **Mechanical Rope Drum Hoists**: Inspection of wire ropes and drum mechanisms.



- **Surface Preparation and Painting**: Ensuring proper surface treatment and protective coatings for durability.
  - **Surfaces Not in Contact with Water**: Painted with general protective coatings.
  - **Surfaces in Contact with Water**: Use of water-resistant, corrosion-resistant paints.

J. Role of Standardization in Ensuring Safety

J.1 Importance of Standardization

Standardization plays a pivotal role in ensuring the safety, longevity, and effectiveness of dam infrastructure. By adhering to well-established standards, dam operators and engineers can mitigate risks, improve operational efficiency, and ensure compliance with national and international benchmarks.

J.2 Key Benefits of Standardization

- **Consistency Across Projects**:
  - Uniform practices reduce variability in safety measures.
  - Enhance reliability in construction, maintenance, and monitoring.

- **Risk Mitigation**:
  - Address common failure points with tried-and-tested methods.
  - Ensure robust safety protocols are in place for emergencies.
- **Enhanced Collaboration**:
  - Facilitate communication between stakeholders using common terminologies and procedures.
  - Promote knowledge sharing through standardized documentation.
- **Cost Optimization**:
  - Reduce wastage and inefficiencies by adhering to proven methods.
  - Streamline procurement processes for materials and equipment.

J.4 Consequences of Non-Standardized Practices

Deviations from standardized procedures can lead to significant risks and inefficiencies, including:

- **Increased Failure Risk**:
  - Non-compliance with safety norms heightens the likelihood of structural failures.
- **Operational Inefficiencies**:
  - Poorly defined practices can lead to delays and resource wastage.
- **Environmental and Social Impact**:
  - Inadequate planning can disrupt ecosystems and displace communities.

K. Notable Case Studies and Learnings

K.1 Chimoni Dam, Kerala

- **Background**:

  - Constructed as a masonry gravity dam, Chimoni Dam faced significant seepage issues and cracks in the masonry structure.
  - Located in a high rainfall area, the dam's challenges were exacerbated by heavy monsoon inflows, leading to operational inefficiencies and safety concerns.
- **Interventions**:
  - **Grouting Operations**: Extensive grouting was conducted to address seepage through the dam body and foundation.

  - **Surface Treatments**: Application of epoxy and polymer-modified coatings to seal cracks and improve the masonry surface.
  - **Improved Instrumentation**: New instruments, including piezometers and seepage measurement devices, were installed to monitor post-repair performance.
- **Outcome**:
  - **Seepage Control**: Significant reduction in water loss through seepage, ensuring better storage capacity.

- o **Structural Integrity**: Enhanced durability of the masonry structure through targeted repairs and monitoring.
- o **Operational Efficiency**: Improved flood handling and water management during monsoons.

K.2 Konar Dam, Jharkhand

- **Background**:
  - o Built in the 1950s, Konar Dam is an important reservoir in the Damodar Valley Project but had aging infrastructure leading to seepage, cracking, and reduced storage efficiency.
  - o The dam faced challenges in handling monsoon inflows and showed signs of structural wear in its spillways and outlet gates.
- **Interventions**:
  - o **Spillway and Gate Repairs**: Replaced corroded gates and reinforced the spillway structure to improve functionality and flood management capacity.
  - o **Seepage Mitigation**: Grouting was employed to address leakage issues in the dam foundation and abutments.

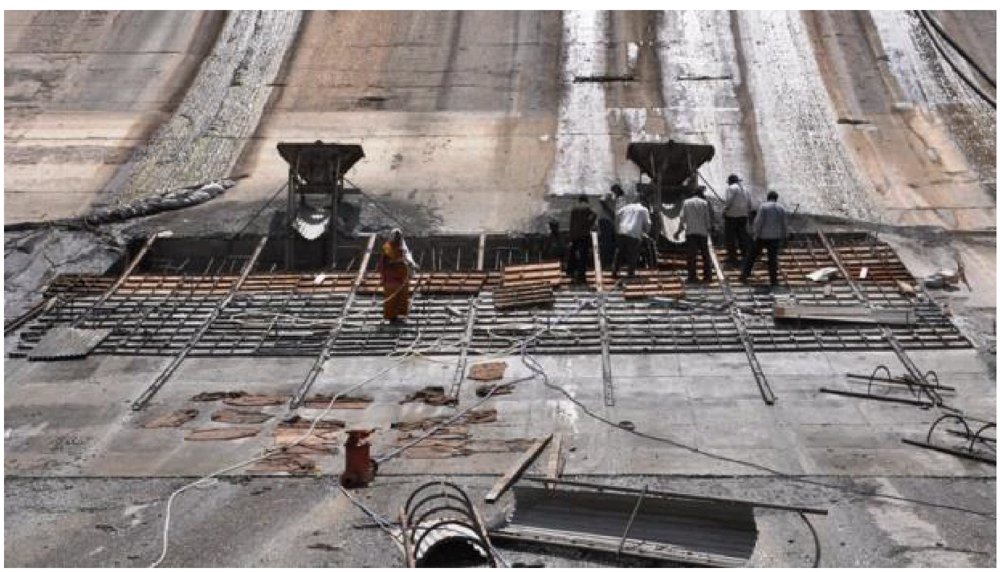
- **Upgraded Hydrological Safety**: Modifications were made to ensure compliance with updated hydrological and seismic standards.

- **Outcome**:
  - **Enhanced Flood Management**: The repaired spillway and gates ensured better flood discharge during peak inflows.
  - **Improved Structural Resilience**: The dam now meets modern safety standards, reducing the risk of failures.
  - **Longer Service Life**: The rehabilitation extended the operational life of the dam while ensuring improved water supply to downstream users.

K.3 Sardar Sarovar Dam, Gujarat

- **Background**:
  - One of India's largest multipurpose dams, the Sardar Sarovar Dam was facing challenges related to sedimentation, aging infrastructure, and downstream flow management.
  - Key issues included the erosion of spillway surfaces, sediment accumulation reducing reservoir capacity, and wear in operational gates.

- **Interventions**:
  - **Sediment Management**: Introduced sediment flushing and desilting operations to maintain reservoir capacity.
  - **Structural Strengthening**: Reinforcement of spillway surfaces with high-performance concrete and anti-abrasion coatings.



- **Gate Refurbishment**: Replaced and upgraded spillway gates and hoisting mechanisms to enhance operational reliability.
- **Advanced Monitoring**: Installed real-time instrumentation for water flow, structural stress, and sediment movement monitoring.

- **Outcome**:
  - **Increased Water Storage Efficiency**: Improved sediment management restored lost storage capacity, ensuring better water availability for irrigation and drinking purposes.
  - **Resilient Infrastructure**: Strengthened spillways and gates minimized maintenance requirements and enhanced operational reliability.

  - **Improved Environmental Management**: Adjustments in downstream flow management benefited aquatic ecosystems and local communities.

K.4 Lessons Learned

Technical Insights

- **Instrumentation is Key**:
  - Regular monitoring helps in early detection of potential failures.
  - Data-driven decisions improve safety outcomes.
- **Tailored Solutions**:
  - Rehabilitation measures should account for the unique characteristics of each dam.
  - Use of site-specific materials and techniques ensures compatibility and durability.

Operational Learnings

- **Stakeholder Engagement**:
  - Collaboration with local communities and governments ensures smoother project implementation.
  - Transparent communication builds trust and reduces resistance.
- **Capacity Development**:
  - Continuous training for engineers enhances technical competency.
  - Institutional strengthening ensures sustained safety practices.

L. Emergency Planning and Risk Mitigation

L.1 Importance of Emergency Action Plans (EAPs)

Emergency Action Plans are critical for mitigating risks associated with potential dam failures. EAPs provide a structured approach for responding to emergencies, minimizing loss of life, and protecting downstream infrastructure.

L.2 Key Components of an EAP

- **Risk Assessment**:
    - Identify potential failure scenarios.
    - Analyze downstream impacts, including affected populations and infrastructure.
- **Preparedness Measures**:
    - Establish communication protocols with stakeholders.
    - Conduct regular drills and training sessions.
- **Response Strategies**:
    - Define roles and responsibilities for emergency response teams.
    - Develop evacuation plans and resource mobilization strategies.
- **Recovery Plans**:
    - Outline steps for post-event assessment and restoration.
    - Include provisions for financial and logistical support.

L.3 Role of Instrumentation in Early Warning Systems

Advanced instrumentation plays a vital role in monitoring dam performance and providing early warnings of potential failures. Real-time data enables proactive decision-making and enhances emergency preparedness.

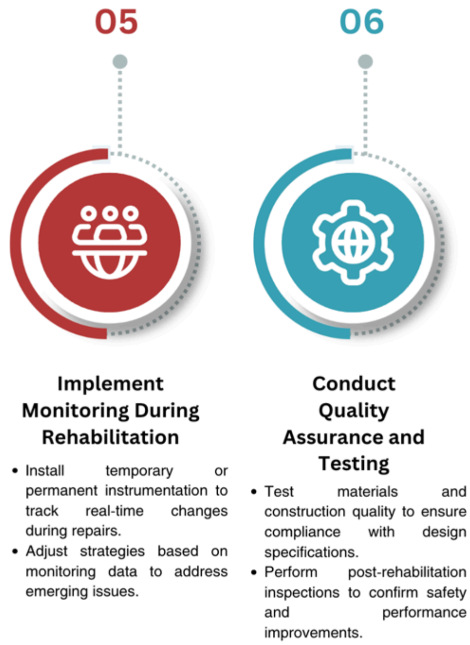
L.4 Types of Instruments

- **Seepage Monitoring**:
    - Piezometers to measure pore water pressure.
    - Flow meters for seepage quantification.
- **Structural Monitoring**:
    - Strain gauges to detect stress and deformation.

- Inclinometers for measuring horizontal displacement.

- **Hydrological Monitoring**:
    - Rain gauges and reservoir level sensors for flood forecasting.

ELEMENTS OF EFFECTIVE DAM REHABILITATION



References:

1. CWC Manual for Rehabilitation of Large Dams

CHAPTER 4

FLOOD CONTROL AND DIVERSION HEAD WORK

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7. **Diversion Head works**
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    - o Construction and Maintenance

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1 INTRODUCTION

1.1 Definition of Floods

Floods are natural events characterized by the overflow of water onto land that is normally dry. They can result from excessive rainfall, river overflows, dam failures, or sudden melting of snow.

Fig.1 Flood

Fig.2 Wild Flooding

1.2 Types of Floods

There are various types of Floods which are discussed below:

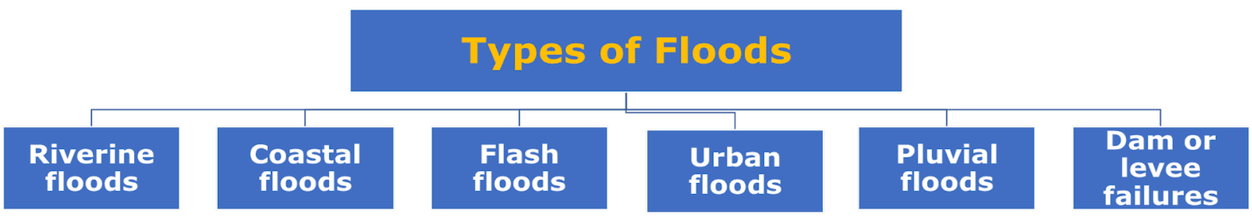


Fig.3 Types of flood

1.2.1 *Riverine floods*

These floods occur when heavy rainfall or snowmelt causes rivers or streams to overflow their banks.

1.2.2 *Coastal floods*

These occur when high tides, storm surges, or large waves cause seawater to flood onto coastal areas.

1.2.3 Flash floods

These floods occur when heavy rainfall occurs in a short period of time, overwhelming the capacity of drainage systems and causing water to rapidly accumulate in low-lying areas.

1.2.4 Urban floods

These occur in urban areas when the built environment and pavement prevent rainwater from being absorbed into the ground.

1.2.5 Pluvial floods

These occur when heavy rainfall exceeds the capacity of drainage systems, causing water to accumulate on the surface of the land.

1.2.6 Dam or levee failures

These occur when dams or levees are unable to withstand the pressure of floodwaters, causing them to breach and release large volumes of water downstream.

1.3 Causes of Floods

India is prone to floods due to its geography, heavy rainfall during the monsoon, changing weather patterns with rising temperatures leading to more frequent and intense rainfall events, snowmelt, river overflows-flooding, rapid snowmelt, dam or levee failure, coastal storms or storm surges, and tsunamis, as well as flash flooding and landslides. Coastal regions are also at risk of flooding due to tropical cyclones and storm surges.

Land-use / land cover changes such as deforestation, rapid urbanization and poor drainage conditions, and poor agricultural practices might have led to flood severity.

During the last four decades, it has been observed that the frequency and severity of floods in India have been increasing.

The main reasons for of flood are discussed below:

a) Excessive rainfall exceeding soil infiltration capacity.
b) River obstructions or inadequate channel capacity.
c) Dam failures or controlled reservoir releases.
d) Land-use changes leading to reduced floodplain storage.

2 FLOOD PREVENTION AND MANAGEMENT

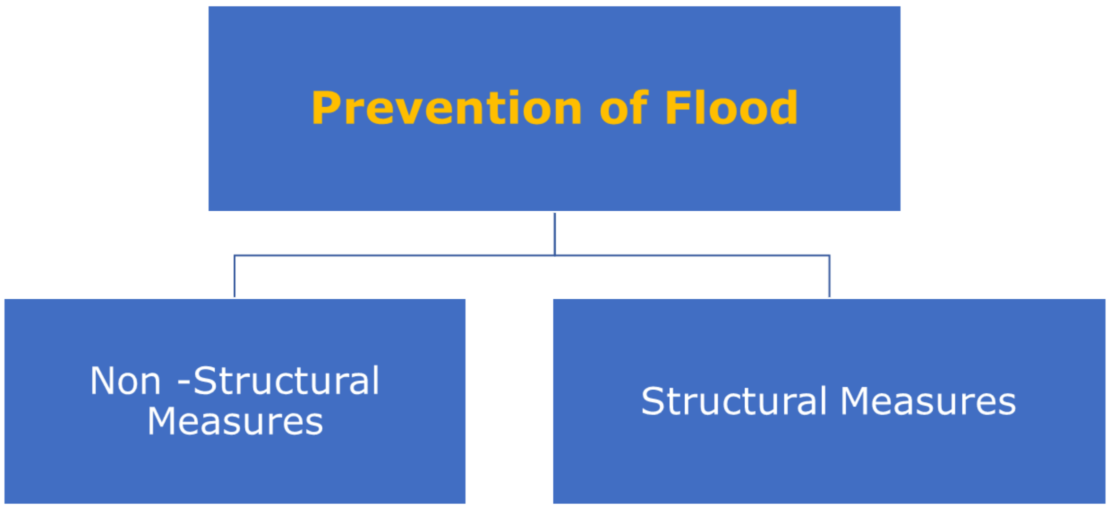


Fig.4 Methods of Flood Prevention

2.1 Non-Structural Measures

These reduce damage by removing people and property out of risk areas. They include elevated structures, property buyouts, permanent relocation, zoning, subdivision, and building codes.

2.1.1 *Floodplain Zoning*

Floodplain zoning is a process that identifies areas that are prone to flooding and regulates land use to minimize damage. Floodplain zoning involves identifying areas with different flood hazards and developing land use regulations for each area Floodplain zoning is an effective non-structural method for flood management. It can help reduce damage from floods in new developments, and it can also help reduce damage from drainage congestion in urban areas regulating development in flood-prone areas - implementing strict zoning laws, building codes that incorporate flood-resistant design features, and environmental impact assessments to minimize the risk of damage from flooding.

2.1.2 *Flood Forecasting and Warning Systems*

Using real-time hydrological data to alert communities - leveraging live information like river levels, rainfall intensity, and water flow to proactively warn residents in vulnerable areas about potential flooding risks, allowing them to take necessary precautions like evacuation or property protection before a flood occurs; this is typically achieved through an early warning system that monitors data, generates alerts.

2.1.3 *Flood Proofing*

Flood proofing is the process of reducing or preventing the impact of flooding on structures and property.

2.2 Structural Measures

They are physical solutions that can reduce the impact of flooding on people and property. These are the form of mitigation to mitigate harm by reconstructing landscapes. They include floodwalls/seawalls, floodgates, levees, and evacuation routes.

2.2.1 Reservoirs

These are large, man-made bodies of water that store water. They are created by building dams across rivers or over the outlet of a natural lake. The dam controls the amount of water that flows out of the reservoir. Reservoirs can also reduce flood risks. These are storage structures for regulating water flow- A primary storage structure used to regulate water flow is a reservoir, which stores excess water during high flow periods and releases it as needed during low flow periods, effectively managing water supply to meet demand throughout the year.

2.2.2 Diversion Channels

An artificial channel built alongside a river to divert excess water during flood events, effectively reducing the water level in the main river channel and minimizing flood damage in populated areas; essentially, it acts as a bypass channel to route excess water away from vulnerable zones. Redirecting excess water diverting floodwater away from vulnerable areas using engineered channels, canals, or flood ways, essentially channelling the excess water to a designated area where it can be safely contained or absorbed, thus minimizing damage to populated regions.

2.2.3 Levees and Embankments

Levees and embankments are both artificial or natural ridges built along the banks of rivers or coastlines to prevent flooding. They are built to control the flow of water and protect the surrounding land from flooding. They are usually made from earth and built wide enough to prevent erosion and collapse.

3 **FLOOD MANAGEMENT STRUCTURES**

3.2 **Embankments**

3.2.1 Planning & Design of River Embankment (IS 12094: 2018)

An embankment (levee) is an artificial bank built along banks of a river for the purpose of protecting adjacent land from inundation by flood. Such type of structure is also called ‘embankment’, ‘stop-bank’, ‘bund’ or ‘dyke’. Construction of embankment to control flood is an age-old practice and is still being followed due to its proven suitability. This standard covers planning and design of river embankments (levees) on dry land. The salient features/main design aspects covered in this standard are as follows:

a) Planning including classification, collection of data, degree of protection, alignment, spacing and length of embankments, etc.
b) Design of embankment such as types, design HFL, freeboard, top width, hydraulic gradient, side slope, safety measures in design, sluices, etc.;
c) Treatment of embankments;
d) Protection of embankments, etc.

3.2.2 Freeboard

Minimum of 1.5m above the design flood level.

3.2.3 Top Width

Typically, 5m for ease of maintenance and inspection.

3.3 **Revetments**

3.2.1 Designed as per IS 14262 for slope protection.

3.2.2 Use of materials like boulders, geo-textiles, and concrete blocks.

3.3 **Spurs and Groynes**

3.3.1 Used to deflect river flow and prevent erosion.

3.3.2 Planning & Design of Groynes in Alluvial River – Guidelines (IS 8408 : 1994)

Groynes (spurs) are structures constructed transverse to the river flow and extend from the bank into the river. These are widely used for river training and bank protection. This standard covers the planning and design of Groynes (Spurs) in alluvial rivers. The salient features/main design aspects covered in the code are described as follows:

a) Design discharge: should be equal to that for which any structure in close proximity is designed or **50-year** flood whichever is higher.
b) Length of spur: - Length of groynes should be decided on the basis of availability of land on the bank. Length should not be less than that required to keep the scour hole formed at the nose away from the bank. Normally, **effective length should not exceed 1/5th of width** of flow in case of single channel. The **spacing of spur is normally 2 to 2.5 times** its effective length.
c) Top level: - Depends on the type namely submerged, partially submerged or non-submerged and will be best decided by model experiment.
d) Top width: **3 to 6 meters** as per requirements.
e) Free board: **- 1 to 1.5 meter** above design flood level.
f) Side slope: **Between 2:1 and 3:1**.

3.4 RCC Porcupines

3.4.1 Permeable structures for bank stabilization.

3.4.2 Cost-effective and environmentally friendly.

4 DESIGN DATA AND EFFECTIVE UTILIZATION

4.1 Key Hydrological and Geological Inputs

4.1.1 Catchment Area Characteristics

Slope, soil type, land use.

4.1.2 Flood Frequency Analysis

Based on historical data.

4.1.3 Sediment Load

For designing scour protection.

4.2 Standards and Codes of Practice

Sl. No.	IS Number	IS Title
1	IS 13739:1993	Guidelines For Estimation Of Flood Damages
2	IS 4410:Part 12: 1993	Glossary of terms relating to river valley projects: Part 12 Diversion works
3	IS 4410:Part 21: 1987	Glossary of terms relating to river valley projects: Part 21 Flood control
4	IS 4410:Part 22: 1994	Glossary of terms relating to river valley projects: Part 22 Barrages & weirs
5	IS 7349: 2012	Barrages and weirs - Operation and maintenance – Guidelines
6	IS 8408: 1994	Planning and design of groynes in alluvial river – Guidelines
7	IS 14262: 1995	Planning and design of revetments – Guidelines
8	IS 12094 : 2018	Planning and design of river embankments (Levees) - Guidelines (Second Revision)
9	IS 11532 : 1995	Construction and maintenance of river embankments (Levees) - Guidelines (First Revision)
10	IS 10751 : 2022	Planning and design of guide banks for alluvial rivers guidelines

11	IS 12926 : 1995	Construction and maintenance of guide banks in alluvial rivers - Guidelines (First Revision)
12	IS 12892 : 1989	Safety of barrage and weir structures – Guidelines
13	IS 14955 : 2001	Guidelines for hydraulic model studies of barrages and weirs

5 CONSTRUCTION PRACTICES

5.1 Material Selection

5.1.1 Soil for Embankments

Prefer coarse-grained soil.

5.1.2 Boulders and Gabions

Use angular, graded stones.

5.2 Quality Control

5.2.1 Testing for soil compaction and permeability.

5.2.2 Regular inspection of gabion wire mesh for rust and damage.

6 MAINTENANCE AND OPERATION

6.1 Inspection Guidelines

6.2.1 Post-monsoon and pre-monsoon inspections.

6.2.2 Checking for erosion, settlement, and vegetation encroachment.

6.2 Operation During Flood Events

6.2.1 Monitoring river levels.

6.2.2 Ensuring functional sluice gates and spillways.

7 DIVERSION HEADWORKS

7.1 Definition and Importance

7.1.1 Diversion headworks are hydraulic structures constructed at the head of a canal in order to divert the river water towards the canal, to ensure a regulated, continuous supply of water with minimal silt entry and a certain head. They play a crucial role in flood mitigation, irrigation, and water resource management.

7.1.2 They serve multiple purposes:

a) Raising the water level in the river to increase the commanded area.

b) Regulating water flow into the canal to ensure a consistent supply.

c) Reducing fluctuations in river flow.

d) Preventing silt entry into the canal.

e) Providing temporary water storage during lean periods.

7.2 Types of Diversion Head works

7.2.1 *Diversion Head works*

To divert required supply to canal from the river.

a) *Temporary spurs or bunds*:

   Low-cost, short-term solutions reconstructed annually after floods.

b) *Permanent weirs and barrages*:

   Designed for long-term use, with weirs being solid obstructions and barrages employing gates for controlled flow.

7.2.2 *Storage Head works*

Dams and reservoirs constructed to store excess water during high-flow periods for later use.

7.3 Design Principles

7.3.1 *Site Selection*

a) Should be located in a narrow, straight, and stable river section with defined banks.

b) Availability of construction materials such as stone and sand in the vicinity.

c) Access to roads and local workforce for efficient project execution.

7.3.2 Hydraulic Design

a) Incorporates Bligh's creep theory for seepage prevention and Khosla's theory for uplift pressure and exit gradient calculations.

b) Ensures smooth flow with minimized head loss and proper energy dissipation.

7.3.3 Structural Design

a) Ensures resistance against seepage, uplift forces, and surface flow stresses.

b) Incorporates safety margins for extreme flood events.

c) *Design of diversion head works IS 10084 (Part 1): 1982*

1) The coffer dam being a temporary structure is normally designed for a flood with frequency less than that for the design of the main structure.

2) While fixing up the top level of the coffer dam, **adequate free board shall be kept**, so that over-topping of the coffer dam due to waves created by wind action is avoided.

3) Length of the coffer dam will depend upon the length and width of the area to be enclosed.

4) For compressive stresses, the p**ermissible stress shall be increased by 20 percent** of the provisions.
5) The upstream of the steel coffer dam shall not be kept flatter than **1 :1** and it may vary up to **1: 1.5**.
6) Design requirements - The design of double wall coffer dam shall satisfy the following conditions of equilibrium:
    i. **$\sum$ horizontal forces =0**
    ii. **$\sum$ moments =0**
7) Stability-The stability of the cellular steel sheet pile coffer dam shall be checked for:
8) Cell shear;
9) Sliding;
10) Tilting;
11) Bursting of cell;
12) Soil support.

7.4 Components of Diversion Head works

7.4.1 *Weir or Barrage*

a) Fixed weirs raise water levels for diversion, while barrages offer adjustable gates for enhanced control.
b) Designed to handle specific flood discharges and sediment loads.

Fig.5 Weir

Fig.6 Barrage

7.4.2 Divide Wall

a) Extends upstream and downstream of the structure to stabilize flow and reduce turbulence.

b) Aids in trapping silt, ensuring cleaner water enters the canal.

Fig.7 Divide Wall

7.4.3 Fish Ladder

a) Essential for ecosystems, allowing aquatic life to migrate upstream.

b) Designed as pool-type, steep channel, fish lock, or fish elevator based on site conditions.

Fig.8 Fish Ladder

7.4.4 Under sluices or Scouring Sluices

a) Located near canal head regulators to maintain a clear channel and prevent silt deposition.

b) Operate effectively during low floods to scour silt upstream.

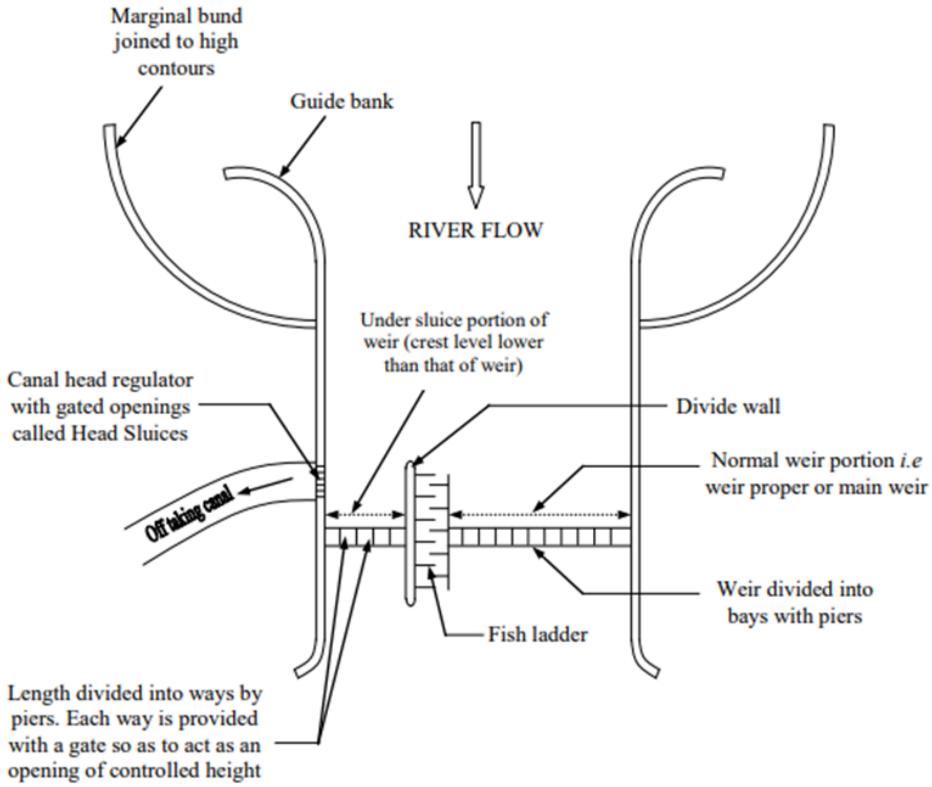


Fig.9 Under Sluice or Scouring Sluice

7.4.5 Silt Excluder

a) Silt excluder are those works which are constructed on the bed of the river, upstream of the head regulator.

b) The clearer water enters the head regulator and the silted water enters the silt excluder.

c) In this type of works, the silt is therefore removed from the water before it enters the canal.

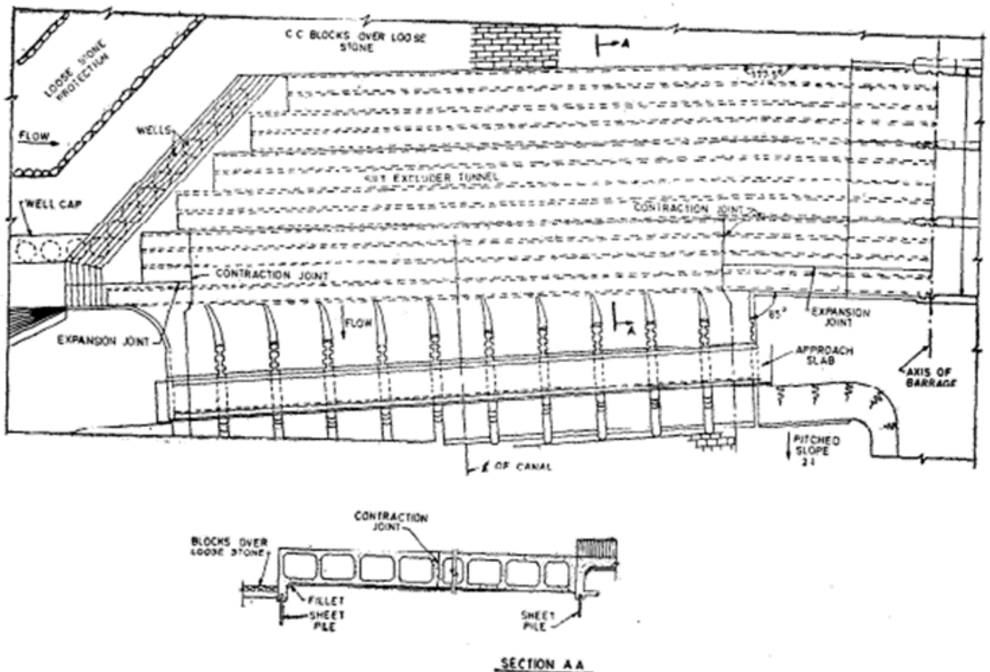


FIG. 4 SILT EXCLUDER BAYS IN A BARRAGE TYPIOAL LAY-OUT AND SECTION

IS : 11130 - 1984

Fig.10 Silt Excluder

7.4.6 Canal Head Regulator

a) Controls the amount and quality of water entering the canal.

b) Includes gates and silt exclusion mechanisms for operational efficiency.

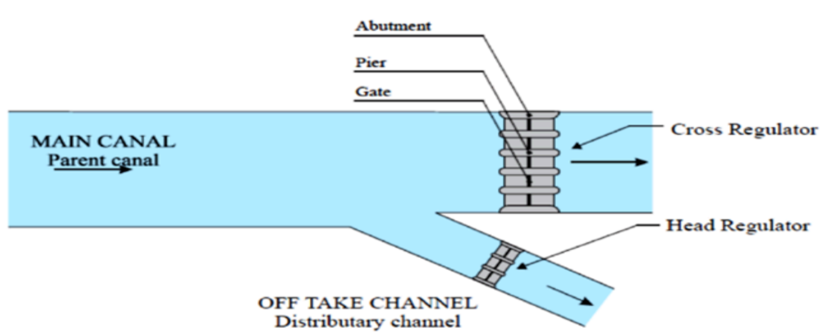


Fig.11 Canal Head Regulator

7.4.7 Guide Banks

a) Protect the head works by directing river flow centrally.

b) Designed with stone pitching and launching aprons to resist erosion.

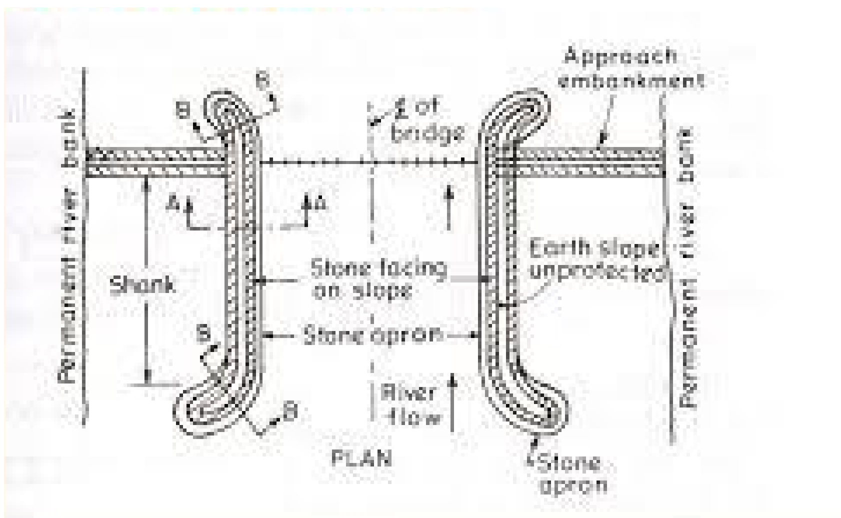


Fig.12 Guide Banks

7.5 Protection Works

7.5.1 Loose Aprons

Laid downstream to absorb the impact of high-velocity flows and prevent scouring.

7.5.2 Launching Aprons

Automatically adjust to scour hole formation, protecting the riverbed and structure foundation.

7.6 Failure Causes and Remedies

7.6.1 Failures Due to Seepage

7.6.1.1 Piping or undermining

Addressed by extending impervious floors and using cutoffs.

7.6.1.2 Uplift pressure

Controlled with thicker floors and upstream piles.

7.6.2 Failures Due to Surface Flow

7.6.2.1 Scour damage

Prevented with deep piles and properly designed protection aprons.

7.6.2.2 Hydraulic jumps

Managed with energy dissipaters to reduce downstream impact.

7.7 Maintenance and Operation

7.7.1 *Regular Inspections*

a) Ensure the integrity of gates, aprons, and embankments.

b) Check for sediment build-up and signs of wear in key components.

7.7.2 Flood Season Preparations

a) Clear debris from under sluices and adjust gates to handle peak flows efficiently.

b) Monitor real-time flow conditions and maintain a responsive control system.

7.7.3 Post-Flood Repairs

Address erosion, structural damage, and sedimentation to restore functionality.

7.7.4 *Maintenance of Diversion Head Works IS 7349: 2012*

a) This should be checked occasionally and adjustment made as needed. In case of shutters, the chains/anchors holding them should be kept free from rust. **IS 10096 (Part 1/Sec 1) and IS 7718** may also be referred for the inspection/ maintenance of the gates considering the type of gates provided on the barrages/weirs.

b) **No painting is required** for machined surfaces and surfaces of stainless steel, brass or bronze.

c) These surfaces should be protected by a **coating of gasoline-soluble rust** preventive non-corrosive compound.

d) All cavities and angles in the gates/shutters should be **kept clear of debris**, driftwood, moss and silt accumulations.

e) All drainage holes in the webs of horizontal structural members should be kept clear to drain off any accumulated water.

f) **Green stains should not be allowed to form** on the steel members at the back of the gates/shutters. The gates and counter balanced boxes should hang perfectly in level and plumb.

7.7.5 *Operation of Diversion Head Works IS 7349: 2012*

a) All lift **gates** should be **operated at suitable intervals**, preferably once in fortnight to clear the gate grooves/slots, flood passage and ensure free movement of moving parts of gate.

b) In low supplies when openings are not desirable, **raising of gates by 150 mm** for a few minutes should suffice.

c) If the gates have not been moved for a sufficiently long time, they should not be forcibly raised all at once but should **be lifted by about 30 mm** or so and left at that position for about 10 to 15 min till the silt deposited against the gates gets softened.

8 FLOOD SAFETY THROUGH DIVERSION HEADWORKS

8.1 Role in Flood Mitigation

8.1.1 Flow Regulation

Diversion head works help regulate excess water during high-flow conditions, minimizing downstream flooding.

8.1.2 Sediment Management

Silt excluders and sedimentation basins at diversion structures ensure that canals and downstream structures are not clogged.

8.1.3 Controlled Releases

By managing reservoir levels, head works allow for controlled water releases to prevent overtopping.

8.2 Case Studies

8.2.1 *Tehri Dam, Uttarakhand*

The Tehri Dam on the Bhagirathi River is one of India's largest multipurpose projects, primarily aimed at power generation and irrigation. It also plays a significant role in flood management:

8.2.1.1 Design features

a) Height: 260.5 m, designed as a rock and earth-fill embankment dam.
b) Flood Cushion: Includes a significant flood storage capacity to mitigate downstream flooding.

8.2.1.2 Flood control mechanism

During the 2013 Uttarakhand floods, the reservoir absorbed excess water, reducing the impact on downstream towns like Rishikesh and Haridwar.

8.2.1.3 Challenges

Sedimentation management remains a critical aspect for long-term efficacy.

8.2.2 *Sarda Diversion Works, Uttar Pradesh*

Built on the Sarda River, this diversion structure is a crucial part of the Sarda Canal system. It is instrumental in irrigation and flood mitigation:

8.2.2.1 Key features

a) Barrage Length: 479 m with gated spillways.
b) Capacity: Designed to handle peak floods of up to 24,000 cumecs.

8.2.2.2 Flood management role

a) Effective distribution of excess water to feeder canals reduces strain on the main river channel.
b) Prevents backwater flooding in adjoining districts.

8.2.2.3 Maintenance practices

Regular silt removal from canals ensures uninterrupted operations during monsoons.

8.2.3 *Kosi Barrage, Bihar*

The Kosi Barrage on the Kosi River is a vital flood control structure for one of India's most flood-prone regions:

8.2.3.1 Design and structure

a) Total Length: 1,149 m.
b) Equipped with 56 gates for controlled water release.

8.2.3.2 Flood mitigation benefits

a) The barrage regulates floodwaters, minimizing downstream inundation.
b) Protects over 2.14 million hectares of agricultural land in North Bihar.

8.2.3.3 Notable event

During the 2008 Kosi flood, partial breaches upstream highlighted the need for integrated basin management beyond individual structures.

8.2.4 *Hirakud Dam, Odisha*

Hirakud Dam on the Mahanadi River is a composite dam structure, built primarily for flood control, irrigation, and hydropower:

8.2.4.1 Specifications

a) Length: 4.8 km (world's longest earthen dam).
b) Spillway Capacity: Designed to manage peak flows of 42,450 cumecs.

8.2.4.2 Flood control contribution

a) Prevents flash flooding in the delta regions of Odisha.
b) During the 2011 monsoon, strategic water releases reduced the severity of downstream flooding.

8.2.4.3 Sustainability measures

Continuous monitoring of reservoir levels ensures optimal performance during extreme weather events.

8.2.5 *Farakka Barrage, West Bengal*

Located on the Ganga River, the Farakka Barrage plays a dual role in irrigation and flood management:

8.2.5.1 Key details

a) Length: 2.24 km.
b) Includes sluices for sediment control and flood management.

8.2.5.2 Flood mitigation role

a) Diverts excess water to the Hoogly River during floods.
b) Supports navigation and prevents sedimentation in the Ganga's distributaries.

8.2.5.3 Lessons learned

Requires better coordination with upstream dams for effective flood forecasting.

9 COMMON MISTAKES AND LESSONS LEARNED

9.1 Design Failures

9.1.1 Under-Designed Embankments

Examples include insufficient freeboard or inadequate soil compaction, leading to breaches during peak floods.

9.1.2 Improper Drainage Systems

Poor alignment and design of sluice gates often result in backwater flooding.

9.1.3 Material Selection Errors

Use of substandard materials in revetments or gabions reduces structure durability.

9.2 Construction and Maintenance Failures

9.2.1 Insufficient Quality Control

Lack of compaction tests or incorrect use of geo-textiles compromises embankment integrity.

9.2.2 Neglected Maintenance

Vegetative overgrowth on embankments weakens structure, while failure to desilt canals reduces capacity.

9.2.3 Delayed Emergency Repairs

Ignoring small damages, such as minor breaches or scours, leads to catastrophic failures over time.

9.2.4 *Construction of Diversion Head Works IS 10788(Part-1): 1984*

a) It should be ensured that a thorough inspection of hydro-mechanical installations/equipment is done at least once in a year to check corrosion.
b) All machinery at the works should be kept clean, tidy and in proper working order and care should be taken to ensure that it is properly handled in conformity with the manufacturer's instructions.
c) The main hydro-mechanical items are generally the gates, hoist equipment, control system, etc. **IS 7718** may also be referred for inspection, testing and maintenance of gates.

9.3 Preventive Measures

a) Strict adherence to IS codes during design and construction.
b) Regular inspections post-monsoon to identify weaknesses.
c) Capacity building for field engineers to ensure use of advanced techniques, like remote sensing for flood prediction.

10 APPLICABLE INDIAN STANDARDS

10.1 Relevant IS Codes

Sl. No	Is Number	Is Title
1	IS 10084 (Part 1) : 1982	Criteria for design of diversion works: Part 1 coffer dams
2	IS 10788 (Part 1) : 1984	Code of practice for construction of diversion works: Part 1 cellular coffer dams

3	IS 11130 : 1984	Criteria for structural design of barrages and whrs
4	IS 11150 : 1993	Construction of concrete barrages - Code of practice (First Revision)
5	IS 11532 : 1995	Construction and maintenance of river embankments (Levees) - Guidelines (First Revision)
6	IS 12094 : 2018	Planning and design of river embankments (Levees) - Guidelines (Second Revision)
7	IS 12892 : 1989	Safety of barrage and weir structures - Guidelines
8	IS 12926 : 1995	Construction and maintenance of guide banks in alluvial rivers - Guidelines (First Revision)
9	IS 13877 : 1993	Planning and design of fish pass - Guidelines
10	IS 14262 : 1995	Planning and design of revetment - Guidelines
11	IS 14815 : 2000	Design flood for river diversion works - Guidelines
12	IS 14955 : 2001	Guidelines for hydraulic model studies of barrages and weirs
13	IS 4410 (Part 12) : 1993	Glossary of terms relating to river valley projects: Part 12 diversion works (First Revision)
14	IS 4410 (Part 22) : 1994	Gloss4ry of terms relating to river valley projects: Part 22 barrages and weirs
15	IS 4410 (Part 3) : 1988	Glossary of terms relating to river valley projects: Part 3 river and river training (First Revision)
16	IS 6966 (Part 1) : 1989R	Hydraulic design of barrages and weirs - Guidelines: Part 1 alluvial reaches (First Revision)
17	IS 7349 : 2012	Barrages and weirs - Operation and maintenance - Guidelines (Second Revision)

18	IS 7720 : 1991	Criteria for investigation, planning and layout for barrages and weirs (First Revision)
19	IS 8408 : 1994	Planning and design of groynes in alluvial river - Guidelines (First Revision)
20	IS 9461 : 1980	Guidelines for data required for design of temporary river diversion worrs
21	IS 9795 (Part 1) : 1981	Guidelines for the choice of the type of diversion works: Part 1 coffer dams
22	IS 10751 : 2022	Planning and design of guide banks for alluvial rivers guidelines

10.2 Guidelines for Application

a) Engineers must review site-specific data, such as hydrological history, sediment load, and river behaviour, before applying these standards.
b) Adopting supplementary resources like IRC-SP59 for geo-synthetics and NDMA guidelines for disaster response enhances the standard practices.

11 CONCLUSION

11.1 Integrated Approach to Flood Management

a) Combining structural and non-structural measures ensures a comprehensive flood management strategy.
b) Promoting sustainable practices, such as watershed management and eco-friendly construction materials, is essential for long-term resilience.

11.2 Recommendations for Irrigation Engineers

a) Emphasize adaptive designs that accommodate future climate uncertainties.

b) Invest in advanced monitoring systems for real-time flood data.
c) Strengthen collaboration among state departments to ensure uniform practices and resource sharing.

12 REFERENCES

a) **BIS Codes**: Standards governing the planning, design, and construction of flood management structures
b) **CWC Guidelines**: Comprehensive guidelines for flood management and river training works.
c) **Handbook for Flood Protection**: Detailing anti-erosion and embankment construction practices.
d) **NDMA Reports**: Guidelines for disaster risk reduction and management.
e) **Case Studies**: Examples from Indian river basins, including Sarda, Ganga, and Brahmaputra.

CHAPTER 5

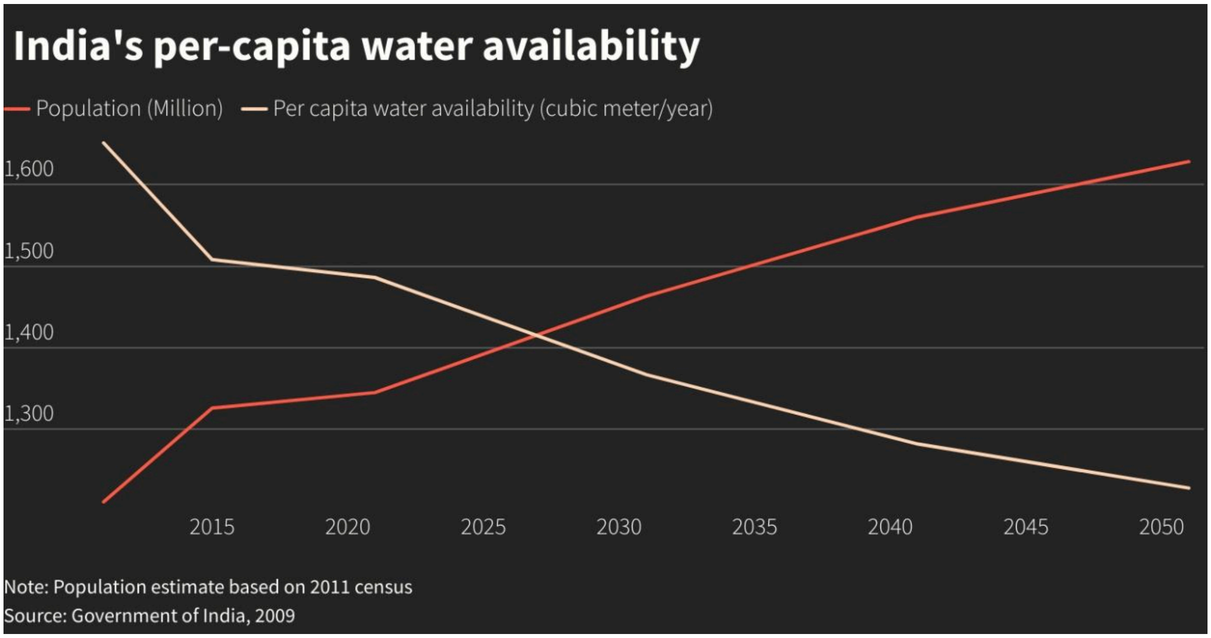
Groundwater and related Investigations and Recharge of Groundwater

Introduction

Groundwater is a crucial natural resource that supports agriculture, drinking water supply, industry, and ecosystems. In India, it accounts for approximately 62% of the country's irrigation and 85% of its rural drinking water supply. However, overexploitation, pollution, and climate variability have put immense pressure on this resource, necessitating effective management and conservation.

This booklet provides a comprehensive understanding of groundwater systems, challenges, and sustainable solutions.

Importance of Groundwater in India

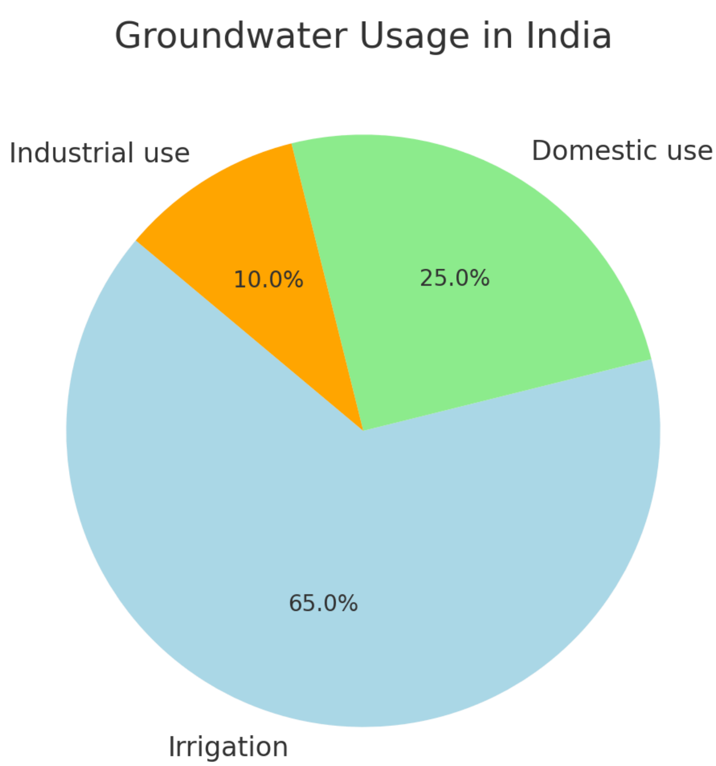


Agriculture:

- India is the world's largest user of groundwater, accounting for nearly 25% of global extraction.
- Groundwater meets around 65% of India's irrigation needs, making it indispensable for food security. Crops like wheat, rice, and sugarcane heavily rely on it, especially during non-monsoon months.

Drinking Water:

- Groundwater provides 80% of rural and 50% of urban drinking water needs (Central Ground Water Board, 2021).
- It is a key resource in regions lacking reliable surface water sources.



1.

Challenges in Groundwater Management

Depletion:

India’s groundwater extraction exceeds recharge rates in several regions, with over 70% of blocks categorized as over-exploited, critical, or semi-critical (NITI Aayog, 2021).

Quality Deterioration

Pollution from fertilizers, pesticides, and industrial effluents leads to contamination with arsenic, fluoride, and nitrates.

The World Bank estimates that 60% of India’s aquifers are contaminated to varying degrees.

Climate Change:

Alters recharge rates, increases evapotranspiration, and exacerbates water stress.

Urbanization and Industrialization:

Rapid urban growth increases dependency on groundwater, while industries contribute to aquifer contamination.

Unregulated Usage:

Lack of effective groundwater governance leads to unregulated extraction, further depleting the resource

Need for Sustainable Management

Recharge and Conservation

Implementing artificial recharge methods, such as check dams and rainwater harvesting (IS 15797)

Promoting watershed management practices

Policy Interventions

Enforcing stricter groundwater extraction norms and promoting water-efficient technologies.

The "Atal Bhujal Yojana" in India is a step towards sustainable groundwater management.

Awareness and Capacity Building:

Encouraging community participation in groundwater conservation

Technological Solutions:

Leveraging GIS, IoT, and satellite data for real-time monitoring of groundwater levels and quality

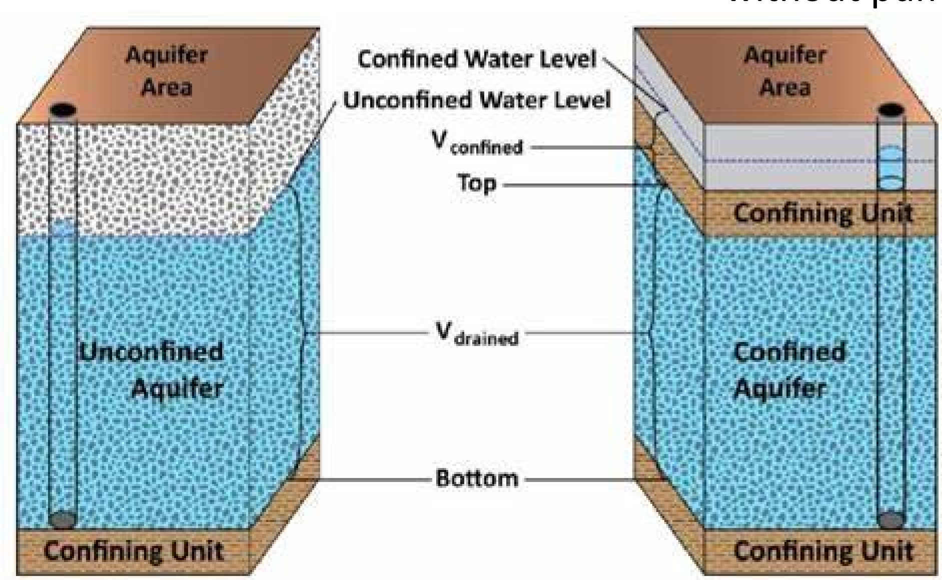
Understanding Groundwater and Aquifer Systems

Introduction

Groundwater, stored beneath the Earth's surface, is a vital natural resource that sustains drinking water, agriculture, and industries. It is stored within geological formations known as aquifers. An aquifer is a permeable rock, sand, or gravel layer that can store, transmit, and yield water to wells and springs. Aquifers play a pivotal role in regulating groundwater systems, acting as both reservoirs and conduits of water.

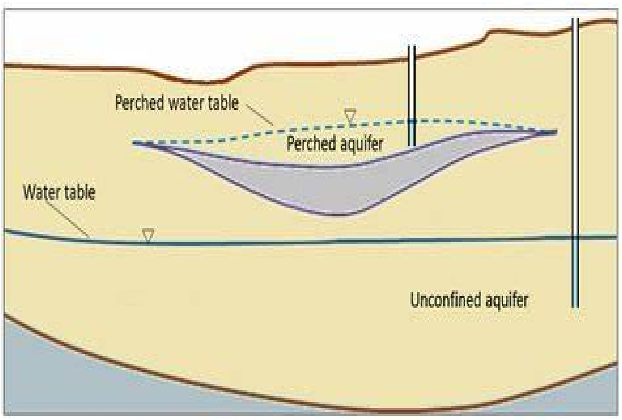
Types of Aquifers

Unconfined Aquifers	Confined Aquifers
Located near the surface, with water directly recharged by precipitation. Vulnerable to contamination due to the absence of an overlying impermeable layer	Sandwiched between impermeable layers of rock or clay, creating pressure. Water in these aquifers is often under artesian pressure, enabling flow without pumping.



Perched Aquifers

Occur when an impermeable layer traps water above the main water table.

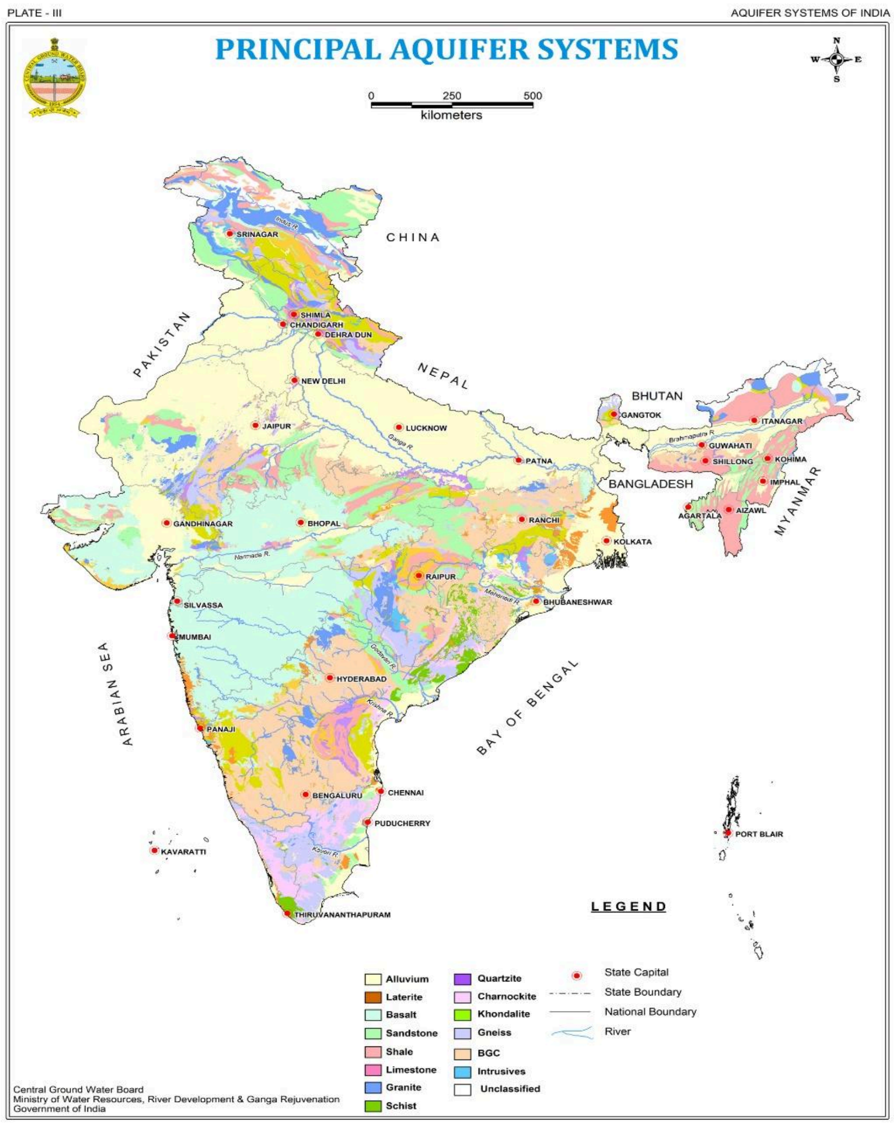


Fossil Aquifers

Contain ancient water deposits with minimal recharge, often found in arid regions.

Aquifer Systems in India

India’s diverse geology gives rise to varied aquifer systems, broadly categorized into hard rock aquifers and soft rock aquifers. The Central Ground Water Board (CGWB) has released an Atlas on Aquifer Systems of India with detailed data on **14 principal and 42 major aquifers**.



National Aquifer Mapping and Management

(NAQUIM) Program

The **NAQUIM program**, launched by the **Central Ground** Water Board (CGWB), aims to identify, map, and manage aquifer systems in India. The program aligns with the **Bureau of Indian Standards (BIS)** It has mapped over 25 lakh square kilometres of aquifers.

Quiz: Select the Correct Option

Question 1: **Which of the following Bureau of Indian Standards (BIS) committees is most directly involved in developing standards related to groundwater management and aquifer systems in India?**

A) Hydrometry Sectional Committee
B) Groundwater and Related Investigations Sectional Committee
C) Geological Investigation and Subsurface Exploration Sectional

Committee
D) Reservoirs and Lakes Sectional Committee

Question 2: **The Bureau of Indian Standards (BIS) plays a key role in ensuring that sustainable groundwater extraction practices are adopted nationwide. Which of the following strategies is most directly linked to BIS standards for aquifer management in over-exploited areas?**

A) Promoting artificial recharge and rainwater harvesting
B) Enhancing desalination of saline groundwater
C) Regulating groundwater use for industrial purposes only
D) Allowing unrestricted extraction for agricultural use

Answers: 1- B, 2- A

BIS's Role in Groundwater Management

The Bureau of Indian Standards (BIS) plays a significant role in ensuring sustainable groundwater management by developing Indian Standards such as:

IS 15797 : 2008 Roof Top Rainwater Harvesting – Guidelines
IS 15792 : 2008 Artificial Recharge to Groundwater - Guidelines

Understanding and managing aquifer systems is crucial for ensuring groundwater sustainability. With programs like NAQUIM and the BIS's active involvement, India is making strides in preserving this invaluable resource for future generations.

Groundwater Level and Measurement

Groundwater level is an essential indicator of the water table's height beneath the earth's surface. It is a crucial parameter for managing groundwater resources, especially in the context of water conservation, drought management, and irrigation planning. Measuring groundwater levels helps in understanding the quantity and quality of water available in aquifers and provides critical data for sustainable groundwater management.

Seasonal Variation and Geographical Trends

Groundwater levels show significant temporal and spatial variations. Understanding these trends is essential for groundwater resource management and prediction.

Seasonal Variation

Monsoon Influence

Groundwater levels typically rise during the monsoon period due to increased recharge from rainfall. The recharge rate, however, depends on the permeability of the surrounding geology and the depth of the water table.

Post-Monsoon to Pre-Monsoon Decline

Groundwater levels often begin to decline post-monsoon as withdrawals for agricultural irrigation, industrial use, and domestic needs outpace recharge.

Geographical Trends

Topography

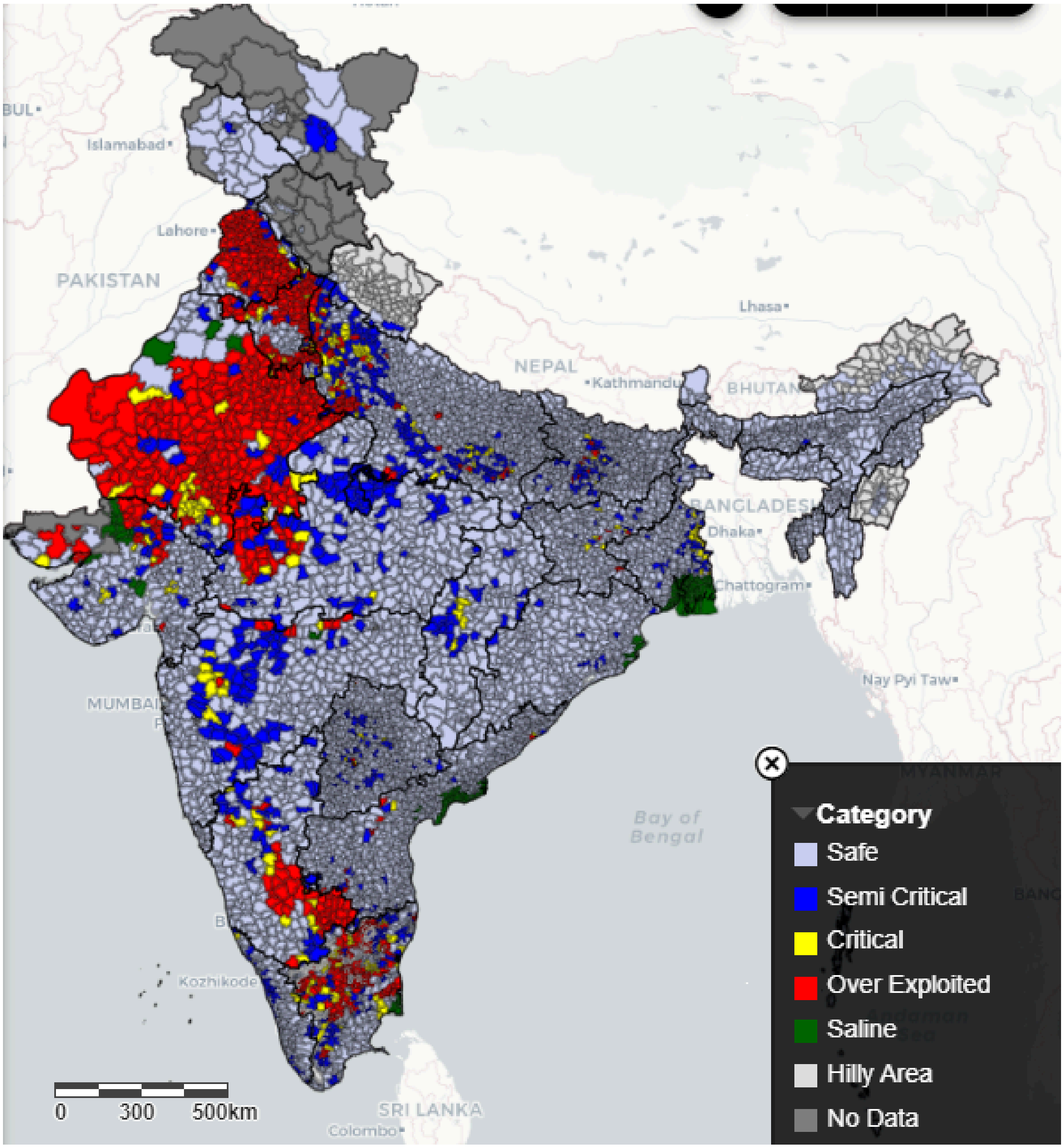
Geological Formation

Groundwater is typically higher in lower-lying areas, such as valleys, where water collects naturally due to gravity. The gradient of the land significantly affects groundwater flow direction.

The aquifer's geological properties (e.g., permeability, porosity) influence the rate of recharge and the storage capacity. Regions with more permeable rock formations such as sandstone or limestone will typically have higher groundwater levels compared to impermeable formations like basalt or granite.

Land Use

Urbanization and agricultural practices are key factors that impact groundwater recharge. Urbanization with impervious surfaces reduces recharge, while agricultural areas can experience significant fluctuations in groundwater levels due to irrigation patterns.



Groundwater Resources

Attribute	2023
Annual Ground Water Recharge	449.08 billion cubic meter (bcm)

Annual Extractable Ground Water Resource	407.21 bcm
Ground Water Extraction	241.34 bcm
Stage of Ground Water Extraction (SoE)	59.26 %

Methods for Groundwater Level Measurement

Groundwater level measurement requires precision and consistency. Several methods exist, from traditional manual techniques to advanced automated systems. Each method has its own set of advantages, limitations, and suitable application contexts.

IS 15896 : 2011 Manual Methods For Measurement of Groundwater Level in a Well

This standard deals with the measurement of a water level in a well which constitutes a data-collection process that provides fundamental information about the status of a groundwater system. Accordingly, measured water levels should be sufficiently accurate and reproducible to meet the needs of most data-collection and monitoring programmes.

Several manual methods commonly used to collect water level data in wells employ relatively simple measuring devices such as graduated steel tapes, electric tapes, and air lines. n some cases, water level measurements are required in flowing wells.

The procedures associated with each of these methods are intrinsically different and subject to varying limitations and accuracies.

Steel Tape Measurement

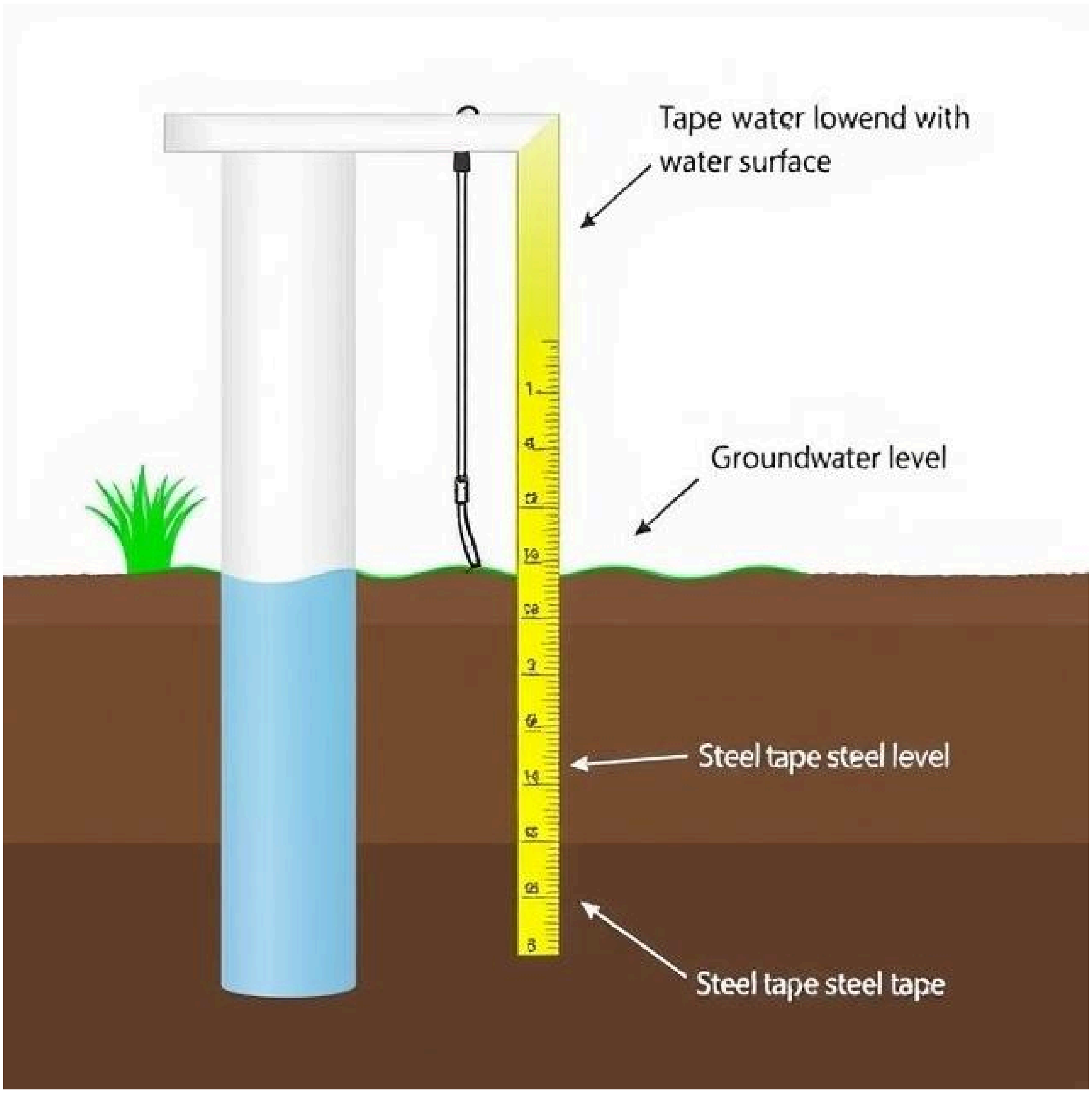
The steel tape method is one of the oldest and most widely used techniques for measuring groundwater levels. It is simple, effective, and reliable, though it requires manual labor and can be subject to errors due to field conditions.

Apply the colored chalk to the lower few centimeter of the tape by pulling the tape across the chalk. The wetted chalk mark will identify that part of the tape that was submerged.

Lower the weight and tape into the well until the lower end of the tape is submerged below the water (more than one attempted measurement may be needed to determine the length of tape required to submerge the weight).

Once the tape is submerged, hold the tape and extend it up to MP and read the measurements on tape opposite to MP. This reading on the tape shall be recorded as the MP HOLD . Pull the tape back to the surface before the wetted chalk mark dries and becomes difficult to read. Measure the number of the wetted chalk mark shall be recorded in the 'WETTED CHALK MARK' column of the water level measurements field

Subtract the wetted chalk mark number from the number held to the MP, and record this number in the 'DEPTH TO WATER FROM MP' column of the water level measurements field form The difference between these two readings is the depth to water below the MP. e) Apply the MP correction to get the depth to water below or above land-surface datum (LSD).



Steel Tape Measurement

IS 16094 : 2018 Hydrometry – Measuring the Water Level in a Well Using Automated Pressure Transducer Methods- Guidelines

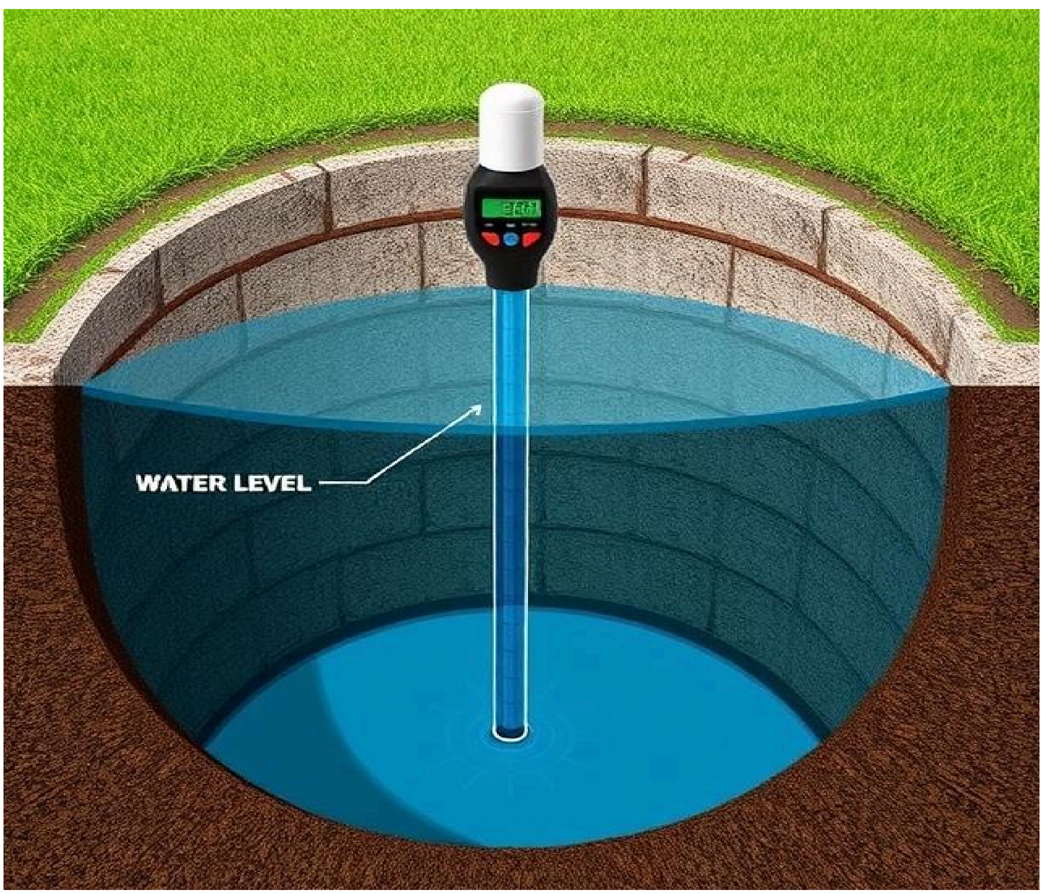
The Automated Pressure Transducer method is an advanced technique for measuring the water level in wells, commonly used in hydrometry for groundwater monitoring.

Step- I: Setup- A **pressure transducer** is carefully submerged in the well, making direct contact with the water column.

Step 2: Measurement – As the water level changes, it exerts pressure on the transducer. This pressure is then converted into an **electrical signal**.

Step 3: Data Recording – The signal is transmitted to a **data logger** that records the water level continuously, providing **real-time data**.

This method ensures **accurate, reliable, and continuous monitoring**, even in remote areas where manual measurements may be difficult.



Automated Method

Interactive Element: Groundwater Level Monitoring Network

For large-scale groundwater monitoring, professionals often employ a combination of manual and automated systems to ensure accurate and continuous data. This approach provides a comprehensive understanding of groundwater trends and helps with sustainable resource management.

Table 1: Comparison of Manual and Automated Groundwater Measurement Methods

Feature	**Manual Method (Steel Tape)**	**Automated Method**
Accuracy	Moderate	High
Cost	Low	High (initial setup)
Labor Requirements	High	Low
Data Frequency	Low (manual interval)	High (continuous or programmable)
Maintenance	Moderate	Low

Feature	Manual Method (Steel Tape)	Automated Method
Application	Shallow wells, small-scale use	Large-scale, continuous monitoring

Accurate measurement of groundwater levels is fundamental for sustainable water resource management. Both manual and automated methods offer distinct advantages and should be selected based on specific project needs, well characteristics, and resource availability. As groundwater monitoring technologies advance, integrating both traditional and modern approaches ensures comprehensive data collection and informed decision-making.

The Bureau of Indian Standards recommends that professionals adopt standardized techniques for groundwater level measurement to ensure consistency and accuracy across monitoring networks.

Groundwater Resources: Annual Assessment and Categorization

Groundwater is a critical resource for India, catering to approximately 65% of the nation's irrigation requirements and 85% of its drinking water needs. The monitoring and management of this invaluable resource are crucial to ensuring sustainability for future generations.

Annual Groundwater Assessment

As per the latest data from the Central Ground Water Board (CGWB), groundwater resources in India have been systematically assessed across various regions. The annual assessment provides a clear picture of the state of groundwater resources in different parts of the country, helping inform policymakers and groundwater professionals about the status of aquifers.

This assessment involves several key components:

Water Level Monitoring: Data from over 20,000 monitoring wells across the country.

Recharge and Discharge Estimates: Based on rainfall patterns and extraction rates.

Groundwater Withdrawal: Documenting the volume of groundwater extracted for irrigation, industrial, and domestic use.

Groundwater Resource Categorization

The categorization of assessment units (based on groundwater depletion and recharge rates) allows stakeholders to understand the level of pressure on groundwater resources in different zones.

Over-Exploited Zones (OE)

These zones are characterized by a groundwater extraction rate that exceeds the annual recharge capacity. These areas face significant depletion and require urgent measures for water conservation and recharge

Critical Zones (C)

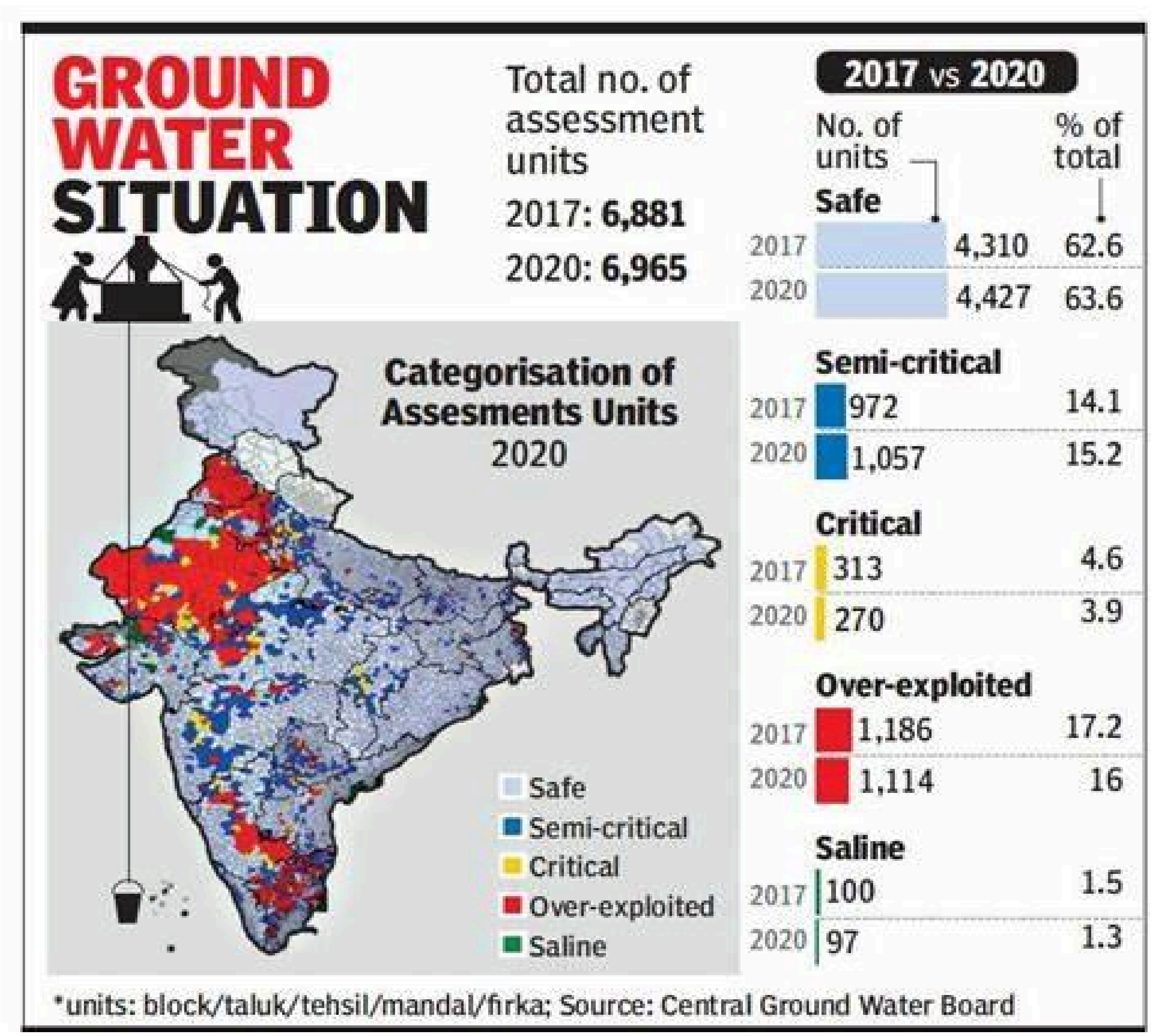
Critical zones are those where groundwater extraction is nearing the limits of the natural recharge capacity. While there is still some water left in the aquifer, sustainable extraction methods must be introduced

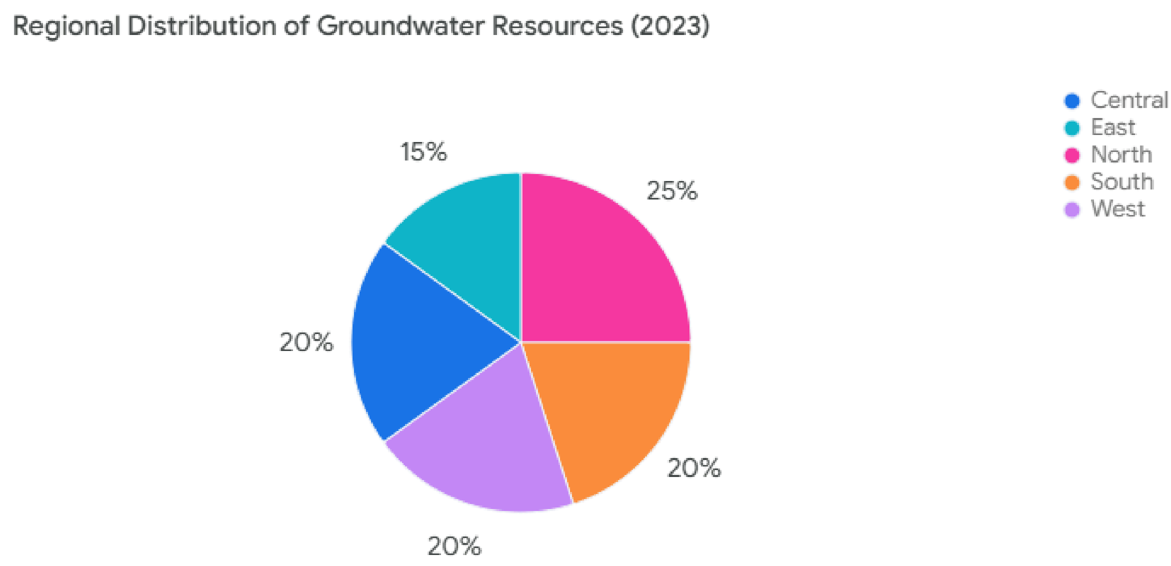
Semi-Critical Zones (SC)

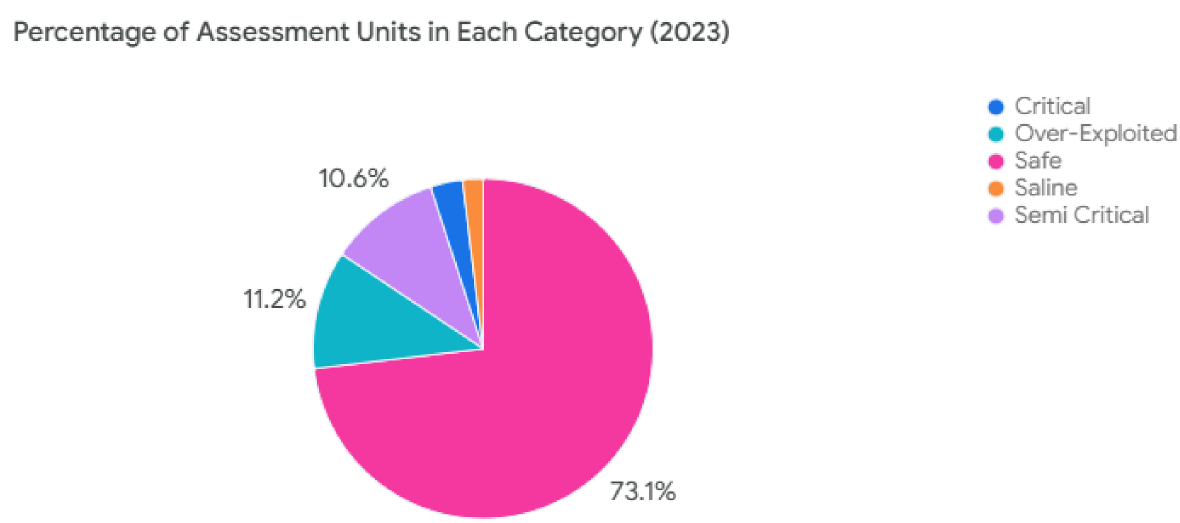
Safe Zones (S)

Semi-critical zones have a moderate extraction rate, where recharge balances extraction. These zones still have a manageable groundwater reserve but require ongoing monitoring and balanced use

These are areas where groundwater extraction is well within the recharge capacity, ensuring sustainability for the long term. Continued conservation measures will maintain these zones in the safe category







Interactive Element: Groundwater Resource Categorization

This fill-in-the-blanks activity is designed to reinforce the understanding of the groundwater categorization system as per BIS standards. It will help groundwater professionals stay aligned with the latest guidelines and practices.

Fill-in-the-Blanks Activity:

1. **Over-exploited zones** refer to areas where the groundwater extraction rate exceeds the _____________ (recharge/discharge) capacity of the aquifer.
2. **Critical zones** are identified when groundwater extraction approaches the _____________ (limit/recharge capacity) of the aquifer.
3. **Semi-critical zones** represent areas with a _____________ (moderate/high) extraction rate, requiring ongoing management to prevent over-exploitation.
4. **Safe zones** are characterized by groundwater extraction that remains well within the _____________ (recharge/extraction) limits of the aquifer.
5. The **IN-GRES system** is primarily designed to estimate the _____________ (groundwater recharge/withdrawal) potential of aquifers.

Answers:

1. Recharge
2. Limit
3. Moderate

4. Recharge
5. Groundwater recharge

BIS plays a pivotal role in the standardization of groundwater management practices in India. The 2023 groundwater assessment provides valuable data that can be used to inform sustainable resource management strategies. By categorizing groundwater resources into Over-exploited, Critical, Semi-Critical, and Safe zones, professionals can prioritize their efforts and apply suitable management techniques.

The integration of systems like IN-GRES further strengthens India's capacity to manage its groundwater resources effectively, ensuring that groundwater professionals have the tools and data they need to implement best practices.

Artificial Recharge to Groundwater

Artificial recharge refers to the process of replenishing or augmenting the groundwater supplies through human intervention. With increasing demands on groundwater resources and the adverse impacts of over-extraction, artificial recharge offers a sustainable method of recharging aquifers to ensure the longevity of groundwater supplies.

The Bureau of Indian Standards (BIS) encourages the adoption of artificial recharge to mitigate the growing water scarcity concerns and to improve the quality and quantity of groundwater reserves. In this line BIS published IS 15792 : 2008 Artificial Recharge to Groundwater – Guidelines

Importance and Benefits of Artificial Recharge

Artificial recharge has gained significant attention due to its ability to address the challenges posed by declining groundwater levels. Some of the key benefits include:

- **Sustainability of Groundwater Supply**: Artificial recharge helps to replenish aquifers, especially in regions facing over-exploitation of groundwater.
- **Improved Water Quality**: Recharging can help improve groundwater quality by reducing contamination, especially in areas with high industrial or agricultural runoff.
- **Increased Water Storage Capacity**: It increases the overall groundwater storage, especially during monsoon seasons, which can be utilized in dry seasons.
- **Mitigation of Flooding**: Surface spreading methods, such as ponding and infiltration basins, help in reducing surface runoff and mitigating flood risks.
- **Ecological Balance**: It contributes to maintaining the natural ecosystem by sustaining vegetation and aquatic systems dependent on groundwater.

Techniques for Artificial Recharge

Artificial recharge methods can be classified into two broad categories: Direct Methods and Indirect Methods.

Direct Methods

These methods involve directly introducing water into the aquifer through surface or subsurface techniques.

Surface Spreading:

This involves spreading water over a large surface area to allow it to percolate into the ground. It is commonly done through techniques such as:

Infiltration Basins: Shallow depressions that store water, which then infiltrates into the groundwater system.

Ponding: A method where water is stored temporarily in a shallow pond before it seeps into the ground.

Injection Wells:

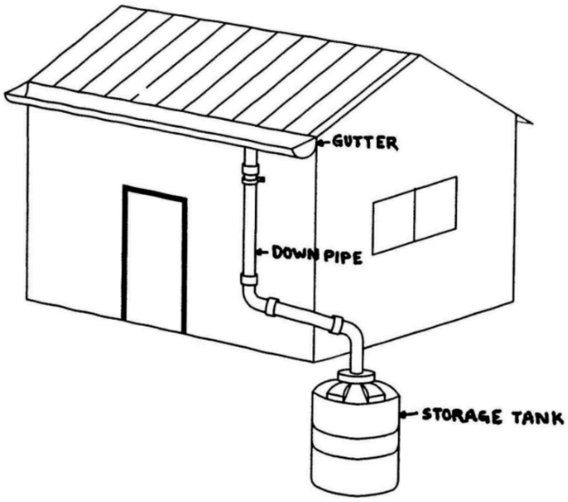
Water is injected into deep wells directly into the aquifers. This method is particularly useful in areas where surface spreading is not feasible due to land constraints or the nature of the aquifer.

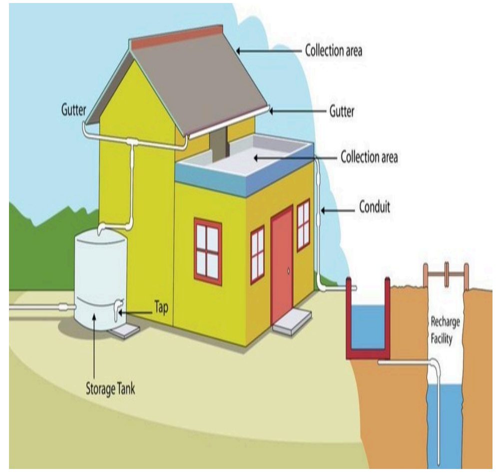
Indirect Methods

Indirect methods involve inducing recharge by utilizing natural or artificial mechanisms.

Induced Recharge: This technique involves pumping water from a nearby surface water source, such as rivers or lakes, to induce the flow of water into the aquifers. This is done by creating a hydraulic gradient that pulls water from the surface into the ground.

Rainwater Harvesting: Water collected through rainwater harvesting systems is directed towards recharge pits or wells, encouraging natural filtration and replenishment of groundwater reserves.

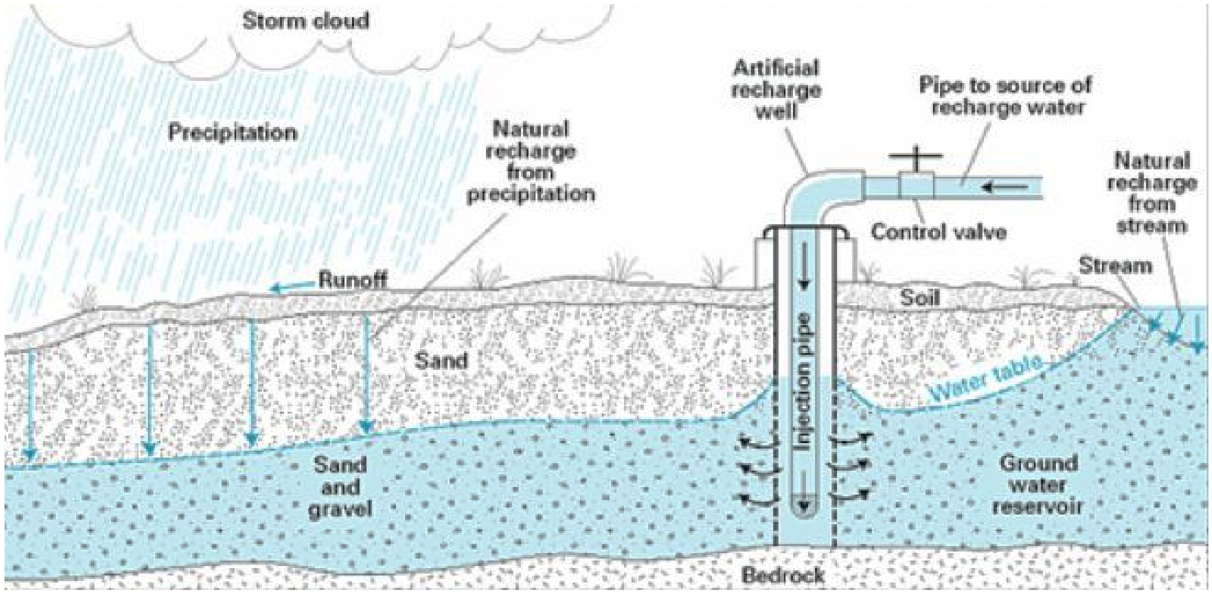




ARTIFICIAL RECHARGE TO GROUND WATER

Method	**Suitability**	**Cost**	**Maintenance**
Surface Spreading	Large open areas, high runoff areas	Low	Medium
Injection Wells	Areas with confined aquifers	High	Low
Induced Recharge	Near surface water bodies	Medium	Medium

Table 1: **Comparison of Recharge Methods**



ARTIFICIAL RECHARGE TO GROUND WATER

Artificial recharge is an essential tool for sustainable groundwater management. By following the guidelines outlined in **BIS standards**, groundwater professionals can contribute significantly to the health and longevity of India's groundwater resources. Effective implementation of artificial recharge projects, in accordance with the **Bureau of Indian Standards**, ensures that groundwater resources are replenished, protected, and preserved for future generations.

Roof Top Rainwater Harvesting

Roof Top Rainwater Harvesting (RWH) is a simple and effective technique for collecting and storing rainwater for various uses. In urban areas, where the demand for water is high, RWH provides a sustainable solution to meet this demand while reducing the pressure on existing water resources. It involves the collection of rainwater from rooftops, followed by filtering, storing, and using it for purposes such as irrigation, domestic use, and recharging groundwater. The importance of RWH is emphasized by the growing concern over water scarcity and the environmental challenges posed by over-exploitation of groundwater.

Benefits and Necessity in Urban Areas

Urban areas face challenges such as rapid population growth, increased demand for water, and the degradation of natural water bodies. In such settings, RWH serves as an invaluable resource, offering the following benefits:

Water Conservation

RWH reduces dependency on municipal water systems and underground water sources

It can help alleviate the strain on local water treatment plants by providing an alternative water source.

Groundwater Recharge

RWH helps replenish groundwater levels, contributing to the long-term sustainability of aquifers.

By capturing rainwater and directing it to recharge wells or borewells, it can mitigate the decline in groundwater levels caused by over-extraction.

Flood Control

In urban areas, stormwater runoff often leads to flooding. By harvesting rainwater, the amount of runoff is reduced, preventing flooding and waterlogging.

Sustainability

RWH promotes self-sufficiency in water usage, especially in areas where water scarcity is acute.

It contributes to the overall environmental sustainability of

RWH systems reduce the burden on stormwater drainage systems.

urban areas by reducing water consumption from conventional sources.

Cost-Effective

While the initial setup may require investment, RWH systems lead to long-term savings in water bills, especially in areas with high water costs

The practice also reduces the need for chemical treatments and pumping costs associated with municipal water supply.

Guidelines from IS 15797: 2008

The Bureau of Indian Standards (BIS) has developed IS 15797: 2008 as a comprehensive guide for roof top rainwater harvesting systems. The standard provides recommendations for the design, installation, and maintenance of RWH systems in urban and rural areas.

Key Guidelines:

Roof Selection: It provides guidelines on the choice of roofing materials for optimal rainwater quality.

System Design: The standard outlines the proper size and design of components such as the roof catchment area, gutters, downpipes, filters, and storage tanks.

Maintenance: Recommendations for the cleaning and maintenance of the system to ensure long-term efficiency and water quality.

Rainwater Quality: Specifies how to filter rainwater and the use of the water for different purposes, such as non-potable and potable uses.

Overflow Management: Guidelines on how to manage overflow during heavy rains to prevent damage to the system and surrounding areas

The Bureau of Indian Standards (BIS) actively promotes this standard to ensure that RWH systems in India are effective and contribute to sustainable water management practices.

Calculating Potential Rainwater Harvest for a Sample Building

Let's calculate the potential rainwater that can be harvested from a building. Use the following formula to estimate:

Rainwater Harvested = Catchment Area (m2) × Annual Rainfall (mm) × Runoff Coefficient

Example:

- **Catchment Area**: 100 m^2 (Roof Area)
- **Annual Rainfall**: 800 mm
- **Runoff Coefficient**: 0.8 (due to smooth roof surface)

Rainwater Harvested = 100 × 800 × 0.8= 64,000 liters/year

Thus, the building can potentially harvest 64,000 liters of rainwater annually. Adjusting the runoff coefficient based on roof type and condition will provide a more accurate estimate.

The **Bureau of Indian Standards (BIS)** has been instrumental in promoting the widespread adoption of RWH systems across India. Through the development of IS 15797: 2008 and collaborations with state and local bodies, BIS ensures that RWH is integrated into urban planning and sustainable development practices.

By adopting these standards, the Bureau plays a crucial role in ensuring that RWH becomes a standard practice, not only improving water conservation but also contributing to the broader goal of sustainable water management.

Groundwater Quality

Groundwater is a critical resource for drinking, irrigation, and industrial uses, particularly in areas where surface water is scarce or unreliable. However, groundwater quality is often compromised by various factors, including pollution, over-extraction, and contamination from both natural and anthropogenic sources. Protecting and improving groundwater quality is essential for ensuring the sustainability of this vital resource.

In this section, we will explore the common groundwater quality issues, policies and regulations governing water pollution control, and methods for monitoring and improving groundwater quality. Additionally, we will analyze a case study to identify pollution sources and suggest solutions.

Overview of Common Groundwater Quality Issues

Groundwater quality can be adversely affected by a wide range of factors. The major issues affecting groundwater quality include:

Chemical Contamination

Nitrate Contamination: Excessive use of chemical fertilizers, particularly in agricultural regions, can lead to nitrate contamination in groundwater. High nitrate levels are harmful, particularly to infants, as they can cause "blue baby syndrome," affecting oxygen transport in the blood.

Heavy Metals: Arsenic, lead, and mercury are common contaminants that pose severe health risks. For instance, arsenic contamination is prevalent in regions like West Bengal and Bihar, leading to chronic health issues such as cancer and skin lesions.

Fluoride Contamination: Fluoride contamination occurs naturally in some areas, especially in Rajasthan and Gujarat. While fluoride is beneficial in small amounts, excessive concentrations can cause dental and skeletal fluorosis.

Microbial Contamination

Fecal contamination from untreated sewage or septic tanks can lead to the presence of harmful bacteria such as E. coli and Salmonella. This makes water unsafe for consumption and increases the risk of waterborne diseases.

Salinity

In coastal areas, seawater intrusion due to over-extraction of groundwater can lead to salinity issues. This renders the water unsuitable for drinking and agriculture and disrupts local ecosystems.

Industrial Contamination

Industrial activities, such as chemical manufacturing, mining, and improper disposal of industrial waste, can introduce toxic substances into the groundwater, resulting in long-term contamination that is difficult to remediate.

Agricultural Runoff

Pesticides, herbicides, and excess fertilizers can leach into groundwater from agricultural fields, leading to chemical contamination. Over time, these contaminants accumulate in the aquifers and degrade the quality of the water.

Policies and Regulations: Water (Prevention and Control of Pollution) Act, 1974

The Water (Prevention and Control of Pollution) Act, 1974 is one of the key legislative frameworks for the protection of water quality in India, including groundwater. The act aims to prevent and control water pollution, maintain or restore the wholesomeness of water, and ensure that water resources are used sustainably.

Key Provisions of the Act:

Establishment of Pollution Control Boards: The Act provides for the establishment of Central and State Pollution Control Boards, responsible for monitoring and regulating the quality of water resources, including groundwater.

Regulation of Effluent Discharge: Industries are required to obtain consent from the Pollution Control Boards for the discharge of any effluent into water bodies, including groundwater recharge zones. The discharge is regulated to ensure that it does not exceed permissible limits for contaminants like chemicals and heavy metals.

Groundwater Pollution Control: The Act lays the groundwork for controlling the contamination of groundwater through regulations on industrial activities, waste disposal, and sewage treatment. It provides for penalties and fines for violations, thereby encouraging compliance with water quality standards.

Groundwater Replenishment: The Act also emphasizes the importance of maintaining groundwater levels and encourages practices that protect groundwater from contamination, such as recharge and conservation techniques.

Other Relevant Policies

National Water Policy (2012): The policy outlines measures for protecting groundwater resources, including promoting artificial recharge and sustainable groundwater management practices.

National Mission for Clean Ganga (NMCG): This mission also focuses on preventing the pollution of water bodies, including groundwater, by controlling industrial effluent discharge and promoting sewage treatment plants.

Monitoring and Improvement Methods

Groundwater Quality Monitoring

Sampling and Analysis: Regular sampling of groundwater from different sources (wells, boreholes) is essential to monitor quality. Parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), heavy metals, and microbial contamination are routinely tested.

Remote Sensing: Satellite imagery and remote sensing technology can be used to track changes in land use patterns, monitor pollution sources, and assess water quality over large areas.

Automated Monitoring Systems: In some regions, automated systems are set up for continuous monitoring of groundwater quality, allowing real-time data to be collected and analyzed**.**

Improvement Methods

Bioremediation: Bioremediation techniques, such as using bacteria and microorganisms to break down organic contaminants, can be employed to clean contaminated groundwater.

Pump-and-Treat Systems: In cases of heavy contamination, such as with chemicals or petroleum products, pump-and-treat systems can be used to extract contaminated groundwater and treat it through filtration or chemical processes.

Artificial Recharge: Recharge techniques like rainwater harvesting, the construction of recharge pits, and check dams can help improve the overall quality of groundwater by diluting contaminants and replenishing aquifers.

Preventive Measures

Control of Industrial Pollution: Strict regulations on industrial waste management can prevent the contamination of groundwater. Industries must treat their effluents before discharging them into the environment.

Promotion of Sustainable Agriculture: Encouraging the use of organic fertilizers and integrated pest management can help reduce the leaching of harmful chemicals into the soil and groundwater.

Public Awareness: Public education on proper waste disposal, sewage treatment, and the importance of protecting groundwater quality is essential in reducing pollution at the source.

Case Study: Fluoride Contamination in Groundwater in Rajasthan, India

Fluoride contamination in groundwater is one of the major environmental and public health concerns in India. Rajasthan, with its arid climate and reliance on groundwater for drinking and irrigation, has seen significant levels of fluoride in its water sources. The state has been recognized as one of the most **fluoride-affected regions** in the country, particularly in areas like **Nagaur**, **Jodhpur**, **Pali**, and **Churu**.

Fluoride, when present in excessive concentrations (above 1.5 mg/l), can cause **fluorosis**, which has harmful effects on human health, including:

- **Dental Fluorosis** (staining and weakening of teeth)
- **Skeletal Fluorosis** (joint pain, stiffness, and bone fractures)
- **Non-Skeletal Fluorosis** (gastrointestinal issues and damage to internal organs)

Fluoride contamination in groundwater is primarily caused by geological processes. In Rajasthan, the groundwater is sourced from deep aquifers that interact with fluoride-bearing minerals such as fluorospar (calcium fluoride), which are common in the region's sedimentary and basaltic formations. The minerals dissolve into the groundwater, increasing fluoride concentrations.

In addition to natural geological factors, the over-extraction of groundwater has exacerbated the problem, leading to the rise in fluoride levels in previously safe sources.

According to the **Central Ground Water Board (CGWB)** and various government surveys, the **fluoride levels** in the groundwater of

Rajasthan were found to exceed the **BIS standard limit of 1.5 mg/l** in many areas, with some regions reporting concentrations as high as **10-15 mg/l**. This is significantly above the permissible limit, and it impacts over **10 million people** in the state, especially in **rural areas**.

Key Affected Districts:

- **Nagaur**
- **Pali**
- **Churu**
- **Jodhpur**
- **Barmer**

These districts, characterized by deep groundwater extraction, have seen higher levels of fluoride contamination. Additionally, groundwater in these areas is often the **only source** of drinking water, making the situation particularly severe.

The population in fluoride-affected areas has experienced widespread health issues:

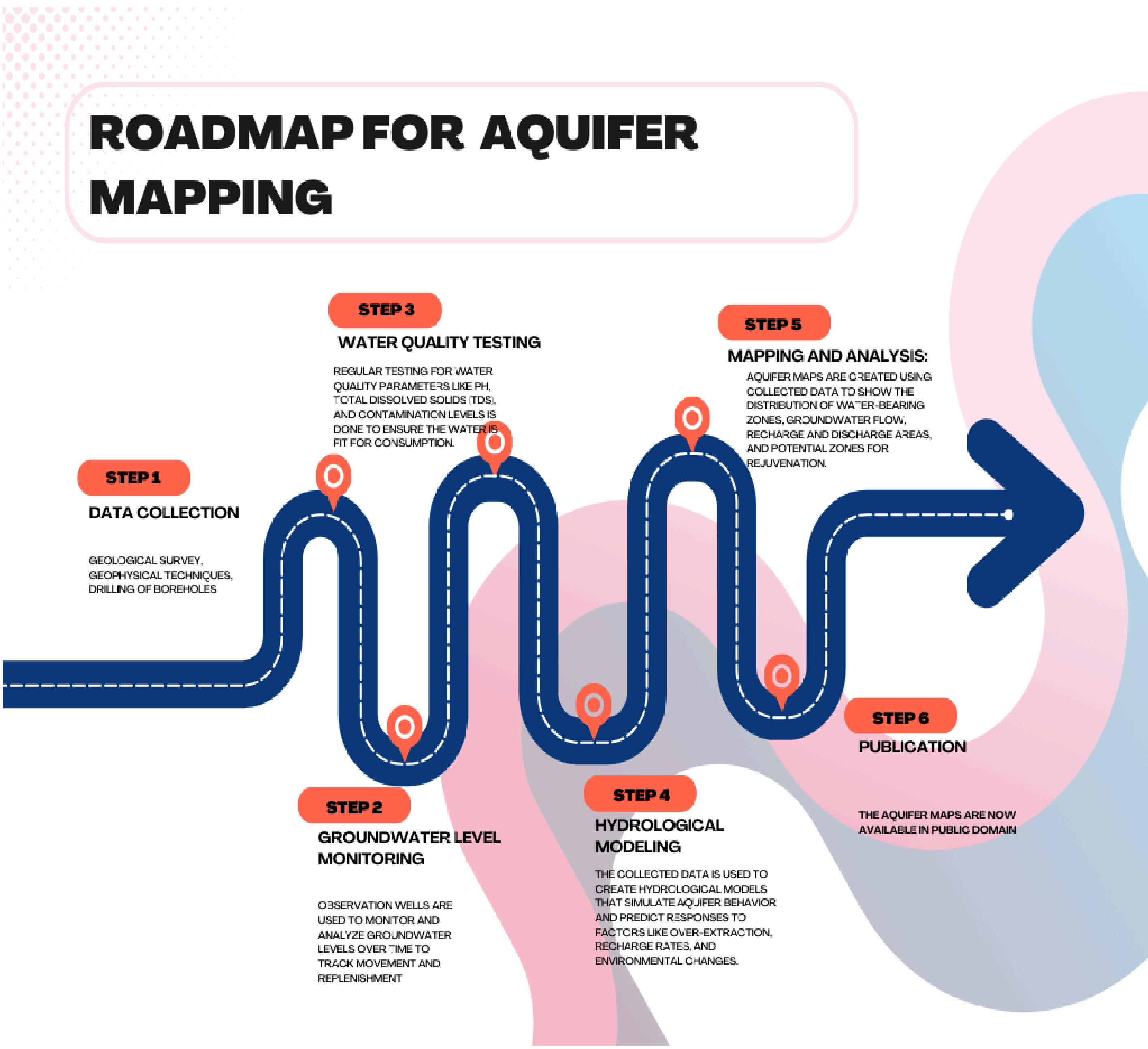
- **Dental Fluorosis**: Yellowish-brown staining of teeth, pitting, and weakening of enamel.
- **Skeletal Fluorosis**: Pain in joints, stiffness, and damage to bones and ligaments.
- **Non-Skeletal Fluorosis**: Issues like gastric problems, kidney damage, and neurological effects.

Many villagers are affected by skeletal fluorosis, making it difficult for them to carry out daily tasks, and this has become a major public health concern in the region.

Aquifer Mapping and Rejuvenation

Aquifer Mapping is a scientific process that helps in identifying and understanding the distribution, characteristics, and potential of aquifers (underground layers of water-bearing rock or sediment). The main goal is to understand the spatial variation of groundwater resources and assess their sustainability. This is crucial for proper groundwater management, especially in water-scarce regions.

Process of Aquifer Mapping



Importance of Aquifer Mapping

Sustainable Groundwater Management

Helps in identifying areas with potential for sustainable water extraction

Prevention of Over-extraction

Mapping helps in understanding the recharge potential of aquifers, thus preventing over-extraction.

Informed Policy Making

Provides data to governments and agencies to make informed decisions regarding groundwater regulations and management.

Identification of Recharge Zones

Maps can highlight areas that need artificial recharge measures to sustain groundwater levels.

By accurately mapping aquifers, authorities can ensure that groundwater is used efficiently and that there are measures in place to protect these valuable resources for future generations.

Steps for Aquifer Rejuvenation (Managed Aquifer Recharge Methods)

Aquifer Rejuvenation involves implementing strategies to replenish and restore the water levels in aquifers, especially in regions where groundwater depletion is a major concern. The process aims to recharge aquifers through natural or artificial means to improve water availability.

Managed Aquifer Recharge (MAR) refers to the practice of intentionally recharging an aquifer by methods that enhance its natural replenishment, usually through surface water. Here are the key steps involved in aquifer rejuvenation:

Step 1 Identification of Suitable Sites:

Mapping the areas that are ideal for **recharge** is the first step in aquifer rejuvenation. These include regions where the **aquifer structure** allows water to seep into the ground effectively.

Sites with permeable soils and favorable topography are selected.

Step 2 Surface Water Collection

Collect surface water from **rivers, ponds, lakes, or reservoirs** during the monsoon or wet seasons. This water can be stored in **surface reservoirs** or **check dams**.

Step 3 Artificial Recharge Techniques: Several methods can be used for recharging aquifers:

- **Recharge Pits**: Small pits dug in the ground filled with gravel or porous material to allow water to percolate into the aquifer.
- **Recharge Wells**: These are vertical wells that direct surface water into the groundwater system. The water is forced through the well using gravity or pumps.
- **Infiltration Galleries**: Pipes or trenches that carry water to the aquifer through the soil surface.

- **Spreading Basins**: Shallow ponds or basins where water is spread over a large surface area, allowing it to seep into the groundwater.

Step 4 Water Quality Monitoring

It's crucial to ensure that the water being recharged does not contain harmful contaminants. Regular testing of recharge water quality is necessary to maintain the health of the aquifer.

Step 5 Monitoring Recharge Efficiency

Monitoring systems are set up to observe the efficiency of recharge activities. This includes checking the rate of infiltration, groundwater levels, and any changes in water quality.

Step 6 Maintenance and Sustainability

Regular maintenance of recharge structures such as **check dams, recharge wells**, and infiltration galleries is necessary to ensure they continue functioning properly over the years.

Long-term monitoring ensures that the recharge method remains sustainable, especially during periods of drought or water scarcity.

Aquifer Mapping & Rejuvenation Puzzle Game

To solve the puzzle by correctly mapping out the aquifer layers and recharge methods. Each step brings the participant closer to successfully "recharging" the aquifer.

Game Instructions:

1. The game consists of **5 sequential stages**.
2. For each stage, the player must choose the correct answer based on their knowledge of aquifers, recharge methods, and related concepts.
3. Completing all stages will successfully "recharge" the aquifer.
4. Each correct answer will unlock the next layer of the aquifer, while incorrect answers will prompt the player to reattempt.

Stage 1: Identifying the Aquifer Layer

The first step in aquifer rejuvenation is identifying the correct layers.

Puzzle:
You have a cross-section of the ground. You need to choose which layer is the **aquifer** from the options below.

Options:

A) Sand (High permeability)

B) Clay (Low permeability)

C) Gravel (Moderate permeability)

D) Bedrock (Non-permeable)

Stage 2: Adding Recharge

Now, you need to understand how water can recharge the aquifer. The next step involves choosing a method to add recharge.

Puzzle:
Choose the method of recharge that will most effectively replenish the aquifer.

Options:

A) Overhead irrigation

B) Managed Aquifer Recharge (MAR) through wells

C) Surface water runoff

D) Drilling more borewells

Stage 3: Identifying Recharge Efficiency

Next, you need to measure the efficiency of the recharge.

Puzzle:
If the aquifer layer has high permeability (like gravel), how quickly would the recharge occur?

Options:

A) Quickly

B) Slowly

C) No recharge happens

D) It depends on the weather

Stage 4: Mitigation Methods

The aquifer is not getting enough recharge. Now, you need to choose a mitigation method to improve the recharge rate.

Puzzle:
What action should you take to improve recharge in a city where the surface is mostly impervious (roads and buildings)?

Options:

A) Construct more rainwater harvesting systems

B) Remove all buildings and roads

C) Dig deeper wells

D) Stop irrigation

Stage 5: Assessing the Results

Finally, you need to assess the total recharge and how well your methods have worked.

Puzzle:
After applying your recharge methods, you measure the total volume of water that has been recharged. What's the next step?

Options:

A) Monitor for contamination

B) Mark the aquifer as fully recharged

C) Continue to monitor and manage the recharge regularly

D) Stop all recharge efforts and let it stabilize

Answer Key:

- **Stage 1:** Correct Answer: **A) Sand** (Aquifers are typically sand or gravel layers that have high permeability)

- **Stage 2:** Correct Answer: **B) Managed Aquifer Recharge (MAR)** (MAR through wells is one of the most effective methods of recharge)
- **Stage 3:** Correct Answer: **A) Quickly** (Water will recharge quickly if the layer is highly permeable, like gravel)
- **Stage 4:** Correct Answer: **A) Construct more rainwater harvesting systems** (In urban areas with impervious surfaces, rainwater harvesting helps in enhancing recharge)
- **Stage 5:** Correct Answer: **C) Continue to monitor and manage the recharge regularly** (Recharging an aquifer is an ongoing process, and continuous monitoring is essential)

Aquifer Mapping and Rejuvenation are vital to sustainable groundwater management. Through systematic mapping, we can understand the distribution and health of aquifers, while **Managed Aquifer Recharge** methods offer solutions to restore depleted groundwater resources. Such practices are critical for ensuring a continuous, reliable supply of groundwater, which is vital for both human consumption and agricultural needs.

Call to Action

Groundwater is the lifeline of our communities, ecosystems, and economy. Its sustainable management is not merely a choice but a pressing necessity. The challenges of groundwater depletion, contamination, and mismanagement affect us all, and the solutions require a collective and coordinated effort from individuals, communities, industries, and governments.

Importance of Collective Responsibility

Every drop of water counts. From the household level to large-scale industries, everyone has a role to play in preserving and replenishing this precious resource. Adopting sustainable groundwater management practices is essential to ensure water security for future generations. The balance between consumption and recharge is delicate, and achieving it demands awareness, action, and accountability.

Call to Action

- **Adopt Rainwater Harvesting**: Use rooftops, open spaces, and specialized structures to capture rainwater and recharge aquifers.
- **Reduce Water Wastage**: Fix leaks, use water-efficient appliances, and follow conservation practices in daily activities.
- **Promote Sustainable Practices**: Support and implement measures such as wastewater recycling, sustainable irrigation, and aquifer mapping.
- **Spread Awareness**: Engage in community initiatives, educate others about the importance of groundwater, and advocate for responsible water usage.

Let us come together to safeguard our groundwater resources. Each step, no matter how small, contributes to the larger goal of sustainable water management. The time to act is now—for us, for our planet, and for generations to come.

CHAPTER 7

Micro Irrigation Systems

INTRODUCTION

Today, I'll be discussing about the Indian Standards on Micro-Irrigation Systems developed by the Bureau of Indian Standards, with a focus on drip and sprinkler irrigation system. Let's dive in and explore the standards that guide the design, manufacturing, and functionality of these systems, ensuring efficiency and sustainability in agricultural practices.

CONTENTS

Our Ist session of today will cover the following topics:

- About Irrigation, the concept, types of irrigation methods and factors affecting irrigation.
- Indian Standards in the field of irrigation.
- What these standards cover for drip and sprinkler irrigation systems.
- A breakdown of specific standards, including their technical specifications and test requirements.

Our 2nd Session will then cover details of

- Indian Standards on different types of Filters, Fertigation Systems,
- Design, Installation and Operation of Sprinkler Irrigation,
- Preventive Maintenance of Drip Irrigation Systems

Let's begin with the basics.

IRRIGATION OVERVIEW

Irrigation refers to the artificial application of water to crops. It is a critical agricultural practice, especially in areas with irregular rainfall or arid climates. The main goal of irrigation is to ensure optimal water availability for crops, maximizing yield and productivity.

As per report of Bureau of Water Use Efficiency, agriculture is the largest consumer of water in India, which accounts up to 80% of the total freshwater withdrawals out which irrigation consumes the most. There are various types of irrigation methods (see Slides), which may be used by the farmer based on various factors (see slides). But out all, Micro Irrigation is the most water efficient methods of irrigation. You all are aware, efficient water use in irrigation is not just a best practice—it is a necessity. MIS ensures that water is delivered exactly where it's needed, in the right amounts, and at the right time, preventing wastage and promoting sustainability

Therefore, objective of this session will be to discuss the standards developed by the BIS on micro-irrigation systems (Drip and Sprinkler Irrigation System), which ensures their performance and reliability.

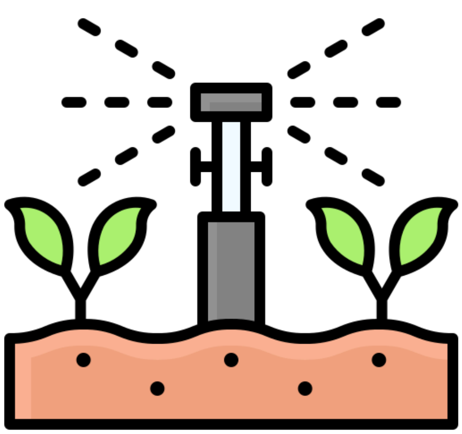
INDIAN STANDARDS IN IRRIGATION

BIS has developed standards on:

- Pipes, Filters, Valves used in Drip and Sprinkler Irrigations Systems
- Standards for fertigation unit
- Code of practices for design, installation, operation, maintenance of sprinkler and drip irrigation
- Quality of Irrigation Water

Adhering to these standards is essential for achieving long-term durability, efficiency, and compatibility of irrigation equipment.

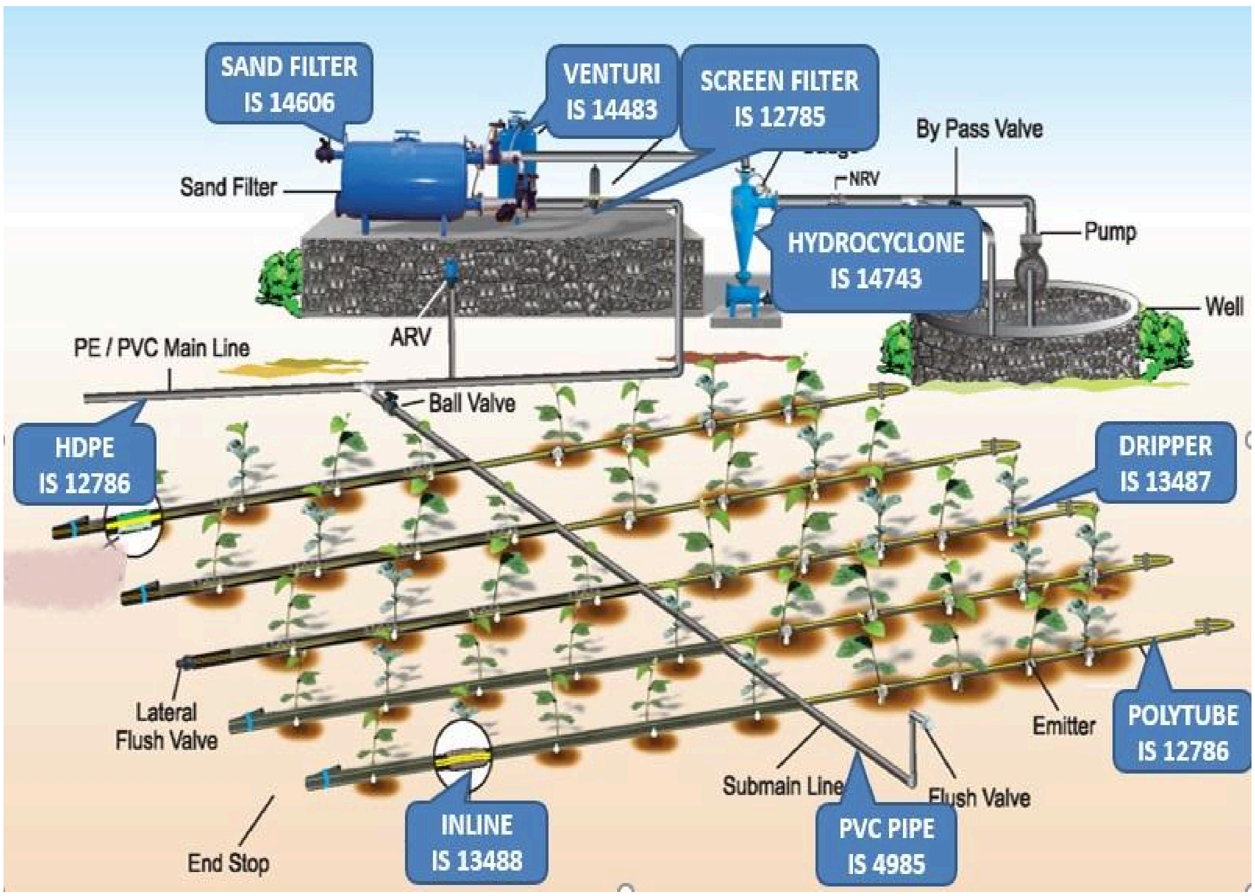
Now, let's delve into the specific standards for drip and sprinkler irrigation systems.



DRIP IRRIGATION STANDARDS

Drip irrigation is a method where water is delivered directly to the root zone of plants in small, controlled quantities. This system is highly efficient as it minimizes water loss due to evaporation or runoff.

You may see the representation of a Drip Irrigation System in the below Picture:



The key standards on drip irrigation include:

1. IS 12786 : 2024
2. IS 13488 : 2008
3. IS 13487 : 2025
4. IS 14971 : 2024

About IS 12786 : 2024 IRRIGATION EQUIPMENT — POLYETHYLENE PIPES FOR IRRIGATION LATERALS — SPECIFICATION (*first revision*)

This standard lays down requirements for pipes of outside diameter from 12 mm up to 32 mm **to be used for irrigation laterals** that is branch supply lines on which sprayers or drippers or emitters are mounted directly or by means of a fitting or formed in the pipe during production.

The pipes must be able to withstand up to 800 working hours annually, at a maximum water temperature of 35°C. Under these conditions, the expected lifespan of the pipes is 10 years.

Classification of Lateral Pipe based on Working Pressure

Class of Pipe	Working Pressure	Colour
Class 1	0.20 MPa	Red
Class 2	0.25 MPa	Yellow
Class 3	0.40 MPa	Green

SPECIFICATION REQUIRMENTS TEST	SIGNIFICANCE
Material	To ensure right quality material with right amount of ingredients to achieve resistance against UV and to withstand environmental conditions.
Dimensions	All the manufacturer follows common dimensions. Makes it easy for the user to select proper tubing according to his requirements.
Hydraulic Characteristic	Pressure withstanding capacity of the tubing for ambient and elevated temperature.
Reversion Test	Checks effect of air temperature on laying length of the lateral.
Tensile Test	Tube shall withstand pulling force while laying and retrieval

Environmental Stress Crack Resistance	Ensure that tube shall not crack due to environmental stresses

Dimensions of Polyethylene Pipes for Irrigation Laterals

Outside Diameter	Tolerance on outside Diameter	Class 1 (0.20 MPa)		Class 2 (0.25 MPa)		Class 3 (0.40 MPa)	
		Min	Max	Min	Max	Min	Max
12	+ 0.2	0.6	0.8	0.9	1.1	1.2	1.4
16	+ 0.2	0.8	1.0	1.1	1.3	1.4	1.6
20	+ 0.2	0.9	1.1	1.2	1.4	1.5	1.7
25	+ 0.3	1.2	1.6	1.7	2.0	2.1	2.4
32	+ 0.3	1.5	1.9	2.0	2.4	2.5	2.9

NOTE — Wall thickness of pipes are based on a safe working stress of 2.5 MPa at 20 °C. Occasional rise ii temperature has no deleterious effects on the life and working pressure of the pipes.

About IS 13488 : 2008 IRRIGATION EQUIPMENT — EMITTING PIPE SYSTEMS — SPECIFICATION (*first revision*)

IS 13488 specifies the mechanical and functional requirements of the emitting pipes and their fittings, test methods and the data to be supplied by the manufacturer to facilitate correct installation and operation in the field.

This standard applies to emitting and trickling pipes, hoses and tubings intended for irrigation. in which the emitting units form an integral part. This standard also applies to the fittings used for connecting these pipes, hoses and tubings. This standard does not apply to continuously porous pipe (porous along its entire length and circumference).

It classifies Emitting Pipes into different Categories:

Based on Pressure Regulation

Unregulated Emitting Pipes
Regulated Emitting Pipes

Based on Uniformity

Uniformity Category A
Uniformity Category B

Based on Working Pressure

Class of Pipe	Working Pressure
Class 1	0.100 MPa
Class 2	0.125 MPa
Class 3	0.250 MPa
Class 3	0.400 MPa

Material Requirement of Emitting Pipes:

- The material used in the manufacture of emitting pipes and their fittings shall be resistant to fertilizers and chemicals commonly employed in irrigation and shall be suitable for use with water at temperatures up to 60°C and at pressures designed for the emitting pipe.

- The materials shall, as far as possible. not support the growth of algae and bacteria. The parts of the emitting pipe that are exposed to sunlight. shall be opaque and protected against UV degradation.

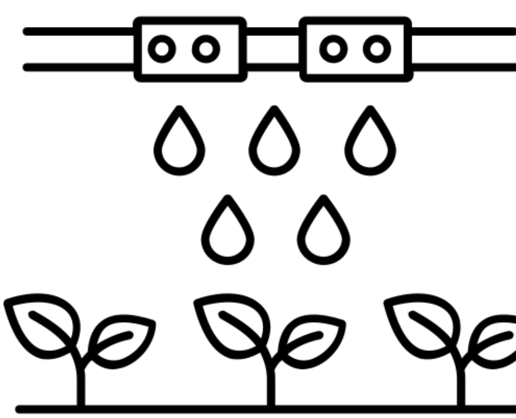
Dimensions of Polyethylene Emitting Pipes ((All dimensions in millimeters)

Sl. No.	Nominal Diameter	Inside Diameter	Tolerance on I.D.	Wall Thickness			
				Class 1 0.100 MPa	Class 2 0.125 MPa	Class 3 0.250 MPa	Class 4 0.400 MPa
	12	10.50	+ 0.20 - 0.00	0.4-0.5	0.6-0.7	0.8-1.0	1.1-1.3
	16	14.20	+ 0.20 - 0.00	0.5-0.6	0.7-0.9	1.0-1.2	1.3-1.5
	20	18.00	+ 0.20 - 0.00	0.7-0.8	0.9-1.1	1.2-1.4	1.5-1.7
	25	22.60	+ 0.20 - 0.00	0.9-1.1	1.2-1.4	1.5-1.7	1.8-2.2

NOTE — The wall thicknesses of pipes are based on safe working stress of 2.5 MPa at 20°C. Occasional rise in temperature has no deleterious effect on the life and working pressure of the pipe. Clamping, such as bands and screws, shall be of non-corrosive materials or of materials protected against corrosion.

SPECIFICATION REQUIRMENTS TEST	Significance
Material	To ensure right quality material with right amount of ingredients to achieve resistance against UV and to withstand environmental conditions.
Dimensions	All the manufacturer follows common dimensions. Makes it easy for the user to select proper tubing according to his requirements.
Uniformity of Flow Rate	Ensures that nearly uniform water shall be delivered to crops.
Emission Rate as a function of inlet pressure	Tells us how flow rate will vary for pressure fluctuations
Hydrostatic Pressure	Sudden change in pressure or operation of the dripline at higher pressure.

Resistance to tension at elevated temperature	Even if temperature increases, there shall not be deviation in flow rate by more than 5%
Resistance to Pull Out	Tube shall not be pulled out of fittings for nominal pulling force.
Environmental Stress Crack Resistance	Ensure that tube shall not crack due to environmental stresses
Emitter Unit Exponent	This is an indicator for performance of the emitter.



About IS 13487 : 2025 IRRIGATION EQUIPMENT — EMITIERS — SPECIFICATION (*first revision*)

Emitters/Drippers are small devices in drip irrigation systems that deliver water directly to plant roots in a controlled and precise manner. They regulate water flow, ensuring efficient use and minimizing wastage. Different types, like pressure-compensating and non-pressure-compensating emitters, cater to varying irrigation needs.

IS 13487 specifies mechanical and functional requirements of irrigation emitters, test methods and the data to be supplied by the manufacturer to permit correct installation and operation in the field.

NOTE - It applies to emitters, with or without pressure regulation, intended for irrigation; it does not apply to emitters which form an integral part of the pipe during manufacture as well as microtubes.

It classifies Emitters into different Categories:

Based on Mounting on Pipes
In-Line Emitters
On-Line Emitters

Based on Pressure Regulation
Unregulated Emitters
Regulated Emitters

Based on Uniformity
Uniformity Category A
Uniformity Category B

Based on Number of Outlets
Single Outlet
Multi Outlet

Material Requirement of Emitting Pipes:

The material used in the manufacture of emitting pipes and their fittings shall be resistant to fertilizers and chemicals commonly employed in irrigation, and shall be suitable for use with water at temperatures up to 60°C and at pressures designed for the emitting pipe.

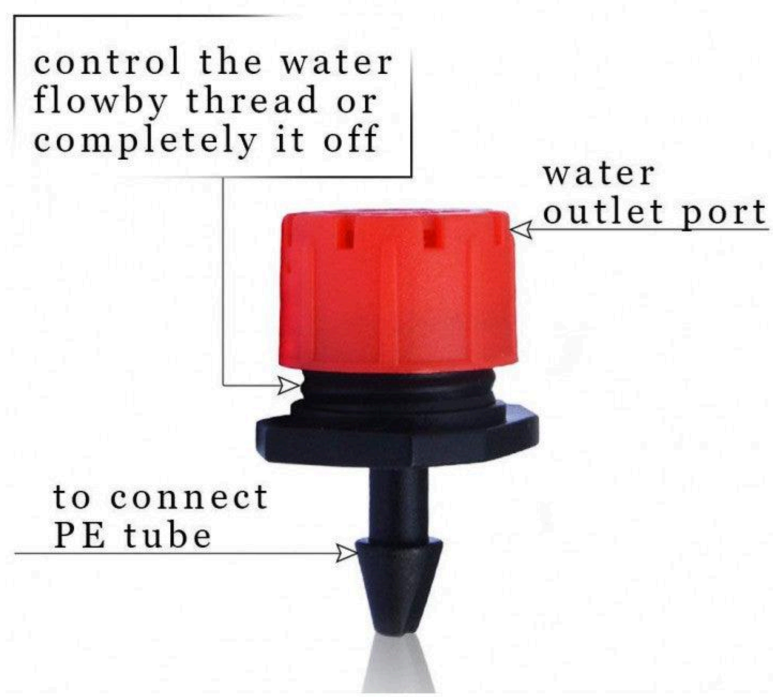
The materials shall, as far as possible. not support the growth of algae and bacteria. The parts of the emitting pipe that are exposed to sunlight. shall be opaque and protected against UV degradation.

Mechanical Tests and Requirements

- Construction and Workmanship – visual inspection for manufacturing defects
- Flow Paths In Emitter – dimension measurement
- Resistance to Hydrostatic Pressure – performance of emitter against high pressure
- Emitter Pull-out Test

Functional Tests and Requirements

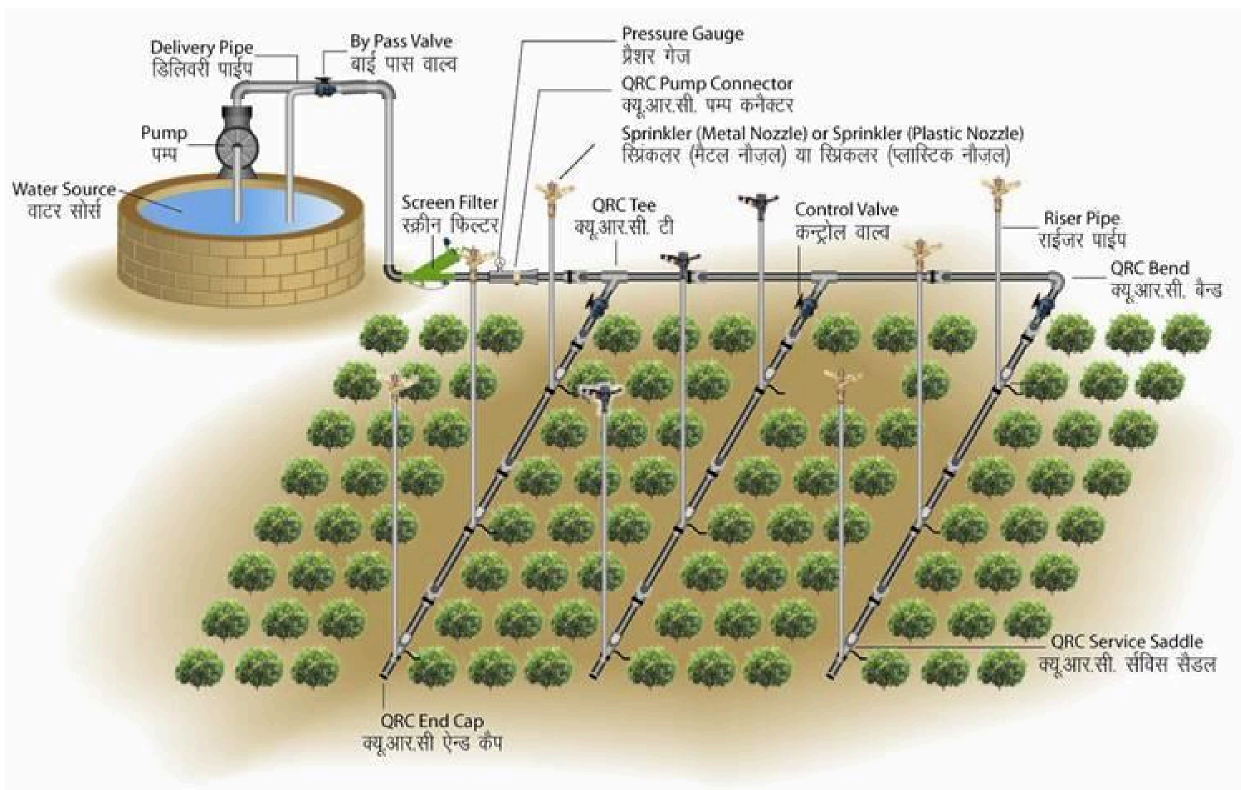
- Uniformly of Emission Rate: Ensures that nearly uniform water shall be delivered to crops from all emitters:
- Emission Rate as a Function of Inlet Pressure: Tells us how flow rate will vary for pressure fluctuations
- Determination of Emitter Exponent: This is an indicator for performance of the emitter.



SPRINKLER IRRIGATION STANDARDS

Sprinkler irrigation systems mimic natural rainfall by spraying water over crops. These systems are versatile and suitable for a variety of terrains and crop types.

You may see the representation of a Drip Irrigation System in the below Picture:



The key standards for sprinkler irrigation include:

1. IS 17425: 2020
2. IS 12232 (Parts 1 and 2)
3. IS 14605: 1998
4. IS 18286: 2023
5. IS 14792 : 2000

About IS 17425 : 2020 IRRIGATION EQUIPMENT - QUICK COUPLED POLYETHYLENE PIPES AND FITTINGS FOR SPRINKLER IRRIGATION SYSTEMS – SPECIFICATION

A vital component of MIS is the piping network, which transports water from the source to the sprinkler heads. Proper sizing, material selection, and installation of pipes are crucial to minimize pressure losses and optimize water distribution.

IS 17425 lays down the general requirements for raw materials, manufacturing, method of tests and testing of quick coupled and plain polyethylene pipes and fittings of outside diameters 40 mm to 200 mm used for portable sprinkler and drip irrigation systems as mains, sub mains or laterals.

Components of Quick Coupled Polyethylene Pipes:

Sprinkler Pipe
Quick Coupled Sprinkler Pipe
Male Coupler
Female Coupler
Sprinkler Quick Coupled Fittings
Quick Coupled Tee
Quick Coupled Bend
Quick Coupled Pump Connector
Quick Coupled End Cap
Quick Coupled Reducer
Quick Coupled Foot Batten Assembly
Sprinkler Riser

Classification of Pipes Based on Working Pressures:

Class of Pipe	Maximum Permissible Working Pressure at 30 °C
Class 1	0.25 MPa
Class 2	0.32 MPa
Class 3	0.40 MPa
Class 4	0.60 MPa

Important Requirements of Quick Coupled Pipes and Fittings

SPECIFICATION	SIGNIFICANCE
Leakage Test	Fittings coupled to the pipe are tested for leakage with water as medium with pressure from 0.0 MPa to maximum working pressure.
Hydraulic Proof Test	Same assembly as above tested at higher pressures checking the Pressure withstanding capacity.
Weldability Test	Hydraulic performance test (7.1.2) performed, to establish the joint between the couplers and pipe.

Important Requirements of Plain Sprinkler Pipes

SPECIFICATION	SIGNIFICANCE
Visual Appearance and Workmanship (7.1.1)	pipes shall be smooth, clean and free from grooving, pit marks and melt fractures.
Hydraulic Performance Characteristics (7.1.2)	Pressure withstanding capacity of the pipe for ambient and elevated temperature.
Reversion Test (7.1.3)	Checks effect of air temperature on laying length of the lateral.
Tensile Test	Tube shall withstand pulling force while laying and retrieval
Fusion Compatibility Test	Testing the pipes joined with butt fusion, friction welding, socket fusion or using electro fusion fitting.
Environmental Stress Crack Resistance	Ensure that tube shall not crack due to environmental stresses

About IS 12232 Part 1 and Part 2 : ROTATING SPRINKLER

IS 12232 (Part 1) specifies the design and operational requirements of rotating sprinklers, sprinkler nozzles and their test methods.

On the other hand **IS 12232 (Part 2)** specifies the conditions and methods used for testing of uniformity of distribution of rotating sprinklers which is important parameter for sprinkler irrigation system to achieve uniform/even application over the covered land area.

Material Requirements:

- Sprinklers shall be made of metals or plastics. Metal sprinklers shall be made from a copper alloy or of other metals whose mechanical properties and resistance to corrosion when used with irrigation water are not less suitable than those of copper alloys.

- Plastics parts of the sprinklers which conduct water and which are exposed to sunlight shall be opaque. Plastics parts of sprinklers exposed to ultraviolet (UV) radiation shall contain an additive resistant to UV radiation.

Performance Requirements (*apply to sprinklers having one or more nozzles*)

- Effective pressures - The sprinkler shall rotate continuously and regularly in its designed direction within its entire range of effective pressure from the minimum effective pressure, P_{min} up to the maximum effective pressure, Pmax.

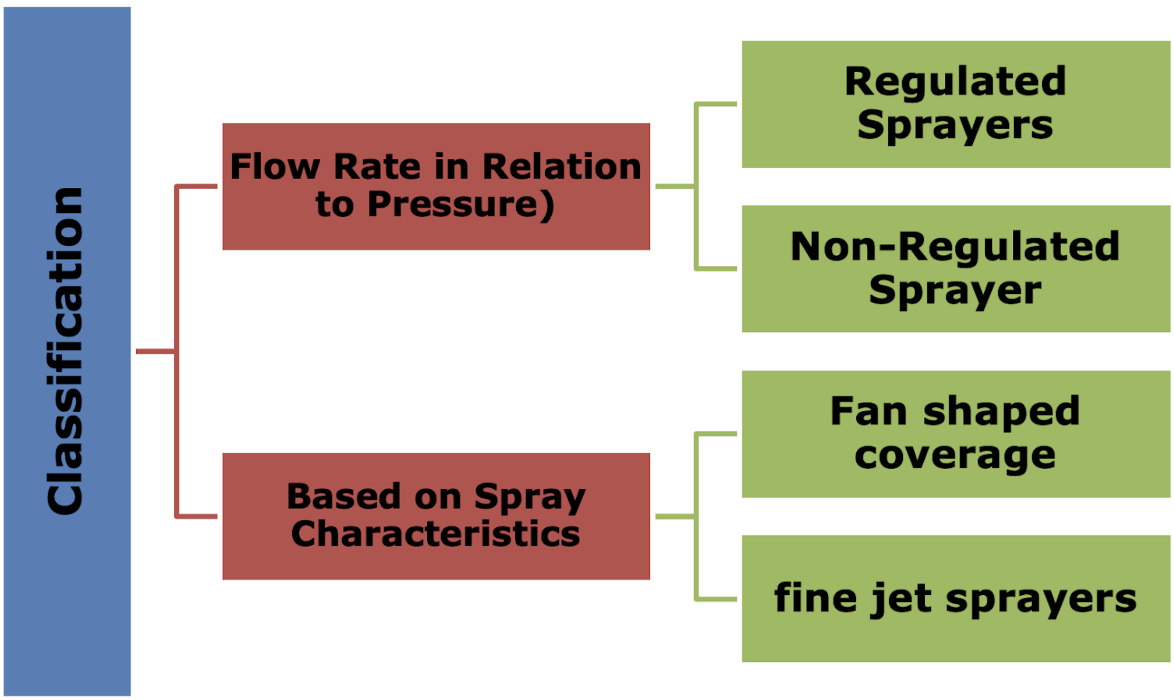
- Actuating mechanism - The actuating mechanism of the sprinkler shall operate in accordance with strength test and operating tests given in the standard at any inclination of the riser up to 10" from the vertical.

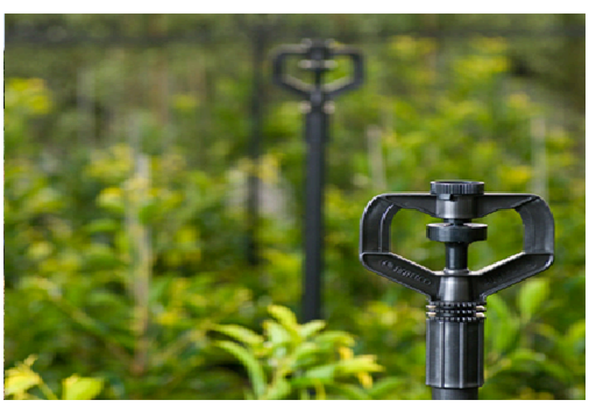
Important Requirements of Rotating Sprinkler

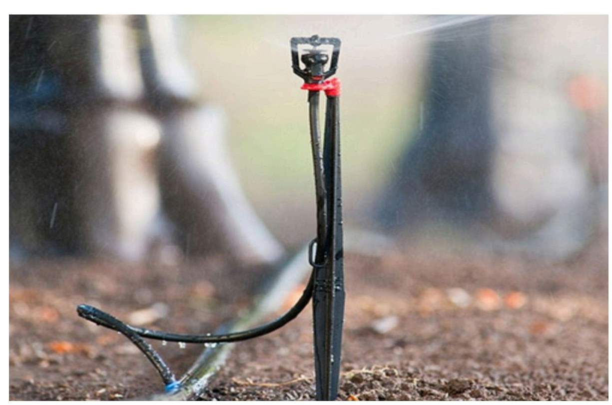
Specification	Significance
Resistance to threaded connection	Sprinkler shall withstand tightening torque
Hydrostatic Pressure	Performance against increase in pressure.
Uniformity of Flow Rate	Ensures that nearly uniform water shall be delivered to crops.
Water Distribution Curve	Ensures uniformity of water distribution
Durability Test	This test ensures performance against life of the sprinkler.

About IS 14605 : 1998 IRRIGATION EQUIPMENT — MICRO SPRAYERS — SPECIFICATION

Micro sprayers are type of sprinklers used to deliver water to the crops as a fine spray or mist, ensuring efficient coverage with minimal water wastage.
IS 14605 specifies the general requirements and test methods for micro sprayers. It applies to sprayers intended for assembly in pipeline networks for irrigation and for operation with irrigation water.







Important Requirements of Micro Sprayers

Specification	Significance
Hydrostatic Pressure	Performance against increase in pressure.
Uniformity of Flow Rate	Ensures that nearly uniform water shall be delivered to crops.
Water Distribution Curve	Ensures uniformity of water distribution

About IS 18286 : 2023 Agricultural Irrigation Equipment — Manually Operated Serviceable Plastics Valves — Specification

Valves in irrigation systems are essential components used to control the flow and distribution of water. They help regulate water supply, direct it to specific zones, and enable efficient operation of the system.

IS 18286 specifies the general requirements and test methods for manually operated serviceable plastics valves intended for operation in agricultural irrigation systems. It is applicable to manually operated plastics valves of diameter nominal (DN) **8 (1/4")** to diameter nominal **110 (4")** including **angle**, **globe**, **diaphragm** and **ball valves**.

The valves are intended for installation in irrigation piping networks, using water at temperatures from **5 °C to 60 °C**. Nominal pressures of the valves are as designated by the manufacturer.

MATERIALS

PVC (Polyvinyl chloride)
PE (Polyethylene)
POM (Poly Oxy Methylene)
Poly Amide
PP (Polypropylene)
EPDM (Ethylene propylene diene monomer)
ABS (Acrylonitrile Butadiene Styrene)
NBR (Nitrile rubber)

All valve components those comes in contact with water shall not support the growth of algae and bacteria, nor be of metal which will corrode. Plastic parts of the valve that are exposed to sunlight shall be opaque and protected against UV degradation.

colour

Colour of Polyvinyl chloride (PVC), Polyethylene (PE), Polypropylene (PP) the compound should be either **Grey or Black** or as agreed between manufacturer and customer.

MECHANICAL AND FUNCTIONAL TESTS

Resistance to Increased Torque – to check the durability of the valve in opening and closing
Resistance of Valve and Valve Material to Internal Hydrostatic Pressure – performance of the valve against pressure variation
Seat and Stem Sealing Test
Valve Performance at Increased Hydraulic Pressure
Endurance Testing

Connections To Pipeline Shall Be in Accordance with Following Table

Material	Reference IS Standard
Polypropylene (PP)	IS 15801
Polyethylene (PE)	IS 4984/IS 17425
Unplasticized polyvinyl chloride (PVC-U)	IS 4985/IS 7834 (Part 1)

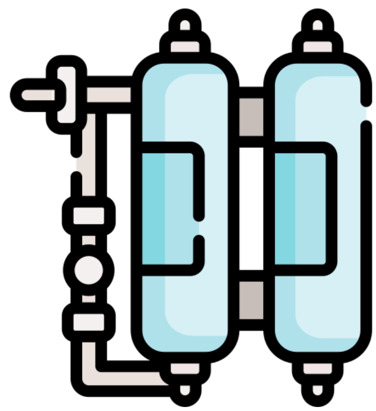
FILTERS

Filters are an essential component of micro-irrigation systems, designed to ensure clean and clog-free operation by removing debris, sediments, and other impurities from water before it enters the irrigation network.

The key standards for sprinkler irrigation include:

1. IS 12785 : 1994
2. IS 14743 : 2024
3. IS 14606 : 2022

About IS 12785 : 1985 IRRIGATION EQUIPMENT — STRAINER-TYPE FILTERS – SPECIFICATION



Strainer type Filters use a fine mesh, screen, disc or combination of these to trap debris/impurities contained in the irrigation water to prevent clogging in micro-irrigation systems.

It is a device containing one or more filtering elements, used for separating suspended solids/impurities from the water passing through the device and collecting them on the filter element.

IS 12785 specifies the general construction requirements and test methods for strainer type filters (hereinafter called filters) intended for operation in agricultural irrigation systems.

IS 12785 classify strainer-type filters into following types:

a) Screen Filter
b) Disc Filter

COMPONENTS

Filter Element

The filter component, consisting of a perforated plate, screen, mesh, or a combination of these, intended to retain solid contaminants larger than a given size from the water flowing through the component.

Disc Filter Element

The component of a filter composed of plastic discs with grooved or textured faces arranged adjacent to the other to form a stack.

Filter Housing

The part of the filter that contains all the filtering components, except for the control equipment.

GENERAL REQUIRMENTS

- The filter parts that are in contact with the water shall be of non-toxic materials and shall be resistant to or protected against degradation caused by existing working conditions and types of water used in agricultural irrigation.

- The filter housing shall also be resistant to environmental conditions. Components belonging to filter of same size, type and model, and produced by the same manufacturer, shall be interchangeable.

- The filter element shall be either made of stainless steel or plastics or combination of both and should be detachable for cleaning

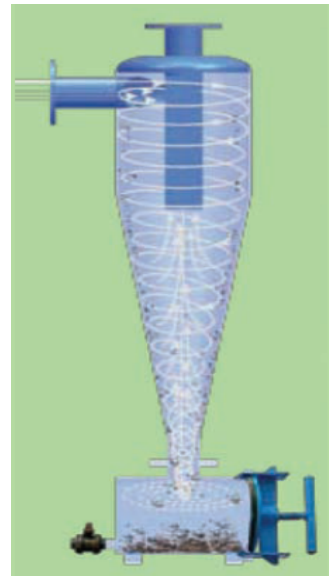
REQUIREMENTS FOR FILTER HOUSING

- The filter shall be so designed that contaminants accumulated on the filter element or in the filter housing, do not enter the supply line when cleaning or replacing the filter element. The construction of the filter element should allow disassembly, cleaning and reassembly of the without removal of the filter from the supply line.

PERFORMANCE TESTS

Tests	Significance
Resistance of Strainer to Internal Hydrostatic Pressure	Filter screen shall withstand pressure
Resistance to Internal Hydrostatic Pressure at High Temperature	Shall withstand even if water temperature is high
Resistance of Filter Element to Buckling or Tearing	Filter element shall not rupture even if filter is completely clogged
Tightness of Filter Element	Water shall not bypass the filter element
Clean Pressure Drop	Filters own pressure drop shall be considered for design of drip system

About IS 14743 : 2024 HYDROCYCLONE FILTERS — SPECIFICATION (*first revision*)



Hydrocyclone filter is an essential component of micro irrigation system used to separate sand from the river or tube-well water. It works on the principle of centrifugal force. it is also called centrifugal filter/sand separator.

It is filtration device consisting of a cyclonic vessel having an arrangement to create spiral vortex flow, an inlet, a centrally rising up outlet and an underflow chamber for sand collection tank connected at the lower end, essentially having an opening for removal of accumulated entrapped particles.

IS 14743 specifies the general constructional requirements and test methods of the hydrocyclone filters, intended for operation in agricultural irrigation systems.

The standard does not deal with filtration ability, efficiency and capacity nor it deals with the hydrocyclone filters that integrate automatic or continued flushing of accumulated sand.

- COMPONENTS
  - **Hydrocyclone Inlet**
    The pipe attached to the body and at the top of the conical/funnel shaped vessel to allow inflow of the stream of raw water and diverting water along the inner wall of the conical vessel to convert into swirling/circular motion.
  - **Hydrocyclone Outlet**
    A straight pipe starting from below the horizontal place of inlet and projecting at right angles from circular top of conical vessel, allowing clean water column to rise and flow out of vessel.
  - **Cyclonic Vessel**
    The vessel provided to generate enough time of concentration to the particles to travel towards outer wall of the vessel. On one side it is connected to inlet chamber and outlet pipe and on the other side it is connected to underflow chamber of sand collection tank.

TECHNICAL REQUIREMENTS

➢ Material

Metallic body or parts shall be coated with durable abrasion resistant coating having a coating thickness more than 70µm or hot dip galvanized to resist corrosion and under scouring.
Plastic body or parts of the filter that are exposed to ultraviolet (UV) radiation shall include additives to improve their resistance to UV radiation

➢ Construction

The filter shall be so designed that after assembly of the filter all the water flowing through the filter shall flow through inlet into cyclonic motion then to the outlet. The accumulated sand/slurry collected in the underflow tank should not be mixed with the processed water flowing through outlet.

➢ Cyclonic Vessel

The cyclonic vessel shall be so designed that the dirt separated should slide easily to the underflow chamber without stoppage on any step or shelf.

➢ Connections

PERFORMANCE TESTS

- Resistance to Internal Hydrostatic Pressure
- Resistance to Internal Hydrostatic Pressure at Elevated Temperatures
- Pressure Drop vs Flow
  - Test Period
  - Loading Rate
  - Flows
  - Testing Sequence
  - Results
  - Observations
- Cyclic Pressure Test

About IS 14606 : 2022 IRRIGATION EQUIPMENT — GRANULATED MEDIA FILTERS — SPECIFICATION

Media Filters also called as sand filters uses a bed of sand or granular media to trap particles/impurities, making them ideal for water sources with high organic loads, such as ponds or reservoirs.

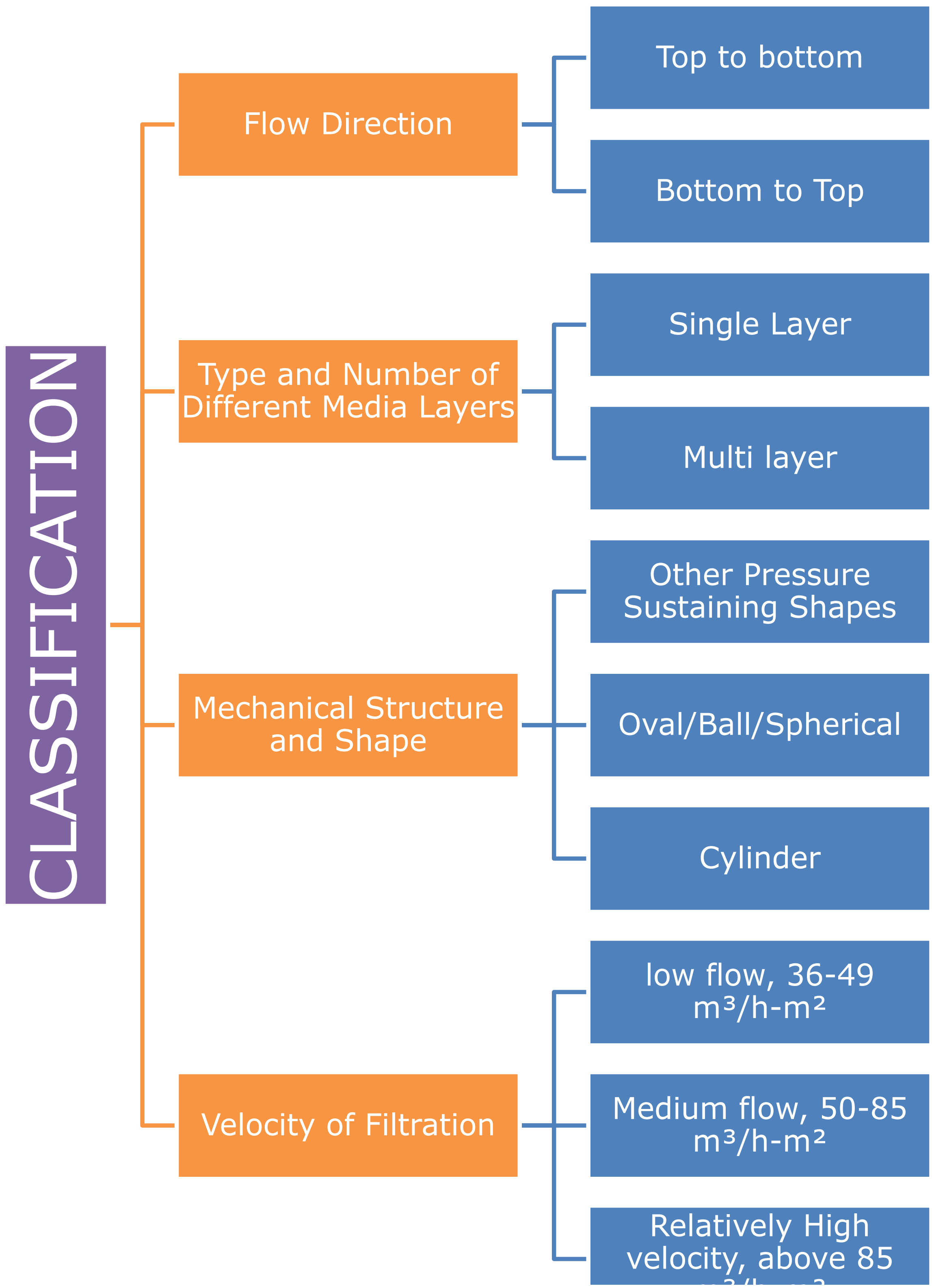
IS 14606 specifies This standard specifies the construction requirements and test methods for “granulated media filters”,, intended for operation in agricultural irrigation systems. It includes manual cleaning media filters and automatic self-cleaning media filter “batteries” (2 units or more working in parallel).

This standard deals with manual and automatic backflow media filters and applies to:

a) manually cleaning filters.
b) complete automatic filters at a single unit level.
c) a filtration battery which is a complete filter system that includes:
   Inlet — Unfiltered supply water;
   Outlet — Filtered water carried to the irrigation network; and
   Back flush outlet — This is for the water and filtrate, flushed out during the backflow procedure.
d) Command power source — Usually hydraulic-filtered water for automatic operation (can also be pneumatic or electric).

This standard deals with the operation and performance of a media filter including related valves, backwash mechanism, under-drains, manifolds and all related accessories necessary for the operation of the filter.

This standard deals only with pressurized filters operating in a range of filtration velocities declared by the manufacturer. The standard does not deal with filtration ability, efficiency and capacity (quality of filtered water, time of operation before media filter becomes entirely clogged, etc).



PERFORMANCE TESTS

TESTS	Significance
Resistance of Strainer to Internal Hydrostatic Pressure	Filter screen shall withstand pressure
Resistance to Internal Hydrostatic Pressure at High Temperature	Shall withstand even if water temperature is high
Requirements of Filter Housing (Metal and Plastic)	to ensure it can withstand operational pressures without leaks or structural failure
Resistance to cyclic pressure	evaluates their durability and reliability under fluctuating pressure conditions
Back flushing hydraulic parameters and tests	Backflushing is done to removes debris, contaminants, and blockages to maintain filter's efficiency and ensure consistent fluid flow. Therefore the test is done to validate filter performance and prevents system damage by clearing clogs.

AUTOMATIC BACK FLUSHING AND CONTROLLER

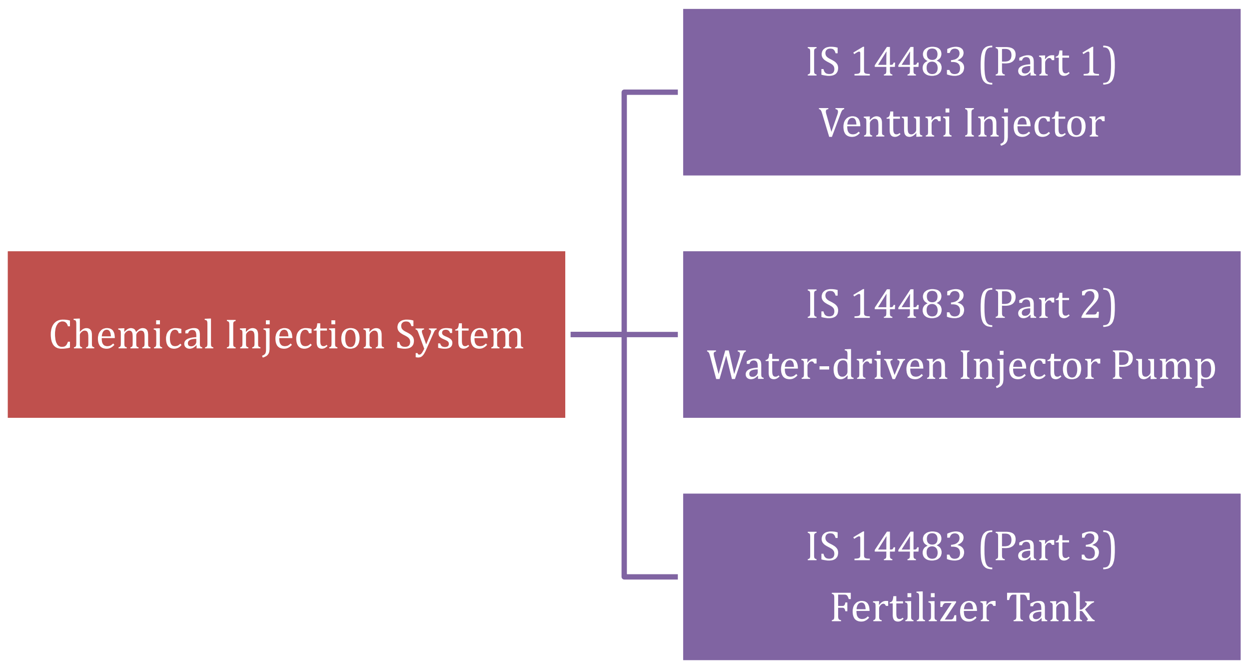
- Backwash Initiation
- Flushing Control Mechanism Testing
  - Mechanism Activated by Pressure Differential Sensor
  - Mechanism Activated by Duration of Operation
  - Mechanism Activated by Volume of Filtered Water
  - Mechanism Activated by Some Other Physical Quantity
  - Test of Protective Device
  - Test for Flushing Mechanism
  - Detecting Media Escape

CHAPTER 8

FERTIGATION

Fertigation is the process of delivering fertilizers/chemicals or nutrients directly to crops through an irrigation system. It ensures precise nutrient application, enhancing plant growth and minimizing waste.

The application of fertilizer or/and other chemicals via irrigation water to crops/plants is based on the principle that a swiftly moving stream of water is able to carry with it the dissolved substances and fine dispersed suspended particles of fertilizer material. Venturi injector, injector pump, fertilizer tank are such equipment used for this purpose



About IS 14483 (Part 1) : 2024 FERTILIZER AND CHEMICAL INJECTION SYSTEM : PART 1 VENTURI INJECTOR (*first revision*)

Venturi Injector is an appliance used for fertigation or chemigation, chlorinating or injecting chemicals in the sprinkler and drip irrigation systems. Venturi injector operates on the principle that, when a pressurized operating (motive) fluid enters the injector, it is constricted towards the injection chamber and changes into a high velocity jet stream. The increase in velocity inside the injection chamber results in decrease in pressure, thereby enabling an additive liquid material to be drawn through the suction port and entrained into the motive stream

IS 14483 (Part 1) prescribes the requirements of venturi injectors used for injecting fertilizer and chemicals in the sprinkler and drip irrigation systems.

MATERIAL REQUIREMENTS

- The material used in the manufacture of venturi injector and their fittings shall be resistant to fertilizers and chemicals commonly employed in irrigation and shall be suitable for use with water at temperatures up to 60°C and at pressures designed for the emitting pipe.

- The materials shall, as far as possible not support the growth of algae and bacteria. The parts of the emitting pipe that are exposed to sunlight. shall be opaque and protected against UV degradation.

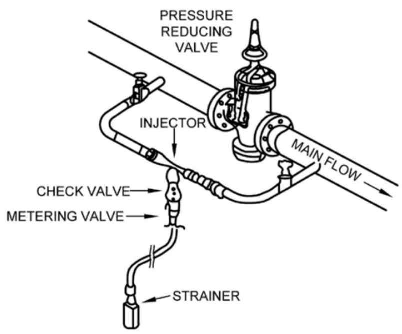
CONSTRUCTIONAL REQUIREMENTS

- Should be detachable for removal when not in use. Suction port shall have suitable connection. inbuilt check valve may be provided. A metering device shall be provided pressure reducing device or flow control device to be provide

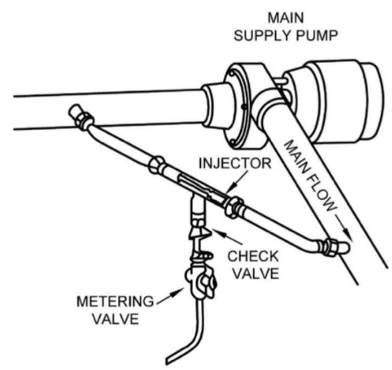
TESTS

- Resistance of Venturi Injector to Internal Hydrostatic Pressure.
- Performance Test as per manufacturer’s declaration

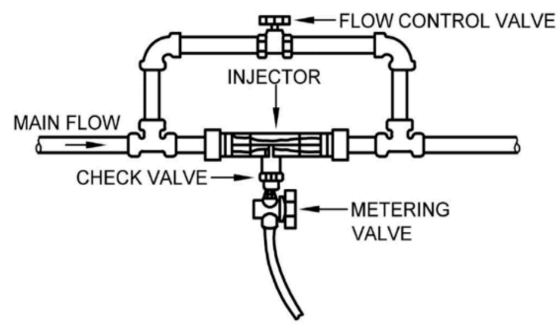
INSTALLATION OF THE VENTURI INJECTOR IN THE IRRIGATION SYSTEMS FOR PERFORMANCE TESTING



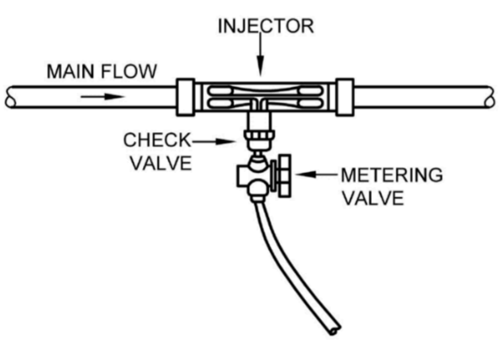
1. A REGULAR VALVE INSTALLED IN BETWEEN THE INLET AND OUTLET CONNECTIONS OF THE VENTURI INJECTOR CREATES DIFFERENTIAL PRESSURE AND FINALLY VACUUM NEAR THE SUCTION PORT.



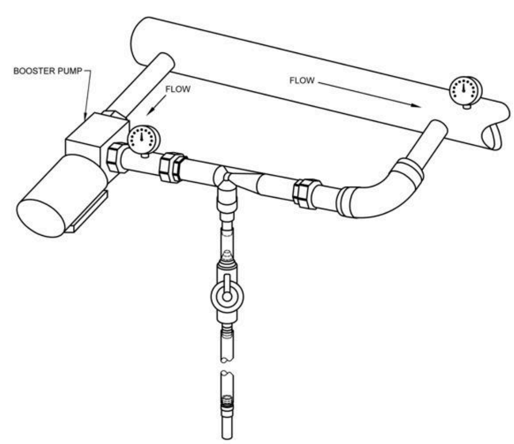
2. INLET OF THE VENTURI CONNECTED TO THE SUCTION PIPE OF A PUMP AND THE OUTLET CONNECTED TO THE DELIVERY PIPE OF THE PUMP. PRESSURE DIFFERENTIAL IS CREATED AUTOMATICALLY WHEN THE PUMP STARTS RUNNING.



3. INJECTOR CAN BE INSTALLED DIECTLY IN THE MAIN LINE WITH A BY-PASS CONNECTION HAVING FLOW CONTROL VALVE. WHEN INJECTION IS NOT REQUIRED MAIN FLOW CAN BE DIVERTED THROUGH THE BY-PASS IN TO THE SYSTEM.



4. INSTALLED IN THE MAIN FLOW LINE TOTAL FLOW OF THE SYSTEM GOES THROUGH THE INJECTOR.



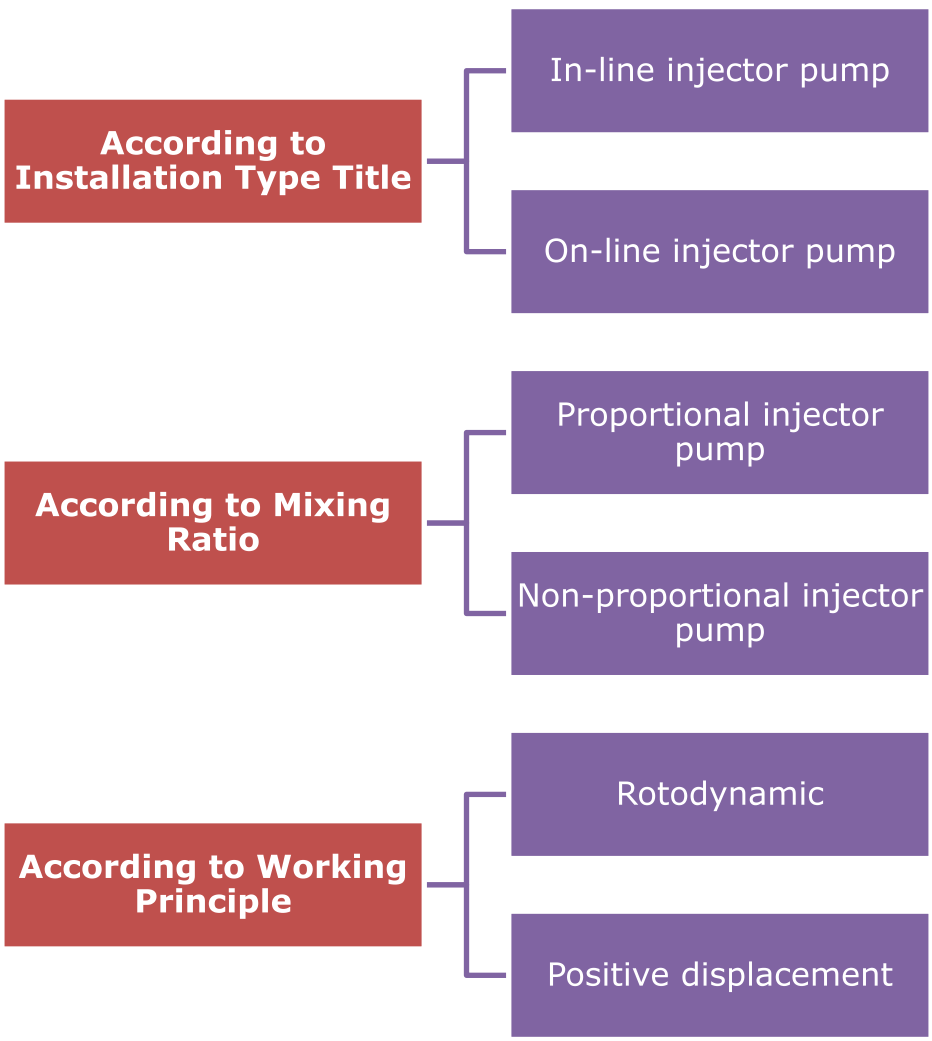
VENTURI INJECTOR WITH BOOSTER PUMP

About IS 14483 (Part 2) : 2025 FERTILIZER AND CHEMICAL INJECTION SYSTEM PART 2 WATER-DRIVEN CHEMICAL INJECTOR PUMP — SPECIFICATION (*first revision*)

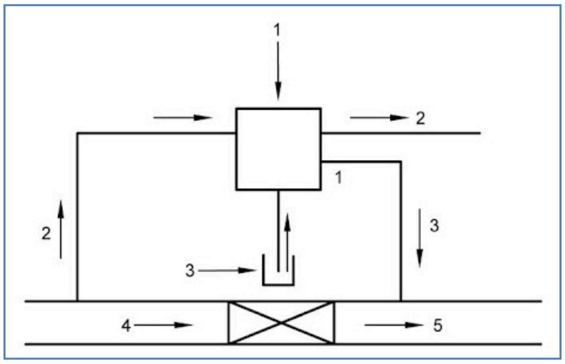
These water-driven chemical injector pumps are used to inject chemicals into irrigation systems. The chemicals include liquid fertilizer, solutions of fertilizers and other soluble agricultural chemicals such as acids and pesticides.

IS 14483 (Part 2) This standard specifies the construction and operational requirements and methods for water driven chemical injector pumps. These injector pumps are intended to operate at water temperatures of up to 50°C and with the types and concentrations of chemicals routinely applied in irrigation.

CLASSIFICATION OF PUMPS

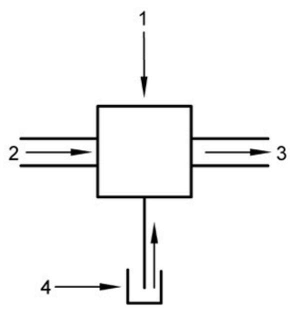


INSTALLATION OF INJECTOR PUMP IN THE IRRIGATION SYSTEMS FOR PERFORMANCE TESTING

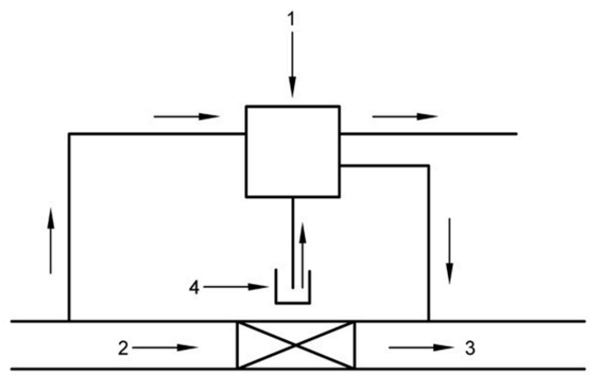


ON-LINE

where
1 Injector pump
2 Drive water
3 Chemicals
4 Irrigation flow
5 Irrigation water with injected chemicals



a) IN LINE FULL FLOW



b) IN LINE BYPASS

where
1 Injector pump
2 Irrigation flow
3 Irrigation water with injected chemicals
4 Chemicals

About IS 14483 (Part 3) : 2018 FERTILIZER AND CHEMICAL INJECTION SYSTEM PART 3 FERTILIZER TANL — SPECIFICATION

Fertilizer Tank is a component of fertigation systems used to mix and inject liquid or soluble fertilizers into irrigation water.

IS 14483 (Part 3) specifies the mechanical and functional requirements for fertilizer tanks used in irrigation systems, test methods and the data to be supplied by the manufacturer to permit correct installation and operation in the field.

This standard applies to fertilizer tanks working on the principle of differential pressure used in irrigation. systems. This standard also applies to the fittings used for connecting fertilizer tanks with the irrigation systems

Classification

- *Quantitative model*
- *Proportionate model with rubber/plastic bladder*

REQUIREMENTS

- Resistance of Fertilizer Tanks to Hydrostatic Pressure at Ambient Temperature
- Resistance to Hydrostatic Pressure at Elevated Temperature
- Injection Rate Calibration

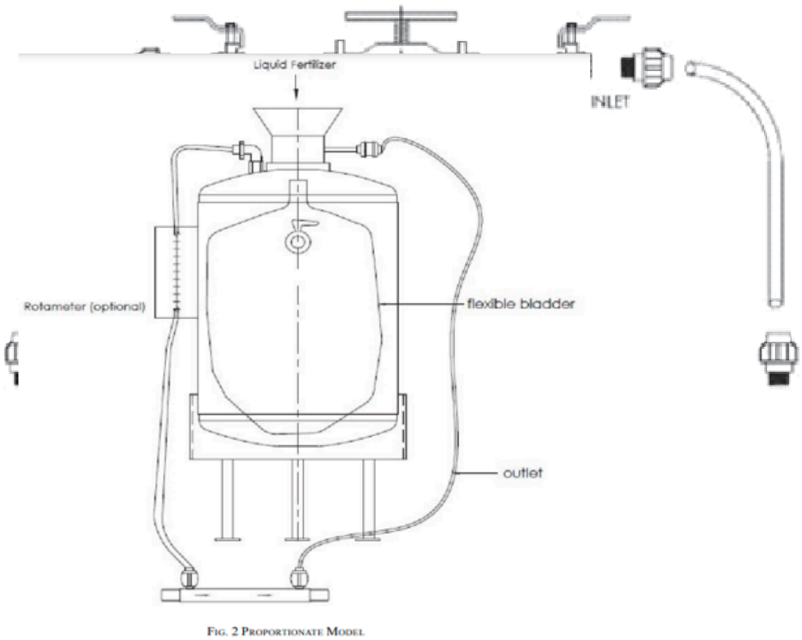


FIG. 1 QUANTITATIVE MODEL

About IS 14791 : 2024 PREVENTION AND TREATMENT OF BLOCKAGE PROBLEM IN DRIP IRRIGATION SYSTEM — CODE OF PRACTICE (*first revision*)

This standard specifies the guidelines for prevention and treatment of blockage problems in drip irrigation system.

- Quality of Water to be supplied.
- Chemical Injection System Installed with DIS.
- Different Blockage Problems associated with DIS.
- Method of Assessment of blockage problems.
- Prevention and treatment of blockage problem.
- Safety Requirements

Various Clauses under the Standard	What is Covered?
Quality of Water	Sample of water supplied to DIS is tested for different parameters such as Suspended Solids, pH, EC, Ca, Mg, Fe, Presence of oil etc. Table 1 of IS 14791 provided the safe limits for presence of above-mentioned parameters in water.
Chemical Injection System Installed with DIS.	Chemical Inject Systems (venturi injector, injector pumps, differential pressure tanks) are used in conjunction with DIS for supplying fertilizers into the field. These equipment's should be well test before installing.
Different Blockage Problems associated with DIS.	• Solid Contaminants • Dissolved Contaminants - Biological or Chemical Clogging Problem • Emitter Suck-back • Physical Blockage of Dripline/Lateral • Failure of Main Filtration System • Poor Maintenance of the System • Quality of Water

<table>
<tr><td>Method of Assessment of blockage problems</td><td>Driplines on Ground Surface : When driplines are laid on the surface, the degree of blockage can be checked by means of visual inspection and measuring the amount and uniformity of discharge through the emitters or orifices and comparing it with the specified discharge.

Dripline Buried Under Ground : When driplines are buried, it is not possible to check individual emitters or orifices by visual inspection and the flow rates in the driplines should be checked by one or more of the following methods:
By inserting a pressure gauge into the tail end of the dripline.
By measuring wetted perimeter.
Visual inspection of the field block for uneven growth of crop.
Measurement of discharge.</td></tr>
<tr><td>Prevention and treatment of blockage problem.</td><td>Physical Treatment :
Use of silting reservoir
use of Filters such as Hydrocyclone, screen filters, media filters, disc filters
Flushing of irrigation pipelines
Chemical Treatment :
Bacterial precipitation of Iron, Sulphur,
Aeration and settling, pH Control
Chlorination of water, Acid Treatment
Algae Control
Emitter Clogging by Roots : trifluorine/ pendimethalin / copper can be used for prevention
Emitter Suck-back</td></tr>
<tr><td>Safety Requirements</td><td>The resistance of drip irrigation components to the chemical used should be taken into consideration.
All chemicals-should be handled cautiously and should be stored in a secured place for the reasons of safety and hazardous nature of the products.
Irrigation water should not be used for consumption by human beings and animals.
Do not inhale acid fumes or chlorine gas.</td></tr>
</table>

Table 1 of IS 14791 Interpretation of Water Analysis

Sl. No.	Parameters	Degree of Presence/Problem			
		Unit	Normal	Higher	Extreme
(1)	(2)	(3)	(4)	(5)	(6)
i)	pH		6.5 - 8.5	4 - 6.5 & 8.5 - 10	pH<4 & pH >10
ii)	Electrical Conductivity (Salinity)	mmhos/cm	<0.8	0.8 - 3.0	>3.0
iii)	Total dissolved solids	ppm	<500	500 - 600	>600
iv)	Hardness	ppm	<200	200 - 300	>300
v)	Calcium	ppm	<60	60 - 100	>100
vi)	Magnesium	ppm	<25	25 - 40	>40
vii)	Carbonate	ppm	<200	200 - 600	>600
viii)	Bicarbonate	ppm	<200	200 - 600	>600
ix)	Chloride (Toxic)	ppm	<140	140 - 350	>350
x)	Sulphates	ppm	<20	20 - 50	>50
xi)	Sodium	ppm	<100	100 - 200	>200
xii)	SAR	-	<3	3 - 9	>9
xiii)	Potassium	ppm	<10	10 - 20	>20
xiv)	Sulphides	ppm	<15	15 - 25	>25
xv)	Iron	ppm	<0.1	0.1 - 0.4	>0.4
xvi)	Manganese	ppm	<0.2	0.2 - 0.4	>0.4
xvii)	Suspended solids	ppm	<10	10 - 100	>100
xviii)	Permeability a) Caused by low salts (EC) b) Caused by sodium	 mmho/cm SAR	 >0.5 <6.0	 0.5 - 0.2 6.0 - 9.0	 <0.2 >9.0

xix)	Toxicity				
	a) Sodium	ppm	<3.0	3.0 - 9.0	>9.0
	b) Chloride	ppm	<140	140 - 350	>350
	c) Boron	ppm	<0.5	0.5 - 2.0	>2.0
xx)	Clogging				
	a) Iron	ppm	<0.1	0.1 - 0.4	>0.4
	b) Manganese	ppm	<0.2	0.2 - 0.4	>0.4
	c) Sulphides	ppm	<0.1	0.1 - 0.2	>0.4
	d) Calcium carbonates	ppm	No level Established	No level Established	No level Established

ABOUT IS 14792: 2000 IRRIGATION EQUIPMENT — DESIGN, INSTALLATION AND OPERATION OF SPRINKLER IRRIGATION SYSTEMS — CODE OF PRACTICE

This standard prescribes the procedure for the design, installation and operation of sprinkler systems used for irrigation of agricultural lands, orchards, lawns and land scoped areas.

HYDROLOGICAL DESIGN

- Depth of Water Application
- Effective Crop Root Depths
- Net Depth of Application
- Leaching Requirement
- Gross Depth of Application
- Estimation of Soil Moisture Loss by Evaporation and Transpiration

Table : Potential Evapotranspiration (PET) (Clause 3.5)

Sl. No.	Climate	mm of Water Used per Day
(1)	(2)	(3)
i)	Cool humid	2.5-3.8
ii)	Cool dry	3.8-5.1
iii)	Warm humid	3.8-5.1
iv)	Warm dry	5.1-6.3
v)	Hot humid	5.1-7.6

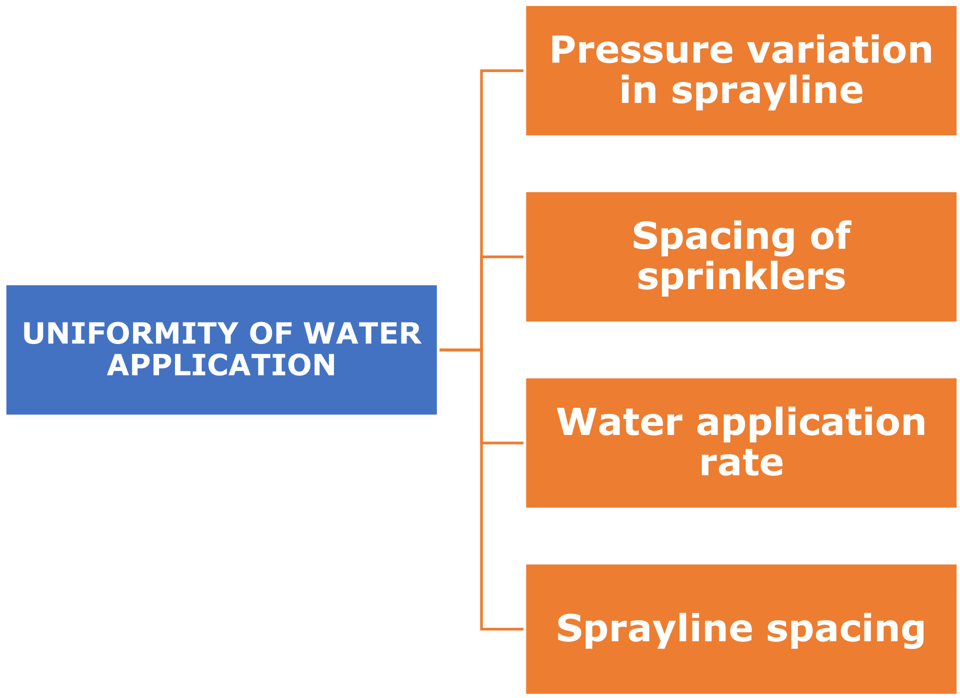
APPLICATION RATE

- 0.8° slope — level to undulating.
- 9°-12.5° slope — undulating to low hill.
- over 12.5° slope — low to steep hills.

Table: Estimated Maximum Water Application Rates for Design

Sl. No.	Soil Groups Based on Texture and Profile	Slopes[1)] 0-8°	Slopes[2)] 9° to 12.5°	Slopes[3)] over 12.5°
i)	Sands and light sandy loams uniform in texture to 1.82 m pumice	31.8	25.4	20.3
ii)	Sandy loams to 0.61 m overlaying a heavier subsoil	20.3	16.5	12.7
iii)	Medium loams to sandy clays over a heavier subsoil	16.5	12.7	10.2
iv)	Clay loams over a clay subsoil	12.7	10.2	7.6
v)	Silt loams and silt clay	10.2	7.6	5.1
vi)	Clays	6.4	5.1	3.8
vii)	Peat	16.5	-	-

see IS 14792 for more details



Lateral spacing (6.2.4.1)

Sl. No.	Wind Velocity (km/h)	Lateral Spacing (% of wetting diameter)
i)	No wind	65
ii)	< 8	60
iii)	8 to 16	50
iv)	> 16	30

Sprinkler spacing (6.2.4.2)

Sl. No.	Pattern	Wind Velocity (km/h	Sprinkler Spacing (% of wetting diameter)
(1)	(2)	(3)	(4)
i)	Square or Rectangular	No wind	65
ii)		< 7	60
iii)		7 to 13	50
iv)		> 13	30

INSTALLATION

Buried Mains - Particular attention is drawn to the necessity for concrete anchor blocks of sufficient size being provided at any significant change in direction or grade, change in diameter, major branch connection or terminal, and adjacent to any values or fittings that may give rise to hydraulic loading along the line.

Pumps and Prime Mover - Internal combustion engines shall be provided with protective devices. Devices shall be supplied that stop the engine if a) engine temperature exceeds the safety point for the prime move and b) oil pressure falls below the minimum specified; or pressure because of loss of suction or reduction in delivery pressure.

OPERATION

The purchaser shall be supplied with written operational data, performance, and layout details of the system and its components including:

a. sprinkler make model, performance, and nozzle diameter.
b. design layout of spraying.
c. design pump duty; and
d. correct range of operating pressures for the system.

The supplier or his agent shall demonstrate the important aspects regarding the operation, care, and maintenance of the unit including methods of shifting and setting up the portable components of the system. Wiring and starting equipment for electrically operated planta shall comply with Electrical Code 1985. Electric motors shall be provided with overload, low-voltage, and inter-phase variation protection. Pumps, power units, and transmission shall be effectively guarded.

RESPONSIBILITIES OF MANUFACTURER/DEALER

- *Investigation*
- *Design and information to the purchaser before the sale*
- *Installation*

RESPONSIBILITIES OF PURCHASER

- Request for service
- Purchase for equipment

About IS 11624 : 2019 QUALITY OF IRRIGATION WATER — GUIDELINES (*first revision*)

The quality of irrigation water is important because it directly affects crop growth, soil health, and overall agricultural productivity. Poor-quality water can introduce salts, toxins, or harmful elements into the soil, leading to reduced crop yields, soil degradation, and long-term fertility issues. Proper water quality ensures efficient nutrient uptake, sustainable farming practices, and minimizes environmental damage.

The quality of irrigation water is evaluated in terms of degree of harmful effects on soil properties with respect to the soluble salts it contains in different concentrations and crop yield. To evaluate the quality of irrigation water, this standard was formulated as a guideline.

IS 11624 prescribes the guidelines for assessing the quality of irrigation water.

SUITABILITY CRITERIA

The suitability of irrigation water depends upon several factors, such as, water quality, soil type, plant characteristics, irrigation method, drainage, climate and the local conditions. The integrated effect of these factors on the suitability of irrigation water (SI) can be qualitatively expressed by the relationship:

$$SI \propto QSPCD$$

Where,

- ***Q*** – quality of irrigation water, that is, total salt concentration, relative proportion of cations/ anions, etc;
- ***S*** – soil type, texture, structure, permeability, fertility, calcium carbonate content, type of clay minerals and initial level of salinity and alkalinity before irrigation;
- ***P*** – salt tolerance characteristics of the crop and its varieties to be grown, and growth stage usually categorized as tolerant, semi-tolerant and sensitive;
- ***C*** – climate, that is the total rainfall, its distribution and evaporation characteristics;
- ***D*** – drainage conditions, depth of water table, nature of soil profile, presence of hard pan or lime concentration and management practices.

•

WATER QUALITY CRITERIA FOR IRRIGATION

a) Total salt concentration (electrical conductivity (EC)
b) pH (6.5 to 8.4 pH)
c) Sodium adsorption ratio;
d) Residual sodium carbonate (RSC) or bicarbonate ion Concentration

$$\mathbf{RSC = (CO_3^{2-} + HCO^{3-}) - (Ca^{2+} + Mg^{2+})}$$

$$SAR = \frac{Na^{++}}{\sqrt{\frac{(Ca^{++}+Mg^{++})}{2}}}$$

where
SAR – sodium adsorption ratio (millimole/litre)$^{1/2}$
Na^+ – sodium ion concentration, me/litre;
$Ca_2{}^+$ – calcium ion concentration, me/litre; and
$Mg_2{}^+$ – magnesium ion concentration, me/litre.

When SAR is more than 10, it could be high SAR saline or high SAR alkali depending upon the EC or RSC of the irrigation water.

e) Mg/Ca Ratio - If Mg/Ca ratio is more than 3.0 addition of gypsum is required to minimize the Mg on the exchange complex of the soils. However, calcium: magnesium ratio above 2.0 in water is beneficial.

f) Cl/SO4 Ratio - Cl salinity is more harmful than the salinity due to SO4 ions. If Cl/SO4 ratio is more than 2, additional steps are required to minimize the harmful effect of chloride ions. On the other hand, sulphate: chloride ratio of more than 2.0 is beneficial.

Table 1 Grouping of Poor Quality Ground Water for Irrigation in India
(*Clauses* 5.1.1 *and* 5.1.3)

Sl No.	Water Quality	ECiw (dS/m)	SARiw (millimole/litre)$^{1/2}$	RSC (me/l)
(1)	(2)	(3)	(4)	(5)
i)	Good	< 0.7	< 10	< 2.5
ii)	Saline:			
	a) Marginally saline	0.7 to 3.0	< 10	< 2.5
	b) Saline	> 3	< 10	< 2.5
	c) High-SAR saline	> 3	> 10	< 2.5
iii)	Alkali water:			
	a) Marginally alkali	< 4	< 10	2.5 – 4.0
	b) Alkali	< 4	< 10	> 4.0
	c) High-SAR alkali	Variable	> 10	> 4.0
iv)	Toxic water	The toxic water has variable salinity, SAR and RSC but has excess of specific ions such as chloride, sodium, nitrate, boron, fluoride, or heavy metals such as selenium, cadmium, lead and arsenic, etc		

g) Boron content **-** Boron, though a nutrient, becomes toxic if present in water beyond a particular level. In relation to boron toxicity, the irrigation water quality rating is given in Table 2.

Table 2 Water Quality Rating Based on Boron Content
(*Clause* 5.1.7.1)

Sl No.	Class	Boron (mg/l)
(1)	(2)	(3)
i)	Low	Below 1.0
ii)	Medium	1.0 – 2.0
iii)	High	2.0 – 4.0
iv)	Very high	Above 4.0

WATER QUALITY IN RELATION TO IMPROVED IRRIGATION TECHNIQUES

- Concentrations of ferrous iron as low as 0.15 - 0.20 mg/l are considered as a potential hazard for clogging of drip systems. Concentrations of manganese should be < 0.10 mg/l for no problem
- For sprinkler irrigation bicarbonate less than 1.5 me/l does not pose much problems but the problems increase and become severe when the bicarbonate content is 8.5 me/l.

WATER QUALITY RATING IN RELATION TO SOIL TYPE, RAINFALL AND CROP TOLERANCE TO SALTS

Table 3 Suitability of Poor Quality Saline Ground Waters (RSC < 2.5 me/l, SAR <10 $(mmol/l)^{1/2}$ for Irrigation in India
(*Clauses* 5.1.5 *and* 6.1)

Sl No	Soil Texture Group	Crop Tolerance	ECiw(dS/m) Limit for Rainfall (mm) Region		
			< 350	350 – 550	> 550
(1)	(2)	(3)	(4)	(5)	(6)
i)	Fine	S	1.0	1.0	1.5
ii)	(>30 percent clay)	ST	1.5	2.0	3.0
iii)	Sandy clay, clay loam, silty clay loam, silty clay, clay	T	2.0	3.0	4.5
iv)	Moderately fine	S	1.5	2.0	2.5
v)	(20 to 30 percent clay)	ST	2.0	3.0	4.5
vi)	Sandy clay loam, loam, silty loam	T	4.0	6.0	8.0
vii)	Moderately coarse	S	2.0	2.5	3.0
viii)	(10 to 20 percent clay)	ST	4.0	6.0	8.0
ix)	Sandy loam, loam, silty loam	T	6.0	8.0	10.0
x)	Coarse	S	--	3.0	3.0
xi)	(<10 percent clay)	ST	6.0	7.5	9.0
xii)	Sand, loamy sand, sandy loam, silty loam, silt	T	8.0	10.0	12.5

Table 7 Crop Groups Based on Response to Soil Salinity
(*Clause* 7)

Sl No.	Sensitive Group		Resistant Group	
	Highly Sensitive	Medium Sensitive	Medium Tolerant	Highly Tolerant
(1)	(2)	(3)	(4)	(5)
i)	Lentil	Radish	Spinach	Barley
ii)	Mash	Cow pea	Sugarcane	Cotton
iii)	Chickpea	Broad bean	Indian mustard	Sugar beet
iv)	Beans	Vetch	Rice (transplanted)	Turnip
v)	Peas	Cabbage	Wheat	Tobacco
vi)	Carrot	Cauliflower	Pearl millet	Safflower
vii)	Onion	Cucumber	Oats	Rapeseed
viii)	Lemon	Gourds	Alfalfa	Karnal grass
ix)	Orange	Tomato	Blue panic grass	Date palm
x)	Grape	Sweet potato	Para grass	Ber
xi)	Peach	Sorghum	Rhodes grass	*Mesquite*
xii)	Plum	Minor millets	Sudan grass	*Casuarina*
xiii)	Pear	Maize	Guava	*Tamarix*
xiv)	Apple	Clover, *berseem*	Pomegranate	*Salvadora*
xv)			*Acacia*	

Table 9 Relative Tolerance of Crops to Boron
(*Clause* 7)

Sensitive (<1 mg/l)	Semi-Tolerant (1.0-2.0 mg/l)	Tolerant (2.0-4.0 mg/l)
Apple	Sunflower	Date palm
Grape	Potato	Sugar beet
Cherry	Cotton	Garden beet
Peach	Tomato	Alfalfa
Orange	Radish	Gladiolus
Grapefruit	Field pea	Broad bean
Lemon	Barley	Onion
	Wheat	Turnip
	Corn	Cabbage
	Rice	Lettuce
	Oat	Carrot
	Bell pepper	Cauliflower
	Sweet potato	

CONCLUSION

Key Specifications of few standards and Testing in Short

To ensure performance and reliability, the components of micro-irrigation systems undergo several tests as outlined in the standards.

These include:

- Hydrostatic pressure tests for pipes, emitters, sprinklers, valves assess their strength and performance under high pressure.
- Emitter pull-out tests to evaluate the robustness of emitters against mechanical stress.
- Uniformity tests for emitters and emitting pipes to ensure consistent water delivery across the system.
- Valve endurance tests to verify their performance under repeated use and varying pressures.

Importance of Standards

Why are these standards important?

- They ensure that irrigation systems perform optimally, even under challenging conditions.
- They promote water conservation by minimizing wastage and ensuring uniform application.
- They enhance compatibility between components, making installation and maintenance more straightforward.
- In essence, these standards are key to advancing sustainable agriculture in India.

Micro-irrigation systems are game-changer in modern agriculture. By adhering to established standards, we can ensure these systems deliver maximum efficiency, durability, and environmental sustainability.

LIST STANDARDS ON MICRO IRRIGATION

S.No.	IS No.	Title
1.	**IS 10799 : 1999**	Irrigation equipment — Design, installation and field evaluation of micro irrigation systems — Code of practice (*first revision*)
2.	**IS 11077 : 1984**	Glossary of Terms on Soil and Water
3.	**IS 11624 : 2019**	Quality of Irrigation Water — Guidelines (*first revision*)
4.	**IS 11711 : 1986**	Recommended Criteria for Adoptability of Different Irrigation Methods
5.	**IS 12232 : Part 1 : 1996/ISO 7749-1 : 1995**	Irrigation equipment — Rotating sprinkler: Part 1 Design and operational requirements (*first revision*)
6.	**IS 12232 (Part 2) : 1995**	Irrigation equipment — Rotating sprinkler: Part 2 Test method for uniformity of distribution (*first revision*)
7.	**IS 12785 : 1994**	Irrigation equipment — Strainer-type filters— Specification (*first revision*)
8.	**IS 12786 : 2024**	Irrigation equipment — Polyethylene pipes for irrigation laterals — Specification (*first revision*)
9.	**IS 13062 : 1991**	Irrigation Equipment and Systems — Evaluation of Field Irrigation Efficiencies — Guidelines
10.	**IS 13487 : 2024**	Irrigation Equipment — Emitters — Specification (first revision)
11.	**IS 13488 : 2008**	Irrigation Equipment - Emitting Pipe Systems - Specification (*first revision*)
12.	**IS 14178 : 1994**	Pressurized Irrigation Equipment Terminology
13.	**IS 14482 : 1997**	Irrigation Equipment — Polyethylene Micro Tubes for Drip Irrigation — Specification
14.	**IS 14483 (Part 1) : 2024**	Fertilizer and chemical injection system Part 1 Venturi injector — Specification (f*irst revision*)
15.	**IS 14483 (Part 2) : 2025**	Fertilizer and chemical injection system: Part 2 Water-driven chemical injector pump — Specification
16.	**IS 14483 (Part 3) : 2018**	Fertilizer and chemical injection system: Part 3 Fertilizer tank — Specification
17.	**IS 14605 : 1998**	Irrigation Equipment — Micro Sprayers — Specification
18.	**IS 14606 : 2022**	Irrigation Equipment — Granulated Media Filters — Specification (f*irst revision*)

19.	**IS 14743 : 2024**	Irrigation equipment - Hydrocyclone filters - Specification (*first revision*)
20.	**IS 14791 : 2024**	Prevention and treatment of blockage problem in drip irrigation system - Code of practice (*first revision*)
21.	**IS 14792 : 2000**	Irrigation equipment — Design, installation and operation of sprinkler irrigation systems — Code of practice
22.	**IS 15386 : 2003**	Pressurized Irrigation Systems — Graphic Symbols
23.	**IS 17425 : 2020**	Irrigation Equipment — Quick Coupled Polyethylene Pipes and Fittings for Sprinkler Irrigation Systems — Specification
24.	**IS 18286 : 2023**	Agricultural irrigation equipment — Manually operated serviceable plastics valves — Specification
25.	**IS 4984 : 2016**	Polyethylene pipes for water supply — Specification (*fifth revision*)
26.	**IS 4985 : 2021**	Unplasticized PVC pipes for potable water supplies — Specification (*fourth revision*)
27.	**FAD 17 (24278) WC**	Irrigation techniques — Localized and remote monitoring and control system for irrigation — Tests