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ASRB-NET

AGRONOMY

Agricultural Scientists Recruitment Board (ASRB)

VOLUME – 4

SIERRA INNOVATIONS

ASRB - NET (Agronomy)

S.N.	Content	P.N.
	UNIT – XII IRRIGATION WATER MANAGEMENT	
1.	Management of Irrigation Water and History of Irrigation in India	1
2.	Major Irrigation Projects in India	5
3.	Water Resources Development	9
4.	Crop Water Requirements	13
5.	Concepts of Irrigation Scheduling	17
6.	Approaches of Irrigation Scheduling	21
7.	Soil Water Depletion, Plant Indices, and Climatic Parameters	26
8.	Critical Stages of Crop Growth in Relation to Water Supplies	34
9.	Methods of Irrigation, Merits, and Demerits	39
10.	Water Management, Legislation, Quality, Conjunctive Use, Irrigation Strategies, Socio-Economic Aspects, Distribution, And Fertilizer Interactions	46
	UNIT – XIII MANAGEMENT OF PROBLEMATIC SOILS AND WATER	
1.	Problem Soils and Their Distribution in India	57
2.	Salt-Affected Soils	61
3.	Acidic Soils	67
4.	Waterlogged Soils	72
5.	Groundwater Resources and Water Quality Criteria	76
6.	Use of Brackish Waters in Agriculture	82
7.	Excess Salt and Salt-Tolerant Crops	88
8.	Hydrological Imbalances and Corrective Measures	93
9.	Critical Water Table Depths and Shallow Water Table Contribution	99
10.	Management Strategies for Flood Prone Areas, Drainage, and Alternate Uses	106
	UNIT – XIV ORGANIC FARMING	
1.	Concept, Definitions, Components, Types, and Relevance of Organic Farming	114
2.	Principles of Organic Farming	119
3.	Organics and Farming Standards	126
4.	Organic Farming and Sustainable Agriculture	134

5.	**Management Practices in Organic Farming**	**139**
6.	**Soil Fertility and Nutrient Management**	**144**
7.	**Water and Fertilizer Use Efficiency, Nutrient Recycling, and Related Technologies**	**152**
8.	**Integrated Organic Farming Systems and Cropping Patterns**	**159**
9.	**Weeds, Diseases, Insect Pest Management, and Food Safety**	**164**
10.	**Socio-Economic Impacts, Marketing, Certification, Losses, and Ethics**	**173**
11.	**Fact Check**	**184**

XII UNIT

Irrigation Water Management

Management of Irrigation Water and History of Irrigation in India

Introduction

Irrigation water management is pivotal for optimizing water use in Indian agriculture, where 48% of arable land is irrigated and water scarcity impacts crops like rice, wheat, and cotton, contributing to 15–40% yield losses in rainfed systems (ICAR, 2023). Effective management ensures efficient water delivery, enhances water use efficiency (WUE), and sustains productivity. The history of irrigation in India, from ancient systems to modern projects, underscores its role in agricultural development. This part emphasizes irrigation management and historical context for their significance in crop production. This part explores irrigation water management principles, historical developments, and applications in Indian agriculture

Management of Irrigation Water

Definition and Importance

Irrigation water management involves the planned application, distribution, and conservation of water to meet crop needs, minimize losses, and enhance WUE. It encompasses scheduling, method selection, and resource allocation to optimize crop growth and yield. In India, where agriculture consumes 80% of freshwater, efficient management is critical for crops like rice (4–6 t/ha), wheat (3–5 t/ha), and cotton (1.5–2 t/ha), especially in water-scarce regions like Rajasthan and Gujarat.

Importance:

- **Yield Enhancement**: Ensures water availability at critical stages (e.g., wheat in Haryana).
- **Water Conservation**: Reduces losses from runoff and deep percolation (e.g., drip irrigation in Gujarat).
- **Sustainability**: Prevents salinization and waterlogging (e.g., rice in Punjab).
- **Economic Benefits**: Lowers irrigation costs, increases farmer income (e.g., sugarcane in Maharashtra).
- **Example**: Drip irrigation in Gujarat's cotton fields saves 30% water, sustaining yields of 1.5–2 t/ha.

Principles of Irrigation Water Management

1. **Matching Water Supply to Crop Demand**:
   - Align irrigation with crop water requirements (e.g., 600–800 mm for cotton).
   - Use scheduling to apply water at critical stages (e.g., flowering in wheat).
   - **Example**: Irrigating rice in Punjab at panicle initiation ensures 4–6 t/ha yields.
2. **Minimizing Water Losses**:
   - Reduce runoff, evaporation, and deep percolation through efficient methods (e.g., drip, sprinkler).
   - **Example**: Mulching in Rajasthan's millets cuts evaporation by 20%.
3. **Optimizing Water Use Efficiency (WUE)**:
   - Maximize yield per unit of water (e.g., 5–10 kg/ha/mm for wheat).
   - Use precision irrigation (e.g., drip in Maharashtra's sugarcane).
   - **Example**: Drip irrigation in Gujarat's cotton achieves WUE of 8 kg/ha/mm.
4. **Maintaining Soil and Water Quality**:
   - Prevent salinization (EC < 4 dS/m) and waterlogging through drainage.
   - **Example**: Gypsum application in Gujarat's saline soils maintains EC < 2 dS/m.

5. **Integrating Water Resources**:
   - o Combine canal, groundwater, and rainwater for conjunctive use.
   - o **Example**: Conjunctive use in Andhra Pradesh's groundnut fields balances canal and groundwater.

Strategies for Irrigation Water Management

1. **Irrigation Scheduling**:
   - o Time applications based on soil moisture, plant indices (e.g., CTD), or climate (e.g., ET).
   - o **Example**: Soil moisture-based scheduling in Haryana's wheat fields applies 50 mm at 50% depletion.
2. **Efficient Irrigation Methods**:
   - o Use drip or sprinkler systems to reduce losses (e.g., 30–50% water savings).
   - o **Example**: Drip irrigation in Maharashtra's sugarcane saves 30% water.
3. **Water Harvesting and Storage**:
   - o Build farm ponds, check dams to store rainwater (e.g., 5,000 m^3/ha).
   - o **Example**: Farm ponds in Rajasthan provide 50 mm irrigation for millets.
4. **Soil Management**:
   - o Apply organic amendments (e.g., FYM) to improve water retention.
   - o **Example**: FYM (5 t/ha) in Madhya Pradesh's soybean fields increases water-holding capacity by 15%.
5. **Monitoring and Technology**:
   - o Use sensors (e.g., tensiometers, TDR) for real-time water status.
   - o **Example**: Tensiometers in Punjab's rice fields guide irrigation at –0.33 MPa.

PYQ Analysis

1. "What is irrigation water management?"
   (A) Nutrient application
   (B) Water application optimization
   (C) Soil aeration
   (D) Pest control

Answer: (B) Water application optimization.

Explanation: Management optimizes water use for crops.

2. "What enhances WUE in irrigation?"
   (A) Flood irrigation
   (B) Drip irrigation
   (C) Deep tillage
   (D) Bare soil

Answer: (B) Drip irrigation.

Explanation: Drip systems reduce losses, improving WUE.

3. "What prevents waterlogging?"
   (A) Mulching
   (B) Drainage
   (C) High irrigation
   (D) Sandy soil

Answer: (B) Drainage.

Explanation: Drainage removes excess water.

4. "What guides irrigation scheduling?"
   (A) Soil moisture
   (B) Soil pH
   (C) Nutrient levels
   (D) Pest density

Answer: (A) Soil moisture.

Explanation: Soil moisture determines irrigation timing.

5. "What conserves water in management?"
   (A) Runoff
   (B) Farm ponds
   (C) Evaporation
   (D) Deep percolation

Answer: (B) Farm ponds.

Explanation: Ponds store water for irrigation.

- **Trend**: PYQs focus on management principles, WUE, and technologies, with recent emphasis on scheduling and conservation.

History of Irrigation in India

Definition and Importance

The history of irrigation in India traces the evolution of water management systems from ancient to modern times, shaping agricultural productivity. From traditional wells to large-scale canal projects, irrigation has supported India's agrarian economy, critical for 48% irrigated land sustaining crops like rice, wheat, and sugarcane. Understanding this history highlights technological and policy advancements, informing modern management.

Importance:

- **Agricultural Development**: Enabled intensive cropping (e.g., rice-wheat in Punjab).
- **Food Security**: Supported Green Revolution (1960s–70s).
- **Economic Growth**: Increased farmer incomes via irrigation projects.
- **Sustainability**: Evolved to address water scarcity and salinization.
- **Example**: Canal irrigation in Punjab increased rice-wheat yields to 8–10 t/ha.

Historical Evolution

1. **Ancient Period (Pre-300 BCE)**:
   - **Systems**: Wells, tanks, and small canals (e.g., Indus Valley Civilization).
   - **Features**: Community-managed, rain-dependent, small-scale (e.g., 1–5 ha coverage).
   - **Example**: Tanks in Tamil Nadu (e.g., Kallanai dam, 1st century CE) irrigated rice.
2. **Medieval Period (300 BCE–1800 CE)**:
   - **Systems**: Persian wheels, inundation canals, stepwells.
   - **Features**: Improved lift irrigation, regional networks (e.g., Yamuna canals under Mughals).
   - **Example**: Mughal canals in Uttar Pradesh irrigated wheat, sugarcane.
3. **Colonial Period (1800–1947)**:
   - **Systems**: Large-scale canals (e.g., Ganga Canal, 1848), barrages.
   - **Features**: British engineering, covered 10–100,000 ha, focused on revenue.
   - **Example**: Upper Bari Doab Canal (1859) in Punjab supported wheat.
4. **Post-Independence (1947–Present)**:
   - **Systems**: Dams, reservoirs, tube wells, drip irrigation.
   - **Features**: Green Revolution (1960s), micro-irrigation (1990s), conjunctive use.
   - **Example**: Bhakra-Nangal Dam (1963) irrigates 1.4 Mha in Punjab, Haryana.
5. **Modern Era (2000–Present)**:
   - **Systems**: Precision irrigation (drip, sprinkler), watershed management.
   - **Features**: PMKSY (2015), focus on WUE, sustainability.
   - **Example**: Drip irrigation in Maharashtra's sugarcane fields saves 30% water.

Key Milestones

- **Kallanai Dam (2nd century CE)**: Oldest functional dam, irrigating 25,000 ha in Tamil Nadu.
- **Ganga Canal (1848)**: Irrigated 0.5 Mha in Uttar Pradesh, boosted wheat production.
- **Green Revolution (1960s)**: Tube wells, canals increased irrigated area to 40 Mha.
- **PMKSY (2015)**: Promotes micro-irrigation, covering 8 Mha by 2023.
- **Example**: Green Revolution doubled rice yields in Punjab to 4 t/ha by 1970s.

PYQ Analysis

1. "What marked ancient irrigation in India?"
   (A) Dams
   (B) Tanks
   (C) Tube wells
   (D) Sprinklers

Answer: (B) Tanks.
Explanation: Tanks were prevalent in ancient India.

2. "What system emerged in the Mughal era?"
   (A) Drip irrigation
   (B) Persian wheel
   (C) Tube wells
   (D) Sprinklers

Answer: (B) Persian wheel.
Explanation: Persian wheels improved lift irrigation.

3. "What boosted irrigation in colonial India?"
   (A) Wells
   (B) Canals
   (C) Drip systems
   (D) Farm ponds

Answer: (B) Canals.
Explanation: Colonial canals expanded irrigation.

4. “What drove the Green Revolution?”
   (A) Tanks
   (B) Tube wells
   (C) Stepwells
   (D) Inundation canals

Answer: (B) Tube wells.

Explanation: Tube wells supported intensive cropping.

5. “What promotes modern irrigation?”
   (A) Persian wheel
   (B) PMKSY
   (C) Ganga Canal
   (D) Tanks

Answer: B) PMKSY.

Explanation: PMKSY promotes micro-irrigation.

- **Trend**: PYQs focus on historical irrigation systems and milestones, with recent emphasis on modern initiatives like PMKSY.

Applications in Indian Agriculture

Contextual Examples

1. **Rice-Wheat in Punjab**:
   - **Management**: AWD, canal irrigation (Bhakra-Nangal).
   - **History**: Green Revolution tube wells, colonial canals.
   - **Impact**: Yields 8–10 t/ha, saves 20% water with AWD.
   - **Example**: AWD maintains $\psi\_soil = -0.3$ MPa for rice.
2. **Wheat in Haryana**:
   - **Management**: Drip irrigation, soil moisture monitoring.
   - **History**: Post-independence canal expansion (Upper Bari Doab).
   - **Impact**: Yields 3–5 t/ha, improves WUE by 15%.
   - **Example**: Tensiometers guide irrigation at 50% depletion.
3. **Cotton in Gujarat**:
   - **Management**: Drip irrigation, gypsum for salinity.
   - **History**: Modern micro-irrigation under PMKSY.
   - **Impact**: Yields 1.5–2 t/ha, saves 30% water.
   - **Example**: Drip reduces deep percolation by 20%.
4. **Millets in Rajasthan**:
   - **Management**: Farm ponds, mulching.
   - **History**: Ancient tanks, modern watershed management.
   - **Impact**: Sustains 0.5–1 t/ha yields, enhances resilience.
   - **Example**: Ponds provide 50 mm irrigation during drought.
5. **Sugarcane in Maharashtra**:
   - **Management**: Drip irrigation, FYM for water retention.
   - **History**: Post-independence dams, modern drip systems.
   - **Impact**: Yields 60–80 t/ha, saves 30% water.
   - **Example**: Drip optimizes WUE at 10 kg/ha/mm.

Challenges

- **Water Scarcity**: Limited groundwater in Rajasthan, Gujarat.
- **Waterlogging**: Excess canal irrigation in Punjab.
- **Cost Barriers**: Drip systems expensive for small farmers (e.g., Maharashtra).
- **Farmer Awareness**: Limited adoption of modern methods (e.g., Karnataka).
- **Example**: High drip irrigation costs restrict use in Telangana’s sorghum fields.

Solutions

- **Subsidies**: PMKSY funds drip, sprinkler systems (e.g., Maharashtra).
- **Training**: Extension services for scheduling, monitoring (e.g., Tamil Nadu).
- **Water Harvesting**: Promote ponds, check dams (e.g., Rajasthan).
- **Community Management**: Cooperatives for canal maintenance (e.g., Punjab).
- **Example**: PMKSY subsidies in Gujarat increase drip adoption by 25%.

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Case Study: Irrigation Evolution in Punjab's Rice-Wheat System

In Punjab:

- **Crop**: Rice-wheat, irrigated, 800–1,000 mm rainfall.
- **Management**: AWD for rice, drip for wheat, canal irrigation (Bhakra-Nangal).
- **History**:
  - Ancient: Tanks, wells irrigated small rice fields.
  - Colonial: Upper Bari Doab Canal expanded wheat irrigation.
  - Post-Independence: Bhakra-Nangal (1963) irrigated 1.4 Mha, Green Revolution tube wells.
  - Modern: PMKSY promotes AWD, drip irrigation.
- **Challenges**: Waterlogging, groundwater depletion (2–3 m/year decline).
- **Strategies**:
  - AWD: Saves 20% water, maintains $\psi\_soil = -0.3$ MPa.
  - Tensiometers: Monitor soil moisture for scheduling.
  - FYM (5 t/ha): Increases water retention by 15%.
- **Impact**: Yields 8–10 t/ha, improves WUE by 20%, reduces waterlogging.
- **Integration**: Combines AWD, drip, and canal systems for sustainable irrigation. This case study illustrates irrigation management and historical evolution in intensive systems, a key exam concept.

Conclusion

This part has explored irrigation water management and the history of irrigation in India, critical for the ASRB NET JRF exam. Management principles like scheduling, drip irrigation, and water harvesting optimize WUE, as seen in Punjab's rice-wheat system. Historical developments from ancient tanks to modern PMKSY shape India's irrigation landscape.

Major Irrigation Projects In India

Introduction

Major irrigation projects in India are large-scale infrastructure initiatives, such as dams, reservoirs, and canal systems, designed to harness and distribute water for agricultural production, critical for a country where 48% of arable land is irrigated and water scarcity impacts crops like rice, wheat, and sugarcane (ICAR, 2023). These projects have transformed India's agrarian landscape, supporting food security and economic growth. This part emphasizes major irrigation projects for their role in water resource management and crop productivity. This part explores key irrigation projects, their scope, impacts, challenges, and applications in Indian agriculture.

Major Irrigation Projects in India

Definition and Importance

Major irrigation projects are defined as schemes with a command area exceeding 10,000 hectares, typically involving large dams, barrages, reservoirs, and extensive canal networks. Managed by central or state governments, these projects supply water for irrigation, hydropower, and domestic use, significantly enhancing agricultural output. In India, where agriculture consumes 80% of freshwater, major projects irrigate 40 million hectares, supporting crops like rice (4–6 t/ha), wheat (3–5 t/ha), and sugarcane (60–80 t/ha), particularly in states like Punjab, Uttar Pradesh, and Andhra Pradesh.

Importance:

- **Agricultural Productivity**: Increases crop yields through reliable water supply (e.g., rice-wheat in Punjab).
- **Food Security**: Supports Green Revolution, doubling food production (1960s–70s).
- **Economic Growth**: Enhances farmer incomes, rural development (e.g., sugarcane in Maharashtra).
- **Water Security**: Mitigates drought in rainfed areas (e.g., millets in Rajasthan).
- **Example**: Bhakra-Nangal project irrigates 1.4 Mha, sustaining 8–10 t/ha rice-wheat yields in Punjab.

Classification of Major Irrigation Projects

- **Storage-Based Projects**:
  - **Description**: Involve large dams and reservoirs to store monsoon runoff for year-round irrigation.
  - **Examples**: Bhakra-Nangal (Punjab), Sardar Sarovar (Gujarat), Hirakud (Odisha).
  - **Features**: High storage capacity (e.g., 9–12 billion m³), irrigate 0.5–2 Mha.
  - **Example**: Sardar Sarovar irrigates 1.8 Mha across Gujarat, Rajasthan.
- **Diversion-Based Projects**:
  - **Description**: Divert river water through barrages and canals without significant storage.
  - **Examples**: Upper Ganga Canal (Uttar Pradesh), Indira Gandhi Canal (Rajasthan).
  - **Features**: Cover 0.1–1 Mha, suited to perennial rivers.
  - **Example**: Indira Gandhi Canal irrigates 0.6 Mha in Rajasthan's desert.
- **Multipurpose Projects**:
  - **Description**: Combine irrigation, hydropower, flood control, and domestic water supply.
  - **Examples**: Damodar Valley (West Bengal), Nagarjuna Sagar (Andhra Pradesh).
  - **Features**: Integrate multiple benefits, irrigate 0.5–1.5 Mha.
  - **Example**: Nagarjuna Sagar irrigates 0.9 Mha, generates 800 MW power.

Key Major Irrigation Projects

1. **Bhakra-Nangal Project (Punjab, Haryana)**:
   - **Location**: Sutlej River, Punjab-Haryana border.
   - **Details**: Completed 1963, 1.4 Mha command area, 9.6 billion m³ storage, 1,325 MW power.
   - **Crops**: Rice, wheat, cotton.
   - **Impact**: Doubled Punjab's rice yields to 4 t/ha by 1970s, supports 8–10 t/ha rice-wheat.
   - **Example**: Irrigates 0.7 Mha in Punjab, enhancing food security.
2. **Sardar Sarovar Project (Gujarat, Rajasthan, Madhya Pradesh, Maharashtra)**:
   - **Location**: Narmada River, Gujarat.
   - **Details**: Completed 2017, 1.8 Mha command area, 12 billion m³ storage, 1,450 MW power.
   - **Crops**: Cotton, wheat, groundnut.
   - **Impact**: Transformed Gujarat's agriculture, irrigating 1.2 Mha, yields 1.5–2 t/ha cotton.
   - **Example**: Supports drip irrigation in Gujarat's Saurashtra region.
3. **Indira Gandhi Canal Project (Rajasthan)**:
   - **Location**: Beas-Sutlej rivers to Thar Desert, Rajasthan.
   - **Details**: Initiated 1958, 0.6 Mha command area, 450 km main canal.
   - **Crops**: Wheat, mustard, millets.
   - **Impact**: Converted desert into arable land, yields 0.5–1 t/ha millets.
   - **Example**: Irrigates 0.4 Mha in Bikaner, supporting mustard production.
4. **Nagarjuna Sagar Project (Andhra Pradesh, Telangana)**:
   - **Location**: Krishna River, Andhra Pradesh-Telangana.
   - **Details**: Completed 1974, 0.9 Mha command area, 11.5 billion m³ storage, 800 MW power.
   - **Crops**: Rice, groundnut, sugarcane.
   - **Impact**: Boosted rice yields to 4–6 t/ha, supports 0.5 Mha rice in Andhra Pradesh.
   - **Example**: Enables conjunctive use with groundwater in Telangana.
5. **Hirakud Project (Odisha)**:
   - **Location**: Mahanadi River, Odisha.
   - **Details**: Completed 1957, 0.25 Mha command area, 5.8 billion m³ storage, 350 MW power.
   - **Crops**: Rice, pulses, vegetables.
   - **Impact**: Irrigates 0.2 Mha, supports 4–5 t/ha rice yields.
   - **Example**: Mitigates drought in Sambalpur, enhancing pulse production.

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Impacts of Major Irrigation Projects

- **Agricultural Benefits**:
  - o Increased irrigated area to 40 Mha, boosting yields (e.g., 8–10 t/ha rice-wheat in Punjab).
  - o Enabled multiple cropping, raising cropping intensity to 140–150%.
  - o **Example**: Bhakra-Nangal supports rice-wheat rotation in Haryana.
- **Economic Benefits**:
  - o Raised farmer incomes by 20–30% through higher yields.
  - o Generated rural employment via canal maintenance, irrigation works.
  - o **Example**: Sardar Sarovar increased Gujarat's cotton income by 25%.
- **Social Benefits**:
  - o Improved food security, reducing hunger (e.g., Green Revolution).
  - o Enhanced rural infrastructure (e.g., roads, markets near projects).
  - o **Example**: Nagarjuna Sagar improved livelihoods in Andhra Pradesh.
- **Environmental Benefits**:
  - o Flood control, groundwater recharge in some areas.
  - o **Example**: Hirakud reduces flooding in Odisha's Mahanadi basin.

Challenges

1. **Waterlogging and Salinization**:
   - o Over-irrigation causes waterlogging (e.g., 10% of Punjab's command area), salinity (EC > 4 dS/m).
   - o **Example**: Indira Gandhi Canal causes salinity in Rajasthan's Ganganagar.
2. **Groundwater Depletion**:
   - o Over-reliance on tube wells in project areas (e.g., 2–3 m/year decline in Punjab).
   - o **Example**: Bhakra-Nangal overexploits groundwater in Haryana.
3. **Environmental Degradation**:
   - o Deforestation, displacement due to dam construction (e.g., 80,000 displaced by Sardar Sarovar).
   - o **Example**: Hirakud altered Mahanadi's ecology in Odisha.
4. **Inefficient Water Use**:
   - o Canal losses (30–40% due to seepage, evaporation) reduce efficiency.
   - o **Example**: Nagarjuna Sagar loses 25% water in canals.
5. **Financial Constraints**:
   - o High maintenance costs (e.g., ₹1,000 crore/year for Bhakra-Nangal).
   - o **Example**: Delayed repairs in Indira Gandhi Canal reduce water delivery.

PYQ Analysis

1. "Which is a major irrigation project?"
   (A) Farm ponds
   (B) Bhakra-Nangal
   (C) Tube wells
   (D) Check dams

Answer: (B) Bhakra-Nangal.

Explanation: Bhakra-Nangal is a major project with 1.4 Mha command area.

2. "What project irrigates Rajasthan's desert?"
   (A) Sardar Sarovar
   (B) Indira Gandhi Canal
   (C) Hirakud
   (D) Nagarjuna Sagar

Answer: B) Indira Gandhi Canal.

Explanation: It irrigates 0.6 Mha in Thar Desert.

3. "What is a multipurpose project?"
   (A) Upper Ganga Canal
   (B) Nagarjuna Sagar
   (C) Farm ponds
   (D) Stepwells

Answer: (B) Nagarjuna Sagar.

Explanation: It combines irrigation, power, and flood control.

4. "What challenge affects major projects?"
   (A) Waterlogging
   (B) High yields
   (C) Low costs
   (D) Soil fertility

Answer: A) Waterlogging.

Explanation: Over-irrigation causes waterlogging.

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5. “Which project supports Gujarat’s cotton?”
   (A) Bhakra-Nangal
   (B) Sardar Sarovar
   (C) Hirakud
   (D) Indira Gandhi Canal

Answer: B) Sardar Sarovar.

Explanation: It irrigates 1.2 Mha in Gujarat, supporting cotton.

- **Trend**: PYQs focus on project identification, command areas, and challenges, with recent emphasis on multipurpose projects and environmental impacts.

Applications in Indian Agriculture

Contextual Examples

- **Rice-Wheat in Punjab (Bhakra-Nangal)**:
  - **Scope**: Irrigates 0.7 Mha, supports rice-wheat rotation.
  - **Impact**: Yields 8–10 t/ha, ensures food security.
  - **Management**: AWD for rice, canal scheduling.
  - **Example**: AWD saves 20% water, maintains $\psi\_soil = -0.3$ MPa.
- **Wheat in Haryana (Bhakra-Nangal)**:
  - **Scope**: Irrigates 0.5 Mha, supports wheat, mustard.
  - **Impact**: Yields 3–5 t/ha, improves WUE by 15%.
  - **Management**: Drip irrigation, tensiometers.
  - **Example**: Irrigates at 50% soil moisture depletion.
- **Cotton in Gujarat (Sardar Sarovar)**:
  - **Scope**: Irrigates 1.2 Mha, supports cotton, groundnut.
  - **Impact**: Yields 1.5–2 t/ha, saves 30% water with drip.
  - **Management**: Drip irrigation, gypsum for salinity.
  - **Example**: Drip reduces deep percolation by 20%.
- **Millets in Rajasthan (Indira Gandhi Canal)**:
  - **Scope**: Irrigates 0.4 Mha, supports millets, mustard.
  - **Impact**: Yields 0.5–1 t/ha, transforms desert agriculture.
  - **Management**: Canal irrigation, farm ponds.
  - **Example**: Ponds provide 50 mm supplemental irrigation.
- **Rice in Andhra Pradesh (Nagarjuna Sagar)**:
  - **Scope**: Irrigates 0.5 Mha, supports rice, groundnut.
  - **Impact**: Yields 4–6 t/ha, enhances conjunctive use.
  - **Management**: Canal and groundwater integration.
  - **Example**: Conjunctive use saves 15% groundwater.

Challenges

- **Waterlogging**: Affects 10–15% of command areas (e.g., Punjab, Rajasthan).
- **Salinization**: High EC (>4 dS/m) in canal-irrigated soils (e.g., Gujarat).
- **Maintenance Costs**: High for canal repairs (e.g., ₹500 crore/year for Sardar Sarovar).
- **Equitable Distribution**: Small farmers receive less water (e.g., tail-end areas in Andhra Pradesh).
- **Example**: Waterlogging in Punjab’s Bhakra-Nangal command area reduces wheat yields by 10%.

Solutions

- **Drainage Systems**: Install subsurface drains to reduce waterlogging (e.g., Punjab).
- **Amendments**: Apply gypsum to manage salinity (e.g., Gujarat).
- **Subsidies**: Fund canal maintenance via PMKSY (e.g., Rajasthan).
- **Water User Associations (WUAs)**: Ensure equitable distribution (e.g., Andhra Pradesh).
- **Example**: WUAs in Nagarjuna Sagar improve tail-end water access by 20%.

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Case Study: Bhakra-Nangal Project in Punjab

In Punjab:

- **Crop**: Rice-wheat, irrigated, 800–1,000 mm rainfall.
- **Project**: Bhakra-Nangal, completed 1963, 1.4 Mha command area, 9.6 billion m^3 storage.
- **Challenges**: Waterlogging (10% area), groundwater depletion (2–3 m/year), salinity (EC = 4–6 dS/m in parts).
- **Scope and Impact**:
  - Irrigates 0.7 Mha in Punjab, supports rice-wheat yields of 8–10 t/ha.
  - Generates 1,325 MW power, supports rural electrification.
  - Enabled Green Revolution, doubling rice yields to 4 t/ha by 1970s.
- **Management**:
  - AWD for rice: Saves 20% water, maintains ψ_soil = –0.3 MPa.
  - Tensiometers: Schedule irrigation at –0.33 MPa.
  - Drainage Channels: Reduce waterlogging by 15%.
  - Gypsum (2 t/ha): Lowers EC to <2 dS/m in saline patches.
- **Measurement**:
  - Tensiometers: Monitor ψ_soil for scheduling.
  - Flow Meters: Track canal water delivery (e.g., 5,000 m^3/ha/season).
  - Soil Testing: Assess EC, salinity levels annually.
- **Impact**: Sustains 8–10 t/ha yields, improves WUE by 20%, mitigates waterlogging.
- **Integration**: Combines AWD, drainage, and gypsum for sustainable irrigation. This case study illustrates the impact of major irrigation projects in intensive systems, a key exam concept.

Conclusion

This part has explored major irrigation projects in India, critical for the ASRB NET JRF exam. Projects like Bhakra-Nangal (1.4 Mha), Sardar Sarovar (1.8 Mha), and Indira Gandhi Canal (0.6 Mha) irrigate 40 Mha, boosting yields, as seen in Punjab's rice-wheat system. Challenges like waterlogging and salinity are addressed through drainage and amendments.

Water Resources Development

Introduction

Water resources development encompasses the strategic planning, conservation, and utilization of surface and groundwater to meet agricultural, domestic, and industrial demands, critical for Indian agriculture where 48% of arable land is irrigated and water scarcity causes 15–40% yield losses in rainfed systems (ICAR, 2023). Effective development ensures sustainable water supply for crops like rice, wheat, and cotton, particularly in water-scarce regions like Rajasthan and Gujarat. This part emphasizes water resources development for its role in irrigation management and crop productivity. This part explores water resource types, development strategies, challenges, and applications in Indian agriculture

<u>Water Resources Development: Overview</u>

Definition and Importance

Water resources development involves the systematic harnessing, storage, distribution, and conservation of water resources (surface water, groundwater, and rainwater) to support agricultural production and other needs. It includes infrastructure like dams, canals, wells, and rainwater harvesting systems, as well as policies for sustainable use. In India, where agriculture consumes 80% of freshwater, developing water resources is vital for crops like rice (4–6 t/ha), wheat (3–5 t/ha), and sugarcane (60–80 t/ha), ensuring food security and economic stability.

Importance:

- **Irrigation Supply**: Provides reliable water for crops (e.g., rice-wheat in Punjab).
- **Drought Mitigation**: Supports rainfed agriculture (e.g., millets in Rajasthan).
- **Groundwater Recharge**: Sustains tube wells in water-scarce areas (e.g., Gujarat).
- **Sustainability**: Prevents overexploitation and salinization (e.g., Andhra Pradesh).
- **Example**: Rainwater harvesting in Rajasthan's farm ponds provides 50 mm irrigation, sustaining millet yields of 0.5–1 t/ha.

Types of Water Resources

1. **Surface Water**:
   - **Description**: Water in rivers, lakes, reservoirs, and canals (e.g., Ganga, Krishna).
   - **Contribution**: Accounts for 60% of irrigation water, irrigating 25 Mha.
   - **Sources**: Major rivers (e.g., Indus, Brahmaputra), dams (e.g., Bhakra-Nangal).
   - **Example**: Ganga Canal irrigates 0.5 Mha in Uttar Pradesh for wheat.
2. **Groundwater**:
   - **Description**: Water stored in aquifers, accessed via wells and tube wells.
   - **Contribution**: Supplies 40% of irrigation water, irrigating 20 Mha.
   - **Sources**: Alluvial aquifers (e.g., Indo-Gangetic plains), hard rock aquifers (e.g., Deccan).
   - **Example**: Tube wells in Punjab irrigate 0.7 Mha for rice-wheat.
3. **Rainwater**:
   - **Description**: Precipitation captured through harvesting systems (e.g., ponds, check dams).
   - **Contribution**: Supports 10–15% of irrigation in rainfed areas (e.g., 300–600 mm rainfall).
   - **Sources**: Monsoon rainfall (e.g., 800–1,000 mm in Punjab).
   - **Example**: Farm ponds in Telangana store 5,000 m³/ha for sorghum irrigation.

Strategies for Water Resources Development

- **Surface Water Development**:
- **Infrastructure**: Build dams, reservoirs, and canals (e.g., Sardar Sarovar, 1.8 Mha).
- **Management**: Improve canal efficiency, reduce seepage (30–40% losses).
- **Example**: Nagarjuna Sagar canal irrigates 0.9 Mha in Andhra Pradesh.
- **Groundwater Development**:
  - **Infrastructure**: Install tube wells, recharge structures (e.g., percolation tanks).
  - **Management**: Regulate extraction to prevent depletion (e.g., 2–3 m/year decline in Punjab).
  - **Example**: Recharge wells in Gujarat raise groundwater levels by 1–2 m.
- **Rainwater Harvesting**:
  - **Infrastructure**: Construct farm ponds, check dams, contour bunds.
  - **Management**: Promote watershed management for runoff capture.
  - **Example**: Check dams in Rajasthan store 10,000 m³/ha, supporting millets.
- **Conjunctive Use**:
  - **Approach**: Combine surface water, groundwater, and rainwater to optimize supply.
  - **Management**: Alternate canal and well irrigation to balance resources.
  - **Example**: Conjunctive use in Andhra Pradesh's groundnut fields saves 15% groundwater.
- **Policy and Legislation**:
  - **Initiatives**: PMKSY (2015), National Water Policy (2012).
  - **Management**: Enforce water allocation, promote WUE through subsidies.
  - **Example**: PMKSY funds drip irrigation in Maharashtra, covering 0.5 Mha.

Technologies for Water Resources Development

1. **Dams and Reservoirs**:
   - Store monsoon water (e.g., 9–12 billion m³), irrigate 10–20 Mha.
   - **Example**: Bhakra-Nangal stores 9.6 billion m³, irrigating 1.4 Mha.
2. **Canal Systems**:
   - Distribute surface water (e.g., 450 km Indira Gandhi Canal).
   - **Example**: Upper Ganga Canal irrigates 0.5 Mha in Uttar Pradesh.
3. **Tube Wells and Pumps**:
   - Extract groundwater (e.g., 200–300 m depth in Punjab).
   - **Example**: 1.2 million tube wells irrigate 0.7 Mha in Haryana.
4. **Rainwater Harvesting Structures**:
   - Capture runoff in ponds, tanks (e.g., 5,000 m³/ha capacity).
   - **Example**: Farm ponds in Madhya Pradesh support soybean irrigation.

5. **Remote Sensing and GIS**:
   - Monitor water availability, plan infrastructure (e.g., watershed mapping).
   - **Example**: GIS maps aquifers in Gujarat for recharge planning.

Challenges in Water Resources Development

- **Water Scarcity**:
  - Declining per capita water availability (1,500 m³ in 2025 vs. 5,000 m³ in 1950).
  - **Example**: Rajasthan's low rainfall (300–400 mm) limits surface water.
- **Groundwater Depletion**:
  - Overexploitation (e.g., 2–3 m/year decline in Punjab, Haryana).
  - **Example**: Gujarat's aquifers drop 1–2 m/year due to tube wells.
- **Waterlogging and Salinization**:
  - Over-irrigation causes waterlogging (10% of canal areas), salinity (EC > 4 dS/m).
  - **Example**: Punjab's canal-irrigated areas face waterlogging, reducing wheat yields by 10%.
- **Infrastructure Maintenance**:
  - High costs (e.g., ₹500 crore/year for Bhakra-Nangal), seepage losses (30–40%).
  - **Example**: Indira Gandhi Canal's seepage reduces water delivery by 25%.
- **Inter-State Disputes**:
  - Conflicts over river water sharing (e.g., Cauvery, Krishna).
  - **Example**: Tamil Nadu-Andhra Pradesh dispute over Krishna water affects rice irrigation.

PYQ Analysis

1. "What is a key water resource for irrigation?"
   (A) Soil moisture
   (B) Surface water
   (C) Air humidity
   (D) Plant sap

Answer: (B) Surface water.
Explanation: Surface water irrigates 25 Mha in India.

2. "What supports groundwater development?"
   (A) Dams,
   (B) Tube wells,
   (C) Farm ponds,
   (D) Canals.

Answer: (B) Tube wells.
Explanation: Tube wells extract groundwater for irrigation.

3. "What captures rainwater?"
   (A) Canals
   (B) Check dams
   (C) Tube wells
   (D) Barrages

Answer: (B) Check dams.
Explanation: Check dams store runoff for irrigation.

4. "What challenge affects water resources?"
   (A) High yields,
   (B) Groundwater depletion,
   (C) Soil fertility,
   (D) Low costs.

Answer: B) Groundwater depletion.
Explanation: Overexploitation depletes aquifers.

5. "What promotes conjunctive use?"
   (A) PMKSY
   (B) Green Revolution
   (C) Ganga Canal
   (D) Persian wheel

Answer: (A) PMKSY.
Explanation: PMKSY encourages integrated water use.

- **Trend**: PYQs focus on water resource types, development strategies, and challenges, with recent emphasis on conjunctive use and policies.

Applications in Indian Agriculture

Contextual Examples

1. **Rice-Wheat in Punjab**:
   - **Resources**: Surface water (Bhakra-Nangal canals), groundwater (tube wells).
   - **Development**: Canal expansion, recharge wells.
   - **Impact**: Yields 8–10 t/ha, sustains food security.
   - **Management**: AWD, conjunctive use save 20% water.

2. **Wheat in Haryana**:
    - o **Resources**: Groundwater (tube wells), surface water (canals).
    - o **Development**: Recharge structures, PMKSY-funded drip systems.
    - o **Impact**: Yields 3–5 t/ha, improves WUE by 15%.
    - o **Management**: Tensiometers guide irrigation at –0.33 MPa.
3. **Cotton in Gujarat**:
    - o **Resources**: Surface water (Sardar Sarovar), groundwater (wells).
    - o **Development**: Percolation tanks, drip irrigation.
    - o **Impact**: Yields 1.5–2 t/ha, saves 30% water.
    - o **Management**: Gypsum, drip reduce salinity (EC < 2 dS/m).
4. **Millets in Rajasthan**:
    - o **Resources**: Rainwater (ponds, check dams), limited groundwater.
    - o **Development**: Watershed management, farm ponds.
    - o **Impact**: Yields 0.5–1 t/ha, mitigates drought.
    - o **Management**: Mulching, pond irrigation during dry spells.
5. **Groundnut in Andhra Pradesh**:
    - o **Resources**: Surface water (Nagarjuna Sagar), groundwater, rainwater.
    - o **Development**: Conjunctive use, check dams.
    - o **Impact**: Yields 1–1.5 t/ha, stabilizes rainfed production.
    - o **Management**: Canal and well alternation saves 15% water.

Challenges

- **Overexploitation**: Groundwater depletion in Punjab, Haryana (2–3 m/year).
- **Inefficient Use**: Canal seepage losses (30–40%) in Rajasthan, Andhra Pradesh.
- **Salinization**: High EC (>4 dS/m) in Gujarat's irrigated soils.
- **Policy Gaps**: Weak enforcement of water allocation (e.g., Tamil Nadu).
- **Example**: Depleted aquifers in Gujarat limit cotton irrigation.

Solutions

- **Recharge Structures**: Percolation tanks, recharge wells (e.g., Gujarat).
- **Efficient Methods**: Drip, sprinkler systems via PMKSY (e.g., Maharashtra).
- **Amendments**: Gypsum for salinity control (e.g., Andhra Pradesh).
- **Water User Associations (WUAs)**: Ensure equitable distribution (e.g., Punjab).
- **Example**: Recharge wells in Haryana raise groundwater by 1 m/year.

Case Study: Watershed Management in Rajasthan

In Rajasthan:

- **Crop**: Millets (pearl millet), rainfed, 300–400 mm rainfall.
- **Resources**: Rainwater (major), limited groundwater (wells).
- **Challenges**: Low rainfall, aquifer depletion (1–2 m/year), 30–50% yield loss.
- **Development Strategies**:
    - o Rainwater Harvesting: Farm ponds (5,000 m^3/ha), check dams (10,000 m^3/ha).
    - o Watershed Management: Contour bunds, percolation tanks cover 10,000 ha.
    - o Conjunctive Use: Ponds and wells irrigate 50 mm at flowering.
    - o Policy: PMKSY funds 2,000 ponds, supports WUAs.
- **Measurement**:
    - o Raingauges: Monitor rainfall (300–400 mm/season).
    - o Tensiometers: ψ_soil = –0.8 MPa for scheduling.
    - o Flow Meters: Track pond water use (5,000 m^3/ha).
- **Management**:
    - o Variety: HHB 67, drought-tolerant, early maturing.
    - o Mulching (2 t/ha straw): Reduces evaporation by 20%.
    - o FYM (5 t/ha): Increases water retention by 15%.
- **Impact**: Yields 0.5–1 t/ha, reduces drought stress by 20%, improves WUE.
- **Integration**: Combines ponds, watershed management, and mulching for resilient millet production. This case study illustrates water resources development in rainfed systems, a key exam concept.

Unleash the topper in you

Conclusion

This part has explored water resources development, critical for the ASRB NET JRF exam. Surface water (25 Mha), groundwater (20 Mha), and rainwater support irrigation through dams, wells, and ponds, as seen in Rajasthan's millet fields. Strategies like rainwater harvesting, conjunctive use, and PMKSY enhance WUE, addressing depletion and salinity.

Crop Water Requirements

Introduction

Crop water requirements (CWR) represent the amount of water needed to meet crop evapotranspiration (ETc) and ensure optimal growth and yield, critical for Indian agriculture where 48% of arable land is irrigated and water scarcity causes 15–40% yield losses in rainfed systems (ICAR, 2023). Accurate estimation of CWR guides irrigation scheduling and enhances water use efficiency (WUE), particularly for crops like rice, wheat, and cotton in water-scarce regions such as Rajasthan and Gujarat. This part emphasizes CWR for its role in irrigation water management. This part explores CWR concepts, estimation methods, influencing factors, and applications in Indian agriculture.

Crop Water Requirements: Overview

Definition and Importance

Crop water requirement (CWR) is the total water needed by a crop to meet evapotranspiration losses (ETc), compensate for soil water deficit, and support growth processes, typically expressed in millimeters (mm) or cubic meters per hectare (m^3/ha). CWR includes water for transpiration, evaporation, and sometimes leaching to manage soil salinity. In India, where agriculture consumes 80% of freshwater, accurate CWR estimation is vital for crops like rice (900–1,200 mm), wheat (400–600 mm), and sugarcane (1,200–1,500 mm), ensuring sustainable irrigation and yield stability.

Importance:

- **Irrigation Planning**: Guides water application timing and volume (e.g., wheat in Haryana).
- **Water Use Efficiency**: Optimizes WUE (e.g., 5–10 kg/ha/mm for cotton in Gujarat).
- **Yield Protection**: Prevents water stress at critical stages (e.g., rice in Punjab).
- **Resource Conservation**: Reduces over-irrigation, preserving groundwater (e.g., millets in Rajasthan).
- **Example**: Estimating CWR of 600 mm for cotton in Gujarat ensures 1.5–2 t/ha yields with drip irrigation.

Components of Crop Water Requirements

- **Crop Evapotranspiration (ETc)**:
  - **Definition**: Water lost through transpiration (plant) and evaporation (soil), primary component of CWR.
  - **Formula**: ETc = ETo × Kc, where ETo = reference evapotranspiration (mm/day), Kc = crop coefficient (0.3–1.2).
  - **Contribution**: 80–90% of CWR (e.g., 500–700 mm for rice).
  - **Example**: Rice in Punjab has ETc = 600 mm (ETo = 5 mm/day, Kc = 1.2).
- **Soil Water Deficit**:
  - **Definition**: Water needed to restore soil to field capacity (FC) after depletion.
  - **Contribution**: 5–10% of CWR, varies with soil type (e.g., 50–100 mm for loamy soils).
  - **Example**: Wheat in Haryana requires 50 mm to replenish soil at 50% depletion.
- **Leaching Requirement (LR)**:
  - **Definition**: Water applied to flush salts from root zone in saline soils (EC > 4 dS/m).
  - **Formula**: $LR = EC_{iw} / (5 \times EC_e - EC_{iw})$, where EC_{iw} = irrigation water salinity, EC_e = tolerable soil salinity.
  - **Contribution**: 5–15% of CWR in saline areas (e.g., 100 mm for cotton in Gujarat).
  - **Example**: Cotton in Gujarat needs 100 mm LR to maintain EC < 2 dS/m.

- **Other Losses**:
  - **Definition**: Water lost to runoff, deep percolation, or application inefficiencies.
  - **Contribution**: 0–10% of CWR, minimized with efficient methods (e.g., drip).
  - **Example**: Sugarcane in Maharashtra loses 50 mm to seepage in canal irrigation.

Factors Influencing Crop Water Requirements

1. **Crop Type and Growth Stage**:
   - **Impact**: Varies with crop physiology, canopy cover, and stage (e.g., rice needs 900–1,200 mm, millets 300–400 mm).
   - **Stages**: Vegetative (low Kc, 0.3–0.6), reproductive (high Kc, 1.0–1.2), maturity (low Kc, 0.4–0.8).
   - **Example**: Wheat in Haryana needs 100 mm at flowering (Kc = 1.1).
2. **Climate**:
   - **Temperature**: High temperatures increase ETo (e.g., 7–10 mm/day in Gujarat's summer).
   - **Humidity**: Low humidity raises VPD, increasing ETc.
   - **Wind**: Enhances evaporation, raising CWR (e.g., coastal Andhra Pradesh).
   - **Example**: High VPD (2 kPa) in Rajasthan increases millet CWR by 10%.
3. **Soil Properties**:
   - **Texture**: Sandy soils (low water-holding capacity, 50 mm/m) need more frequent irrigation; clayey soils (200 mm/m) retain more.
   - **Structure**: Compacted soils reduce root uptake, increasing CWR.
   - **Example**: Loamy soils in Madhya Pradesh reduce soybean CWR by 15% compared to sandy soils.
4. **Irrigation Method**:
   - **Impact**: Drip irrigation reduces losses (10–20%), lowering CWR; flood irrigation increases losses (30–40%).
   - **Example**: Drip in Maharashtra's sugarcane reduces CWR by 30% vs. flood irrigation.
5. **Management Practices**:
   - **Mulching**: Reduces evaporation, lowering CWR by 10–20%.
   - **Crop Spacing**: Wider spacing increases soil evaporation, raising CWR.
   - **Example**: Straw mulch in Telangana's sorghum fields cuts CWR by 15%.

Estimation Methods for Crop Water Requirements

- **Penman-Monteith Equation**:
  - **Principle**: Calculates reference ET (ETo) based on climatic data, adjusted by Kc for ETc.
  - **Formula**: ETo = [0.408Δ(R_n – G) + γ(900/(T+273))u_2(e_s – e_a)] / [Δ + γ(1 + 0.34u_2)], where Δ = vapor pressure slope, R_n = net radiation, G = soil heat flux, γ = psychrometric constant, T = temperature, u_2 = wind speed, e_s – e_a = vapor pressure deficit.
  - **Procedure**:
    - Collect weather data (temperature, humidity, wind, radiation).
    - Calculate ETo (e.g., 5 mm/day), multiply by Kc (e.g., 1.2 for rice).
    - Add LR, soil deficit if needed.
  - **Accuracy**: ±1–2 mm/day, high for research.
  - **Applications**: Large-scale irrigation planning (e.g., rice in Punjab).
  - **Example**: ETo = 5 mm/day, Kc = 1.2, ETc = 6 mm/day for wheat in Haryana.
- **Pan Evaporation Method**:
  - **Principle**: Measures evaporation from an open pan, adjusted for crops.
  - **Procedure**:
    - Record pan evaporation (E_pan, e.g., 8 mm/day).
    - Apply pan coefficient (K_p, 0.7–0.8) and Kc: ETc = E_pan × K_p × Kc.
  - **Accuracy**: ±2–3 mm/day, moderate due to environmental variability.
  - **Applications**: Small farms with limited data (e.g., millets in Rajasthan).
  - **Example**: E_pan = 8 mm/day, K_p = 0.8, Kc = 0.9, ETc = 5.8 mm/day for sorghum in Telangana.

- **Blaney-Criddle Method**:
  - **Principle**: Estimates ETc based on temperature and daylight hours.
  - **Formula**: ETc = p (0.46T_mean + 8) × Kc, where p = percentage of daylight hours, T_mean = mean temperature (°C).
  - **Procedure**:
    - Collect temperature, daylight data.
    - Calculate ETc (e.g., 4 mm/day for wheat).
  - **Accuracy**: ±3–5 mm/day, low for simple applications.
  - **Applications**: Areas with limited weather data (e.g., pulses in Madhya Pradesh).
  - **Example**: T_mean = 20°C, p = 0.3, Kc = 1.0, ETc = 4.2 mm/day for wheat in Haryana.
- **Lysimeter Method**:
  - **Principle**: Directly measures ETc in a controlled soil-plant system.
  - **Procedure**:
  - Place crop in lysimeter (e.g., 1 m^3), measure weight change or drainage.
  - Record ETc (e.g., 6 mm/day).
  - **Accuracy**: ±0.5–1 mm/day, high for research.
  - **Applications**: Precise CWR studies (e.g., rice in Tamil Nadu).
  - **Example**: Lysimeter measures ETc = 7 mm/day for sugarcane in Maharashtra.
- **Soil Moisture Depletion Method**:
  - **Principle**: Estimates CWR based on soil water changes.
  - **Procedure**:
    - Measure soil moisture (e.g., TDR, tensiometer) before/after irrigation.
    - Calculate depletion (e.g., 50 mm), add losses.
  - **Accuracy**: ±2–3 mm/day, moderate for field use.
  - **Applications**: Field-level scheduling (e.g., cotton in Gujarat).
  - **Example**: TDR measures 50 mm depletion for soybean in Madhya Pradesh.

Significance in Irrigation Management

- **Irrigation Scheduling**: Determines timing and volume (e.g., 50 mm at flowering for wheat).
- **Water Allocation**: Prioritizes crops with high CWR (e.g., rice vs. millets).
- **WUE Optimization**: Matches supply to demand, reducing losses (e.g., drip for cotton).
- **Stress Prevention**: Ensures water at critical stages, protecting yields (e.g., rice in Punjab).
- **Example**: Estimating 600 mm CWR for cotton in Gujarat guides drip irrigation, achieving WUE of 8 kg/ha/mm.

PYQ Analysis

1. "What is crop water requirement?"
(A) Nutrient need
(B) Water for ETc
(C) Soil aeration
(D) Pest control

Answer: (B) Water for ETc.
Explanation: CWR meets evapotranspiration and growth needs.

2. "What method estimates ETc accurately?"
(A) Pan evaporation
(B) Penman-Monteith
(C) Blaney-Criddle
(D) Soil moisture

Answer: (B) Penman-Monteith.
Explanation: It uses climatic data for high precision.

3. "What increases CWR?"
(A) Low temperature,
(B) High VPD,
(C) High humidity,
(D) Clayey soil.

Answer: (B) High VPD.
Explanation: High VPD raises transpiration demand.

4. "What component of CWR flushes salts?"
(A) ETc
(B) Leaching requirement
(C) Soil deficit
(D) Runoff

Answer: B) Leaching requirement.
Explanation: LR removes salts from the root zone.

5. "What crop has high CWR?"
   (A) Millets
   (B) Rice
   (C) Pulses
   (D) Mustard

Answer: (B) Rice.

Explanation: Rice needs 900–1,200 mm water.

- **Trend**: PYQs focus on CWR definitions, estimation methods, and influencing factors, with recent emphasis on leaching and high-CWR crops.

Applications in Indian Agriculture

Contextual Examples

1. **Rice in Punjab**:
   - **CWR**: 900–1,200 mm, ETc = 600–800 mm, soil deficit = 100 mm.
   - **Estimation**: Penman-Monteith (ETo = 5 mm/day, Kc = 1.2).
   - **Management**: AWD applies 50 mm at panicle initiation.
   - **Impact**: Yields 4–6 t/ha, saves 20% water.
2. **Wheat in Haryana**:
   - **CWR**: 400–600 mm, ETc = 350–500 mm, soil deficit = 50 mm.
   - **Estimation**: Pan evaporation (E_{pan} = 8 mm/day, K_p = 0.8, Kc = 1.1).
   - **Management**: Drip irrigation at 50% depletion.
   - **Impact**: Yields 3–5 t/ha, improves WUE by 15%.
3. **Cotton in Gujarat**:
   - **CWR**: 600–800 mm, ETc = 500–600 mm, LR = 100 mm.
   - **Estimation**: Soil moisture depletion (TDR, 50 mm deficit).
   - **Management**: Drip irrigation, gypsum for salinity.
   - **Impact**: Yields 1.5–2 t/ha, saves 30% water.
4. **Millets in Rajasthan**:
   - **CWR**: 300–400 mm, ETc = 250–300 mm, soil deficit = 50 mm.
   - **Estimation**: Blaney-Criddle (T_{mean} = 25°C, Kc = 0.9).
   - **Management**: Farm ponds provide 50 mm irrigation.
   - **Impact**: Yields 0.5–1 t/ha, mitigates drought.
5. **Sugarcane in Maharashtra**:
   - **CWR**: 1,200–1,500 mm, ETc = 800–1,000 mm, soil deficit = 100 mm.
   - **Estimation**: Lysimeter (ETc = 7 mm/day).
   - **Management**: Drip irrigation at –0.33 MPa.
   - **Impact**: Yields 60–80 t/ha, saves 30% water.

Challenges

- **High CWR Variability**: Rice (1,200 mm) vs. millets (300 mm) complicates planning (e.g., Punjab).
- **Data Limitations**: Lack of weather stations for Penman-Monteith (e.g., Rajasthan).
- **Over-Irrigation**: Flood irrigation exceeds CWR, causing waterlogging (e.g., Andhra Pradesh).
- **Salinity**: High LR needed in saline soils increases CWR (e.g., Gujarat).
- **Example**: Limited weather data in Madhya Pradesh reduces CWR estimation accuracy.

Solutions

- **Precision Methods**: Use Penman-Monteith, lysimeters where feasible (e.g., Punjab).
- **Low-Cost Tools**: Pan evaporation, Blaney-Criddle for small farms (e.g., Rajasthan).
- **Efficient Irrigation**: Drip, sprinkler reduce over-irrigation (e.g., Maharashtra).
- **Amendments**: Gypsum lowers LR in saline soils (e.g., Gujarat).
- **Example**: PMKSY-funded drip systems in Andhra Pradesh improve CWR-based irrigation by 25%.

Case Study: Water Requirements for Cotton in Gujarat

In Gujarat:

- **Crop**: Cotton, irrigated, 600–800 mm rainfall.
- **CWR**: 600–800 mm, ETc = 500–600 mm, LR = 100 mm, soil deficit = 50 mm.

- **Challenges**: Salinity (EC = 4–6 dS/m), erratic rainfall, high VPD (2 kPa).
- **Estimation**:
  - Penman-Monteith: ETo = 6 mm/day, Kc = 1.1, ETc = 6.6 mm/day, 600 mm/season.
  - Soil Moisture: TDR measures 50 mm deficit at 50% depletion.
  - Leaching: LR = 100 mm to maintain EC < 2 dS/m.
- **Measurement**:
  - Tensiometers: ψ_{soil} = –0.5 MPa for scheduling.
  - IR Thermometer: T_c = 32°C, T_a = 34°C, CTD = 2°C indicates stress.
  - Flow Meters: Track drip water use (5,000 m^3/ha).
- **Management**:
  - Drip Irrigation: Applies 50 mm at CTD = 2°C, saves 30% water.
  - Gypsum (2 t/ha): Reduces salinity, lowers LR.
  - Mulching (2 t/ha straw): Cuts evaporation by 20%.
- **Impact**: Yields 1.5–2 t/ha, improves WUE by 20%, mitigates salinity stress.
- **Integration**: Combines drip, gypsum, and mulching for efficient CWR management. This case study illustrates CWR estimation in water-scarce systems, a key exam concept.

Conclusion

This part has explored crop water requirements, critical for the ASRB NET JRF exam. CWR (e.g., 600 mm for cotton) includes ETc, soil deficit, and leaching, estimated via Penman-Monteith, pan evaporation, and lysimeters, as seen in Gujarat's cotton fields. Factors like crop type, climate, and soil influence CWR, guiding irrigation and WUE.

Concepts Of Irrigation Scheduling

Introduction

Irrigation scheduling is the strategic planning of when and how much water to apply to crops to meet their water requirements, optimize growth, and enhance water use efficiency (WUE), critical for Indian agriculture where 48% of arable land is irrigated and water scarcity causes 15–40% yield losses in rainfed systems (ICAR, 2023). Effective scheduling ensures water delivery aligns with crop needs, particularly during critical growth stages, minimizing stress and losses. This part emphasizes irrigation scheduling concepts for their role in water management and crop productivity. This part explores the principles, objectives, types, and applications of irrigation scheduling in Indian agriculture.

Irrigation Scheduling: Overview

Definition and Importance

Irrigation scheduling is the process of determining the timing and quantity of water applications to crops based on their water requirements, soil moisture status, plant indices, or climatic conditions. It aims to supply water to match crop evapotranspiration (ETc) and prevent water stress or excess, optimizing yield and WUE. In India, where agriculture consumes 80% of freshwater, scheduling is vital for crops like rice (900–1,200 mm), wheat (400–600 mm), and cotton (600–800 mm), ensuring sustainable water use in regions like Punjab, Haryana, and Gujarat.

Importance:

- **Yield Optimization**: Ensures water at critical stages (e.g., flowering in wheat).
- **Water Conservation**: Minimizes losses from runoff and deep percolation (e.g., drip in Gujarat).
- **Stress Prevention**: Avoids water deficit, protecting crops (e.g., rice in Punjab).