IRRIGATION ENGINEERING

UNIT 01 –
INTRODUCTION TO IRRIGATION

Irrigation is the backbone of agriculture in regions where rainfall is seasonal, insufficient, or unpredictable.

1.1 Definition of Irrigation

Irrigation is the **artificial process** of applying water to the soil for the purpose of assisting in the growth of agricultural crops. It is used to supplement natural rainfall and maintain the **optimum moisture conditions** required for plants during their entire growth period.

The Engineering Perspective

From an Engineering standpoint, **Irrigation Engineering** is a specialized branch of Civil Engineering that deals with:

- **Planning**: Identifying water sources (rivers, groundwater) and calculating the water requirements of different crops.
- **Designing**: Creating blueprints for hydraulic structures like **Dams, Weirs, Barrages, and Headworks**.
- **Construction**: The physical building of **Canal Networks, Aqueducts, and Siphons** to transport water over long distances.
- **Management/Distribution**: Controlling the flow of water so that every farm—from the head of the canal to the "tail-end"—receives its fair share.

1.2 Necessity of Irrigation (Why do we need it?)

Irrigation is not just an option; in many countries, it is a survival requirement due to:

1. **Inadequate Rainfall**: When the total rainfall in a year is less than what the crops need to survive.
2. **Uneven Distribution**: When it rains heavily in one month (Monsoon) but stays dry for the rest of the year.
3. **Growing Cash Crops**: High-value crops like **Sugar Cane, Tobacco, and Cotton** require a constant and heavy water supply that rain alone cannot provide.
4. **Controlled Moisture**: Certain growth stages of a plant (like flowering or grain filling) are "critical." Missing water during these days can ruin the entire harvest.
5. **Insurance against Famine**: Irrigation ensures food security even during years of extreme drought.

1.3 Benefits of Irrigation

Benefit	Explanation
Increase in Food Production	Multiple crops can be grown in a single year (Rabi and Kharif).
Revenue Generation	The government charges "Water Tax" to farmers, which helps the economy.
Hydroelectric Power	Multipurpose dams produce electricity along with providing water.
Groundwater Recharge	Seepage from canals helps raise the local water table.
Navigation	Large canals can be used for transporting goods via boats.

1.4 Ill-Effects (Disadvantages) of Excess Irrigation

While irrigation is good, **over-irrigation** can lead to serious problems:

- **Water Logging**: The soil becomes saturated, and air cannot reach the plant roots, literally "suffocating" the crop.
- **Salinity (Alkalinity)**: Excess water brings underground salts to the surface. When the water evaporates, a white crust of salt is left behind, making the land barren (unproductive).
- **Mosquito Breeding**: Standing water in canals or fields can lead to diseases like Malaria and Dengue.
- **Dampness**: Nearby buildings may suffer from damp walls and foundations due to rising water tables.

1.2 NECESSITY OF IRRIGATION IN INDIA

Agriculture in India is often called a "gamble on the monsoon." Because over **80% of rainfall** occurs in just 3–4 months (June to September), artificial water application is essential for year-round survival.

A. Nature of Indian Rainfall

- **Seasonal Nature**: Rainfall is restricted to the monsoon season. For the remaining 8–9 months, the land remains dry, making irrigation mandatory for **Rabi (winter)** and **Zaid (summer)** crops.
- **Uneven Distribution**: Rainfall varies drastically by region. While the Northeast may receive over 200 cm, parts of Rajasthan and the interior Deccan Plateau receive less than 50 cm.
- **Uncertainty & Gaps**: The monsoon is highly unpredictable. Long "monsoon gaps" (dry spells of 2+ weeks) during the growing season can lead to total crop failure without a backup water supply.

B. Major Necessities

- **Insufficient Rainfall**: Only about **30% of India's farmland** receives enough natural rain (>100 cm annually) to support crops without extra help.
- **High Evaporation Losses**: India's tropical climate leads to high temperatures and rapid evaporation of soil moisture, especially in arid zones.
- **Drought-Prone Regions**: Large parts of Maharashtra, Karnataka, and Rajasthan frequently face drought. Irrigation acts as an "insurance policy" against famine.
- **Support for HYV Seeds**: Modern High-Yielding Variety (HYV) seeds and chemical fertilisers require a **constant and heavy water supply** to be effective; they cannot survive on erratic rainfall alone.

C. Economic & Social Importance

- **Food Security**: With record foodgrain production reaching over **332 million tonnes in 2023–24**, irrigation is the backbone that sustains India's growing population.
- **Multiple Cropping**: Irrigation allows farmers to grow 2 or 3 crops a year (increasing "cropping intensity") instead of just one, directly doubling or tripling their income.
- **Poverty Reduction**: Studies show that irrigation has the strongest marginal impact on **reducing rural poverty**, even more than literacy or road infrastructure, by providing stable employment and higher wages.
- **Rural Economy**: Over **45-50% of India's workforce** depends on agriculture. Irrigation stabilises this sector, reducing distress-driven migration to cities.

1.3 HISTORY OF IRRIGATION IN INDIA

The history of irrigation in India is as old as its civilization. The country has transitioned from traditional community-managed systems to massive state-engineered projects.

A. Ancient Period (Early Civilizations to 1800 AD)

In ancient India, irrigation was considered a "Dharma" (religious duty) of the King.

- **Indus Valley Civilization (2500 BC):** Evidence of sophisticated canal networks and reservoir systems found in **Dholavira** and **Lothal**.
- **Grand Anicut (Kallanai):** Built by King Karikala Chola in the 2nd Century AD on the Kaveri River. It is one of the **oldest functional water-regulators** in the world.
- **Tank Irrigation:** Traditional "Chain of Tanks" in South India (Tamil Nadu and Karnataka) captured rainwater for year-round use.
- **Mughal Era:** Construction of the **Western Yamuna Canal** by Firoz Shah Tughlaq and later extended by Akbar and Shah Jahan.

B. British Period (1800 – 1947 AD)

The British shifted the focus to large-scale **Perennial Irrigation** (year-round supply) to grow cash crops like cotton and opium.

- **Upper Ganga Canal (1854):** Engineered by Sir Proby Cautley, it was the largest canal in the world at that time.
- **Sir Arthur Cotton:** Known as the "Father of Irrigation in South India" for his work on the Godavari and Krishna Delta systems.
- **Growth of Canals:** By 1947, India had the largest irrigated area in the world (approx. 28 million hectares), but most of it went to Pakistan during the partition.

C. Post-Independence Era (1947 – 1990s)

Jawaharlal Nehru famously called mega-dams the **"Temples of Modern India."**

- **Bhakra Nangal Project:** One of the highest gravity dams in the world, transforming Punjab and Haryana into the "Granary of India."

- **Hirakud Dam (Odisha):** Built across the Mahanadi, it is one of the longest earthen dams in the world.
- **Nagarjuna Sagar:** A massive masonry dam on the Krishna River serving Andhra Pradesh and Telangana.
- **Indira Gandhi Canal (Rajasthan):** One of the longest canal systems in the world, bringing life to the Thar Desert and turning arid land into green fields.

D. Modern Focus (2000s – Present)

The focus has shifted from "Large Dams" to **"Efficiency and Sustainability."**

- **Micro-Irrigation:** Promoting **Drip and Sprinkler** systems to achieve "More Crop Per Drop."
- **Groundwater Management:** Schemes like *Atal Bhujal Yojana* focus on stopping the over-extraction of borewell water.
- **Watershed Development:** "Per Drop More Crop" initiative under **PMKSY (Pradhan Mantri Krishi Sinchayee Yojana)**.
- **Interlinking of Rivers:** The ambitious plan to connect surplus river basins (like Ganga) to deficit basins (like Cauvery) to solve droughts.

Comparison of Eras

Era	Primary Technology	Key Goal
Ancient	Tanks & Wells	Local Food Survival
British	Perennial Canals	Revenue & Cash Crops

Post-Indep.	Mega Dams	National Food Security
Modern	Micro-Irrigation	Water Conservation

1.4 CLASSIFICATION OF IRRIGATION PROJECTS

The classification is based on the **Scale of Coverage (CCA)** and the financial/technical requirements of the project.

1. Major Irrigation Projects

- **CCA Limit**: Projects having a Culturable Command Area of **more than 10,000 hectares (ha)**.
- **Infrastructure**: These usually involve large **Dams, Reservoirs, and extensive Canal networks** spanning multiple districts or even states.
- **Cost & Time**: High capital investment; takes 10–20 years to complete.
- **Examples**: Bhakra Nangal (Punjab/HP), Tehri Dam (Uttarakhand), Nagarjuna Sagar (Telangana/AP).

2. Medium Irrigation Projects

- **CCA Limit**: Projects covering an area between **2,000 hectares and 10,000 hectares**.
- **Infrastructure**: Usually involves smaller storage dams or medium-sized canal systems.
- **Cost & Time**: Moderate investment; completed within 5–10 years.
- **Focus**: These projects are vital for regional irrigation in specific districts.

3. Minor Irrigation Projects

- **CCA Limit**: Projects having a CCA of **less than 2,000 hectares**.

- **Infrastructure**: These use both surface water (small tanks) and groundwater.
- **Cost & Time**: Low cost; can be completed in 1–2 years.
- **Main Components**:
  - **Tube Wells / Bore Wells**: Extracting groundwater (Private or Community owned).
  - **Lift Irrigation**: Pumping water from a lower level (river/canal) to a higher field.
  - **Small Tanks / Check Dams**: Capturing local rainwater runoff.
  - **Drip/Sprinkler Systems**: Micro-irrigation setups.

UNIT 02 –
WATER REQUIREMENT OF CROPS

What is Water Requirement (WR)?

In simple terms, Water Requirement is the total amount of water a crop needs from the day it is planted until the day it is harvested.

Think of it as a **Total Budget**. The plant gets its water from two places:

1. **Irrigation:** The water we give it manually.
2. **Effective Rainfall:** The rain that actually stays in the soil for the plant to use.

What is included in this "Budget"?

- **Consumptive Use (CU):** Water the plant "drinks" and "sweats."
- **Land Preparation:** Water used to soften the soil before sowing seeds.
- **Leaching Requirement:** Extra water used to wash away harmful salts from the soil.

- **Conveyance Losses:** Water lost through leaks or evaporation while traveling through pipes or canals to the field.

2. Consumptive Use (CU)

Consumptive Use is basically the water the plant "consumes" to stay alive and grow. It consists of two main processes:

A. Evaporation

Water turning into vapor from the **soil surface** or the leaves of the plant.

B. Transpiration

Water taken up by the **roots**, used by the plant, and then released into the air through tiny holes in the leaves.

The Formula:

Evapotranspiration (ET) = Evaporation + Transpiration

(In most farming discussions, ET and Consumptive Use are treated as the same thing.)

3. Important Definitions to Remember

- **Effective Rainfall:** Not all rain is helpful. Some rain runs off into drains. Effective rainfall is only the part that stays in the root zone for the plant to use.
- **Irrigation Requirement:** This is the "gap" we have to fill.
  - *Formula:* **Irrigation Need = Total Water Requirement - Rain.**

2.2 Principal Crops (Water Needs)

Every crop requires a different amount of water depending on its growth duration and the climate it grows in.

- **Rice (Kharif Crop):** Needs a lot of water (**120–150 cm**) because it is usually grown in standing water (submerged) to control weeds and ensure growth.
- **Wheat (Rabi Crop):** Needs moderate water (**45–60 cm**). It is grown in cooler months when evaporation is lower.
- **Sugarcane (Perennial Crop):** Needs the most water (**150–250 cm**) because it stays in the field for nearly a full year and grows very tall.
- **Cotton (Kharif Crop):** Needs **70–120 cm** of water. It requires frequent but lighter watering compared to rice.

2.3 Duty, Delta, and Base Period

These three terms are the foundation of irrigation planning.

- **Base Period (B):** The total number of **days** from the first watering (at sowing) to the last watering (before harvest).
  - *Unit:* Days.
- **Delta:**The total **depth** of water (in cm or meters) required by the crop over its entire base period.
  - *Unit:* cm or meters.
- **Duty (D):** The total **area** (in hectares) that can be irrigated if 1 cubic meter per second (1 cumec) of water is supplied continuously for the entire base period.

The Relationship Formula:

Delta = (8.64 x Base Period) / Duty

(Where: Delta is in meters, Base Period is in days, Duty is in hectares/cumec)

2.4 Command Areas & Intensity

These terms define how much land a canal can actually reach.

- **Gross Command Area (GCA):** The total geographical area that a canal system can theoretically supply water to. It includes everything—farms, roads, villages, and ponds.
- **Culturable Command Area (CCA):** The actual portion of the GCA where crops **can** be grown. We find it by subtracting uncultivable land (roads, buildings, alkaline soil) from the GCA.
  - ➔ CCA = Gross Command Area (GCA) - Unculturable Area (Roads/Buildings
- **Intensity of Irrigation:** Since we don't have enough water to irrigate 100% of the land all the time, we only water a certain percentage of the CCA in a season.

➔ Intensity (%) = (Area actually irrigated / CCA) x 100.

1. Gross Command Area (GCA)

The **GCA** is the total area that can be physically reached by an irrigation canal system. It is defined by the topography of the land.

- **Includes:** Cultivable land, barren land, local forests, villages, roads, ponds, and alkaline soil.
- **Boundary:** It is generally bounded by the drainage divide (watershed line) on either side of the canal.

2. Cultivable Command Area (CCA)

The **CCA** is the portion of the GCA where agriculture is actually possible. This is the "revenue-generating" part of the land.

- **Formula:**
- **Cultivable Cultivated:** Land actually being farmed.
- **Cultivable Uncultivated:** Land that could be farmed but is currently fallow or broken.

3. Intensity of Irrigation (IOI)

The **Intensity of Irrigation** represents the percentage of the CCA that is actually irrigated during a specific season or year. Since land is often rotated or left fallow, the intensity isn't always 100%.

- **Seasonal Intensity:** The ratio of the area irrigated during a specific season (like Kharif or Rabi) to the CCA.
- **Annual Intensity:** The sum of the seasonal intensities. Interestingly, the Annual Intensity can exceed 100% if the same piece of land is irrigated multiple times a year for different crops.

1. The Hydrological Cycle

The Hydrological Cycle (water cycle) is the continuous movement of water from the Earth's surface to the atmosphere and back again. It has no starting point, but we usually describe it in these steps:

- **Evaporation:** Solar energy turns water from oceans and lakes into water vapor.
- **Condensation:** Vapor cools down as it rises and forms clouds.
- **Precipitation:** Water falls back to Earth as rain, snow, or sleet.
- **Runoff:** Water that doesn't soak into the ground flows over the surface into rivers and oceans.
- **Infiltration:** Water seeps through the soil surface.
- **Groundwater Recharge:** Infiltrated water moves deeper to refill underground aquifers.

2. Rain Gauges

A rain gauge is an instrument used to measure the amount of liquid precipitation over a set period.

- **Non-Recording Type (Symon's Gauge):** The most common type. It simply collects water; a human must manually measure it every 24 hours.
- **Recording Type:** Automatically records the "intensity" of rainfall and the time it occurred. Common types include:
  - **Tipping Bucket:** Uses a small bucket that tips when full.
  - **Weighing Bucket:** Weighs the incoming rain.
  - **Floating Type:** Uses a float that rises as the container fills.

3. Key Formulas

- **Average Rainfall (Arithmetic Mean):**
- P_avg = (P1 + P2 + P3 + ... + Pn) / n
- **Average Rainfall (Thiessen Polygon):**
- P_avg = (P1*A1 + P2*A2 + ... + Pn*An) / (Total Area)
- **Runoff Coefficient (C):**
- C = Runoff / Rainfall
- **Rational Formula (Peak Discharge):**
- Q = (1/36) * C * i * A
- (Note: Q is in m3/sec, i is intensity in cm/hr, A is area in hectares)

1. Types of Rain Gauges

Rain gauges are used to measure the depth of rainfall (usually in mm).

- ➔ **Non-recording Type:**
  - ◆ **Ordinary Gauge (Symon's Gauge):** It only collects the rain. It does **not** record the time or intensity. A person must manually measure the water every 24 hours.
- ➔ **Recording Type (Automatic):**
  - ◆ **Tipping Bucket:** Uses two small buckets; when one fills, it tips and sends an electric pulse to record the data.

- **Automatic Gauge:** Provides a continuous plot of rainfall over time (creates a "Mass Curve").

2. Calculating Average Rainfall

When you have multiple rain gauge stations in an area, you find the average:

P = (P1 + P2 + ... + Pn) / n

(Where P1, P2... are rainfall values at each station and n is the total number of stations)

3. Runoff

Runoff is the portion of precipitation (rain) that does not soak into the ground but flows over the land into rivers or streams.

Factors Affecting Runoff:

- **Rainfall Intensity:** Heavy rain leads to more runoff because the soil cannot absorb water fast enough.
- **Soil Type:** Hard or clay-like soil produces more runoff; sandy soil absorbs more water.
- **Slope:** Steeper land causes water to flow faster, increasing runoff.
- **Vegetation:** Trees and grass slow down the water and help it soak into the ground (reducing runoff).

4. Hydrograph

A **Hydrograph** is a graph that shows the **Discharge (Q)** of a river versus **Time (t)** at a specific point.

- It helps engineers see how a river responds after a rainstorm.
- The peak of the graph represents the maximum flow (flood level).

Formulas:-

Arithmetic Mean Rainfall:

P_avg = (P1 + P2 + ... + Pn) / n

Runoff Coefficient (C):

C = Runoff / Rainfall

Peak Runoff (Rational Formula):

Q = (1/36) * C * i * A

4. Hydrograph

A **Hydrograph** is a graph showing the **Discharge ()** of a stream or river over a period of **Time ()**. It shows how a drainage basin responds to rainfall.

Components of a Hydrograph:

1. **Rising Limb:** The upward part of the curve. It represents the rapid increase in river flow as rainwater reaches the channel.
2. **Peak (Crest):** The highest point on the graph. This is the maximum discharge (flow) during or after a storm.
3. **Recession Limb (Falling Limb):** The downward part of the curve. It shows the flow decreasing as the rain stops and the water drains away.

5. Unit Hydrograph (UH)

The **Unit Hydrograph** is a special type of hydrograph used by engineers to predict floods.

- **Definition:** It is a hydrograph resulting from **1 cm of "Effective Rainfall"** (rainfall that actually becomes runoff) occurring uniformly over the entire area for a specific duration.
- **Key Idea:** If you know the hydrograph for 1 cm of rain, you can multiply it to find the discharge for 2 cm, 5 cm, etc.

Formulas:-

Discharge Relationship:

Total Runoff = Area of Hydrograph

Peak Discharge (Qp):

Q_peak = (Peak of Unit Hydrograph) * (Depth of Effective Rainfall)

Effective Rainfall (P_e):

P_e = Total Rainfall - Losses (Infiltration)

UNIT 04 – METHODS OF IRRIGATION

4.1 Flow Irrigation

In this method, water is supplied to the field by the force of **gravity**. The water source (canal or reservoir) is at a higher level than the agricultural field.

- ➔ **How it works:** Water flows through canals or channels and is released into the fields without using pumps.
- ➔ **Advantages:**
  - ◆ **Simple:** No complex machinery or electricity is needed.
  - ◆ **Low Cost:** Very cheap to operate because there are no fuel or power bills.
  - ◆ **High Command Area:** Can cover large areas of land if the slope is consistent.
- ➔ **Limitations:**
  - ◆ **Uneven Distribution:** Areas near the canal get too much water, while far-off areas may get too little.
  - ◆ **Water Wastage:** High risk of "Deep Percolation" (water sinking too deep into the soil where roots can't reach).
  - ◆ **Waterlogging:** Excess water can collect in low-lying areas, damaging crops.

4.2 Types of Flow Irrigation

1. **Perennial Irrigation:** Water is supplied throughout the year according to crop requirements.
2. **Inundation (Flood) Irrigation:** Fields are flooded with a large amount of water during the rainy season when rivers are high.

Formulas

Water Application Efficiency (n_a):

Efficiency = (Water stored in root zone / Water delivered to field) * 100

Field Capacity (FC):

FC = (Weight of water retained / Weight of dry soil) * 100

4.2 Lift Irrigation

In this method, water is at a lower level than the agricultural land. Therefore, water must be **lifted** using mechanical devices like pumps (electric or diesel) or manual methods.

- **How it works:** Water is drawn from underground sources or low-lying rivers and pushed up to the fields.
- **Advantages:**
  - **Controlled Supply:** You only lift the water you need, reducing wastage.
  - **No Waterlogging:** Since you control the volume, the soil doesn't get oversaturated easily.
  - **Can Reach High Ground:** Useful for hilly areas where gravity flow isn't possible.
- **Limitations:**
  - **Expensive:** High initial cost for pumps and ongoing costs for electricity or fuel.
  - **Maintenance:** Pumps and pipes require regular repairs.

Sources of Lift Irrigation:

1. **Tube Wells:**
    1. These reach deep into the ground to tap into deep **aquifers**.
    2. They provide a large, constant supply of water.
2. **Open Wells:**
    1. These are wide, shallow wells that collect water from the top layers of the soil.
    2. Usually used for smaller farms.

Formulas

Power Required for Lifting Water (P):

P (in kW) = (w * Q * H) / (102 * Efficiency)

(Where w = density of water, Q = discharge, H = total head/height)

Specific Capacity of a Well:

Specific Capacity = Discharge (Q) / Drawdown (s)

4.3 Sprinkler Irrigation

In this method, water is pushed through a system of pipes under pressure and **sprayed** into the air through nozzles, falling on the crops like natural rain.

- **Best Suited For:**
    - **Sandy Soil:** Water is absorbed quickly, so frequent light spraying is better than flooding.
    - **Uneven (Undulating) Land:** No need to level the ground (saves land-leveling costs).
    - **Shallow Soils:** Where the soil layer is too thin for deep channels.
- **Advantages:**
    - **Uniform Application:** Every part of the field gets an equal amount of water.
    - **Water Saving:** Saves about **30% to 50%** more water compared to surface irrigation.

    - **Frost Protection:** Can be used to protect crops from freezing in winter.
    - **Fertigation:** Liquid fertilizers can be mixed into the water and sprayed directly.
- **Limitations:**
    - **High Wind:** Strong winds can blow the spray away, causing uneven watering.
    - **Costly:** High initial cost for pipes, pumps, and nozzles.
    - **Technical Knowledge:** Requires clean water to prevent nozzle clogging.

Formulas

Uniformity Coefficient (Cu):

Cu = 100 * [1 - (Sum of deviations / n * Mean Depth)]

(Note: A higher Cu means more even water distribution)

Water Application Rate (R):

R = (Discharge of Nozzle) / (Spacing of Sprinklers)

4.4 Drip Irrigation

In this method, water is delivered slowly and directly to the **root zone** of the plants through a network of narrow pipes and "emitters" (drippers).

- **How it works:** Water is applied **drop-by-drop** at a very low rate, keeping the soil moisture at an optimum level constantly.
- **Advantages:**
    - **Maximum Water Saving:** Saves up to **70%** water compared to flood irrigation. No evaporation or runoff losses.
    - **Reduces Weed Growth:** Only the area near the plant gets wet. The dry soil between rows prevents weeds from growing.
    - **Higher Yield:** Plants grow faster and healthier because they are never "thirsty" or "drowned."

    - **Fertigation:** Fertilizers are mixed with water and delivered directly to the roots, reducing waste.
- **Limitations:**
    - **High Initial Cost:** Very expensive to install (pipes, filters, and drippers).
    - **Clogging:** Small dripper holes can get blocked by sand, algae, or salt (requires good filtration).

Formulas

Water Application Efficiency (n_a):

n_a = (Water stored in root zone / Water delivered) * 100

(Note: For Drip, this is usually 90% or higher)

Discharge through Emitter (q):

$q = k * H^x$

(Where H is the pressure head and k is a constant for the dripper)

Unit 05-
<u>Canals</u>

5.1 Classification of Canals

Canals are classified based on their **source of supply**:

- ➔ **Perennial Canal:**
    - ◆ Maintained by a permanent source (like a river with a dam or weir).
    - ◆ Water is available **throughout the year**.
    - ◆ Used for crops in all seasons (Kharif and Rabi).
- ➔ **Inundation Canal:**
    - ◆ Does not have a permanent headwork (dam).
    - ◆ Water only flows when the river level is high (usually during **monsoon/floods**).

- ◆ Only provides water for a limited time.

5.2 Canal Appurtenances (Structures)

These are structures built on a canal to control and regulate the flow of water.

- ➔ **Head Regulator:** Built at the start of a canal to control the amount of water entering from the river.
- ➔ **Cross Regulator:** Built across the main canal to head up (raise) the water level so it can flow into a distributary (branch) canal.
- ➔ **Canal Falls:** Built when the ground slope is steeper than the canal bed slope. It "drops" the water safely to a lower level to prevent erosion.
- ➔ **Canal Escapes:** Acts as a "safety valve." If there is excess water in the canal, it is released into a nearby natural drain to prevent a breach.

5.3 Key Formulas

Chezy's Formula (Velocity):

$V = C * \sqrt{R * S}$

(Where V = Velocity, C = Chezy's constant, R = Hydraulic radius, S = Bed slope)

Manning's Formula (Velocity):

$V = (1/n) * (R^{2/3}) * (S^{1/2})$

(Where n = Rugosity/Manning's coefficient)

Discharge Equation (Q):

Q = Area (A) * Velocity (V)

Hydraulic Mean Depth (R):

R = Area (A) / Wetted Perimeter (P)

5.2 Canal Lining

Canal lining is an **impermeable layer** (like a skin) added to the bed and sides of a canal to prevent water from soaking into the ground.

Types of Lining:

- **Concrete Lining:** The most common and durable type. It uses cement concrete slabs or cast-in-place concrete. It is very strong but expensive.
- **Brick Lining:** Bricks are laid with cement mortar. It is easy to repair and cheaper than concrete, but not as strong.
- **Stone (Masonry) Lining:** Uses dressed stones or boulders. It is very effective in areas where stones are easily available.

Advantages of Lining:

1. **Reduces Seepage:** Saves up to **30-40%** of water that would otherwise be lost to the ground.
2. **Prevents Erosion:** Allows water to flow at a **higher velocity** without washing away the canal banks.
3. **Prevents Waterlogging:** Since water doesn't seep into the ground, the water table in nearby fields doesn't rise too high.
4. **Increases Capacity:** A smooth lined surface has less friction, so water flows faster, allowing the canal to carry more water
5. **Reduces Maintenance:** Prevents the growth of weeds and plants inside the canal.

5.3 Key Formulas

Copy these into your Google Doc to solve "Lining vs. Unlined" problems:

Velocity in Lined Canal (Manning's):

$V = (1/n) * (R^{(2/3)}) * (S^{(1/2)})$

(Note: 'n' is lower for lined canals, so 'V' is higher)

Seepage Loss Formula:

Loss (in cumecs) = $C * A * d$

(Where C = Seepage coefficient, A = Wetted area, d = depth of water)

Benefit-Cost Ratio (B/C Ratio):

B/C = (Annual Saving in Water) / (Annual Cost of Lining)

(If $B/C > 1$, lining is economically justified)

5.3 Canal Breaches

A breach occurs when the canal bank fails, causing water to flood the surrounding fields. This is a serious emergency in irrigation engineering.

Main Causes of Breaches:

- **Weak Banks:** If the soil used to build the banks is not compacted properly or is made of loose sandy soil, it can collapse under water pressure.
- **Overtopping:** If there is a sudden heavy rain or an error at the head regulator, the water level rises above the bank height and "tops over," washing the soil away.
- **Animal Burrows:** Crabs, rats, or other animals digging holes through the banks create small leaks that eventually turn into large breaks.
- **High Velocity:** If water flows too fast (usually in unlined canals), it causes "scouring" (erosion) of the banks.

Control and Prevention:

- **Immediate Repair:** The moment a leak is spotted, it must be plugged with soil and brushwood.
- **Sand Bags:** These are the most common tool for emergency control. Bags filled with sand or earth are stacked to create a temporary wall and stop the flow.
- **Dowla and Berms:** Providing extra soil (Berms) on the inside and small mounds (Dowla) on the top of the banks adds strength.
- **Canal Escapes:** Opening the "Escape" gates further upstream helps reduce the water pressure at the breach site

5.4 Canal Maintenance

To keep a canal running at its "Design Discharge," regular upkeep is required. If maintenance is ignored, the canal capacity reduces, and the risk of breaches increases.

Key Maintenance Activities:

- **Weed Removal:**
  - Aquatic plants and weeds grow on the bed and sides of unlined canals.
  - **Problem:** They increase friction, which slows down the water velocity and reduces total discharge
- **Desilting:**
  - Silt (mud/sand) settles at the bottom of the canal over time.
  - **Problem:** It reduces the "Cross-sectional Area" of the canal. Regular dredging or flushing is needed to remove it.
- **Repairing Cracks (for Lined Canals):**
  - In concrete or brick linings, cracks can develop due to temperature changes or soil settlement.
  - **Problem:** Cracks lead to heavy seepage and can eventually cause the entire lining to collapse. They are filled using **bitumen** or **cement grout**.
- **Bank Strengthening:**
  - Adding extra soil to the "Berms" and "Banks" to ensure they can handle the water pressure.

UNIT 06 –
<u>TUBE WELL IRRIGATION</u>

6.1 Important Groundwater Terms

Groundwater is the water stored in the spaces between soil and rocks beneath the Earth's surface.

- **Water Table:**

    - The top level of the underground water.
    - Above this level, the soil is dry or moist; below this level, the soil is completely saturated with water.
- **Cone of Depression:**
    - When a pump starts pulling water out of a well, the water level drops immediately around the pipe.
    - This creates a **v-shaped "funnel"** in the water table known as the Cone of Depression.
- **Confined Aquifer (Artesian Aquifer):**
    - A water-bearing layer trapped between **two impermeable layers** (like hard rock or clay) that don't let water pass through.
    - The water here is usually under high pressure.
- **Unconfined Aquifer (Non-Artesian):**
    - A water layer where the top is the **Water Table** itself.
    - It is open to the atmosphere through the soil above it.

6.2 Well Hydraulics Formulas (Copy-Paste Ready)

These are the most important formulas for calculating well discharge

1. Discharge from Unconfined Aquifer (Dupuit's Formula):

Q = [pi * K * (H^2 - h^2)] / [2.303 * log10(R / r)]

2. Discharge from Confined Aquifer (Thiem's Formula):

Q = [2 * pi * K * D * (H - h)] / [2.303 * log10(R / r)]

(Where: K = Permeability, H = Original water level, h = Water level while pumping, R = Radius of influence, r = Radius of well, D = Thickness of confined layer)

3. Specific Yield:

Specific Yield = (Volume of water drained by gravity) / (Total Volume)

Why Tube Wells?

- **Deep Source:** Unlike open wells, tube wells can reach very deep aquifers (up to 100m - 200m).

- **High Discharge:** They provide a much larger amount of water for big farms.
- **Clean Water:** Since they are deep and sealed, the water is usually free from surface pollution.

6.2 Types of Tube Wells

The type of tube well is decided based on the soil layer (aquifer) it taps into.

- **Strainer Type:**
  - The most common type.
  - A mesh or "strainer" is wrapped around the pipe to let water in but keep sand and dirt out.
  - **Best for:** Sandy aquifers.
- **Cavity Type:**
  - It doesn't use a strainer. It draws water from a hollow "cavity" formed at the bottom of a strong clay layer.
  - **Best for:** Areas with a strong clay layer over a water-bearing layer.
- **Slotted Type:**
  - Uses a pipe with vertical slots or holes. It is usually used in very deep wells or rocky areas where a fine strainer isn't needed.

6.3 Yield of a Well

Yield is the most important measurement for a farmer or engineer.

- **Definition:** The total quantity (volume) of water that can be pumped out of a well per unit of time (e.g., Liters per second)
- **Yield Formula:**
  Yield (Q) = Area (A) * Velocity (V)

Specific Capacity = Yield (Q) / Drawdown (s)
(Note: Drawdown is the drop in water level during pumping).

6.4 Water Harvesting

This is the practice of collecting and storing rainwater for future use or to refill the ground.

- **Recharge Pits:** Small, square, or circular pits filled with pebbles and sand that allow surface water to soak into the shallow ground.
- **Recharge Wells:** Deep wells used to push surface water directly into deep aquifers.
- **Rooftop Harvesting:** Collecting rain from the roof of a house via pipes and storing it in a tank or sending it to a recharge pit.

UNIT 07 – DAMS

7.1 Classification of Dams

Dams are classified based on the materials used and how they resist water pressure.

- **Gravity Dams:**
  - **Material:** Built using **Concrete or Masonry**.
  - **How they work:** They are very heavy. Their massive **weight** (gravity) resists the horizontal push of the water.
  - **Life:** Very long-lasting and require little maintenance.
  - **Example:** Bhakra Dam.
- **Earthen Dams (Embankment Dams):**
  - **Material:** Built using **Soil, Gravel, and Clay**.

    - **How they work:** They are wider at the base. They use a "Clay Core" in the center to stop water from seeping through.
    - **Cost:** Much cheaper than gravity dams because local soil is used.

7.2 Causes of Failure
Dams can fail due to technical errors or natural disasters.
For Earthen Dams:

- **Hydraulic Failure:** Water flows over the top (**Overtopping**) and washes away the soil.
- **Piping:** Water creates a small "pipe" or tunnel through the dam, eventually causing it to collapse.
- **Slumping:** The sides (slopes) of the dam slide down because they are too wet or too steep.

For Gravity Dams:

- **Overturning:** The water pressure "flips" the dam over its toe (front edge).
- **Sliding:** The entire dam "skids" forward on its foundation.
- **Cracking:** High internal pressure or temperature changes cause the concrete to break.

7.3 Key Formulas

Factor of Safety (F.O.S) against Overturning:

F.O.S = Sum of Restoring Moments / Sum of Overturning Moments

(Note: F.O.S should be > 1.5)

Factor of Safety (F.O.S) against Sliding:

F.O.S = (mu * Sum of Vertical Forces) / Sum of Horizontal Forces

(Where mu = coefficient of friction, usually 0.65 to 0.75)

Principal Stress at the Toe (sigma):

sigma = (P / B) * [1 + (6 * e / B)]

(Where P = Vertical force, B = Base width, e = Eccentricity)

7.4 Detailed Failure Causes

- **Piping:** Water seeps through the dam or foundation, carrying soil particles with it. This creates a hollow "pipe" or tunnel, leading to a sudden collapse.
- **Overtopping:** When the reservoir level rises above the top of the dam (crest) during a flood. This is the #1 cause of failure for **Earthen Dams**.
- **Foundation Failure:** If the ground beneath the dam is soft or has cracks, it can settle unevenly or slide, causing the entire structure to break.

7.5 Spillways (The "Safety Valve")

A **Spillway** is a structure built to release surplus (excess) water from the reservoir that cannot be stored.

- **Purpose:** It prevents **Overtopping** by passing flood water safely downstream.
- **Types:**
    - **Ogee Spillway:** Most common; shaped like an 'S' to follow the natural flow of water.
    - **Chute Spillway:** Water flows down a steep open channel.
    - **Side Channel Spillway:** Used in narrow valleys where space is limited.

7.6 Coffer Dams (Temporary Support)

A **Coffer Dam** is a temporary, watertight structure built to exclude water from a construction area.

- **Purpose:** It allows engineers to pump water out of a specific area so they can build the actual dam foundation on **dry ground**.
- **Types:**
  - **Earthen Coffer Dam:** Built with local soil.
  - **Rockfill Coffer Dam:** Stronger, built with boulders.
  - **Cellular Coffer Dam:** Steel sheets driven into the ground to form "cells."

Formulas

➔ **Discharge over an Ogee Spillway (Q):** $Q = C * L * H^{(3/2)}$

(Where C = Coefficient of discharge, L = Length of crest, H = Head of water)

➔ **Exit Gradient (G_e) - To prevent Piping:** $G_e = (H / d) * (1 / (\pi * \sqrt{\lambda}))$

(Note: If G_e is too high, piping occurs. It must be kept within safe limits)

UNIT 08 –
<u>CANAL HEAD WORKS</u>

Canal Head Works are structures built **across a river** to **divert water into a canal** and control its flow.

They are called the **"heart of the canal system"** because they control how water enters the canal.

Purpose of Canal Head Works

1. Divert Water

- Guides river water into the canal

Example: Taking water from a river into an irrigation canal

2. Raise Water Level

- Increases water level (called **head**) so water can flow **by gravity**

Example: Without raising level, water cannot enter canal easily

3. Control Silt

- Prevents sand and silt from entering the canal

Example: Stops canal from getting blocked

4. Regulate Supply

- Controls how much water enters the canal

Example: More water in summer, less in rainy season

5. Flood Protection

- Prevents flood water from damaging the canal

Example: During floods, excess water is controlled

Key Components of Canal Head Works

1. Weir or Barrage

- Main structure built across the river to raise water level

Weir

- Fixed wall
- Water flows **over it**

Example: Simple concrete wall in river

Barrage

- Has **gates** for control
- More flexible and modern

Example: Gates opened/closed to control flow

2. Under Sluices (Scouring Sluices)

- Openings at the bottom
- Used to **remove silt and sand**

Example: Dirty water with sand is flushed out

3. Divide Wall

- Wall separating **under sluices and main weir**
- Creates calm (quiet) water near canal entry

Example: Helps smooth water flow into canal

4. Fish Ladder

- Passage for fish to move across the structure

Example: Fish can go upstream even after dam/weir

5. Canal Head Regulator

- Gate at the start of canal
- Controls water entering the canal

Example: Opening gate to allow required water only

6. Silt Excluder

- Prevents heavy silt from entering canal
- Usually tunnels in river bed

Example: Clean water goes to canal, silt stays behind

Short Summary

- Canal Head Works → Divert & control river water into canal
- Weir/Barrage → Raise water level
- Under sluices → Remove silt
- Divide wall → Smooth flow
- Fish ladder → Fish movement
- Head regulator → Control entry
- Silt excluder → Stop silt

UNIT 09 –
<u>CROSS DRAINAGE WORKS</u>

Cross Drainage Works (CDW)

Definition

Cross Drainage Works are structures constructed **when a canal crosses a natural drain, river, or stream**.

The main aim is:

- To **allow water to flow properly** in both canal and drain
- To **avoid mixing or disturbance of water**

Types of Cross Drainage Works

1. Aqueduct (Canal over Drain)

- In this structure, the **canal flows above** the drain
- The drain water flows **below the canal**

Example:
If an irrigation canal has to cross a small river, the canal is taken over it using a bridge-like structure.

Simple idea: Canal passes over the drain

2. Super Passage (Drain over Canal)

- Here, the **drain flows above** the canal
- The canal water flows **below the drain**

Example:
If the drain has higher water level than the canal, it is taken over the canal.

Simple idea: Drain passes over the canal

3. Level Crossing (Same Level)

- Both canal and drain **flow at the same level**
- Water may mix, so **regulators (gates)** are used to control flow

Example:
Used where both canal and drain have nearly equal water levels.

Simple idea: Both cross at the same level

4. Inlet and Outlet

- Drain water is **allowed to enter the canal (inlet)**
- Then it is **released back (outlet)** after some distance
- Flow is controlled using gates

Example:
During heavy rain, extra drain water is temporarily diverted into the canal.

Simple idea: Water is controlled by entering and leaving the canal

5. Pipe Crossing

- Used for **small drains**
- Water passes through **pipes under or across the canal**

Example:
A small stream passing through a pipe under a road or canal.

Simple idea: Small drain passes through a pipe

Short Summary

- Aqueduct → Canal over drain
- Super Passage → Drain over canal
- Level Crossing → Same level
- Inlet & Outlet → Controlled flow

- Pipe Crossing → Small drain through pipe

UNIT 10 –
HYDRAULIC STRUCTURES

Hydraulic structures are **structures used in canals to control, regulate, and manage water flow**.

1. Falls (Canal Falls)

Function:
Falls are used to **reduce the velocity (speed) of water** in a canal.

Why needed?
When canal water flows from a **higher level to a lower level**, speed increases and can damage the canal.

Example:
Like a **small step or drop** in the canal where water falls down and loses speed.

Simple idea: *Water speed control by dropping it down*

2. Cross Regulators

Function:
Used to **control the discharge (amount of water flow)** in the canal.

Location:
Built **across the canal**

Example:
If too much water is flowing, gates are adjusted to reduce it.

Simple idea: *Controls how much water flows forward*

3. Head Regulators

Function:
Control the **entry of water into a branch canal** from the main canal.

Location:
At the **starting point (head)** of a branch canal

Example:
Water is allowed into a smaller canal only when needed for irrigation.

Simple idea: *Controls water entering another canal*

4. Outlets

Function:
Supply water from the canal **directly to agricultural fields**

Example:
Small openings in the canal through which farmers get water for crops.

Simple idea: *Water goes from canal to fields*

5. Canal Escapes

Function:
Used to **remove excess water** from the canal safely.

Why needed?
To prevent **flooding or damage** when water level becomes too high.

Example:
During heavy rain, extra water is diverted into a river or drain.

Simple idea: *Extra water exit system*

Short Summary

- Falls → Reduce water speed
- Cross regulators → Control flow in canal
- Head regulators → Control entry to branch canal
- Outlets → Supply water to fields

- Canal escapes → Remove extra water

UNIT 11 –
RIVER TRAINING WORKS

Definition

River training works are structures and methods used to control and guide the flow of a river.

Purpose

- To prevent flooding
- To stabilize the river path (course)
- To protect nearby land, roads, and structures

Simple idea: *Control the river so it does not cause damage*

Methods of River Training

1. Guide Banks

Function:
Guide banks are **embankments built along the river** to guide water in a fixed direction.

Example:
Used near bridges to make sure river water flows properly under the bridge.

Simple idea: *Direct the river flow in one path*

2. Levees (Embankments)

Function:
Levees are **raised walls or embankments along river sides** to prevent water from overflowing.

Example:
During heavy rain, levees stop river water from entering nearby villages.

Simple idea: *Walls that stop flooding*

3. Groynes (or Spurs)

Function:
Groynes are **structures built from river bank into the river** to control flow and reduce erosion.

Example:
Placed where river is cutting (eroding) the bank too much.

Simple idea: *Blocks that push water away from the bank*

4. Spurs

Function:
Spurs are **similar to groynes**, used to **divert water flow away from banks**

Example:
Used to protect roads or land near the river.

Simple idea: *Deflect water direction*

5. Cut-off

Function:
A cut-off is used to **shorten the river path** by cutting a new straight channel.

Why needed?
To reduce **bends (meanders)** and control flooding.

Example:
If a river has a big curve, a straight path is created to control flow.

Simple idea: *Make river shorter and straighter*

Short Summary

- Guide banks → Direct river flow
- Levees → Prevent flooding
- Groynes/Spurs → Reduce erosion & control direction
- Cut-off → Shorten and straighten river

UNIT 12 –
WATER LOGGING & DRAINAGE

1. Water Logging (Definition)

Water logging occurs when the water table rises near or up to the ground surface, and the soil becomes over-saturated with water.

This condition affects plant growth because roots do not get enough air.

Example:
After heavy irrigation or rainfall, fields remain wet for a long time and crops start dying.

Simple idea: *Too much water in soil → crops cannot grow properly*

Causes of Water Logging

1. Over Irrigation

- Too much water is supplied to fields
- Soil cannot absorb all the water

Example: Farmers watering crops more than required

2. Poor Drainage

- Water cannot flow out properly

- It gets collected in fields

Example: No proper drainage system in agricultural land

3. Seepage from Canals

- Water leaks from nearby canals into the soil
- This increases underground water level

Example: Unlined canals causing water leakage

Effects of Water Logging

1. Reduced Crop Yield

- Roots do not get oxygen
- Plant growth becomes weak

Result: Less production

2. Salinity

- Excess water brings salts to the surface
- Soil becomes salty and infertile

Result: Land becomes unsuitable for farming

Remedies (Solutions)

1. Surface Drainage

- Excess water is removed from the **surface of land** using drains

Example: Open channels to carry water away

2. Subsurface Drainage

- Water is removed from **below the ground** using pipes

Example: Underground drainage pipes

3. Tube Wells

- Tube wells are used to **pump out excess groundwater**

Example: Removing extra water to control water table

4. Controlled Irrigation

- Supply only the **required amount of water**

Example: Proper scheduling of irrigation

Short Summary

- Water logging → Excess water in soil
- Causes → Over irrigation, poor drainage, canal seepage
- Effects → Low crop yield, salinity
- Remedies → Surface drainage, subsurface drainage, tube wells, controlled irrigation