Water Supply Engineering (DI05006021)

Complete Lecture Deck – All 45 Lectures

GTU Diploma Engineering

Water Supply Engineering

July 25, 2026

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Importance and Fundamentals of Water Supply

Unit 1: Introduction to Water Supply Engineering

GTU Diploma Engineering

Water Supply Engineering

July 25, 2026

Agenda

- Necessity of Water
- Importance of Water Supply Engineering
- Objectives of Water Supply Schemes
- Role of a Water Supply Engineer
- Public Health and Protected Water

The Fundamental Necessity of Water

- Water is essential for life; the human body consists of about 60-70% water.
- Without water, no civilization can survive. Historically, major civilizations developed along riverbanks (e.g., Indus Valley, Nile).
- Modern society relies on water not just for drinking, but for sanitation, industrial processes, and agriculture.
- Rapid urbanization has led to concentrated demand, requiring engineered supply systems.

What is Water Supply Engineering?

- It is a branch of civil engineering that deals with the collection, treatment, and distribution of water.
- Ensures water provided is safe for human consumption (potable).
- Involves the design and construction of structures like dams, intake structures, treatment plants, and distribution networks.
- Focuses on maintaining a continuous, pressurized supply to every household or industry.

Importance of Water Supply Engineering

- Prevention of Waterborne Diseases: Typhoid, cholera, and dysentery are prevented by supplying treated water.
- Industrial and Economic Growth: Industries require a massive and reliable water supply to function (e.g., cooling, processing).
- Fire Protection: A robust water distribution system with hydrants is the primary defense against urban fires.
- Public Convenience and Sanitation: Enables the use of flush toilets and modern sewerage systems, improving overall hygiene.

Objectives of a Public Water Supply Scheme

Objectives of a Public Water Supply Scheme

- To supply safe and wholesome water to the public.
- To supply water in adequate quantity to meet daily domestic, commercial, and industrial demands.
- To make water readily available to consumers to encourage personal and household cleanliness.
- To supply water at convenient points and at a reasonable cost.
- To ensure sufficient pressure in the distribution system for firefighting.

Need for Protected Water Supply

- Raw water from natural sources often contains pathogenic bacteria, suspended impurities, and dissolved salts.
- Consuming untreated water leads to severe epidemics and high mortality rates, especially in developing regions.
- 'Protected' means the water is safeguarded against contamination from its source all the way to the consumer's tap.
- Involves strict regulatory standards (e.g., WHO guidelines, IS 10500 in India) for drinking water quality.

Role and Duties of a Water Supply Engineer

- Forecasting Demand: Estimating the future population and their per capita water requirement over the design period (usually 30 years).
- Source Identification: Locating sustainable and economical water sources (rivers, lakes, aquifers).
- Design of Structures: Designing intake works, conduits, pumping stations, and treatment plant units.
- Distribution Network Planning: Layout of pipes, valves, and elevated service reservoirs (ESRs) to maintain pressure.
- Maintenance and Operation: Ensuring the system runs efficiently, minimizing water loss (Non-Revenue Water), and managing repairs.

Challenges in Modern Water Supply

- Depletion of Sources: Over-extraction of groundwater and drying up of surface sources due to climate change.
- Pollution: Increasing industrial effluents and untreated sewage contaminating fresh water bodies.
- Aging Infrastructure: Leaky pipes leading to high percentage of unaccounted-for water in older cities.
- Financial Constraints: High capital and maintenance costs versus low water tariffs recovered from consumers.

Impact on Public Health

- Historical perspective: John Snow's 1854 Broad Street cholera outbreak investigation proved water transmits disease.
- Providing clean water reduces morbidity and mortality, increasing life expectancy and economic productivity.
- Water sanitation and hygiene (WASH) are fundamental components of global public health strategies.

Summary

- Water supply engineering is vital for civilization, health, and industry.
- The main objective is to provide safe, adequate, and pressurized water economically.
- A water engineer plans, designs, and maintains these complex systems.
- Modern challenges require innovative and sustainable engineering solutions.

Preview of Next Lecture

- Where do we get this water from?
- Types of water sources: Surface vs. Subsurface.
- How do we evaluate if a source is suitable?
- Criteria for the selection of a water source for a city.

Sources of Water: Suitability and Selection

Unit 1: Introduction to Water Supply Engineering

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Agenda

- Hydrological Cycle Overview
- Classification of Water Sources
- Surface Water Sources (Rivers, Lakes, Reservoirs)
- Subsurface/Groundwater Sources (Springs, Wells, Infiltration Galleries)
- Suitability of Sources: Quality and Quantity
- Criteria for Selection of a Source

The Hydrological Cycle

- All fresh water originates from precipitation (rain, snow).
- The hydrological cycle involves Evaporation, Condensation, Precipitation, and Runoff/Infiltration.
- Precipitation that flows over land forms Surface Sources (runoff).
- Precipitation that percolates into the ground forms Subsurface Sources (groundwater).

Classification of Water Sources

- Based on where the water is tapped, sources are broadly classified into two categories:
- 1. Surface Sources: Water available on the surface of the earth. Examples: Ponds, Lakes, Streams, Rivers, Storage Reservoirs.
- 2. Subsurface (Groundwater) Sources: Water available below the earth's surface. Examples: Springs, Wells, Tube wells, Infiltration galleries/wells.

Surface Water Sources: Ponds & Lakes

- Ponds: Natural depressions filled with rainwater. Small quantity, highly susceptible to pollution. Rarely used for large schemes.
- Lakes: Larger bodies of standing water. If situated in mountainous/catchment areas free from human habitation, the water can be of very high quality.
- Quantity is highly dependent on catchment area rainfall.
- Quality issues: Algae growth, silt accumulation, and stagnation can cause taste and odor problems.

Surface Water Sources: Rivers & Impounded Reservoirs

- Rivers & Streams: Most common source for large cities. Perennial rivers provide a continuous supply. Non-perennial dry up in summer.
- Impounded Reservoirs: Created by constructing a dam across a river valley. Stores monsoon runoff for use during dry periods.
- Quality: River water contains high suspended solids (turbidity), clay, and pathogenic bacteria due to surface runoff and wastewater discharge.
- Extensive treatment (coagulation, filtration, disinfection) is always required.

Subsurface Sources: Springs & Infiltration Galleries

- Springs: Natural outflow of groundwater to the surface. Good for small hilly towns, but yield is usually low and variable.
- Infiltration Galleries: Horizontal tunnels constructed at shallow depths along river banks to intercept groundwater flow.
- Infiltration Wells: Shallow wells sunk in riverbeds to tap the sub-surface water.
- Advantage: The surrounding soil acts as a natural filter, providing relatively clear water.

Subsurface Sources: Wells and Tube Wells

- Open Wells: Dug manually, tap shallow aquifers. Yield is limited, highly susceptible to surface contamination.
- Tube Wells: Deep pipes driven into the ground tapping one or more confined aquifers using strainers.
- Quantity: Deep tube wells can yield large, reliable quantities of water.
- Quality: Groundwater is naturally filtered, so it has low turbidity and bacteria. However, it often contains dissolved minerals (hardness, iron, fluoride).

Surface vs. Subsurface Sources

Concept 1	Concept 2
Quantity: Surface sources usually offer higher yields suitable for large cities. Subsurface is better for smaller towns or localized supplies.	
Quality (Physical): Surface water is turbid; groundwater is clear.	
Quality (Biological): Surface water is highly contaminated; groundwater is relatively safe.	
Quality (Chemical): Surface water is softer; groundwater is often hard and may contain dissolved iron/fluorides.	
Cost: Surface water requires expensive treatment plants; groundwater requires high pumping costs.	

Suitability of a Source

- A source is considered suitable if it can reliably meet the requirements of both Quantity and Quality.
- Quantity Suitability: Must meet the peak demand during the driest months of the design period.
- Quality Suitability: The raw water must be treatable using standard, economically viable purification methods.
- Sources containing toxic chemicals, heavy metals, or radioactive substances should be rejected.

Criteria for Selection of a Source

- 1. Quantity available: Must satisfy present and future demand.
- 2. Quality of water: Determines the complexity and cost of the treatment plant.
- 3. Distance from the demand area: Longer distances require expensive transmission mains and high pumping costs.
- 4. Elevation of the source: A source located at a higher elevation allows for gravity flow, eliminating huge daily pumping costs.
- 5. Topography: Determines the feasibility of laying pipelines and constructing reservoirs.

Summary

- Water sources are primarily classified into surface (rivers, lakes) and subsurface (wells, springs).
- Surface water is abundant but requires extensive treatment for turbidity and pathogens.
- Groundwater is generally pure biologically but may require treatment for hardness or dissolved minerals.
- Selection of a source depends on quantity, treatability, distance, and elevation to minimize lifecycle costs.

Preview of Next Lecture

- How much water do we actually need?
- Types of water demands (Domestic, Industrial, Fire, etc.).
- Per capita demand and its calculations.
- Factors affecting the rate of water demand.

Types of Water Demand and Computation

Unit 2: Quantity and Quality of Water

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Agenda

- Introduction to Water Quantity
- Components of Total Water Demand
- Domestic, Industrial, and Commercial Demand
- Public Use and Fire Demand
- Formulas for Fire Demand
- Per Capita Demand and Computation

Introduction to Water Quantity

- First step in designing a water supply scheme is determining the total quantity of water required.
- Must account for present requirements and future growth over the design period.
- Total quantity depends on population and per capita consumption.

Components of Total Water Demand

- Domestic water demand
- Industrial water demand
- Commercial and institutional water demand
- Water for public uses
- Fire demand
- Losses and wastes

Domestic Water Demand

- Water required for drinking, cooking, bathing, washing, and sanitation.
- Constitutes the largest portion of total demand (about 50-60%).
- According to IS: 1172-1993, normal requirement is 135 to 200 liters per capita per day (lpcd).

Industrial Water Demand

- Water used in manufacturing processes, cooling, and boiler feed.
- Varies greatly depending on the type and size of industries in the area.
- Usually ranges from 50 to 450 lpcd for an industrial city.

Commercial and Institutional Demand

- Requirements for offices, schools, hospitals, hotels, and restaurants.
- Hospitals generally require 340-450 liters per bed per day.
- Schools/Offices typically require 45-50 lpcd.
- Overall average is considered about 20 lpcd.

Demand for Public Uses

- Water used for municipal tasks like street washing, sewer flushing, and public parks.
- Accounts for roughly 5% to 6% of total consumption.
- Typically taken as 10 to 20 lpcd in total calculations.

Fire Demand

- Quantity required for firefighting is relatively small over a year, but the rate of flow required is very high.
- Water pressure must be adequate (usually 1.0 to 1.5 kg/cm2 minimum at hydrants).
- Calculated empirically based on population to ensure pipe sizes are sufficient.

Kuichling's and Freeman's Formulas

Concept 1	**Concept 2**
Kuichling's Formula: Q = 3182 * P	
Freeman's Formula: Q = 1136 * [(P/5) + 10]	
Where Q = Quantity in liters/minute, P = Population in thousands	

National Board of Fire Underwriters Formula

- For central congested high-value cities: Q = 4637 * P * (1 - 0.01 * P)
- Where Q = Quantity in liters/minute, P = Population in thousands.
- Considered one of the most reliable and widely used formulas globally.

Losses and Wastes

- Water lost due to defective pipe joints, cracked pipes, and faulty valves.
- Theft or unauthorized illegal connections.
- Generally estimated to be around 15% of the total water demand.

Per Capita Demand (q)

- Defined as the annual average amount of water required by one person per day.
- q = (Total yearly water requirement in liters) / (365 * Total population).
- Typically ranges from 250 to 350 lpcd for a standard Indian city.

Computation of Total Quantity

- Determine the design population (P).
- Determine the per capita demand (q).
- Total daily demand = P * q.
- Design components based on this total daily demand plus peak factors.

Summary

- Total water demand comprises domestic, industrial, commercial, public, and fire demands.
- Losses and theft account for 15% of the total.
- Empirical formulas like Kuichling's determine fire demand flow rates.
- Total daily quantity = Population * Per Capita Demand.

Fluctuation in Demand & Factors Affecting Demand

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- Factors Affecting Per Capita Demand
- Size of City, Climate, and Habits
- Impact of Metering and Pressure
- Introduction to Demand Fluctuations
- Seasonal and Daily Variations
- Hourly Variations and Peak Factors
- Coincident Draft

Factors Affecting Water Demand: Size and Characteristics

- Size of the City: Larger cities have higher per capita demand due to more commercial activities, sewer systems, and public uses.
- Characteristics of City: Industrial towns require vastly more water than purely residential towns.

Factors Affecting Water Demand: Climate and Habits

- Climatic Conditions: Hot and dry climates lead to more bathing, lawn watering, and air cooler usage, increasing demand.
- Habits of People: Higher socio-economic status generally correlates with more water usage (flush toilets, washing machines, car washing).

Factors Affecting Water Demand: Metering and Pressure

- System of Supply: Intermittent supply limits use, continuous supply increases it.
- Metering: Metered water costs money per unit; users tend to waste less, reducing demand by 15-20%.
- Pressure in System: Higher pressure leads to greater losses through leaks and open taps.

Factors Affecting Water Demand: Cost & Sewerage

- Cost of Water: High tariffs discourage excessive use and wastage.
- Presence of Sewerage System: Water-borne sewerage systems (flush toilets) drastically increase water consumption compared to dry latrines.

Introduction to Demand Fluctuations

- Water is not drawn at a uniform rate throughout the year, month, or day.
- Average Daily Demand (q) only gives a baseline.
- Facilities must be designed to handle the absolute peak requirements, not just the average.

Seasonal and Monthly Variations

- Demand peaks during summer months due to heat (bathing, cooling, lawn watering).
- Demand drops during winter and monsoon seasons.
- Maximum Daily Demand = 1.8 * Average Daily Demand.

Daily and Hourly Variations

- Even on the maximum day, hourly demand fluctuates.
- Peak hours are typically morning (6 AM - 10 AM) and evening (5 PM - 8 PM).
- Lowest demand occurs during the night.

Peak Factor & Maximum Hourly Demand

- Maximum Hourly Demand = 1.5 * Average Hourly Demand of the Maximum Day.
- Maximum Hourly Demand = 1.5 * (1.8 * Average Daily Demand / 24).
- Therefore, Peak Factor is 2.7 * Annual Average Hourly Demand.

Impact of City Size on Fluctuations

- Smaller towns have highly pronounced peaks because activities are synchronized.
- Larger cities have more uniform demand due to diverse demographics and staggered industrial shifts.
- Peak factor reduces as population increases.

Coincident Draft

- A critical condition where a fire breaks out during the peak daily demand.
- Coincident Draft = Maximum Daily Demand + Fire Demand.
- Total design capacity of the distribution system is the MAXIMUM of (Coincident Draft) OR (Maximum Hourly Demand).

Design Capacities of Components

- Source (Dams): Maximum Daily Demand
- Treatment Plant: Maximum Daily Demand
- Main Conveyance Pipe: Maximum Daily Demand
- Distribution Network: Maximum Hourly Demand or Coincident Draft

Summary

- Water demand varies by city size, climate, cost, and sewerage facilities.
- Demand fluctuates seasonally, daily, and hourly.
- Max Daily Demand = 1.8 * Avg Daily Demand.
- Distribution systems are designed for Max Hourly Demand or Coincident Draft, whichever is greater.

Population Forecasting Methods

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- Concept of Design Period
- Factors Affecting Design Period
- Population Growth Dynamics
- Arithmetic Increase Method
- Geometric Increase Method
- Incremental Increase Method
- Decreasing Rate of Growth Method
- Comparative Suitability

Need for Population Forecasting

- Water supply projects take years to build and are expensive.
- They cannot be easily replaced or expanded once installed.
- Systems must be designed for the population expected at the end of their useful life.
- This future timeframe is called the 'Design Period'.

Design Period

- Typically ranges from 15 to 30 years for water supply components.
- Dams and reservoirs: 50 years.
- Treatment plants: 15 years.
- Distribution pipes: 30 years.

Factors Affecting Population Growth

- Birth rates and Death rates (Natural increase).
- Migration (Inward and Outward due to jobs, education, refugees).
- Industrial and commercial expansion.
- Annexation of surrounding suburban areas.

Methods of Population Forecasting

- Mathematical Methods:
- 1. Arithmetic Increase Method
- 2. Geometric Increase Method
- 3. Incremental Increase Method
- 4. Decreasing Rate of Growth Method
- Graphical Methods (Simple, Comparative, Master Plan).

Arithmetic Increase Method

- Assumes the rate of growth is constant.
- Formula: $P\_n = P\_0 + n * c$
- Where: P_n = Future pop., P_0 = Present pop., n = decades, c = average increase per decade.
- Suitable for large, old, established cities that have reached saturation.

Geometric Increase Method

- Assumes the percentage rate of growth remains constant.
- Formula: P_n = P_0 * $(1 + r/100)^n$
- Where r = average percentage growth rate per decade.
- Suitable for young, rapidly expanding cities with vast scope for development.

Incremental Increase Method

- A combination of both Arithmetic and Geometric methods.
- Formula: P_n = P_0 + n*X + [n(n+1)/2]*Y
- Where X = average increase, Y = average incremental increase.
- Best suited for average cities with normal, moderately changing growth.

Decreasing Rate of Growth Method

- Populations eventually reach a saturation point due to limited resources/space.
- As a city matures, its growth rate naturally declines.
- This method applies a decreasing percentage to future decades.
- Used for older cities showing a clear downward trend in growth rate.

Graphical Methods

- Simple Graphical: Plot past census data on a graph and extend the curve smoothly.
- Comparative Graphical: Compare the city's curve with older, similar cities when they were at the same population.
- Master Plan Method: Growth controlled strictly by zoning regulations (e.g., max density per sector).

Comparative Suitability

Concept 1	Concept 2
Arithmetic: Old, saturated cities (Lowest values)	
Geometric: Young, booming cities (Highest values)	
Incremental: Normal, growing cities (Moderate values)	
Engineers must choose the method that best matches the city's specific socio-economic profile.	

Summary

- Water projects are designed for a future 'Design Period' (usually 30 years).
- Population growth is driven by births, deaths, and migration.
- Geometric method yields the highest forecast; Arithmetic the lowest.
- Incremental Increase method is the most commonly recommended for average cities.

Water Impurities and Collection of Samples

Unit 2: Quantity and Quality of Water

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Agenda

- Pure, Potable, and Palatable Water
- Classification of Impurities
- Physical Impurities
- Chemical Impurities
- Biological Impurities
- Purpose of Water Sampling
- Procedures for Collection
- Preservation of Samples

Types of Water Terminology

- Pure Water: Consists ONLY of H2O molecules (Distilled water). Not ideal for drinking.
- Potable Water: Safe to drink. Free from disease-causing bacteria and toxic chemicals.
- Palatable Water: Aesthetically pleasing. Good taste, odor-free, clear, and cool.

Classification of Impurities

- Water is a universal solvent. As it travels through the hydrological cycle, it picks up impurities.
- Impurities are broadly classified into:
- 1. Physical Impurities
- 2. Chemical Impurities
- 3. Biological / Bacteriological Impurities

Physical Impurities

- Impurities that affect the appearance, taste, or odor of water.
- Suspended Solids: Clay, silt, sand, mud (causes turbidity).
- Dissolved Organics: Decaying leaves/algae (causes color and odor).
- Temperature: High temperatures reduce dissolved oxygen and promote bacterial growth.

Chemical Impurities

- Substances that dissolve in water altering its chemical properties.
- Inorganic Salts: Calcium and Magnesium (causes hardness), Chlorides, Sulfates.
- Toxic Metals: Lead, Arsenic, Fluoride, Mercury.
- Dissolved Gases: CO_2, H_2S (rotten egg smell), Methane.

Biological Impurities

- Pathogenic (disease-causing) micro-organisms.
- Bacteria: Salmonella (Typhoid), Vibrio cholerae (Cholera).
- Viruses: Hepatitis A, Polio.
- Protozoa: Giardia, Cryptosporidium.
- Non-pathogenic: Algae, fungi (cause odors but generally harmless).

Purpose of Water Sampling

- To determine the nature and extent of impurities present.
- To decide on the necessary sequence of water treatment units.
- To check the efficiency of the treatment plant operations.
- To ensure the final supplied water meets BIS / WHO standards.

Types of Samples

- Grab Sample: Collected at a specific spot at a specific time. Represents conditions only at that instant.
- Composite Sample: A mixture of multiple grab samples collected over a period (e.g., 24 hours). Represents average conditions.

Collection for Physical/Chemical Tests

- Use clean glass or plastic bottles (usually 2 to 3 liters).
- Rinse the bottle 2-3 times with the water being sampled before filling.
- Fill completely and tightly cap to prevent aeration (which alters dissolved gases).
- Label clearly with location, date, time, and sampler's name.

Collection for Bacteriological Tests

- Requires utmost care to avoid accidental contamination.
- Use STERILIZED glass bottles (typically 250 ml).
- Keep the bottle closed until the exact moment of sampling.
- Do not touch the inside of the cap or the neck of the bottle.
- If sampling from a tap, flame the tap mouth first.

Preservation and Transportation

- Samples undergo rapid chemical and biological changes once collected.
- Tests must be conducted as soon as possible.
- Store in an ice box at 4°C to slow down biological activity.
- Chemical preservatives (like acids) may be added for specific heavy metal tests.

Summary

- Water contains physical, chemical, and biological impurities.
- Biological impurities cause diseases; physical/chemical affect aesthetics and long-term health.
- Physical/Chemical samples require clean bottles and rinsing.
- Bacteriological samples require strictly sterilized bottles and aseptic techniques.

Water Testing and Quality Standards

Unit 2: Quantity and Quality of Water

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Agenda

- Physical Tests: Turbidity, Color, Taste/Odor
- Chemical Tests: pH, Hardness
- Chemical Tests: Chlorides, Nitrogen, Residual Chlorine
- Bacteriological Tests: MPN and E. coli
- Indian Standard BIS 10500 for Drinking Water
- Unit 2 Summary

Physical Tests: Turbidity

- Measures the resistance to the passage of light through water due to suspended matter.
- Measured using Jackson Turbidimeter (historical) or Nephelometer (modern).
- Nephelometric Turbidity Units (NTU) measure scattered light at 90 degrees.
- High turbidity shields bacteria from disinfectants like chlorine.

Physical Tests: Color and Taste/Odor

- Color: Measured on the Platinum-Cobalt scale (Hazen Units) using a Tintometer. True color (dissolved) vs Apparent color (suspended).
- Taste and Odor: Measured by Threshold Odor Number (TON).
- TON = (Volume of Sample + Volume of Odor-free water) / (Volume of Sample).
- Determined subjectively by the human nose (Osmoscope).

Chemical Tests: pH Value

- Indicates the intensity of acidity or alkalinity.
- pH = -log[H+]. Scale ranges from 0 to 14.
- pH ¡ 7 is acidic (corrosive to pipes).
- pH ¿ 7 is alkaline (can cause scaling).
- Measured using a Potentiometer (pH meter) or indicators like methyl orange/phenolphthalein.

Chemical Tests: Total Hardness

- Caused mainly by Calcium (Ca^{++}) and Magnesium (Mg^{++}) ions.
- Temporary Hardness: Carbonates and Bicarbonates (removed by boiling).
- Permanent Hardness: Sulfates, Chlorides, Nitrates (requires special treatment).
- Tested via EDTA Titration using Eriochrome Black T indicator.

Chemical Tests: Chlorides and Residual Chlorine

- Chlorides: Indicates sewage pollution or seawater intrusion. Tested via Mohr's method (Silver Nitrate titration).
- Residual Chlorine: The amount of chlorine remaining after the chlorine demand is satisfied.
- Crucial for preventing recontamination in the distribution system.
- Tested using DPD method or Chloroscope.

Chemical Tests: Nitrogen Content

- Indicates organic pollution (sewage). Exists in four forms:
- 1. Free Ammonia: Recent, fresh pollution.
- 2. Organic/Albuminoid Nitrogen: Undecomposed organics.
- 3. Nitrites: Partially decomposed (Highly dangerous).
- 4. Nitrates: Fully oxidized (Old pollution; Causes 'Blue Baby Syndrome').

Bacteriological Tests: Indicator Organisms

- Testing for every specific pathogen is impossible.
- Instead, we test for 'Indicator Organisms' like the Coliform group (E. coli).
- Coliforms live in human intestines. Their presence proves fecal contamination.
- If E. coli is present, pathogens like Typhoid or Cholera might also be present.

Bacteriological Tests: MPN Method

- Most Probable Number (MPN) / Multiple Tube Fermentation.
- Inoculate water into tubes with MacConkey broth.
- Incubate at 37°C for 48 hours.
- Positive result: Production of acid and gas (bubbles).
- Use statistical tables to determine the MPN index per 100 ml.

Drinking Water Quality Standards

- In India, water quality is governed by IS 10500:2012.
- Provides an 'Acceptable Limit' (ideal) and a 'Permissible Limit in Absence of Alternate Source'.
- Ensures water is safe for lifetime consumption without adverse health effects.

IS 10500: Physical & Chemical Parameters

- Turbidity: Acceptable = 1 NTU, Permissible = 5 NTU
- pH Value: Acceptable = 6.5 to 8.5, No relaxation
- Total Hardness (as $CaCO_3$): Acc = 200 mg/L, Perm = 600 mg/L
- Chlorides: Acc = 250 mg/L, Perm = 1000 mg/L
- Residual Chlorine: 0.2 mg/L minimum at consumer end.

IS 10500: Toxic & Biological Limits

- Nitrate (as NO_3): Max 45 mg/L (No relaxation).
- Fluoride: Acceptable = 1.0 mg/L, Permissible = 1.5 mg/L.
- Bacteriological standard: E. coli or Thermotolerant coliform bacteria must not be detectable in any 100 ml sample.
- Zero tolerance for fecal contamination.

Unit 2 Summary

- We determined total quantity (Population * Per capita demand).
- We accounted for fluctuations (Max daily and hourly demands).
- We learned to collect and test water samples.
- We compared quality against IS 10500 standards.
- Next Unit: We will design the treatment processes to fix these impurities!

Objects, Location, and Layout of Water Treatment Plants

Unit 3: Treatment of Water

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Water Supply Engineering

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Lecture Agenda

- Need for Water Treatment
- Primary Objectives of Treatment
- Principles of Water Purification
- Site Selection for Water Treatment Plants
- Typical Layout and Flow Diagram
- Overview of Unit Operations

The Need for Water Treatment

- Raw water from natural sources (rivers, lakes, groundwater) is rarely pure enough for direct consumption.
- Surface water often contains suspended solids, organic matter, and pathogenic microorganisms.
- Groundwater may contain dissolved minerals, hardness, iron, or manganese.
- Treatment is mandatory to bridge the gap between raw water quality and statutory drinking water standards.

Objectives of Water Treatment (Part 1)

- Public Health Protection: Removal or inactivation of pathogenic organisms (bacteria, viruses, protozoa) to prevent waterborne diseases like cholera and typhoid.
- Aesthetic Improvement: Removal of turbidity (suspended solids), color, taste, and odor to make water visually appealing and palatable.
- Chemical Safety: Reduction of toxic chemicals, heavy metals, and harmful organic compounds to safe limits.

Objectives of Water Treatment (Part 2)

- Corrosion Control: Preventing water from being too acidic or corrosive to protect the distribution pipes and plumbing fixtures.
- Scale Prevention: Managing water hardness to prevent scale formation in boilers, pipes, and household appliances.
- Industrial Suitability: Providing water that meets the specific quality requirements of local industries (e.g., textiles, food processing).

Principles of Water Treatment

- Physical Processes: Rely on physical forces. Examples include screening (physical barrier), aeration (gas transfer), and sedimentation (gravity settling).
- Chemical Processes: Involve chemical reactions to alter impurities. Examples include coagulation (destabilizing particles) and disinfection (oxidizing pathogens).
- Biological Processes: Rarely used for primary municipal water supply but common in wastewater; utilizes microorganisms to consume organics.
- A typical water treatment plant combines physical and chemical processes sequentially.

Location of a Water Treatment Plant

- Proximity to Water Source: The plant should be as close to the raw water source as practical to minimize the cost of large raw water transmission mains.
- Proximity to City/Demand Center: Balancing source distance with distance to the distribution network to reduce pumping costs for treated water.
- Topography: Ideally located on elevated ground to allow gravity flow of treated water to the city distribution system.

Additional Site Selection Criteria

- Availability of Land: Sufficient land area must be available for present plant construction and future expansion (typically 10-30 years ahead).
- Flood Protection: The site must be above the highest flood level (HFL) of the nearby river or water body to ensure uninterrupted operation during monsoons.
- Soil Bearing Capacity: Firm soil is required to support the massive weight of concrete water-retaining structures.
- Accessibility: Good road connectivity for transporting heavy equipment, daily chemical supplies (like alum and chlorine), and personnel.

Typical Layout of a Treatment Plant

- Sequential Flow: Units are arranged so water flows logically from one stage to the next, preferably by gravity.
- Compact Design: Units should be closely spaced to minimize interconnecting pipework, reducing head loss and cost.
- Bypass Arrangements: Every unit should have a bypass line and parallel duplication to allow maintenance without shutting down the entire plant.
- Administrative and Chemical Buildings: Located centrally or near the entrance for easy access and chemical dosing.

Flow Diagram of Conventional Treatment

- Raw Water Intake -¿ Screens
- Screens -¿ Aeration (Optional)
- Aeration -¿ Coagulation/Rapid Mix
- Rapid Mix -¿ Flocculation
- Flocculation -¿ Sedimentation Clarifiers
- Sedimentation -¿ Rapid Sand Filters
- Filters -¿ Disinfection (Chlorination)
- Disinfection -¿ Clear Water Reservoir (CWR)

Overview of Unit Operations

- Screening: Removes large floating debris (leaves, branches).
- Aeration: Removes dissolved gases (CO_2, H_2S) and oxidizes iron/manganese.
- Coagulation & Flocculation: Clumps together microscopic colloidal particles into larger flocs.
- Sedimentation: Settles out the heavy flocs via gravity.
- Filtration: Removes remaining fine suspended matter and bacteria.
- Disinfection: Kills remaining pathogenic microorganisms.

Summary and Next Steps

- Water treatment is essential for public health, aesthetics, and protecting infrastructure.
- Plant location relies on topography, proximity to source/city, and flood protection.
- Conventional treatment involves screening, coagulation, sedimentation, filtration, and disinfection.
- Next Lecture: We will dive deep into the first major chemical processes: Coagulation and Flocculation.

Coagulation and Flocculation Processes

Unit 3: Treatment of Water

GTU Diploma Engineering

Water Supply Engineering

July 25, 2026

Lecture Agenda

- The Problem with Colloidal Particles
- Theory of Coagulation
- Common Types of Coagulants
- Chemistry of Alum
- Rapid Mixing (Flash Mixing)
- The Flocculation Process
- The Jar Test for Optimum Dosage

The Challenge of Colloidal Impurities

- Water contains suspended, colloidal, and dissolved solids.
- Large suspended solids (like sand) settle rapidly by gravity.
- Colloidal particles (like fine clay, silt, and organic matter) are extremely small (1 nm to 1 micron).
- They have a large surface-area-to-volume ratio and possess a negative electrical charge.
- Due to electrostatic repulsion (negative repels negative), colloids remain stable and will not settle even over long periods.

Theory of Coagulation

- Coagulation is the chemical process of destabilizing these negatively charged colloidal particles.
- Chemicals called 'coagulants' (which carry strong positive charges) are added to the water.
- The positive ions neutralize the negative surface charges on the colloids.
- Once neutralized, the repulsive forces are eliminated, allowing the particles to come together (agglomerate) upon collision.

Common Types of Coagulants

- Aluminium Sulphate (Alum): The most widely used coagulant in municipal water treatment. Cheap, effective, and readily available.
- Iron Salts: Ferric Chloride, Ferric Sulphate, and Ferrous Sulphate. Form heavier flocs and work over a wider pH range than alum.
- Polyelectrolytes (Polymers): Synthetic high-molecular-weight polymers used as primary coagulants or as coagulant aids to strengthen flocs.
- Sodium Aluminate: Used for specific applications, often in conjunction with alum.

Chemistry of Alum Coagulation

- Chemical Formula: Al2(SO4)3 · 18H2O
- Alum requires naturally occurring alkalinity in the water (usually in the form of Calcium Bicarbonate) to react.
- Reaction: Al2(SO4)3 + 3Ca(HCO3)2 -¿ 2Al(OH)3 (precipitate) + 3CaSO4 + 6CO2
- The product, Aluminium Hydroxide (Al(OH)3), is a sticky, gelatinous precipitate called 'floc' that traps suspended particles.
- If natural alkalinity is low, lime (Ca(OH)2) or soda ash must be added artificially.

Factors Affecting Coagulation

- pH of Water: The most critical factor. Alum works best between pH 6.5 and 8.5. Outside this range, the floc does not form properly.
- Coagulant Dosage: Too little fails to neutralize charges; too much can reverse the charge (restabilize) or waste chemicals.
- Temperature: Cold water slows down the chemical reactions and increases water viscosity, making floc formation slower.
- Characteristics of Raw Water: High turbidity and varying organic content affect the required dose.

Rapid Mixing (Flash Mixing)

- Objective: To instantaneously and uniformly disperse the coagulant chemical throughout the raw water mass.
- Time scale: Mixing must occur in a few seconds (typically 30 to 60 seconds).
- Mechanism: Achieved using a mechanical mixer (impeller/propeller) in a small chamber.
- Why Rapid? The charge neutralization reactions occur in fractions of a second; if mixing is slow, the chemicals are wasted on a small portion of the water.

The Flocculation Process

- After rapid mixing, the water enters the Flocculation Basin.
- Objective: To gently agitate the water, causing the neutralized, micro-flocs to collide and stick together into larger, heavier macro-flocs.
- Mixing Speed: Slow and gentle (paddle speeds of 0.2 to 0.6 m/s).
- Detention Time: Typically 20 to 40 minutes.
- Warning: If mixing is too fast, the shear forces will break apart the fragile flocs!

Types of Flocculators

- Baffle Type Flocculators: Use zig-zag flow paths around baffles to create turbulence and mixing. No moving parts, but high head loss.
- Mechanical Flocculators (Paddle Type): Large horizontal or vertical rotating paddles driven by motors. Allows operators to adjust the mixing speed (velocity gradient, G).
- Tapered Flocculation: Providing higher mixing energy at the inlet and gradually reducing it toward the outlet to prevent breaking fully formed flocs.

The Jar Test

- Purpose: A laboratory procedure used to determine the optimum dosage of coagulant for the current raw water conditions.
- Procedure: Six jars are filled with raw water. Different doses of alum are added to each.
- Simulation: The jars are rapidly mixed for 1 minute, then slowly mixed for 20 minutes, mirroring the actual plant process.
- Observation: The stirrer is stopped, and settling is observed. The lowest dose that produces large flocs and clear water is selected as the optimum.

Summary

- Colloids remain suspended due to negative electrical charges.
- Coagulation neutralizes these charges using chemicals like Alum via rapid flash mixing.
- Flocculation is the gentle agglomeration of particles into heavy flocs over 20-40 minutes.
- The Jar Test is essential for determining the correct chemical dosage.

Sedimentation Processes

Unit 3: Treatment of Water

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Water Supply Engineering

July 25, 2026

Lecture Agenda

- Principles of Sedimentation
- Stokes' Law and Particle Settling
- Plain vs. Coagulation-aided Sedimentation
- Types of Sedimentation Tanks
- Key Design Parameters (SOR, Detention Time)
- Inlet, Outlet, and Sludge Removal
- Tank Efficiency and Short-Circuiting

Principles of Sedimentation

- Definition: Sedimentation is the process of removing solid particles heavier than water by gravity settling.
- When the velocity of flowing water is reduced, the turbulence that keeps particles in suspension is minimized.
- Particles naturally fall to the bottom of the tank, leaving clarified water at the top.
- The settled mass of particles is called 'sludge'.

Stokes' Law

- The settling velocity (Vs) of a discrete spherical particle in a viscous fluid is given by Stokes' Law.
- $Vs = (g * (G - 1) * d^2)/(18 * v)$
- Where: g = acceleration due to gravity, G = specific gravity of particle, d = particle diameter, v = kinematic viscosity of water.
- Key takeaway: Settling velocity is highly dependent on particle diameter (d squared). Doubling the particle size increases settling speed by four times.

Plain vs. Coagulation-Aided Sedimentation

Concept 1	Concept 2

Plain Sedimentation: Water is retained in a reservoir for days or weeks. Removes heavy sand/silt. No chemicals used. Requires massive land area.

Sedimentation with Coagulation (Clarification): Water is pre-treated with coagulants. Removes fine silt, clay, and organics. Detention time is only 2 to 4 hours. Much smaller footprint.

Modern municipal plants almost exclusively use coagulation-aided sedimentation due to space constraints and higher raw water pollution.

Types of Sedimentation Tanks

- Based on Flow Direction:
- 1. Horizontal Flow Tanks: Typically rectangular. Water flows straight from one end to the other.
- 2. Radial/Up-flow Tanks: Typically circular. Water enters the center and flows radially outward and upward toward the edges.
- Based on Operation:
- Fill-and-Draw type (obsolete, batch process)
- Continuous Flow type (standard in all modern plants)

Key Design Parameters: Surface Overflow Rate (SOR)

- Also known as Surface Loading Rate.
- Formula: SOR = Total Flow (Q) / Surface Area of Tank (A). Units: Liters/m2/day or m3/m2/day.
- Concept: It represents the upward velocity of the water. For a particle to settle, its downward settling velocity (Vs) must be greater than the upward overflow rate (SOR).
- It is the most critical parameter in clarifier design. Tank depth is surprisingly less important than surface area.

Other Design Parameters

- Detention Time (t): The theoretical time water spends in the tank. t = Volume / Flow rate (Q). Usually 2.5 to 4 hours for alum flocs.
- Flow Velocity (V): The horizontal speed of water through a rectangular tank. Must be low enough to prevent scouring (resuspending settled sludge). Max usually 0.3 m/min.
- Weir Loading Rate: The volume of water passing over a unit length of the outlet weir per day. Too high a rate pulls flocs out of the tank.

Inlet and Outlet Arrangements

- Inlet Zone: Designed to dissipate the high velocity of incoming water and distribute it evenly across the tank width/depth using baffle walls with orifices.
- Outlet Zone: Uses a 'Weir' (a notched barrier) to collect the clarified water from the top surface gently.
- V-notch weirs are commonly used to ensure uniform flow even if the tank is not perfectly leveled.

- Sludge accumulates at the bottom and must be removed before it turns septic or occupies too much volume.
- Rectangular Tanks: Use mechanical chain-and-flight scrapers that drag sludge to a hopper at the inlet end.
- Circular Clarifiers: Use slowly rotating radial arms equipped with squeegees that push sludge to a central hopper.
- Removal: Sludge is drawn off via hydrostatic pressure or sludge pumps for further treatment/disposal.

Tank Efficiency and Short-Circuiting

- Theoretical detention time is rarely achieved due to 'Short-Circuiting'.
- Short-Circuiting occurs when water takes a fast, direct path from inlet to outlet, bypassing the main volume of the tank.
- Causes: Density currents (temperature differences), wind effects on the surface, or poor inlet baffle design.
- Effect: Reduces actual settling time, leading to floc carry-over into the filters.
- Mitigation: Proper baffling and maintaining low flow velocities.

Summary

- Sedimentation relies on gravity to settle flocs, governed by Stokes' Law.
- Surface Overflow Rate (SOR) is the most critical design parameter.
- Mechanical scrapers continuously remove sludge to maintain tank volume.
- Next Lecture: We will look at Filtration, the polishing step to catch what didn't settle.

Filtration Processes

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Water Supply Engineering

July 25, 2026

Lecture Agenda

- Purpose of Filtration
- Mechanisms of Filtration
- Filter Media (Sand & Gravel)
- Slow Sand Filters (SSF)
- Rapid Sand Filters (RSF)
- Comparison: SSF vs. RSF
- Filter Cleaning (Backwashing)
- Operational Troubles (Mud balls, Air binding)

Purpose and Mechanisms of Filtration

- Purpose: To remove fine flocs, colloidal matter, bacteria, and color that did not settle in the clarifier.
- Mechanism 1: Mechanical Straining - Particles larger than the voids between sand grains are physically caught.
- Mechanism 2: Sedimentation - Tiny particles settle on the surface of the sand grains inside the filter bed.
- Mechanism 3: Flocculation - Particles collide and stick together within the pore spaces.
- Mechanism 4: Biological Action - A sticky layer of harmless bacteria forms on the sand, consuming organic matter and trapping pathogens (Schmutzdecke).

Filter Media

- Sand: The primary filtering medium. Must be hard, durable, free of clay, and chemically stable.
- Effective Size (D10): The sieve size through which 10% of the sand passes by weight. Controls the hydraulic performance.
- Uniformity Coefficient ($Cu = D60/D10$): Indicates how uniform the sand grains are. Lower Cu means more uniform size.
- Gravel: Placed at the bottom to support the sand layer and prevent it from washing into the underdrain system. It is graded in layers (coarsest at the bottom).

Slow Sand Filters (SSF)

- The oldest form of water filtration.
- Filtration Rate: Very slow, about 100 to 200 liters/m2/hour.
- Media: Uses fine sand (Effective size 0.2-0.3 mm) and a deep bed.
- Pre-treatment: Does not require coagulation; raw water must have low turbidity (usually plain sedimentation is enough).
- Biology: Relies heavily on the biological 'Schmutzdecke' (dirty skin) layer on the top surface to remove 99% of bacteria.

Cleaning Slow Sand Filters

- Process: When head loss becomes too high (clogged), the filter is drained.
- Scraping: Laborers manually scrape off the top 1.5 to 3 cm of dirty sand (the Schmutzdecke) using flat shovels.
- Frequency: Cleaned every 1 to 3 months, depending on raw water quality.
- Ripening: After cleaning, the filter must run to waste for a few days until the biological layer regrows.
- Limitations: Labor-intensive and cannot handle highly turbid water.

Rapid Sand Filters (RSF)

- The standard for modern municipal treatment.
- Filtration Rate: Extremely fast, 3000 to 6000 liters/m2/hour (30 times faster than SSF).
- Media: Uses coarser sand (Effective size 0.45-0.7 mm) to allow high flow.
- Pre-treatment: Mandatory! Water must undergo coagulation, flocculation, and sedimentation before entering the RSF.
- Mechanism: Depth filtration. Particles penetrate deep into the sand bed, not just the surface.

Underdrain System in RSF

- Functions:
- 1. Collect filtered water uniformly across the entire bottom of the filter.
- 2. Distribute high-pressure wash water uniformly during backwashing.
- Types: Pipe and lateral systems (perforated pipes), porous plates, or nozzle/strainer systems.
- Design Importance: If wash water is not distributed evenly, it will cause 'boils' and disrupt the gravel layers, destroying the filter.

Cleaning RSF: Backwashing

- Indicator: Cleaned when 'Head Loss' reaches a limit (e.g., 2.5 meters) or turbidity breaks through.
- Process: Reversing the flow of water. Clean water is forced upwards through the underdrains at a high velocity.
- Fluidization: The upward flow lifts and expands the sand bed by 20-50%, causing grains to rub together, scrubbing off the dirt.
- Wash Troughs: The dirty wash water overflows into suspended troughs and is drained away.
- Frequency: Typically every 24 to 48 hours. Takes only 10-15 minutes.

Comparison: SSF vs. RSF

Concept 1	**Concept 2**
Filtration Rate: SSF is slow (100-200 L/m2/h); RSF is fast (3000-6000 L/m2/h).	
Space Required: SSF needs massive area; RSF is compact.	
Pre-treatment: SSF needs none/little; RSF requires full chemical coagulation.	
Cleaning: SSF is scraped manually every few months; RSF is backwashed mechanically every 1-2 days.	
Bacterial Removal: SSF is excellent (98-99%); RSF is good (80-90%), meaning RSF strictly requires post-disinfection.	

Operational Troubles in RSF

- Mud Ball Formation: If backwashing is inadequate, dirt and coagulant stick to sand grains, forming heavy mud balls that sink and clog the filter.
- Air Binding: Dissolved gases release due to negative pressure in the filter bed, forming air bubbles that block water flow and reduce capacity.
- Sand Cracking: Shrinkage of the sand bed creates cracks where raw water can bypass the media, leading to poor effluent quality.
- Solution: Proper backwash velocity, use of surface wash/air scour, and maintaining adequate water depth.

Summary

- Filtration removes particles through straining, sedimentation, and biology.
- Slow Sand Filters are large, natural biological filters cleaned by scraping.
- Rapid Sand Filters are compact, high-rate physical filters cleaned by backwashing.
- RSF is the industry standard but requires strict pre-treatment and post-disinfection.
- Next Lecture: Disinfection - the final barrier to ensure water is biologically safe.

Disinfection of Water

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Lecture Agenda

- Disinfection vs. Sterilization
- Requirements of a Good Disinfectant
- Methods of Disinfection (Boiling, UV, Ozone)
- Chlorination: The Industry Standard
- Chemistry of Chlorine in Water
- Free and Combined Chlorine
- Breakpoint Chlorination Curve
- Factors Affecting Chlorination

Disinfection vs. Sterilization

- Disinfection: The process of selectively destroying or inactivating pathogenic (disease-causing) microorganisms to make water safe to drink.
- Sterilization: The complete destruction of ALL living microorganisms, pathogenic or harmless.
- In water treatment, we aim for Disinfection, not sterilization.
- Sterilization is impractically expensive for municipal scales and unnecessary since many bacteria in water are harmless.

Requirements of a Good Disinfectant

- Effective: Must destroy pathogens within a practical time frame and at reasonable temperatures.
- Safe: Must not be toxic to humans or domestic animals at the applied doses.
- Residual Protection: MUST leave a residual concentration in the water to protect against re-contamination in the distribution pipes.
- Economical: Must be cheap, readily available, and easy to transport/store.
- Analytical: Should be easy to measure its concentration in the water.

Minor Methods of Disinfection

- Boiling: Kills pathogens by heat. Excellent for households during emergencies, impractical for city supplies.
- Ozone (O3): A powerful oxidizing gas. Kills viruses faster than chlorine and removes color/odor. Drawback: Expensive and leaves NO residual.
- Ultraviolet (UV) Light: Scrambles the DNA of pathogens, preventing replication. Drawback: Leaves NO residual, and water must be completely clear for UV to penetrate.
- Potassium Permanganate: Used mainly for village wells, effective against cholera, but colors water pink/brown.

Chlorination: The Standard Method

- Most widely used disinfectant globally due to its low cost, reliability, and residual capability.
- Can be applied as:
- 1. Chlorine Gas (Cl_2): Very cheap, highly toxic gas, used in large plants.
- 2. Sodium Hypochlorite ($NaOCl$): Liquid bleach, safer to handle, used in medium plants.
- 3. Calcium Hypochlorite / Bleaching Powder ($Ca(OCl)_2$): Solid powder, used in small plants or rural areas.

Chemistry of Chlorine in Water

- When Chlorine gas dissolves in water, it forms Hypochlorous Acid (HOCl) and Hydrochloric Acid (HCl).
- Reaction: Cl2 + H2O ¡-¿ HOCl + HCl
- Hypochlorous acid (HOCl) is highly unstable and partially dissociates into Hypochlorite ions (OCl-).
- Reaction: HOCl ¡-¿ H+ + OCl-
- HOCl (Hypochlorous Acid) is the most powerful disinfecting agent. It is roughly 80 times more effective than the OCl- ion.

Effect of pH on Chlorination

- The balance between HOCl and OCl- is entirely dependent on the pH of the water.
- At lower pH (below 7), HOCl dominates (highly effective disinfection).
- At higher pH (above 8), OCl- dominates (poor disinfection).
- Therefore, chlorination is most effective in slightly acidic to neutral water (pH 6.5 to 7.5).
- If water pH is high, operators must increase the chlorine dose or contact time to compensate.

Chlorine Demand and Residual

- Chlorine Demand: The amount of chlorine consumed by organic matter, iron, manganese, and ammonia in the raw water.
- These impurities 'eat' the chlorine before it can kill bacteria.
- Residual Chlorine: The amount of chlorine left in the water AFTER the demand is satisfied.
- Equation: Applied Dose = Chlorine Demand + Residual Chlorine.
- A residual of 0.2 mg/L must be maintained in the distribution system to protect against pipeline leaks.

Free vs. Combined Chlorine

- Free Available Chlorine: Unreacted HOCl and OCl-. This is fast-acting and highly potent.
- Combined Chlorine (Chloramines): Formed when chlorine reacts with Ammonia (NH3) in the water.
- Chloramines (NH2Cl, NHCl2) are weak disinfectants (25x weaker than free chlorine) but last a very long time in pipes.
- Some cities intentionally form chloramines to maintain a residual in massive, long distribution networks without creating taste/odor issues.

Breakpoint Chlorination

- A curve plotting Chlorine Added (x-axis) vs. Residual Chlorine (y-axis).
- Stage 1: Chlorine destroys easily oxidized compounds (Iron/Mn). No residual.
- Stage 2: Chlorine reacts with ammonia to form chloramines. Residual rises.
- Stage 3: Additional chlorine destroys the chloramines, releasing nitrogen gas. Residual drops to a minimum (The Breakpoint).
- Stage 4: Any chlorine added past the breakpoint forms Free Available Chlorine. The residual rises proportionally to the dose.

Summary

- Disinfection kills pathogens; it does not sterilize water.
- Chlorine is favored because it leaves a protective residual in the pipes.
- HOCl is the active killer, and its formation requires a pH below 8.
- Breakpoint chlorination ensures we achieve strong Free Available Chlorine.
- Next Lecture: Water Softening - addressing the chemical issue of hard water.

Water Softening

Unit 3: Treatment of Water

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Water Supply Engineering

July 25, 2026

Lecture Agenda

- What is Hardness?
- Causes and Types of Hardness
- Disadvantages of Hard Water
- Methods of Removing Temporary Hardness
- The Lime-Soda Process (Chemistry & Plant)
- The Zeolite (Ion Exchange) Process
- Comparison of Softening Methods

What is Water Hardness?

- Hardness is a characteristic of water that prevents the formation of lather with soap.
- It is primarily caused by the presence of multivalent metallic cations.
- The principal culprits are Calcium ($Ca2+$) and Magnesium ($Mg2+$) ions.
- Other minor contributors include Iron, Strontium, and Manganese.
- Hardness is usually expressed in terms of equivalent Calcium Carbonate (CaCO3) in mg/L.

Types of Hardness

- 1. Temporary Hardness (Carbonate Hardness):
- Caused by the carbonates and bicarbonates of Calcium and Magnesium.
- Easily removed by simple boiling.
- 2. Permanent Hardness (Non-Carbonate Hardness):
- Caused by sulfates, chlorides, and nitrates of Calcium and Magnesium.
- Cannot be removed by boiling; requires specific chemical treatment.
- Total Hardness = Temporary Hardness + Permanent Hardness.

Disadvantages of Hard Water

- Domestic Issues: Excessive soap consumption, clothes become stiff when washed, formation of sticky soap scum on bathroom fixtures.
- Industrial Issues: Forms hard scale inside boilers, severely reducing heat transfer efficiency and potentially causing boiler explosions.
- Plumbing: Scale buildup clogs hot water pipes and reduces the lifespan of water heaters.
- Food Industry: Can affect the taste of foods and beverages during commercial preparation.

Removal of Temporary Hardness

- 1. Boiling: Heat drives off CO2, causing calcium bicarbonate to convert into insoluble calcium carbonate, which settles out.
- Reaction: Ca(HCO3)2 + Heat -¿ CaCO3 (precipitate) + CO2 + H2O
- 2. Addition of Lime: For municipal scale, boiling is too expensive. We add hydrated lime (Ca(OH)2).
- Reaction: Ca(HCO3)2 + Ca(OH)2 -¿ 2CaCO3 (precipitate) + 2H2O
- The precipitate is then removed in a standard sedimentation tank.

Lime-Soda Process for Permanent Hardness

- To remove permanent hardness (sulfates/chlorides), both Lime (Ca(OH)2) and Soda Ash (Na2CO3) are added.
- Lime removes carbonate hardness and magnesium.
- Soda Ash removes the non-carbonate (permanent) calcium hardness.
- Reaction (Soda Ash): CaSO4 + Na2CO3 -¿ CaCO3 (precipitate) + Na2SO4 (soluble, non-hardness causing).
- Result: Heavy precipitates of CaCO3 and Mg(OH)2 are formed and settled out in clarifiers.

Features of the Lime-Soda Process

- Advantages:
- Very economical for large municipal supplies.
- Also removes iron, manganese, and reduces bacteria due to high pH.
- Disadvantages:
- Produces a massive volume of chemical sludge that is difficult to dispose of.
- Requires skilled supervision for precise chemical dosing.
- Can leave water unstable (scaling), requiring 'Recarbonation' (adding CO2) to stabilize pH.

The Zeolite (Ion Exchange) Process

- Zeolites are natural or synthetic resins that contain exchangeable Sodium ($Na+$) ions.
- Process: Hard water is passed through a bed of zeolite.
- Ion Exchange: The zeolite 'grabs' the Calcium ($Ca2+$) and Magnesium ($Mg2+$) from the water and releases Sodium ($Na+$) into the water in their place.
- Reaction: Na2Ze + Ca(HCO3)2 -¿ CaZe (exhausted resin) + 2NaHCO3
- Result: Water leaving the filter has zero hardness (contains only harmless sodium).

Regeneration of Zeolite

- Eventually, the zeolite bed runs out of sodium and is saturated with calcium/magnesium (exhausted).
- Regeneration: We wash the bed with a concentrated brine (NaCl / Salt) solution.
- The high concentration of sodium forces the reaction in reverse, driving the calcium off the resin and replacing it with sodium.
- Reaction: CaZe + 2NaCl -¿ Na2Ze (regenerated) + CaCl2 (waste washed to drain).
- The resin is ready to be used again.

Comparison: Lime-Soda vs. Zeolite

Concept 1	**Concept 2**
End Result: Zeolite achieves Zero hardness. Lime-Soda leaves about 50 mg/L (good for municipal).	
Sludge: Lime-soda produces huge amounts of sludge. Zeolite produces no sludge (only a salty liquid waste).	
Operation: Lime-soda is complex and requires daily dosing adjustments. Zeolite is simple and automated.	
Cost: Lime-soda is cheaper for massive municipal plants treating highly hard water. Zeolite is favored for industry, hospitals, and homes.	

Summary

- Hardness is caused by Calcium and Magnesium ions (temporary = carbonates, permanent = sulfates/chlorides).
- Lime-Soda process precipitates out hardness, producing sludge, suitable for municipalities.
- Zeolite process trades sodium for calcium, producing zero hardness, suitable for industry.
- Next Lecture: Miscellaneous treatments including Iron removal, RO, and addressing Taste/Odour.

Miscellaneous Water Treatment

Unit 3: Treatment of Water

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Water Supply Engineering

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Lecture Agenda

- The Problem with Iron and Manganese
- Methods of Iron/Manganese Removal (Aeration)
- Causes of Taste and Odour in Water
- Treatment for Taste and Odour (Activated Carbon)
- Introduction to Desalination
- Principles of Reverse Osmosis (RO)
- Applications and Limitations of RO

The Problem with Iron and Manganese

- Source: Very common in groundwater (borewells) where oxygen levels are low.
- In anaerobic conditions, Iron and Manganese exist in their soluble forms (Fe2+ and Mn2+). The water looks clear when pumped.
- Issues:
- When exposed to air, they oxidize into insoluble forms (Fe3+), turning the water yellow, brown, or black.
- Stains laundry and plumbing fixtures severely.
- Promotes the growth of 'Iron Bacteria' which create slimy, foul-smelling deposits in pipes.

Removal of Iron and Manganese

- The fundamental strategy is Oxidation followed by Filtration.
- Step 1: Aeration. Water is cascaded over trays or sprayed into the air. The oxygen in the air reacts with the soluble iron.
- Reaction: 4Fe(HCO3)2 + O2 + 2H2O -¿ 4Fe(OH)3 (precipitate) + 8CO2
- Step 2: Settling/Filtration. The insoluble rust precipitate (Fe(OH)3) is then easily removed using a standard sand filter.
- For stubborn Manganese, chemical oxidants like Chlorine or Potassium Permanganate are used instead of just air.

Causes of Taste and Odour

- Dissolved Gases: Hydrogen sulfide (H2S) gives a 'rotten egg' smell. Often found in groundwater.
- Organic Matter & Algae: Decaying vegetation or algae blooms in surface reservoirs release smelly oils (earthy or fishy odors).
- Industrial Pollution: Phenols or other synthetic chemicals discharged into rivers.
- Chlorination By-products: Chlorine combining with organics or phenols can create strong medicinal or chemical tastes.

Treatment for Taste and Odour

- 1. Aeration: Excellent for stripping volatile gases like H2S and volatile organic compounds (VOCs) out of the water.
- 2. Powdered Activated Carbon (PAC): The most common method. PAC is a highly porous form of carbon.
- Mechanism: Adsorption. The foul-smelling molecules stick to the massive internal surface area of the carbon particles.
- PAC is dosed into the water before the clarifier and settles out with the floc.
- 3. Copper Sulfate: Added to reservoirs to kill algae blooms before they reach the plant.

Introduction to Desalination

- Desalination is the removal of dissolved salts from seawater or brackish groundwater.
- Why needed? Freshwater scarcity. As traditional sources dry up, coastal cities must turn to the ocean.
- Methods:
- Thermal: Multi-Stage Flash distillation (boiling water and capturing condensation). Highly energy-intensive.
- Membrane: Reverse Osmosis (RO). Now the dominant technology globally due to better energy efficiency.

Principles of Osmosis

- Normal Osmosis: If you separate fresh water and salt water with a semi-permeable membrane, nature wants to balance the concentration.
- Fresh water will naturally flow THROUGH the membrane into the salt side to dilute it.
- This natural flow creates 'Osmotic Pressure'.
- The membrane has microscopic pores that let water molecules pass, but block salt ions (Na^+, Cl^-).

Reverse Osmosis (RO) Process

- To purify water, we must fight nature. We apply massive external pressure to the salty side.
- If the applied pressure exceeds the natural osmotic pressure, the flow is reversed.
- Pure water is forced OUT of the salty side, through the membrane, leaving the concentrated salts behind.
- Required Pressure: For seawater, pressures can be as high as 60 to 80 bar (800-1100 psi).

RO System Components

- 1. Extensive Pre-treatment: Crucial! Sand, silt, or algae will instantly plug the expensive RO membranes. Requires microfiltration and anti-scalants.
- 2. High-Pressure Pump: The heart (and main energy consumer) of the system.
- 3. Membrane Assembly: Usually spiral-wound polyamide membranes housed in pressure vessels.
- 4. Energy Recovery Device (ERD): Captures the pressure from the reject brine stream to help power the pump, saving massive amounts of electricity.

Applications and Limitations of RO

- Applications:
- Seawater desalination for coastal cities.
- Treating brackish inland groundwater.
- Producing ultra-pure water for electronics and pharmaceutical industries.
- Limitations:
- High energy consumption and operational cost.
- Generates a highly concentrated toxic brine waste that is difficult to dispose of without harming marine life.
- Membranes are fragile and degrade with chlorine, requiring dechlorination beforehand.

Unit 3 Summary

- Iron and Odours are removed via aeration and activated carbon.
- Reverse Osmosis utilizes high pressure to overcome osmotic forces, removing dissolved salts.
- We have now covered the entire water treatment train: from raw water intake, coagulation, sedimentation, filtration, disinfection, to specialized treatments.

Types of Pipes for Water Supply

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Requirements of a Good Pipe Material

- Must have carrying capacity adequate for the design life.
- Should be durable, structurally strong, and resistant to wear and tear.
- Must be resistant to internal and external corrosion.
- Should not impart taste, color, or odor to the water.
- Ease of transportation, handling, and jointing is essential.

Common Types of Pipes

- Cast Iron (CI) Pipes
- Ductile Iron (DI) Pipes
- Steel Pipes
- Concrete Pipes (RCC & PSC)
- Asbestos Cement (AC) Pipes
- Plastic Pipes (PVC, HDPE)

Cast Iron (CI) Pipes

- Historically the most widely used material for water distribution.
- Manufactured by sand casting or centrifugal casting (spun iron pipes).
- Advantages: Highly resistant to corrosion, long service life (100+ years), moderate cost.
- Disadvantages: Heavy to handle, brittle (subject to breakage during transport), high internal friction if unlined.

Ductile Iron (DI) Pipes

- An evolution of CI pipes where graphite is present in nodular form instead of flakes.
- Provides the corrosion resistance of CI with the tensile strength and flexibility of steel.
- Advantages: High impact strength, lighter than CI, can withstand high water hammer pressure.
- Widely replaces CI in modern municipal water distribution networks.

Steel Pipes

- Used for very large diameter transmission mains where pressure is extremely high.
- Advantages: High tensile strength, lightweight compared to CI/Concrete, easy to transport and weld.
- Disadvantages: Highly susceptible to corrosion; requires internal lining (cement mortar) and external coating (epoxy or wrapping).
- Prone to failure under external loads or vacuum conditions if not properly stiffened.

Concrete Pipes (RCC)

- Reinforced Cement Concrete (RCC) pipes are used for gravity mains or low-pressure pumping mains.
- Advantages: No corrosion issues, low maintenance, smooth internal surface initially.
- Disadvantages: Extremely heavy, difficult to repair, susceptible to acid attacks.
- Joints are usually made with cement mortar or rubber gaskets.

Prestressed Concrete (PSC) Pipes

- High tensile steel wire is wrapped around a concrete core under tension.
- Can withstand much higher internal pressures than standard RCC.
- Often used in large diameter transmission mains (e.g., Narmada canal bulk pipelines).
- More economical than steel for large diameters, though still heavy and difficult to tap for service connections.

Asbestos Cement (AC) Pipes

- Made from a mix of asbestos fiber, silica, and cement.
- Advantages: Very smooth interior (low friction loss), light weight, highly corrosion-resistant.
- Disadvantages: Brittle (easily damaged in handling), structurally weak against heavy earth loads.
- Health Concerns: Asbestos fibers in drinking water and dust during cutting/laying have led to its ban in many countries.

Plastic Pipes - PVC & CPVC

- Polyvinyl Chloride (PVC) is extensively used for secondary distribution and house plumbing.
- Advantages: Very cheap, extremely lightweight, completely immune to galvanic/soil corrosion, very smooth (Hazen-Williams C=150).
- Disadvantages: Loses strength at high temperatures, degrades under prolonged UV exposure (sunlight).
- CPVC (Chlorinated PVC) can handle hot water and is preferred for indoor plumbing.

High-Density Polyethylene (HDPE) Pipes

- Tough, flexible plastic pipes, usually black with blue stripes for water.
- Advantages: Can bend around obstacles without joints (delivered in coils), excellent resistance to soil movements and earthquakes.
- Joints are made via butt-fusion or electrofusion, creating a monolithic, leak-proof system.
- Increasingly replacing PVC in urban distribution grids due to fewer joints and higher durability.

Comparison of Pipe Materials

Concept 1	Concept 2
Cost: PVC/HDPE (Low) ¡ DI (Medium) ¡ Steel/PSC (High for small diam)	
Life Span: CI/DI (100 yrs) ¿ Plastics (50-100 yrs) ¿ Steel (Depends on coating)	
Friction Loss: Plastics (Lowest) ¡ AC ¡ DI (Cement lined) ¡ CI (Unlined - Highest)	
Ease of Tapping: DI/CI (Easy) ¿ Steel (Requires welding) ¿ Plastics (Requires special saddles)	

Summary of Pipe Types

- Cast Iron and Ductile Iron are traditional, durable choices for distribution mains.
- Steel and PSC are reserved for large diameter, high-pressure bulk transmission.
- Plastic pipes (PVC, HDPE) dominate smaller distribution networks due to cost, flow characteristics, and corrosion resistance.
- Material selection depends on pressure, soil conditions, budget, and water chemistry.

Pipe Joints and Laying of Pipes

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Spigot and Socket (Bell and Spigot) Joint

- Most common joint for CI and DI pipes.
- One end of the pipe is enlarged (socket/bell), and the other is plain (spigot).
- The spigot is inserted into the socket. A rubber gasket (Tyton joint) is compressed between them to ensure watertightness.
- Historically, molten lead or cement mortar was used for sealing CI pipes.

Flanged Joint

- Used mostly in pumping stations, filter plants, and for connecting valves or meters.
- Pipe ends have flat rings (flanges) that are bolted together.
- A rubber or compressed fiber gasket is placed between the flanges to prevent leakage.
- Advantage: Easy to assemble and dismantle.
- Disadvantage: Rigid joint; cannot accommodate settlement or deflection.

Mechanical Joint (Gland Joint)

- Similar to the bell and spigot, but uses a bolted follower ring (gland) to compress a rubber gasket into the socket.
- Provides a very secure, watertight seal.
- Allows for some deflection and is highly resistant to vibration.
- Commonly used in locations subject to minor ground movement or heavy traffic vibrations.

Expansion and Flexible Joints

- Expansion Joints: Used in exposed pipelines (like steel mains on bridge crossings) to absorb thermal expansion and contraction.
- Flexible Joints (Ball and Socket): Allow large deflections (up to 15 degrees).
- Used for laying pipes across rivers, submerged outfalls, or in highly seismically active zones.

Joints for Plastic Pipes

- PVC Pipes: Typically joined using solvent cement (chemical welding) or push-on elastomeric ring joints.
- HDPE Pipes: Joined using Butt-Fusion (melting pipe ends and pressing them together) or Electro-fusion (using a special heated sleeve).
- HDPE joints become as strong as the pipe itself, eliminating weak leak points.

Laying of Pipes: Preparatory Works

- 1. Setting out the alignment on the ground.
- 2. Excavation of trenches to required depth and gradient.
- 3. Preparation of the trench bottom (bedding).
- Proper planning of underground utilities is essential to avoid damaging existing cables or sewers.

Trenching and Bedding

- Trench Width: Must be wide enough for workers to joint pipes (usually pipe outer diameter + 30-45 cm on each side).
- Bedding: The material on which the pipe rests. Crucial for structural support.
- Types of Bedding: Granular (sand/gravel), concrete cradle (for heavy loads), or shaping the native soil.
- Uneven bedding causes point loads, leading to pipe fracture, especially in brittle materials.

Lowering and Laying the Pipes

- Pipes are lowered into the trench using ropes, tripods, or excavators (never dropped).
- Laying usually proceeds in an uphill direction to allow water to drain away from the working area.
- Sockets should ideally face uphill.
- Pipe interiors must be inspected and cleaned of debris before jointing.

Thrust Blocks

- Water under pressure exerts massive dynamic and static thrust forces at changes in direction (bends, tees) or dead ends.
- Unrestrained joints can blow apart under this thrust.
- Thrust Blocks are mass concrete poured between the pipe fitting and the undisturbed trench wall to transfer the load to the soil.

Backfilling the Trench

- Initial Backfill: Done immediately around the pipe up to 30 cm above the crown using selected fine material. Hand-tamped.
- Main Backfill: Remaining trench depth filled with excavated soil in layers.
- Compaction is necessary to prevent future settlement of roads above the trench.
- Joints are left exposed during initial backfilling for pressure testing.

Testing of Pipelines

- Before commissioning, pipelines must be tested for watertightness.
- Hydraulic Testing: The isolated pipe section is filled with water slowly (to expel air) and pressurized using a hand pump.
- Test pressure is typically 1.5 times the maximum working pressure.
- Pressure must be maintained for a specified duration (e.g., 2 hours). Acceptable leakage rates are strictly defined by codes.

Disinfection of New Pipelines

- After successful pressure testing, the pipeline must be flushed and disinfected.
- A strong chlorine solution (e.g., 50 mg/L) is injected and left in the pipe for 24 hours.
- The heavily chlorinated water is then flushed out until residual chlorine drops to normal levels (0.2 - 0.5 mg/L).
- Bacteriological testing (Coliform test) is conducted before putting the line into public service.

Summary of Joints and Laying

- Joints like spigot-socket and mechanical joints allow slight flexibility, while flanged joints are rigid.
- Proper trenching, bedding, and thrust block construction are critical for structural stability.
- Hydraulic pressure testing and disinfection are mandatory final steps before commissioning a water main.

Distribution Systems - Layouts and Design

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Requirements of a Good Distribution System

- Water quality must not deteriorate in the distribution pipes.
- It should supply water at all intended locations with adequate pressure head (e.g., sufficient to reach a 2nd story building).
- It should be capable of supplying water during fire fighting emergencies.
- The layout should be such that no consumer is left without water during pipe repairs.

Layouts of Distribution Networks

- The arrangement of pipes depends on the road layout and topography of the city.
- Four primary types of layouts:
- 1. Dead End or Tree System
- 2. Grid Iron System
- 3. Ring or Circular System
- 4. Radial System

Dead End / Tree System

- Resembles a tree: A main pipe bifurcates into sub-mains, which bifurcate into branches, ending in dead ends.
- Suitable for irregularly developed or older, unplanned towns.
- Water flows in one direction only.

Dead End System: Pros and Cons

Concept 1	Concept 2
Advantages: Easy to design (simple calculations), cheap to install, fewer valves required.	
Disadvantages: Stagnation of water at dead ends causes health hazards (loss of residual chlorine).	
During repairs of a main line, all downstream areas are completely deprived of water.	
Limited discharge available for fire fighting at the dead ends.	

Grid Iron System (Interlaced System)

- Suitable for well-planned cities with rectangular road layouts (e.g., Chandigarh, Gandhinagar).
- Mains, sub-mains, and branches are all interconnected, forming a grid.
- Eliminates dead ends; water circulates continuously.

Concept 1	**Concept 2**
Advantages: Water reaches any point from multiple directions. High flow available for fire fighting.	
During repairs, only a small block is isolated by closing valves; the rest of the city gets water.	
Disadvantages: Complex hydraulic design (requires Hardy Cross method or software).	
High cost due to longer pipe lengths and a massive number of sluice valves required at every junction.	

Ring / Circular System

- A closed ring of main pipes is laid around the periphery of the distribution area.
- Sub-mains branch off from this ring and cross the interior area, forming a grid.
- Often combined with the Grid Iron system to form a 'Ring and Grid' layout.

Ring System: Characteristics

- Advantages: Pressure is well equalized across the network. Very reliable supply.
- Heavy draw-off in one area is compensated by flow from the other side of the ring.
- Disadvantages: Requires large diameter pipes for the entire peripheral ring, making it costly.
- Applicability: Excellent for towns that have a circular or radiating road pattern.

Radial System

- The city is divided into several zones. A central Elevated Service Reservoir (ESR) is provided for each zone.
- Pipes radiate outwards from each central ESR towards the periphery of that zone.
- It's essentially a reverse Dead End system, but fed from the center rather than one edge.

Radial System: Pros and Cons

Concept 1	**Concept 2**
Advantages: Ensures high and uniform pressure throughout the zone.	
Calculations for pipe sizes are simple and straightforward.	
Disadvantages: Requires construction of multiple Elevated Service Reservoirs (high capital cost).	
If a zonal ESR fails or requires maintenance, that entire zone loses water pressure.	

Comparison of Layouts

Concept 1	Concept 2
Cost: Dead End (Lowest) ¡ Radial ¡ Ring ¡ Grid Iron (Highest)	
Reliability: Grid Iron (Highest) ¿ Ring ¿ Radial ¿ Dead End (Lowest)	
Design Complexity: Grid/Ring (Complex) vs. Dead End/Radial (Simple)	

Summary of Distribution Layouts

- Dead-end networks are cheap but suffer from poor water quality and low reliability.
- Grid iron and Ring networks provide continuous flow and high redundancy, ideal for modern cities.
- Radial systems optimize pressure by distributing from central elevated reservoirs.
- Network choice is heavily dictated by existing town planning and topography.

Methods of Water Supply and Storage

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Gravity System

- Used when the source of water (lake, reservoir) is located at a much higher elevation than the distribution area.
- Water flows entirely under the force of gravity.
- Advantages: No pumping costs, highly reliable, simple operation, no power failures to worry about.
- Disadvantages: Dependent entirely on topography. High pressure near the source might require Pressure Reducing Valves (PRVs).

Direct Pumping System

- Treated water is pumped directly into the distribution mains without storing it in elevated tanks.
- Pumps must operate 24/7. Pump speed varies to match the fluctuating consumer demand.
- Advantages: No cost of constructing large Elevated Service Reservoirs (ESRs).
- Disadvantages: Highly vulnerable to power outages. Constant operation of pumps causes wear and tear.

Combined Gravity and Pumping System

- The most common system worldwide.
- Treated water is pumped at a constant rate into an Elevated Service Reservoir (ESR).
- From the ESR, water flows to the consumers via gravity.
- The ESR acts as a buffer. Pumps run at a steady, efficient rate, while the ESR handles peak demand.

Advantages of Combined System

- Reliability: If power fails, the water stored in the ESR continues to supply the city by gravity.
- Efficiency: Pumps can operate at their Best Efficiency Point (BEP) constantly.
- Fire Reserve: A portion of the ESR capacity is always reserved for fire-fighting emergencies.
- Pressure buffering: The ESR dampens pressure surges (water hammer) from the pumps.

Systems of Supply: Time-based

- Apart from hydraulic methods, we classify supply based on timing:
- 1. Continuous Supply System (24x7)
- 2. Intermittent Supply System (Few hours a day)

Continuous Supply System (24x7)

- Water is available at the consumer's tap all day, every day.
- Advantages: Water is always fresh. Consumers don't need large household storage tanks. Less risk of contamination.
- Pipes are always under positive pressure, preventing groundwater infiltration.
- Disadvantages: High water wastage if leaks are not fixed. Requires a large, consistent water source.

Intermittent Supply System

- Water is supplied for fixed hours (e.g., 2 hours in morning, 2 hours in evening).
- Adopted when water source is limited or treatment capacity is insufficient.
- Advantages: Forces water conservation (rationing). Less water lost to continuous leaks.
- Disadvantages: Severe health risks. When pipes are empty, negative pressure sucks in sewage from surrounding soil.

Service Reservoirs (Distribution Reservoirs)

- Facilities used to store treated water just before distribution.
- Functions:
- 1. Balancing or Equalizing demand fluctuations.
- 2. Storing water for breakdowns (pumps/power failure).
- 3. Storing reserve water for fire fighting.

Types of Service Reservoirs

- Surface Reservoirs (GSR - Ground Service Reservoirs): Built at ground level. Used when there is high natural ground available nearby.
- Elevated Service Reservoirs (ESR - Overhead Tanks): Constructed on towers (staging) to provide the necessary gravity head for flat terrain.
- Materials: Usually Reinforced Cement Concrete (RCC) or Steel.

Capacity of Service Reservoirs

- Total Capacity = Balancing Storage + Breakdown Storage + Fire Storage.
- Balancing Storage: Calculated using a Mass Curve (cumulative supply vs cumulative demand).
- Breakdown Storage: Usually 25% of total capacity to sustain supply during 4-6 hour power cuts.
- Fire Storage: Maintained at the bottom of the tank, reserved strictly for emergencies.

Appurtenances in Reservoirs

- Inlet pipe: Usually discharges at the top.
- Outlet pipe: Draws water from slightly above the floor (to avoid silt).
- Overflow pipe: Connected to drains to prevent flooding if pumps overfill.
- Washout/Scour valve: At the lowest point to drain the tank for cleaning.
- Ventilators: To allow air entry/exit as water level rises and falls, preventing structural collapse.

Summary of Methods of Supply

- The combined gravity and pumping system utilizing Elevated Service Reservoirs is the most practical and reliable system globally.
- Continuous (24x7) supply is structurally and hygienically vastly superior to intermittent supply.
- Service reservoirs act as critical buffers, balancing demand, handling emergencies, and maintaining pressure.

Valves, Meters, Fittings and Fixtures

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Sluice Valves (Gate Valves)

- The most common type of valve in a water supply system.
- Function: To completely stop or fully allow the flow of water (Isolating valve).
- Mechanism: A wedge-shaped gate is lowered or raised by a threaded stem.
- Location: Installed at regular intervals (150-300m) and at street intersections to isolate blocks for repairs.

Check Valves (Reflux / Non-Return Valves)

- Function: Allows water to flow in one direction only. Prevents backflow.
- Mechanism: A hinged flap that swings open with forward flow and slams shut if water tries to reverse.
- Location: Placed strictly on the delivery side of pumping sets.
- Purpose: Protects pumps from water hammer and prevents the reservoir from draining backward through the pump when power fails.

Air Relief Valves

- Water contains dissolved air which separates out under varying pressure and accumulates at high points in the pipeline.
- Trapped air reduces the pipe's carrying capacity (air binding) and causes surges.
- Function: Automatically exhausts accumulated air from the pipeline.
- Location: Installed strictly at the summits (highest points) of the pipeline profile.

Working of an Air Valve

- Contains a hollow ball float inside a chamber.
- When air accumulates, it displaces the water, the ball drops, and opens the vent to release air.
- As water rushes back in, it lifts the float, sealing the vent tightly before water escapes.
- Also allows air to enter the pipe when it is being drained, preventing vacuum collapse.

Scour Valves (Blow-off Valves)

- Function: To drain out water and settled sediment/silt from the pipeline during maintenance.
- Location: Installed at the lowest points (valleys/depressions) of the pipeline.
- Discharge is usually directed into nearby natural drains or streams.
- Also used at dead-ends in distribution systems to flush out stagnant water.

Pressure Relief Valves & PRVs

- Pressure Relief Valve: Acts like a safety valve. If pressure exceeds a safe limit (water hammer), it blows open to discharge water and relieve pressure, protecting pipes from bursting.
- Pressure Reducing Valve (PRV): Automatically reduces high upstream pressure to a steady lower downstream pressure.
- Used when a gravity main from a high mountain enters a low valley town, to prevent bursting consumer pipes.

Fire Hydrants

- Specialized outlets provided on the distribution mains to tap water for fire fighting.
- Types: Post Hydrants (stand above ground, common in US) and Flush Hydrants (below ground in chambers, common in India/UK).
- Requirements: Must deliver heavy discharge instantly. Placed 90m - 120m apart in urban areas.

Water Meters

- Function: To measure and record the volume of water consumed by a user.
- Promotes water conservation by charging consumers based on actual usage (volumetric tariff) rather than a flat rate.
- Commonly installed at the boundary of a property on the service pipe.

Types of Water Meters

- Displacement (Volumetric) Meters: Water physically displaces a piston or oscillating disk. Highly accurate for low flows (domestic use).
- Velocity (Inferential) Meters: Water spins a turbine or propeller. The speed of rotation infers flow rate. Used for large mains (bulk meters).
- Electromagnetic/Ultrasonic Meters: No moving parts. Use magnetic fields or sound waves. Very accurate and low maintenance, but expensive.

Pipe Fittings

- Fittings are used to change direction, branch off, or change the diameter of a pipeline.
- Bends/Elbows: Change direction (e.g., 90°, 45°, 22.5°).
- Tees and Crosses: Used to create branches from the main line.
- Reducers: Connect a larger pipe to a smaller one (Eccentric or Concentric).
- Caps and Plugs: Used to close off the dead end of a pipe.

Fixtures (Household Plumbing)

- Fixtures are the terminal points of the water supply where water is drawn for use.
- Taps / Faucets (Bib cocks): Used over sinks and washbasins.
- Stop Cocks: Small valves used to isolate individual sections of household plumbing.
- Mixer taps: Combine hot and cold water streams.
- Flush valves / Cisterns: Used in sanitary appliances (toilets).

Summary of Valves and Fittings

- Sluice valves isolate sections, Check valves prevent backflow, Air valves release trapped air, and Scour valves remove silt.
- Water meters are essential tools for demand management and fair billing.
- Fittings guide the pipeline layout, while fixtures provide the final interface for the consumer.
- This concludes Unit 4 on the Conveyance of Water.

Maintenance of Water Supply Mains & Leak Detection

Unit 5: Maintenance of Water Supply Mains

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Agenda

- Importance of Maintenance
- Types of Maintenance (Preventive, Corrective)
- Causes and Consequences of Leaks
- Traditional and Acoustic Leak Detection
- Advanced Detection: Correlators and Loggers
- Methods for Leak Repair

Why Maintain Water Supply Mains?

- Ensure continuous and reliable water supply to consumers at adequate pressure.
- Prevent the contamination of treated water in the distribution network.
- Minimize physical water losses and reduce non-revenue water.
- Extend the useful life of the pipeline infrastructure, delaying costly replacements.

Types of Maintenance

Concept 1	Concept 2
Preventive Maintenance: Scheduled tasks to prevent failures. Includes systematic flushing, valve exercising, and routine inspections.	
Corrective Maintenance: Reactive work performed after a failure occurs, such as repairing a burst main or replacing a broken valve.	
Predictive Maintenance: Using condition monitoring and data analytics (e.g., continuous acoustic logging) to predict and prevent imminent failures.	

Routine Preventive Tasks

- **Unidirectional Flushing (UDF)**: Closing specific valves to create high-velocity flow, scouring biofilms, sediments, and tuberculation from pipes.
- **Valve Exercising**: Fully opening and closing valves annually to prevent them from seizing due to corrosion or mineral buildup.
- **Hydrant Maintenance**: Inspecting fire hydrants for leaks, proper drainage, and adequate flow capacity.

Causes of Pipe Leaks

- **Internal and External Corrosion**: Weakens pipe walls, especially in older cast iron and steel mains, creating pinholes.
- **Ground Movement**: Soil subsidence, frost heave, or earthquakes can cause shear stress and break rigid pipes.
- **Water Hammer**: Sudden changes in flow (e.g., rapid valve closure) cause pressure surges that rupture pipes.
- **Traffic Loads**: Heavy vehicles create continuous vibrations and dynamic loads on shallowly buried pipes.
- **Poor Workmanship**: Improper bedding, poor jointing, or damaged O-rings during installation.

Consequences of Leaks

- **Financial Loss**: Significant loss of treated, pumped water which costs money to produce (electricity and chemicals).
- **Contamination Risk**: During low pressure events, negative pressure can pull contaminated groundwater into the pipe through the leak.
- **Property Damage**: Washouts can undermine roads, causing sinkholes, and flood basements.
- **Reduced Pressure**: Large leaks lower the hydraulic gradient, leaving downstream consumers with inadequate water pressure.

Introduction to Leak Detection

- **Passive Leak Control**: Waiting for leaks to show up on the surface (e.g., wet spots, sinkholes) or relying on customer complaints.
- **Active Leak Control (ALC)**: Systematically searching for hidden, underground leaks using specialized equipment.
- **Step-Testing**: Closing valves sequentially at night to isolate sections; observing sudden drops in flow meters indicates a leak in the isolated section.

Acoustic Leak Detection: Principles

- Water escaping under pressure creates a distinct 'hissing' sound or vibration.
- This sound travels along the pipe wall and through the surrounding soil.
- Metallic pipes (iron, steel) transmit sound very well over long distances.
- Plastic pipes (PVC, PE) absorb sound, making acoustic detection much more difficult and limiting the listening range.

Acoustic Equipment: Geophones and Microphones

- **Listening Sticks**: Simple mechanical devices placed on valves or hydrants to listen for vibrations.
- **Geophones (Ground Microphones)**: Electronic listening devices with highly sensitive microphones placed on the ground surface above the pipe.
- **Operation**: The operator walks the pipe route, placing the geophone at intervals. The loudest sound indicates the point directly above the leak.

Advanced Detection: Leak Correlators

- Uses two sensors placed on contact points (e.g., valves) on either side of a suspected leak.
- The leak sound travels to both sensors. Because the leak is usually not exactly in the middle, the sound arrives at one sensor slightly before the other.
- The correlator measures the time delay (t).
- Using the distance between sensors (D) and the velocity of sound in that specific pipe material (V), it calculates the exact leak location.

Advanced Detection: Noise Loggers

- Small, magnetic sensors deployed temporarily or permanently on valves across the network.
- They record acoustic noise overnight (e.g., 2 AM to 4 AM) when ambient traffic noise and normal water usage are minimal.
- If a continuous noise is recorded every night, it strongly indicates a leak.
- Data is transmitted via cellular networks to the utility's control center for analysis.

Preventing Leaks and Repair Methods

- **Prevention**: Installing pressure relief valves to stop water hammer, using cathodic protection to halt corrosion, and ensuring proper pipe bedding.
- **Repair Clamps (Stainless Steel)**: Wrapped around a cracked pipe or pinhole leak and bolted tight. A fast, permanent fix for localized damage.
- **Repair Sleeves/Collars**: Used to connect a replacement segment when a large section of the pipe is shattered.
- Repairs must be done under sanitary conditions, often requiring localized disinfection of the repaired segment.

Summary

- Maintenance is crucial for network longevity, water quality, and minimizing losses.
- Leaks are caused by corrosion, pressure surges, and physical stress.
- Active Leak Control uses acoustic methods (geophones, correlators) to find hidden leaks.
- Modern technology like noise loggers enables continuous monitoring of the distribution system.

Next Lecture Preview

- Water Conservation Strategies
- Understanding Non-Revenue Water (NRW)
- Pressure Management Techniques
- Trenchless Pipe Rehabilitation (Slip lining, CIPP)

Water Conservation and Pipe Rehabilitation

Unit 5: Maintenance of Water Supply Mains

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Agenda

- Utility-Level Water Conservation
- Understanding Non-Revenue Water (NRW)
- The IWA Water Balance
- Pressure Management for Leak Reduction
- The Need for Pipe Rehabilitation
- Trenchless Techniques: Slip Lining, CIPP, and Pipe Bursting

Water Conservation at the Utility Level

- Conservation is not just for consumers; utilities must conserve treated water to delay costly infrastructure expansion.
- **Key Strategies**:
- 1. Universal metering and replacing old, under-registering meters.
- 2. Implementing active leak detection and rapid repair programs.
- 3. Managing system pressure to reduce flow rates through existing leaks.
- 4. Public education and implementing tiered pricing (higher rates for excessive use).

What is Non-Revenue Water (NRW)?

- **Non-Revenue Water (NRW)** is the difference between the volume of water put into the distribution system and the volume that is billed to customers.
- It represents water that generates no revenue for the utility.
- High NRW leads to financial instability for the utility and requires higher tariffs for paying customers.
- In many developing nations, NRW can exceed 40-50%.

The IWA Water Balance: NRW Components

- The International Water Association (IWA) defines NRW in three parts:
- **1. Unbilled Authorized Consumption**: Firefighting, flushing mains, watering public parks (water used legitimately but not billed).
- **2. Apparent Losses (Commercial Losses)**: Meter inaccuracies, data handling errors, and water theft/illegal connections.
- **3. Real Losses (Physical Losses)**: Leakage from transmission mains, distribution pipes, service connections, and storage tank overflows.

Tackling Apparent Losses

- **Meter Replacement Programs**: Mechanical meters wear out and under-register at low flows over time. Replacing them recovers lost revenue.
- **Advanced Metering Infrastructure (AMI)**: Smart meters transmit data daily, detecting tampering and identifying customer-side leaks early.
- **Audits and Inspections**: Physically inspecting connections to find illegal bypasses and prosecuting water theft.

Tackling Real Losses: Pressure Management

- Leakage rate is highly dependent on system pressure (Q = Cd * A * (2gH)). Higher pressure = Higher leakage.
- Networks must maintain high pressure during peak day demand. However, at night, demand drops, and pressure rises unnecessarily.
- **Pressure Reducing Valves (PRVs)**: Installed to automatically lower the downstream pressure during off-peak hours.
- Reduces the flow from existing background leaks and prevents new pipe bursts caused by high night-time pressures.

The Need for Pipe Rehabilitation

- As pipes age (especially cast iron and steel), they suffer from internal tuberculation and external corrosion.
- **Tuberculation**: Iron oxide mounds that grow inside the pipe, drastically reducing the effective diameter and increasing friction (lowering the 'C' value).
- Open-cut trenching to replace pipes is highly disruptive to traffic, expensive, and time-consuming.
- **Solution**: Trenchless rehabilitation techniques restore structural integrity and flow capacity with minimal digging.

Cleaning and Cement Mortar Lining

- Used for structurally sound pipes suffering from tuberculation.
- **Process**:
- 1. Pipe is isolated and bypassed.
- 2. Mechanical scrapers or high-pressure water jets remove tubercles and clean the pipe wall.
- 3. A centrifugal spinning machine applies a thin, smooth layer of cement mortar to the inside.
- **Benefits**: Stops corrosion, restores flow capacity, seals small pinholes.

Trenchless Tech: Slip Lining

- A structural rehabilitation method.
- A new, continuous flexible pipe (usually High-Density Polyethylene - HDPE) is pulled or pushed into the existing old pipe.
- The new pipe has a slightly smaller outer diameter than the old pipe's inner diameter.
- The annular space between the old and new pipe is filled with grout.
- **Trade-off**: Reduces the cross-sectional area, but the smooth plastic often maintains or improves overall flow capacity.

Trenchless Tech: Cured-in-Place Pipe (CIPP)

- A flexible felt or fiberglass tube saturated with a thermosetting resin is inverted or pulled into the old pipe.
- Hot water or steam is circulated through the tube to cure (harden) the resin.
- Forms a tight-fitting, jointless, and structurally sound 'pipe-within-a-pipe'.
- Minimal reduction in pipe diameter compared to slip lining.
- Can negotiate bends and accommodate slight changes in pipe alignment.

Trenchless Tech: Pipe Bursting

- Used when a larger diameter pipe is required to increase capacity.
- A conical bursting head is pulled through the old rigid pipe (cast iron, clay).
- The head fractures the old pipe and pushes the fragments outwards into the surrounding soil.
- Simultaneously, it pulls a new, larger diameter HDPE pipe into the cavity created.
- Provides a brand new structural pipe and an upgrade in hydraulic capacity without trenching.

Comparing Rehabilitation Methods

Concept 1	Concept 2
Cement Mortar Lining: Non-structural. Restores water quality and flow. Cheapest.	
Slip Lining: Structural. Reduces diameter. Very fast for straight, long runs.	
CIPP: Structural. Minimal diameter loss. Can handle bends. Excellent for urban areas.	
Pipe Bursting: Structural. Allows for capacity increase (upsizing). Requires old pipe to be fracturable.	

Summary

- Non-Revenue Water (NRW) consists of apparent losses, real losses, and unbilled authorized use.
- Pressure management via PRVs is a critical tool for reducing real physical losses.
- Trenchless rehabilitation renews aging mains with minimal surface disruption.
- Techniques like CIPP, slip lining, and pipe bursting offer varying levels of structural renewal and hydraulic capacity.

Next Lecture Preview

- Introduction to Unit 6: Valves and Fittings
- Types of Valves in Water Supply
- Sluice Valves, Check Valves, Air Valves
- Fire Hydrants and Water Meters

Sanitation Concepts and Objectives

Unit 6: Sanitation System

GTU Diploma Engineering

Water Supply Engineering

July 25, 2026

Agenda

- Introduction to Sanitary Engineering
- Key Terminology in Sanitation
- Basic Concepts of Sanitation
- Objectives of Sanitary Works
- Public Health and Environmental Impact

What is Sanitary Engineering?

- Branch of public health engineering that deals with the proper collection, treatment, and disposal of waste.
- Aims to preserve and promote public health.
- Prevents the outbreak of epidemic diseases.
- Ensures a clean and healthy living environment.

Key Terminology: Refuse and Garbage

- Refuse: General term indicating all kinds of solid wastes generated from a community.
- Garbage: Dry refuse such as decayed fruits, vegetables, grass, leaves, and food waste.
- Garbage is highly putrescible (decomposes easily) and attracts flies and rodents.
- Requires immediate collection and disposal to avoid foul odors.

Key Terminology: Rubbish and Ashes

- Rubbish: Non-putrescible solid waste (excluding ashes), consisting of combustible and non-combustible materials.
- Examples: Paper, rags, plastics, glass, metal, and ceramics.
- Ashes: Residue left after the combustion of fuels like coal, wood, and charcoal.
- Generally handled under Solid Waste Management.

Key Terminology: Sullage

- Sullage: Wastewater generated from bathrooms, kitchens, washing places, and washbasins.
- It does NOT contain human or animal excreta.
- Less offensive and less hazardous than sewage.
- Can sometimes be reused for gardening after basic treatment.

Key Terminology: Sewage

- Sewage: Liquid waste containing human and animal excreta, along with sullage and industrial wastewater.
- Highly offensive and contains pathogenic (disease-causing) bacteria.
- Requires complex treatment before safe disposal into water bodies.
- Also referred to as 'black water' in modern terminology.

Key Terminology: Storm Water and Sub-soil Water

- Storm Water: Runoff from rainfall, street washing, and melting snow.
- Generally clean, but can wash pollutants from streets.
- Sub-soil Water: Groundwater that enters sewers through leaks or poorly constructed joints.
- Increases the total volume of wastewater to be treated (infiltration).

Objectives of Sanitation System

- To collect all waste and wastewater from towns and cities efficiently.
- To transport it to the point of treatment and disposal without causing a nuisance.
- To treat wastewater to acceptable standards before discharging it into the environment.
- To dispose of solid waste safely (e.g., sanitary landfilling, composting).

Public Health Importance

- Prevention of Waterborne Diseases: Cholera, typhoid, dysentery, and hepatitis are transmitted via contaminated water.
- Vector Control: Proper waste disposal eliminates breeding grounds for mosquitoes and flies.
- Improved Hygiene: Provides communities with a clean environment, reducing illness and healthcare costs.
- Historical Context: Epidemics in the 19th century drove the development of modern sanitary systems.

Environmental Protection

- Prevention of Water Pollution: Protects rivers, lakes, and oceans from eutrophication and toxic contamination.
- Maintenance of Aquatic Ecosystems: Ensures sufficient dissolved oxygen for fish and aquatic life.
- Soil Protection: Prevents contamination of agricultural land by heavy metals and pathogens.
- Odor and Aesthetic Control: Maintains visually appealing and odor-free urban spaces.

Role of a Sanitary Engineer

- Designing collection networks (sewers, drains).
- Selecting appropriate treatment technologies.
- Managing construction and operation of treatment plants.
- Ensuring compliance with environmental discharge standards.

Summary

- Sanitation is essential for public health and environmental protection.
- Wastes are categorized based on their characteristics (garbage, rubbish, sullage, sewage).
- Sewage contains excreta and is highly hazardous.
- The main objective is safe collection, treatment, and disposal of waste.

Next Lecture Preview

- Methods of Collection of Waste.
- The Conservancy System (Dry Carriage System).
- Advantages and disadvantages of the conservancy system.
- Where is it still applicable?

Methods of Collection: Conservancy System

Unit 6: Sanitation System

GTU Diploma Engineering

Water Supply Engineering

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Agenda

- Overview of Waste Collection Methods
- Introduction to the Conservancy System
- Handling Different Types of Waste
- Advantages of the Conservancy System
- Disadvantages and Health Risks
- Suitability and Current Context

Methods of Collection

- Once waste is generated, it must be collected and removed.
- There are two principal methods of collection:
- 1. Conservancy System (Dry Carriage System)
- 2. Water Carriage System
- The choice depends on water availability, topography, financial resources, and technological development of the town.

What is the Conservancy System?

- Also known as the 'Dry Carriage System'.
- Different types of refuse and storm water are collected, conveyed, and disposed of separately.
- Solid wastes (garbage, rubbish) and human excreta (night soil) are collected in containers or dry latrines.
- They are periodically removed manually by sanitary workers.

Handling of Solid Waste (Garbage & Rubbish)

- Collected in dustbins placed along streets or at houses.
- Transported via trucks or tractor trailers.
- Disposal methods include sorting for combustibles and non-combustibles.
- Combustible refuse is burnt; non-combustible is used for filling low-lying areas.

Handling of Storm Water and Sullage

- Storm water (rainwater) and sullage (kitchen/bath wastewater) are usually allowed to mix.
- Carried away in open or semi-closed surface drains.
- Discharged into nearby natural watercourses like rivers or streams.
- Relatively less harmful, but open drains can become blocked or emit odors.

Handling of Human Excreta (Night Soil)

- Collected in pans or buckets in dry privies/latrines.
- Manually emptied into covered carts or trucks by sweepers.
- Transported to disposal sites outside the town.
- Commonly disposed of by 'Trenching' - buried in trenches to decompose and form manure.

Advantages of the Conservancy System

- Initial Cost: Low capital cost as underground sewer networks are not required.
- Water Conservation: Requires very little water, making it suitable for areas with severe water scarcity.
- Manure Value: Night soil can be directly converted into valuable agricultural fertilizer through composting.
- Storm Water: No risk of sewage overflowing into streets during heavy rains (as systems are separate).

Disadvantages: Health and Hygiene

- Highly unhygienic and poses severe health hazards to sanitation workers.
- Dry latrines and open transport carts cause extreme foul odors and visual nuisance.
- Spillage during transport spreads pathogens in streets.
- Flies and insects breed in dry latrines, leading to outbreaks of diseases like dysentery and typhoid.

Disadvantages: Operational Challenges

- Labor Intensive: Requires a large, continuous workforce of sweepers.
- Unreliable: Strikes or absence of workers lead to immediate and severe sanitary crises.
- Space Requirement: Requires large land areas outside the city for trenching.
- Building Design: Latrines must be placed on outside walls for access, restricting architectural freedom.

Disadvantages: Sub-soil Pollution

- Seepage of liquid waste from dry latrines can pollute shallow groundwater.
- Open drains carrying sullage may percolate into the soil.
- Polluted groundwater can contaminate nearby wells, causing waterborne epidemics.

Suitability

- Small towns or villages with very limited financial resources.
- Areas facing extreme water scarcity where a water carriage system is impossible.
- Temporary camps, fairs, or military bases.
- Largely obsolete in modern urban planning due to public health and social (manual scavenging) concerns.

Summary

- Conservancy system collects solid, liquid, and human waste separately.
- Relies heavily on manual labor for collection and transport.
- Low initial cost and low water requirement are the main benefits.
- High health risks, odors, and unreliability are major drawbacks.

Next Lecture Preview

- The Water Carriage System.
- How water is used to transport waste.
- Advantages and disadvantages of the water carriage system.
- Direct comparison between Conservancy and Water Carriage systems.

Methods of Collection: Water Carriage System & Comparison

Unit 6: Sanitation System

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Agenda

- Introduction to Water Carriage System
- Working Mechanism
- Advantages of Water Carriage System
- Disadvantages and Requirements
- Comparison: Conservancy vs. Water Carriage
- Conclusion on Collection Methods

What is the Water Carriage System?

- A system where water is used as the medium to convey waste from its source to the point of treatment and disposal.
- Feces, urine, and sullage are flushed away using water.
- The solid matter remains suspended in the flowing water.
- Requires a network of closed, underground pipes called sewers.

Working Mechanism

- Collection: Waste is collected in sanitary fittings (water closets, sinks) inside buildings.
- Flushing: A large volume of water flushes the waste into house drains.
- Conveyance: Gravity flows move the waste (now called sewage) through branch sewers to main sewers.
- Treatment: Sewage reaches a centralized Sewage Treatment Plant (STP) before final disposal.

Advantages: Health and Hygiene

- Highly hygienic: Waste is removed immediately, preventing putrefaction near homes.
- No manual handling of human waste, eliminating social stigma and health risks to workers.
- Closed underground system prevents foul odors, flies, and mosquito breeding.
- Drastically reduces the incidence of waterborne and vector-borne epidemic diseases.

Advantages: Operation and Architecture

- Reliability: Does not depend on a large manual workforce for daily collection.
- Architectural Freedom: Bathrooms and toilets can be located anywhere inside a building.
- Aesthetics: Underground sewers are invisible and maintain the aesthetic appearance of the city.
- Compactness: Requires less land area compared to trenching grounds.

Disadvantages: Cost and Complexity

- High Capital Cost: Requires immense investment for laying underground sewer networks and constructing STPs.
- High Water Requirement: Requires a continuous and abundant piped water supply (at least 135 LPCD) to function.
- Skilled Engineering: Designing and laying sewers at proper gradients requires high technical expertise.

Disadvantages: Environmental Risks

- Pollution Risk: If the STP fails or is inadequate, large volumes of concentrated sewage pollute receiving water bodies.
- Maintenance Difficulties: Blockages in underground sewers are difficult and hazardous to clear.
- Pumping Costs: Flat terrain may require pumping stations, increasing operational costs.

Comparison: Hygiene & Environment

Concept 1	**Concept 2**
Conservancy: Highly unhygienic; risk of flies, odors, and epidemics. Open drains.	
Water Carriage: Highly hygienic; closed system, no odors or vector breeding.	
Conservancy: Night soil used for manure; potential for groundwater pollution.	
Water Carriage: Requires complex treatment; potential for severe surface water pollution if untreated.	

Comparison: Economics & Resources

Concept 1	**Concept 2**

Conservancy: Low initial cost, high operating cost (labor).

Water Carriage: High initial cost, low operating cost (gravity flow).

Conservancy: Requires very little water.

Water Carriage: Requires abundant, continuous water supply.

Conservancy: Large labor force required.

Water Carriage: Skilled engineers and technicians required.

Comparison: Design & Urban Planning

Concept 1	Concept 2
Conservancy: Toilets must be on outer walls for sweeper access. Prevents dense, high-rise development.	
Water Carriage: Toilets can be anywhere. Essential for high-rise buildings and dense urban areas.	
Conservancy: Requires large land for trenching outside city.	
Water Carriage: Requires specific land for Sewage Treatment Plants.	

Conclusion on Collection Methods

- The Water Carriage system is universally preferred for modern urban environments.
- The Conservancy system is virtually obsolete in cities due to human rights and health concerns.
- Transitioning from conservancy to water carriage requires simultaneous development of a reliable water supply network.

Summary

- Water carriage system uses water to transport waste automatically via underground pipes.
- It provides excellent hygiene and allows for modern building design.
- Requires high capital, abundant water, and skilled maintenance.
- It solves the health issues of the conservancy system but requires careful environmental management of the outfall.

Next Lecture Preview

- Types of Sewerage Systems.
- Separate System vs. Combined System.
- Partially Separate System.
- Advantages and disadvantages of each sewerage system.

Drains Classification and Sewer Sections

Unit 7: Drains and Sewers

GTU Diploma Engineering

Water Supply Engineering

July 25, 2026

Agenda

- Introduction to Drains and Sewers
- Classification of Drains
- Requirements of an Ideal Sewer Section
- Circular Sewer Sections
- Non-Circular Sewer Sections
- Comparison of Various Sewer Shapes

Introduction to Drains and Sewers

- Drain: A conduit or channel primarily meant for carrying off surface water, stormwater, or excess groundwater. They often function under gravity flow.
- Sewer: An underground closed pipe or conduit specifically designed to carry foul sewage or wastewater away from a community to a treatment plant.
- While drains can be open to the atmosphere (open channels) or closed, sanitary sewers must always be closed conduits to prevent health hazards, foul odors, and public nuisance.

Classification of Drains

- Drains are broadly classified based on their location and primary function into two categories:
- 1. Surface Drains: Located at or near the ground surface. Designed to intercept, collect, and convey stormwater, street washings, and surface runoff to natural water bodies.
- 2. Subsurface Drains: Laid below the ground level, usually consisting of perforated pipes. Their main function is to lower the groundwater table and prevent waterlogging of soils.

Types of Surface Drains

- Open Surface Drains: Can be V-shaped, U-shaped, or semi-circular channels. Typically constructed using brickwork, stone masonry, or precast concrete.
- Cost-effective and easy to inspect, but highly prone to blockages from solid waste and can become breeding grounds for mosquitoes if water stagnates.
- Closed Surface Drains: Underground pipes equipped with street inlets and catch basins. Used in urban areas to carry heavy stormwater flow without causing surface flooding or obstructing traffic.

Requirements of an Ideal Sewer Section

- Hydraulic Efficiency: Must yield maximum discharge and velocity for a given cross-sectional area and bed slope (maximum hydraulic mean depth).
- Self-Cleansing Velocity: Should maintain a sufficient flow velocity (usually ¿ 0.6 m/s) even at minimum dry weather flow to prevent the deposition of suspended organic solids.
- Structural Stability: Must be robust enough to resist internal hydraulic pressure, external earth pressure, and superimposed traffic loads without deformation.
- Economy and Maintenance: Should be economical to construct, manufacture in standard sizes, and easy to clean, inspect, and maintain.

Circular Sewer Sections

- The circular shape is the universal standard for separate sanitary sewer systems.
- Advantages: Offers the maximum cross-sectional area for the least perimeter, resulting in high hydraulic efficiency when running full or half-full.
- Highly economical to manufacture in standard pipe lengths and provides excellent structural strength (arch action) under uniform external pressure.
- Limitation: Becomes hydraulically inefficient at very low flow depths (less than $1/3$ full), causing velocity to drop and silting to occur.

Need for Non-Circular Sewers

- Non-circular sections are primarily required in combined sewer systems.
- Combined systems face massive fluctuations: huge volumes during wet weather (stormwater + sewage) and very small volumes during dry weather (sanitary sewage only).
- During dry weather, flow depth in a large circular sewer becomes extremely shallow. Velocity drops below the self-cleansing limit, leading to sludge deposition.
- Non-circular sections are specifically designed to provide a narrower channel at the invert (bottom), increasing flow depth and velocity during dry periods.

Egg-Shaped Sewers

- Designed with a larger radius arch at the top and a smaller radius invert at the bottom (Standard Egg-Shaped).
- Excellent Hydraulic Properties: The narrower bottom ensures a greater hydraulic depth and higher self-cleansing velocity even at minimum dry weather flows.
- Mostly constructed in-situ using brick masonry or concrete. They are more difficult and expensive to construct compared to circular pipes.
- Inverted Egg-Shaped: Sometimes used in extremely soft yielding soils where the wider base provides better load distribution.

Horseshoe Shaped Sewers

- Shape: Resembles a horseshoe with a semi-circular arch top, diverging or vertical sides, and a flat or curved invert (bottom).
- Application: Primarily used for massive outfall sewers carrying huge combined discharges. Often used for heavy structural loads.
- Structural Considerations: Requires substantial side wall thickness or heavy reinforcement to bear the lateral earth pressure, making them expensive.
- Usually provided with a central V-notch or small channel at the invert to handle minimum dry weather flow effectively.

Parabolic and Semi-Elliptical Sewers

- Parabolic Section: Top is a parabola with an elliptical invert. Very suitable for carrying relatively small discharges under high external loads.
- Semi-Elliptical Section: A highly stable arch shape that effectively resists external earth pressure due to strong arch action.
- Mostly adopted for large storm drains running full or partially full, where deep excavations in loose soils are required.
- Limitation: They are less stable under internal hydraulic pressure and are strictly meant for gravity flow.

Rectangular and Box Sewers

- Rectangular or Box sections are primarily used for conveying large volumes of purely stormwater.
- Construction: Very easy to construct in the field using standard reinforced concrete forms and flat shuttering.
- Highly suitable for flat terrains where the available slope is minimal, yet a large cross-sectional area is needed without deep excavation.
- Corners at the bottom are typically filleted (chamfered) to prevent the deposition of grit and solids in dead zones.

Comparison of Sewer Sections

Concept 1	Concept 2
Circular: Best for separate sanitary systems; highly economical to manufacture; poor velocity at low flows.	
Egg-Shaped: Best for combined systems; maintains self-cleansing velocity at low flows; expensive and difficult to construct.	
Horseshoe: Best for large trunk/outfall sewers with heavy flows; requires heavy masonry/concrete base for lateral stability.	
Rectangular: Best for stormwater in flat areas; easy to cast in RCC; poor hydraulic mean depth for sewage flows.	

Summary

- Drains handle surface/subsurface water, while sewers carry hazardous wastewater.
- An ideal sewer must maintain self-cleansing velocity, be structurally sound, and be economical.
- Circular sewers are the standard for separate sanitary lines due to structural and hydraulic efficiency when flowing full.
- Non-circular sections, especially Egg-shaped and Horseshoe, are crucial for combined systems to handle highly variable flow rates.

Next Lecture Preview

- Sewer Joints and Materials
- Importance of leak-proof joints in sewer lines.
- Types of joints: Bell and Spigot, Collar, Mechanical, Flexible.
- Materials used for manufacturing sewers: RCC, Stoneware, Cast Iron, and Plastics.

Sewer Joints and Materials

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Agenda

- Importance of Sewer Joints
- Requirements of a Good Joint
- Types of Sewer Joints (Bell & Spigot, Collar, Mechanical, Flexible)
- Selection Criteria for Sewer Materials
- Common Sewer Materials (Stoneware, Concrete, Cast Iron, Plastics)
- Advantages and Disadvantages of Materials

Importance of Sewer Joints

- Preventing Infiltration: Leaky joints allow groundwater to enter the sewer (infiltration). This unnecessarily increases the hydraulic load on the pumping stations and treatment plants.
- Preventing Exfiltration: Leaky joints allow toxic sewage to escape (exfiltration), which can contaminate the surrounding soil and groundwater aquifers.
- Root Intrusion: Poorly sealed joints allow tree roots to enter the pipe in search of moisture, leading to severe blockages and structural pipe damage.

Requirements of a Good Sewer Joint

- Watertightness: Must be strictly impermeable to prevent infiltration and exfiltration.
- Durability and Chemical Resistance: Must withstand corrosive sewage gases (like Hydrogen Sulfide, H2S) and industrial effluents.
- Flexibility: Should ideally allow slight angular deflection without breaking, accommodating minor soil settlements or seismic vibrations.
- Constructability: Must be easy to assemble in the field, often in narrow, deep, and wet trench conditions.

Types of Sewer Joints

- Sewer joints are selected based on the pipe material, internal pressure, and environmental conditions.
- 1. Bell and Spigot Joint (Socket and Spigot)
- 2. Collar Joint (Sleeve Joint)
- 3. Mechanical Joint (Flanged Joint)
- 4. Flexible Joint
- 5. Simplex Joint (for Asbestos Cement pipes)

Bell and Spigot Joint

- Also known as Socket and Spigot joint. The most widely used joint for cast iron, stoneware, and concrete pipes.
- Mechanism: The plain end (spigot) of one pipe is pushed into the enlarged end (bell/socket) of the next pipe.
- Construction: Jute yarn dipped in cement slurry is caulked tightly into the inner annular space. The remaining outer space is packed with 1:1 or 1:2 cement mortar.
- The mortar is finished smoothly at a 45-degree angle to the pipe surface.

Collar Joint

- Used for joining plain-ended (spigot-spigot) pipes, primarily RCC or asbestos cement sewers.
- Mechanism: The ends of two pipes are brought together in perfect alignment. A separate loose collar (sleeve) slightly larger than the pipes is slipped over the junction.
- Construction: The annular space between the pipe ends and the inner face of the collar is packed tightly with cement mortar.
- This joint is rigid and mostly used for large diameter gravity sewers.

Mechanical and Flexible Joints

- Mechanical (Flanged) Joint: Used for pipes under pressure (force mains) or subject to vibration (e.g., laid on bridges). Involves bolting two flanged ends together with a rubber gasket in between.
- Flexible Joint: Adopted in areas prone to uneven soil settlement or seismic activity.
- Uses a compressed rubber O-ring or tyton gasket inside the socket. When the spigot is pushed in, the gasket compresses, forming a watertight seal that allows slight angular deflection.

Materials for Sewers: Selection Criteria

- Structural Strength: Must resist heavy superimposed loads (traffic) and deep earth cover.
- Corrosion Resistance: Must withstand highly corrosive sewer gases (H_2S converting to sulfuric acid) and industrial chemicals.
- Hydraulic Smoothness: A lower Manning's 'n' value (smooth inner surface) is required to maintain self-cleansing velocity.
- Imperviousness: Material itself must not be porous to prevent leakage.
- Cost and Availability: Must be economically viable in long lengths to minimize the number of joints.

Stoneware (Vitrified Clay) Pipes

- Characteristics: Manufactured from clay and shale, fired at high temperatures, and salt-glazed for a smooth finish.
- Advantages: Exceptionally resistant to corrosion, acid attacks, and erosion. Extremely durable with a long service life.
- Disadvantages: Highly brittle and fragile (can break during transport). Manufactured only in short lengths (0.6 to 1.2 m), meaning many joints are required.
- Usage: The absolute best choice for small diameter (up to 600mm) sanitary branch sewers carrying highly foul domestic sewage.

Concrete and RCC Pipes

- Characteristics: Plain concrete is used for small diameters; Reinforced Cement Concrete (RCC) is used for large diameters.
- Advantages: Very strong under heavy loads. Can be cast-in-situ for massive profiles (e.g., horseshoe sewers). Economical for large sizes.
- Disadvantages: Highly susceptible to 'Crown Corrosion' caused by H2S gas. Heavy to transport and handle.
- Usage: Widely used for large trunk sewers and storm drains. In sanitary sewers, they must be lined with protective coatings (PVC, epoxy, or high-alumina cement).

Cast Iron (CI) and Ductile Iron (DI) Pipes

- Advantages: Very high structural strength, can withstand high internal pressure and heavy external traffic loads. Available in long lengths (100% watertight joints).
- Disadvantages: Expensive and susceptible to corrosion if not properly coated (usually cement mortar lined internally).
- Usage: Used specifically for Force Mains (where sewage is pumped under pressure), outfall sewers, or gravity sewers laid beneath railway tracks or heavy traffic roads.

Plastic Pipes (PVC, HDPE)

- Polyvinyl Chloride (PVC) and High-Density Polyethylene (HDPE) are increasingly replacing traditional materials.
- Advantages: Absolute resistance to chemical corrosion and H2S gas. Very lightweight, easy to handle. Exceptionally smooth interior (excellent hydraulics). Available in very long lengths.
- Disadvantages: Lower structural strength compared to RCC/CI. Can deform under heavy soil loads if trench bedding is not perfectly compacted.
- Usage: Highly popular for house connections and small to medium diameter municipal branch sewers.

Summary

- Sewer joints must be watertight to prevent infiltration (groundwater entering) and exfiltration (sewage escaping).
- Bell and spigot joints with cement mortar are traditional, but flexible rubber gasket joints are preferred to accommodate soil settlement.
- Stoneware is chemically excellent but brittle. RCC is structurally strong but vulnerable to corrosion.
- Plastic pipes (PVC/HDPE) offer a modern compromise of excellent chemical resistance and smooth hydraulics, though they require careful bedding.

Next Lecture Preview

- Manholes and Flushing Tanks
- Introduction to Sewer Appurtenances.
- Why manholes are needed, where they are placed, and their types (shallow, deep, drop).
- How flushing tanks maintain self-cleansing velocity in flat sewer lines.

Manholes and Flushing Tanks

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Agenda

- Introduction to Sewer Appurtenances
- Manholes: Purpose and Location Criteria
- Components of a Manhole
- Types of Manholes (Shallow, Normal, Deep)
- Drop Manholes: Design and Necessity
- Flushing Tanks: Purpose and Automatic Siphon Mechanism

Sewer Appurtenances

- Definition: Specialized masonry or concrete structures constructed at various intervals along a sewer line to assist in its proper operation and maintenance.
- Since sewers are underground closed conduits, they cannot be maintained without access points and regulating structures.
- Primary Appurtenances Include:
- - Manholes (Inspection and cleaning)
- - Flushing Tanks (Maintaining flow velocity)
- - Catch Basins and Street Inlets (Stormwater entry)
- - Inverted Siphons (Crossing obstructions)

Manholes: Purpose and Location

- Purpose: The primary access point for workers or equipment to inspect, clean, clear blockages, and ventilate the sewer line.
- Location Criteria: Manholes are mandatory at:
- 1. Every change of sewer alignment (straight lines only between manholes).
- 2. Every change of gradient or pipe diameter.
- 3. Every junction/intersection of two or more sewers.
- 4. Standard straight intervals depending on pipe size (e.g., 30m for small pipes up to 300m for very large outfall pipes).

Components of a Manhole

- Cover and Frame: Heavy-duty Cast Iron or RCC, designed to bear traffic loads without rattling.
- Access Shaft: Vertical passage (circular, usually 0.7 to 0.9m dia) leading down from the cover.
- Working Chamber: The expanded bottom portion providing sufficient room for a worker to stand and operate cleaning rods (min 1.2m diameter).
- Benching: The sloping floor inside the chamber that guides sewage directly into the semi-circular central channel, preventing sludge accumulation.
- Step Irons: Cast iron steps embedded in the wall to allow descent.

Shallow Manholes (Inspection Chambers)

- Depth: Typically less than 0.9 meters.
- Shape: Usually rectangular (e.g., 0.9m x 0.6m).
- Features: They do not have a separate access shaft and working chamber. The cover directly opens to the bottom channel.
- Application: Commonly constructed at the start of a branch sewer line or within house drainage systems before connecting to the municipal sewer.

Normal / Standard Manholes

- Depth: Varies between 0.9 meters and 2.0 meters.
- Shape: Can be rectangular or circular. Circular is preferred as it is structurally stronger under earth pressure.
- Features: Consists of a distinct working chamber (min 1.2m dia) to allow a worker to operate comfortably, and an access shaft connecting to the ground level.
- The roof of the working chamber is often designed as an eccentric cone or arch to narrow down to the access shaft.

Deep Manholes

- Depth: Greater than 2.0 meters, sometimes exceeding 5-6 meters in deep trunk sewers.
- Shape: Always circular to best resist massive lateral earth pressures.
- Features: Distinct access shaft and large working chamber. Heavy-duty cast iron step irons or fixed steel ladders are mandatory.
- In extremely deep manholes, intermediate 'Rest Chambers' or platforms are provided every few meters to prevent fatal falls and allow workers to rest.

Drop Manholes

- Constructed when a branch sewer connects to a main sewer at a significantly higher elevation (drop ¿ 0.6 meters).
- Problem without Drop Manhole: High-velocity sewage would fall freely, splashing in the chamber. This releases foul H2S gases and poses severe danger to workers.
- Solution: The branch sewer connects to a vertical 'drop pipe' outside or inside the manhole wall, discharging smoothly at the main sewer's invert level.
- An inspection/cleaning eye is provided straight ahead at the branch pipe level.

Flushing Tanks: Purpose

- Problem: In exceptionally flat terrains or at the dead ends of branch sewers, flow volumes are too low to maintain 'self-cleansing velocity' (0.6 m/s). Solid waste settles and blocks the pipe.
- Solution: Flushing tanks are installed to store water and periodically release it in a massive sudden surge to wash away deposited sludge.
- Location: Typically located at the extreme upstream ends (dead ends) of branch sewer lines where flow is naturally the lowest.

Automatic Siphon Flushing Tank

- Mechanism: Works entirely automatically without moving mechanical parts or manual intervention, using a siphonic bell and a U-trap.
- Clean water fills the tank slowly via a trickle tap. As water rises, air is compressed inside the bell.
- When the water reaches the critical discharge level, the compressed air forces water out of the U-trap (sniff hole), instantly starting a siphonic action.
- The entire tank volume is discharged into the sewer in seconds until air enters the bell, breaking the siphon.

Advantages & Disadvantages of Flushing Tanks

- Advantages:
- - Prevents foul odors and blockages in flat sewer networks.
- - Reduces manual maintenance requirements at dead ends.
- Disadvantages:
- - High initial construction cost.
- - Consumes a large volume of clean municipal water.
- - The siphonic mechanism can fail if the sniff hole is blocked by debris.
- Modern Trend: Often replaced by periodic manual flushing using fire hydrants, water tanker trucks, or high-pressure jetting machines.

Summary

- Manholes are essential access points placed at changes in alignment, size, or slope for sewer maintenance.
- Benching in manholes prevents sewage from pooling.
- Drop manholes safely connect high-level branch sewers to low-level main sewers to prevent splashing and gas release.
- Flushing tanks are used at dead ends with flat gradients to provide artificial surges to maintain self-cleansing velocity.

Next Lecture Preview

- Catch Basins and Other Appurtenances
- Understanding Stormwater Inlets and Catch Basins.
- How Inverted Siphons cross physical obstructions.
- Role of Grease and Oil traps in industrial and commercial sewers.

Catch Basins and Sewer Appurtenances

Unit 7: Drains and Sewers

GTU Diploma Engineering

Water Supply Engineering

July 25, 2026

Agenda

- Street Inlets (Types and Functions)
- Catch Basins (Design and vs. Inlets)
- Inverted Siphons (Depressed Sewers)
- Grease and Oil Traps
- Clean-outs and Lamp Holes
- Stormwater Regulators

Street Inlets

- Definition: Street inlets are openings with gratings located along the roadside to admit surface stormwater runoff directly into the storm sewer or combined sewer.
- Types of Inlets:
- 1. Curb Inlets: Vertical openings cut into the road curb. Good for streets with heavy traffic as they don't impede vehicles.
- 2. Gutter Inlets: Horizontal iron gratings placed directly in the road gutter. Highly effective at catching water but can clog with leaves.
- 3. Combination Inlets: Combines both curb and gutter openings for maximum efficiency.

Catch Basins: Purpose

- Problem with Simple Inlets: Street runoff carries heavy grit, sand, leaves, and debris. If these enter the main sewer, they cause silting and blockages.
- Definition: A Catch Basin is a specialized inlet structure provided with a deep sump (depression) designed to 'catch' and retain heavy debris before the water enters the sewer.
- Application: Essential in combined sewer systems where preventing grit deposition in the main pipe is highly critical.

Design and Components of Catch Basins

- Grate/Inlet: Allows water in while filtering out very large debris.
- Sump (Grit Chamber): The bottom of the basin is extended 0.6m to 0.9m below the outlet pipe to collect settled grit and sand.
- Hood / Baffle Wall: A downward-pointing hood or trap is placed over the outlet pipe. This prevents floating debris (oil, leaves) from exiting and acts as a water seal to block foul sewer gases from reaching the street.

Catch Basins vs. Street Inlets

Concept 1	Concept 2
Street Inlet: - Direct entry into the sewer. - No sump for grit collection. - No gas trap. - Low maintenance, used mainly for separate storm sewers. Catch Basin: - Retains grit and floating debris. - Prevents foul gas escape using a hood trap. - Requires frequent manual cleaning of the sump, otherwise, decomposing organic matter causes foul street odors. Used in combined sewers.	

Inverted Siphons (Depressed Sewers)

- Problem: Gravity sewers cannot easily cross major physical obstructions at the same grade level (e.g., rivers, railway cuts, highways, or deep utility lines).
- Solution: An Inverted Siphon (or Depressed Sewer) is constructed.
- Definition: A section of sewer pipe that drops below the hydraulic grade line (HGL) to pass under the obstruction and rises back up on the other side.
- Unlike normal sewers, an inverted siphon always flows full and operates under hydraulic pressure.

Design Principles of Inverted Siphons

- Maintaining Velocity: Since it flows full, it is highly prone to silting if velocity drops. Minimum self-cleansing velocity of 0.9 m/s must be maintained.
- Multiple Pipes: To handle varying flows (Dry Weather vs Wet Weather) while maintaining high velocity, siphons are designed with 2 or 3 parallel pipes of varying diameters.
- Weir Arrangement: The inlet chamber has overflow weirs. Only the smallest pipe is used during low flow. When flow increases, water spills over the weir into the second, and then the third pipe.

Grease and Oil Traps

- Purpose: Intercepting chambers designed to remove oil, grease, and fat from wastewater before it enters the municipal sewer.
- Necessity: Oil and grease can solidify and form hard, impenetrable crusts on sewer walls, severely reducing pipe capacity or causing complete blockages.
- Location: Mandatory for commercial kitchens, restaurants, automobile garages, and specific industries.

Working of Grease Traps

- Mechanism: Sewage enters a large chamber where the flow velocity drastically drops.
- Separation: Due to lower density, oil and grease float to the surface (forming scum). Heavy solids settle to the bottom.
- Outlet Design: The outlet pipe draws water from the middle clear layer, leaving the floating grease and settled sludge behind.
- Maintenance: The trapped grease must be regularly skimmed off the top manually or mechanically.

Clean-outs and Lamp Holes

- Clean-outs: An inclined pipe extending from the underground branch sewer to the ground surface, fitted with a removable cap. Used for flushing or pushing rodding cables to clear obstructions in small sewers where manholes are too expensive.
- Lamp Holes: Small vertical pipes (stoneware or concrete) with a cover, provided between widely spaced manholes.
- A lamp is lowered into it. Workers in the adjacent manhole look for the light. If visible, the line is straight and clear. (Mostly obsolete with modern CCTV inspection).

Stormwater Regulators (Overflow Weirs)

- Purpose: Used in Combined Sewer Systems to protect treatment plants from hydraulic overload during heavy rainstorms.
- Function: They divert the excess volume of diluted stormwater directly to a natural outfall (river/lake).
- Mechanism: A side weir is constructed in the sewer. During dry weather, all foul sewage goes to the plant. During a storm, the water level rises above the weir crest, and the excess spills over into a relief pipe.
- This ensures the 'first flush' of polluted street water is treated, but the later, relatively clean stormwater is bypassed.

Summary

- Catch basins protect combined sewers from heavy grit but require frequent cleaning to prevent odors.
- Inverted siphons allow gravity sewers to cross physical obstructions by operating under pressure in multiple parallel pipes.
- Grease traps are essential commercial appurtenances to prevent the formation of 'fatbergs' in sewers.
- Stormwater regulators divert excess monsoon flow to prevent overloading treatment plants.

Next Lecture Preview

- Laying, Testing, and Maintenance of Sewers
- How are sewers actually constructed in the field?
- Excavation, bedding, and laying of pipes.
- Hydrostatic and Smoke testing for leakage.
- Sewer cleaning equipment and safety.

Laying, Testing, and Maintenance of Sewers

Unit 7: Drains and Sewers

GTU Diploma Engineering

Water Supply Engineering

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Agenda

- Setting Out the Alignment
- Trench Excavation and Timbering
- Bedding and Laying of Sewers
- Testing: Straightness and Obstruction
- Testing: Water, Air, and Smoke Tests
- Backfilling of Trenches
- Maintenance: Common Issues and Cleaning Equipment

Setting Out the Alignment

- Before digging, the exact center line of the sewer must be marked on the ground using surveying instruments (Theodolite/Total Station).
- Sight Rails: Horizontal wooden boards set up at fixed heights above the proposed invert level of the sewer. Placed at manhole locations and changes in gradient.
- Boning Rods: T-shaped wooden rods of a fixed length. Used by sighting across two sight rails to ensure the trench bottom and pipe invert are at the exact required gradient.

Excavation and Timbering of Trenches

- Excavation: Done manually or using backhoes. The trench width should be just wide enough to allow pipe laying and jointing (usually pipe diameter + 30 to 45 cm clearance on sides).
- Timbering (Shoring and Strutting): Essential in loose soils or deep trenches to prevent the collapse of vertical earth walls.
- Involves placing wooden boards (poling boards) against the trench walls, held apart by horizontal struts.
- Dewatering: If the groundwater table is high, trenches must be kept continuously dry using sump pumps or well-point systems.

Bedding of Sewers

- Pipes must not be laid directly on hard rocks or uneven soil, as concentrated point loads will crack them.
- Granular Bedding: A layer of compacted sand or gravel is placed at the trench bottom to distribute the earth load evenly around the pipe.
- Concrete Cradle Bedding: Required when the soil is very soft and yielding, or when the pipe is under extreme traffic loads. The pipe is partially embedded in a concrete cradle for maximum support.

Pipe Laying Process

- Direction: Laying always proceeds from the downstream end (outfall or lower manhole) towards the upstream end.
- Orientation: The Socket (Bell) end of the pipe must face upstream, while the Spigot end faces downstream.
- Reasoning:
- - Prevents flowing sewage from pushing into the joint packing material.
- - Makes it much easier to push the next spigot into the established socket on the trench floor.

Testing of Sewers: Why is it Necessary?

- Before the trench is backfilled with earth, the newly laid sewer must be rigorously tested.
- Objectives of Testing:
- 1. Ensure Watertightness: To guarantee no infiltration or exfiltration will occur at the joints.
- 2. Ensure Perfect Alignment: To verify the pipe is perfectly straight and the gradient is correct.
- 3. Ensure No Obstructions: To confirm no construction debris (tools, cement blocks) has been left inside the pipe.

Straightness and Obstruction Tests

- Mirror/Lamp Test (Straightness): A mirror is placed at a 45-degree angle at one manhole. A bright lamp is held at the other manhole. If the pipeline is perfectly straight, a full circle of light is seen in the mirror. Any misalignment shows as a crescent.
- Ball Test (Obstruction): A smooth, heavy ball (about 10% smaller than the pipe diameter) is rolled from the upstream end. If it emerges seamlessly at the downstream end, the pipe is clear of debris.

Water Test (Hydrostatic Test)

- The most common test for watertightness in gravity sewers.
- Procedure: The lower end of the sewer section is plugged watertight. The pipe is filled with water from the upper manhole to create a specific head of water (usually 1.0m to 1.5m above the pipe crown).
- The water is allowed to stand for 1 to 2 hours to allow the pipe material to absorb moisture.
- Result: Any drop in the water level in the upper manhole indicates a leak. The allowable leakage is strictly defined by codes (e.g., liters/cm diameter/km/day). Leaking joints are repaired and re-tested.

Air Test and Smoke Test

- Air Test: Used for large diameter pipes where huge volumes of water are impractical. Both ends are plugged, and air pressure (approx 100mm of water gauge) is applied. A specific pressure drop over 5 minutes indicates leaks.
- Smoke Test: Primarily used to detect leaks in soil pipes, vent pipes, and house drainage connections, or to find illegal stormwater connections to sanitary sewers.
- Smoke is pumped into the pipe using a blower. Visual inspection easily locates leaks where smoke escapes from the ground or joints.

Backfilling of Trenches

- Once tests are passed, the trench is backfilled.
- Process: Fine soil (free from large stones/boulders) is placed around and up to 30 cm above the pipe to prevent impact damage.
- The remaining trench is filled in horizontal layers of 150mm. Each layer is thoroughly watered and rammed (compacted).
- Importance: Proper compaction prevents future settlement of the trench, which would otherwise ruin the road surface above and potentially damage the pipe.

Maintenance of Sewers: Common Issues

- Despite perfect design, sewers require routine maintenance.
- Common Causes of Blockages:
- - Accumulation of grit, sand, and grease (fatbergs).
- - Intrusion of tree roots through minor joint cracks.
- - Structural collapse or pipe deformation.
- - Dumping of solid waste (plastics, rags) into open manholes or inlets.
- Sewer Gas Hazards: Accumulation of $H2S$ and Methane poses deadly risks to maintenance workers. Ventilation and gas detection are mandatory before entry.

Sewer Cleaning Equipment

- Rodding Machines: Flexible steel rods with cutting tools pushed through the pipe to cut away tree roots and break hard grease crusts.
- High-Pressure Water Jetting: A specialized nozzle blasted backward with high-pressure water (up to 2000 psi) scours the pipe walls clean and flushes grit to the downstream manhole.
- Bucket Machines: Used for large sewers heavily choked with silt. A winch pulls a bucket through the pipe from one manhole to another, scooping out the sediment.

Summary of Unit 7

- We classified drains and analyzed hydraulic sewer sections (Circular vs Non-circular).
- We studied the importance of watertight joints and selected pipe materials (Stoneware, RCC, PVC).
- We explored appurtenances that make the system workable: Manholes, Catch Basins, and Siphons.
- Finally, we detailed the rigorous field execution: precise laying, mandatory hydrostatic testing, and ongoing mechanical maintenance.

End of Unit 7

- Next steps: Prepare for the unit assessment.
- Review all diagrams regarding sewer cross-sections and manhole components.
- Ensure understanding of the hydraulic logic behind non-circular sewers and flushing tanks.

Characteristics of Sewage and Sampling Techniques

Unit 8: Sewage Treatment and Disposal

GTU Diploma Engineering

Water Supply Engineering

July 25, 2026

Agenda

- Introduction to Sewage
- Physical Characteristics
- Chemical Characteristics
- Biological Characteristics
- Importance of Sampling
- Types of Sampling Techniques

Introduction to Sewage

- Sewage is primarily water (approx. 99.9%) and about 0.1% solid matter.
- The solid matter exists in suspended, dissolved, and colloidal states.
- It contains organic matter, inorganic salts, and numerous microorganisms.
- Characteristics vary based on water usage, industrial discharge, and seasonal changes.

Physical Characteristics: Colour and Odour

- Fresh domestic sewage is slightly grey or light brown.
- Stale or septic sewage becomes dark grey or black due to anaerobic decomposition.
- Fresh sewage has a mildly soapy or oily odour.
- Septic sewage emits offensive odours, primarily Hydrogen Sulphide (H2S), due to the breakdown of organic matter containing sulfur.

Physical Characteristics: Temperature and Turbidity

- Temperature of sewage is generally slightly higher than the local water supply.
- Higher temperatures accelerate biological activity and decrease gas solubility (e.g., oxygen).
- Turbidity indicates the presence of suspended matter, including faecal matter, paper, and soap.
- Turbidity is measured using a turbidimeter in NTU (Nephelometric Turbidity Units).

Chemical Characteristics: Solids

- Total Solids (TS) = Suspended Solids (SS) + Dissolved Solids (DS).
- Volatile Solids (organic) evaporate at 550°C and represent the organic load.
- Fixed Solids (inorganic) remain as ash after heating to 550°C.
- Settleable solids are those that settle out in an Imhoff cone within one hour.

Chemical Characteristics: Organic Matter

- Organic matter in sewage consists of proteins (approx. 65%), carbohydrates (approx. 25%), and fats/oils (approx. 10%).
- Proteins contain nitrogen and sulfur, which lead to foul odors during anaerobic breakdown.
- Fats and oils can cause blockages in sewers and inhibit oxygen transfer in treatment plants.
- Organic strength is primarily measured by BOD and COD tests (covered in next lecture).

Chemical Characteristics: Nitrogen and Phosphorus

- Nitrogen exists in four forms: Free ammonia, Albuminoid ammonia, Nitrites, and Nitrates.
- Free ammonia indicates recent pollution. Nitrates indicate stable, fully oxidized organic matter.
- Phosphorus comes from synthetic detergents and human waste.
- Excessive Nitrogen and Phosphorus in receiving waters cause eutrophication (algal blooms).

Chemical Characteristics: pH and Chloride

- Fresh sewage is generally alkaline (pH ¿ 7.0), ideal for biological treatment.
- Septic sewage turns acidic (pH ¡ 7.0) due to the formation of organic acids.
- Chlorides (NaCl) in sewage come from human urine and industrial discharges.
- Abnormally high chloride levels can indicate seawater infiltration or industrial waste.

Biological Characteristics

- Sewage contains millions of microorganisms per milliliter, primarily bacteria, viruses, fungi, and protozoa.
- Bacteria are classified as Aerobic (require oxygen), Anaerobic (function without oxygen), and Facultative (can adapt to both).
- Pathogenic organisms are disease-causing microbes (e.g., Salmonella, Vibrio cholerae) excreted by infected individuals.
- Indicator organisms like E. coli are tested to determine the likelihood of pathogen presence.

Importance of Sewage Sampling

- Sampling ensures the correct characterization of sewage for plant design.
- Sewage flow and strength vary diurnally (hourly), daily, and seasonally.
- A single isolated sample rarely represents the true average characteristics.
- Proper sampling locations, equipment, and preservation techniques are critical for accurate results.

Types of Sampling: Grab Samples

Concept 1	**Concept 2**
Grab Sample: A single sample taken at a specific time and location.	
Represents the composition of sewage only at that specific moment.	
Useful for testing parameters that change rapidly, such as pH, dissolved oxygen, and residual chlorine.	
Not suitable for determining the average organic load (BOD) over a day.	

Types of Sampling: Composite Samples

- Composite Sample: A mixture of multiple grab samples collected over a specific period (usually 24 hours).
- Time-proportional composite: Samples of equal volume collected at regular time intervals.
- Flow-proportional composite: Sample volumes collected are proportional to the flow rate at the time of sampling.
- Flow-proportional composite samples provide the most accurate representation of the average sewage characteristics.

Summary

- Sewage characteristics are physical, chemical, and biological.
- Temperature, color, and odor provide preliminary physical indicators.
- Solids, organic matter (N, P), pH, and chlorides define chemical strength.
- Pathogens and beneficial treatment bacteria constitute biological characteristics.
- Proper sampling (especially composite sampling) is essential for accurate representation.

Next Lecture: BOD and COD Tests

- In the next lecture, we will dive deeper into measuring the organic strength of sewage.
- We will cover the principles of Biochemical Oxygen Demand (BOD).
- We will understand Chemical Oxygen Demand (COD).
- We will learn how to interpret BOD/COD ratios for treatability.

Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) Tests

Unit 8: Sewage Treatment and Disposal

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Water Supply Engineering

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Agenda

- Concept of Oxygen Demand
- Biochemical Oxygen Demand (BOD) Defined
- The Standard BOD5 Test Procedure
- BOD Kinetics and Calculations
- Chemical Oxygen Demand (COD) Defined
- BOD vs. COD Comparison

The Concept of Oxygen Demand

- Aerobic bacteria require dissolved oxygen (DO) to break down organic matter in sewage.
- The more organic matter present, the more oxygen the bacteria will consume.
- If discharged into a river, high organic load rapidly depletes the river's DO.
- Depleted DO can lead to fish kills and septic, foul-smelling conditions.
- Measuring this 'oxygen demand' quantifies the pollution potential of the sewage.

Biochemical Oxygen Demand (BOD)

- BOD is the amount of oxygen required by aerobic microorganisms to decompose biodegradable organic matter.
- It is an indirect measure of the concentration of biodegradable organics.
- The standard test measures oxygen consumed over 5 days at 20°C (denoted as BOD5).
- Why 5 days? It was originally based on the maximum travel time of rivers in the UK from source to sea.

The Standard BOD5 Test Procedure

- 1. Dilute the sewage sample with specially prepared, fully oxygenated dilution water.
- 2. Dilution water contains nutrients (N, P) and buffer solutions to support bacterial growth.
- 3. Measure the initial Dissolved Oxygen (DO_initial) using the Winkler method or a DO probe.
- 4. Incubate the sample in the dark at 20°C for exactly 5 days.
- 5. Measure the final Dissolved Oxygen (DO_final).

BOD Calculation

- BOD5 (mg/L) = (DO_initial - DO_final) * Dilution Factor
- Dilution Factor = (Volume of diluted sample) / (Volume of undiluted sewage sample)
- Example: If 10 mL of sewage is diluted to 300 mL, Dilution Factor = 30.
- If DO_initial = 8.5 mg/L and DO_final = 3.5 mg/L after 5 days.
- BOD5 = (8.5 - 3.5) * 30 = 5.0 * 30 = 150 mg/L.

BOD Kinetics: Carbonaceous vs. Nitrogenous

- First Stage BOD (Carbonaceous BOD or CBOD): Oxygen used to oxidize carbon-based compounds. Dominates the first 5-8 days.
- Second Stage BOD (Nitrogenous BOD or NBOD): Oxygen used by nitrifying bacteria to oxidize ammonia to nitrites and nitrates.
- Nitrification typically begins after 8-10 days, hence the 5-day test primarily measures CBOD.
- Inhibitors can be added to the BOD test to suppress nitrification if only CBOD is desired.

Limitations of the BOD Test

- Time-consuming: Results take 5 days, making it unsuitable for real-time process control.
- Requires acclimated seed bacteria: If toxic substances are present, bacteria may die, giving artificially low BOD readings.
- Measures only biodegradable organics: Does not account for non-biodegradable plastics or certain industrial chemicals.
- Precision is typically lower than purely chemical tests.

Chemical Oxygen Demand (COD)

- COD is the oxygen equivalent of the organic matter that is susceptible to oxidation by a strong chemical oxidant.
- Instead of bacteria, we use Potassium Dichromate (K2Cr2O7) in an acidic medium (H2SO4) at high temperatures.
- The test measures the total organic matter (both biodegradable and non-biodegradable).
- It does not measure oxygen consumed by bacteria, but chemically oxidized carbon.

The COD Test Procedure

- 1. Add known excess amount of Potassium Dichromate, Sulfuric Acid, and silver sulfate (catalyst) to the sample.
- 2. Reflux (boil) the mixture for 2 hours.
- 3. The organic matter reduces the dichromate ion (orange) to chromic ion (green).
- 4. Titrate the remaining unreacted dichromate with Ferrous Ammonium Sulfate (FAS) to determine how much was consumed.
- 5. The consumed dichromate is proportional to the COD.

Comparison: BOD vs. COD

Concept 1	Concept 2
BOD measures biodegradable organics; COD measures both biodegradable and non-biodegradable organics.	
BOD takes 5 days; COD takes 2-3 hours.	
COD values are almost always higher than BOD values for a given sample.	
BOD involves biological processes (living organisms); COD involves harsh chemical reactions.	
COD is unaffected by toxic substances in the wastewater.	

The BOD/COD Ratio

- The ratio of BOD to COD helps determine the 'treatability' of the wastewater.
- Typical untreated domestic sewage has a BOD/COD ratio of 0.4 to 0.8.
- Ratio ¿ 0.5: Highly biodegradable. Biological treatment will be highly effective.
- Ratio ¡ 0.3: Largely non-biodegradable or toxic. Requires physical-chemical treatment methods.
- As sewage undergoes biological treatment, the ratio decreases because BOD is removed faster than total COD.

Summary

- BOD measures the biodegradable organic fraction over 5 days at 20°C.
- Dilution is essential in BOD testing for high-strength wastes.
- COD measures total organic fraction using potassium dichromate in just a few hours.
- COD is always greater than BOD.
- The BOD/COD ratio dictates whether biological treatment is feasible.

Next Lecture: Preliminary Sewage Treatment

- With sewage characteristics understood, we move to actual treatment.
- Next lecture covers Preliminary Sewage Treatment.
- We will discuss the removal of floating objects and heavy inorganic grit.
- Key components: Screens, Grit Chambers, and Comminutors.

Preliminary Sewage Treatment

Unit 8: Sewage Treatment and Disposal

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Water Supply Engineering

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Agenda

- Overview of Treatment Stages
- Purpose of Preliminary Treatment
- Screening Devices
- Comminutors and Macerators
- Grit Chambers
- Skimming Tanks

Stages of Sewage Treatment

- 1. Preliminary Treatment: Removal of large debris, grit, and oil.
- 2. Primary Treatment: Removal of settleable suspended organic solids (Primary Clarification).
- 3. Secondary Treatment: Biological removal of dissolved and colloidal organics (Aeration, Trickling Filters).
- 4. Tertiary/Advanced Treatment: Removal of nutrients, pathogens, and specific chemicals.

Purpose of Preliminary Treatment

- Primary goal: Protect downstream mechanical equipment (pumps, aerators) from damage.
- Prevent blockages in pipes and valves.
- Remove heavy inorganic material (sand, gravel) that would occupy valuable space in digesters.
- It does NOT significantly reduce the BOD of the sewage; it is purely a physical conditioning step.

Screening: The First Barrier

- Screens consist of parallel steel bars placed across the flow channel.
- They capture large floating and suspended matter: rags, wood, plastics, and sanitary products.
- Types based on clear spacing: Coarse screens (¿50mm), Medium screens (20-50mm), Fine screens (¡20mm).
- Screens are placed at an angle (usually 30 to 60 degrees) to the flow to increase screening area and ease cleaning.

Manual vs. Mechanical Screens

Concept 1	**Concept 2**
Manual Screens: Cleaned by operators using hand rakes. Used in very small plants or as a bypass/backup.	
Drawbacks: Labor-intensive, risk of sudden clogging during peak flows causing backwater effects.	
Mechanical Screens: Cleaned automatically by motorized rakes. Used in medium to large plants.	
Advantages: Continuous cleaning, prevents severe head loss, reduces operator contact with raw sewage.	

Comminutors (Shredders)

- Instead of removing the debris via screens, comminutors grind and shred the coarse solids while they remain in the wastewater stream.
- The shredded particles (typically 6mm) pass through and settle out later in the primary clarifiers.
- Advantage: Eliminates the messy, odorous job of handling and disposing of screenings.
- Disadvantage: Can result in shredded plastics binding together and causing issues downstream.

Grit Chambers: Principles

- Grit consists of heavy inorganic matter: sand, gravel, eggshells, coffee grounds.
- Specific gravity of grit is around 2.65, much heavier than organic matter (approx. 1.02).
- Grit chambers are designed as enlarged channel sections to reduce the flow velocity of sewage.
- Velocity is controlled to approx. 0.3 m/s. This allows heavy grit to settle while keeping lighter organic matter suspended.

Types of Grit Chambers

- 1. Horizontal Flow Grit Chamber: Long, narrow channels. Velocity is controlled by a proportional weir or Parshall flume at the exit.
- 2. Aerated Grit Chamber: Air is injected near the bottom, creating a spiral flow pattern. The rolling action keeps organics suspended while heavy grit falls into a hopper.
- Aerated chambers also freshen the raw sewage and strip out odorous gases.

Proportional Weirs

- In horizontal grit chambers, maintaining a constant velocity of 0.3 m/s despite varying flow rates is critical.
- A proportional weir (Sutro weir) is installed at the outlet.
- The weir is shaped such that discharge is directly proportional to the head (height of water).
- This ensures that as flow increases, water depth increases proportionally, maintaining a constant horizontal velocity ($V = Q/A$).

Skimming Tanks

- Used to remove lighter-than-water substances: fats, oils, greases (FOG), and soaps.
- Air is introduced from the bottom to create bubbles. The FOG coagulates and attaches to the air bubbles, rising to the surface.
- The floating scum layer is then mechanically skimmed off the top.
- Essential for industrial wastes or where large amounts of grease are expected, as FOG interferes with biological treatment.

Flow Equalization (Optional but important)

- Sewage flow is highly variable throughout the day.
- Equalization basins are large holding tanks that temporarily store excess flow during peak hours.
- They release the wastewater at a constant, steady rate into the downstream treatment units.
- Benefits: Improves clarifier efficiency, dilutes sudden toxic industrial shocks, and stabilizes biological processes.

Summary

- Preliminary treatment prepares sewage for further processing and protects equipment.
- Screens remove large floating and suspended debris.
- Comminutors shred debris directly within the flow.
- Grit chambers use controlled velocity (0.3 m/s) to settle heavy inorganic sand.
- Skimming tanks utilize aeration to float and remove oils and greases.

Next Lecture: Primary Sewage Treatment

- In the next lecture, we transition to Primary Treatment.
- We will discuss the removal of settleable organic solids.
- We will learn about Primary Sedimentation Tanks (Clarifiers).
- We will explore design criteria like Surface Overflow Rate (SOR) and Detention Time.

Primary Sewage Treatment

Unit 8: Sewage Treatment and Disposal

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Agenda

- Objective of Primary Treatment
- Principle of Sedimentation
- Types of Settling Tanks (Clarifiers)
- Key Design Parameters
- Sludge and Scum Removal Mechanisms
- Efficiency of Primary Treatment

Objective of Primary Treatment

Objective of Primary Treatment

- Primary treatment aims to remove settleable organic and inorganic solids from wastewater.
- It relies entirely on physical settling (gravity).
- The organic solids that settle at the bottom form a highly putrescible substance called 'Primary Sludge'.
- Reducing the suspended solids greatly reduces the organic load (BOD) that the secondary biological treatment must handle.

Principle of Sedimentation

- Sedimentation relies on Stoke's Law, where particle settling velocity depends on particle size and density.
- In sewage, organic particles are light (Specific Gravity approx 1.01 to 1.02) and settle very slowly.
- To allow settling, the flow velocity must be drastically reduced compared to grit chambers.
- Flow in a primary clarifier is kept calm and laminar, avoiding turbulence that would resuspend particles.

Types of Sedimentation Tanks

- Primary sedimentation tanks are also called Primary Clarifiers.
- They are generally classified by their shape and flow direction:
- 1. Rectangular Tanks: Horizontal flow from one end to the other.
- 2. Circular Tanks: Radial flow from a central inlet to a peripheral weir.
- Both types perform effectively; selection depends on site constraints, economics, and operator preference.

Circular Clarifiers

- Wastewater enters through a central column and flows upward into a stilling well.
- Flow then moves radially outward towards the perimeter of the tank.
- The clarified water overflows a V-notch weir at the perimeter.
- A slowly rotating bridge (scraper mechanism) pushes the settled sludge to a central hopper for removal.

Rectangular Clarifiers

- Long, narrow concrete basins. Length to width ratio is typically 3:1 to 5:1.
- Wastewater enters through baffles at one end to distribute flow evenly.
- Water flows horizontally to the effluent weirs at the far end.
- A chain-and-flight mechanism moves continuously along the bottom to push sludge to a hopper at the inlet end.

Design Parameters: Detention Time

- Detention Time (t) is the theoretical average time a drop of water spends in the tank.
- Formula: t = Volume of Tank (V) / Flow Rate (Q)
- Typical detention time for primary clarifiers: 1.5 to 2.5 hours.
- If detention time is too short, solids won't settle.
- If detention time is too long (¿ 3 hours), sewage may turn septic and create foul odors.

Design Parameters: Surface Overflow Rate (SOR)

- Surface Overflow Rate (SOR) is the volume of water applied per unit surface area per day.
- Formula: SOR = Flow Rate (Q) / Surface Area (A)
- Expressed in m3/m2/day or liters/m2/day.
- It is the most critical design parameter. It represents the settling velocity of the slowest settling particle that is 100% removed.
- Typical SOR for primary clarifiers: 30 to 50 m3/m2/day.

Design Parameters: Weir Loading Rate

- Weir Loading Rate is the volume of water passing over a unit length of the exit weir per day.
- Formula: Flow Rate (Q) / Total Length of Weir (L).
- Typical values: 125 to 250 m3/m/day.
- If the rate is too high, the strong current near the weir will lift settled sludge and carry it out with the effluent (carryover).
- V-notch weirs are commonly used to ensure uniform flow distribution across the entire perimeter.

Efficiency of Primary Treatment

- Primary clarifiers are highly efficient relative to their operational cost.
- Typical Removals:
- Suspended Solids (TSS): 50% to 70% removed.
- Biochemical Oxygen Demand (BOD): 25% to 40% removed.
- By removing settleable solids, we indirectly remove the BOD associated with those solid particles.
- Dissolved organics (like dissolved sugar) pass right through primary treatment.

Chemical Enhanced Primary Treatment (CEPT)

- Chemicals (coagulants like Alum or Ferric Chloride) can be added before the clarifier.
- These chemicals neutralize particle charges, causing fine and colloidal solids to clump together (flocculate).
- Heavier flocs settle much faster and more completely.
- CEPT increases TSS removal to 80-90% and BOD removal to 50-60%.
- Trade-off: High chemical costs and significantly increased sludge volume.

Summary

- Primary treatment uses gravity in sedimentation tanks (clarifiers) to remove settleable organic solids.
- Tanks can be circular (radial flow) or rectangular (horizontal flow).
- Surface Overflow Rate (SOR) and Detention Time are the defining design parameters.
- Effectively removes 50-70% of Suspended Solids and 25-40% of BOD.
- Generates primary sludge which must be removed frequently to prevent septicity.

Next Lecture: Secondary Sewage Treatment

- In the next lecture, we tackle Secondary Treatment.
- We will focus on Aerobic biological processes.
- How do microorganisms consume dissolved organic matter?
- Key technologies: Trickling Filters and the Activated Sludge Process (ASP).

Secondary Sewage Treatment: Aerobic Processes

Unit 8: Sewage Treatment and Disposal

GTU Diploma Engineering

Water Supply Engineering

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Agenda

- Principles of Biological Treatment
- Aerobic vs. Anaerobic Processes
- Attached Growth vs. Suspended Growth
- Trickling Filters: Design and Operation
- The Activated Sludge Process (ASP)
- Secondary Clarifiers

Principles of Biological Treatment

- Primary treatment removes solids, but dissolved and colloidal organic matter remains.
- Secondary treatment is a biological process.
- We create an optimal environment for microorganisms (mainly bacteria) to consume the dissolved organics as food.
- The bacteria convert the dissolved organic matter into new bacterial cells (biomass), carbon dioxide, and water.
- The newly formed biomass (sludge) is then settled out in a secondary clarifier.

Aerobic Systems

- Aerobic bacteria require dissolved oxygen to survive and metabolize organics.
- Aerobic processes are faster, highly efficient (90%+ BOD removal), and generally do not produce foul odors.
- However, they are energy-intensive because massive amounts of air must be mechanically supplied.
- Key aerobic systems: Trickling Filters and Activated Sludge Process.

Attached vs. Suspended Growth

Concept 1	Concept 2
Attached Growth Systems (e.g., Trickling Filters): Microorganisms grow on a solid medium (rocks, plastic). Wastewater trickles over them. Suspended Growth Systems (e.g., Activated Sludge): Microorganisms are mixed freely in the liquid. They are kept suspended by mechanical agitation or aeration. Attached growth is generally simpler to operate but requires more land. Suspended growth is more compact and flexible but requires intensive operational control.	

Trickling Filters: Components

- A trickling filter consists of a bed of highly permeable media (crushed rock, gravel, or specialized plastic modules).
- A rotary distributor uniformly sprays primary effluent over the top of the bed.
- An underdrain system collects the treated liquid at the bottom and allows air to ventilate upward.
- The depth of the filter medium is typically 1.5 to 2.5 meters for rock media.

Trickling Filters: The Biological Zoogleal Film

- A sticky, gelatinous layer of microorganisms called the 'zoogleal film' or 'biofilm' grows on the media.
- As wastewater trickles over this film, the bacteria absorb and metabolize the dissolved organics.
- Oxygen is absorbed from the air circulating through the void spaces in the media.
- Over time, the biofilm grows thicker. The inner layers become anaerobic and lose their grip on the media.

Trickling Filters: Sloughing

- When the biofilm becomes too thick, the inner anaerobic layer weakens its attachment to the media.
- The hydraulic force of the wastewater washes the biofilm off the rocks.
- This periodic shedding of the biological slime layer is called 'sloughing'.
- The sloughed-off biomass exits the filter with the effluent and must be settled out in a secondary clarifier.

Activated Sludge Process (ASP)

- ASP is a suspended growth process and the most widely used secondary treatment method globally.
- Primary effluent enters an Aeration Tank, where it is mixed with a heavily concentrated mass of microorganisms called 'Activated Sludge'.
- The mixture of wastewater and microbes is called Mixed Liquor Suspended Solids (MLSS).
- Air is continuously pumped into the tank via diffusers or surface aerators to provide oxygen and maintain mixing.

ASP: The Role of Return Sludge

- After aeration (typically 4-8 hours), the mixed liquor flows to a Secondary Clarifier.
- The bacteria clump together (flocculate) and settle to the bottom as sludge.
- To maintain a high concentration of bacteria in the aeration tank, a portion of this settled sludge is pumped back to the inlet.
- This is called Return Activated Sludge (RAS). It ensures the incoming food immediately meets a massive hungry bacterial workforce.

ASP: Key Operating Parameters

- F/M Ratio (Food to Microorganism Ratio): The balance between incoming BOD (food) and MLSS (microorganisms). Proper ratio ensures efficient treatment and good settling.
- Mean Cell Residence Time (MCRT) or Sludge Age: The average number of days a bacterium stays in the system.
- Excess sludge that is not returned (Waste Activated Sludge, WAS) must be removed daily to maintain the system balance.

Secondary Clarifiers

- Follows both Trickling Filters and ASPs.
- Purpose: To separate the biological mass (sloughed film or activated sludge flocs) from the treated water.
- The effluent from the secondary clarifier is typically very clear, with 85-95% of BOD and Suspended Solids removed.
- Design is similar to primary clarifiers but requires careful consideration of sludge settling characteristics (Sludge Volume Index, SVI).

Summary

- Secondary treatment relies on aerobic bacteria to consume dissolved organics.
- Trickling Filters are attached-growth systems relying on a zoogleal film and natural sloughing.
- Activated Sludge Process (ASP) is a suspended-growth system relying on active aeration and sludge recirculation (RAS).
- Both systems require a secondary clarifier to remove the resulting bacterial biomass from the treated effluent.

Next Lecture: Sludge Digestion

- We have treated the water, but now we have tons of sludge (Primary + Secondary WAS).
- Next lecture covers Anaerobic Treatment and Sludge Digestion.
- We will look at how we safely treat and dispose of this biological waste.
- Key technologies: Anaerobic Digesters and Sludge Drying Beds.

Anaerobic Processes and Sludge Digestion

Unit 8: Sewage Treatment and Disposal

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Water Supply Engineering

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Agenda

- The Sludge Problem
- Principles of Anaerobic Digestion
- Stages of Digestion (Acid & Methane Formers)
- Design of a Sludge Digester
- Biogas Production and Use
- Sludge Dewatering: Sludge Drying Beds

The Sludge Problem

- Primary Sludge: Raw organic solids settled in the primary clarifier (highly putrescible, very odorous).
- Secondary Sludge (WAS): Waste bacterial biomass from the activated sludge process.
- Combined, this sludge is mostly water (95-99% water) and contains active pathogens and decomposing organics.
- If disposed of improperly, it poses severe health and environmental hazards.
- Goal: Stabilize the organics, destroy pathogens, and reduce volume by removing water.

Anaerobic Treatment Principles

- Anaerobic bacteria thrive in the strict absence of dissolved oxygen.
- They break down complex organic matter into simpler compounds and eventually into gases (primarily Methane and Carbon Dioxide).
- Process is slower than aerobic treatment but yields very little new bacterial biomass.
- It is highly suitable for treating high-strength wastes like sludge.
- Byproduct: Biogas, a valuable renewable energy source.

Stages of Anaerobic Digestion

- The process occurs in three main biological stages:
- 1. Hydrolysis: Complex solids (proteins, fats, carbs) are broken down into soluble amino acids, sugars, and fatty acids.
- 2. Acidogenesis (Acid Formers): Fermentative bacteria convert soluble compounds into volatile organic acids (e.g., acetic acid). pH drops.
- 3. Methanogenesis (Methane Formers): Methanogenic archaea consume the organic acids and produce Methane (CH_4) and CO_2. pH rises and stabilizes.

The Delicate Balance

- The success of digestion depends entirely on the Methane formers.
- Methane formers are highly sensitive to pH changes, temperature fluctuations, and toxins.
- Optimal pH: 6.8 to 7.2.
- If the system is overloaded with sludge, Acid formers produce acid too quickly. The pH drops, killing the Methane formers.
- This is called a 'sour' or 'stuck' digester, resulting in terrible odors and no methane production.

Sludge Digester: Physical Components

- Digesters are large, enclosed, airtight concrete or steel tanks.
- Components include:
- - Sludge inlet and outlet pipes.
- - Heating system (usually hot water pipes) to maintain mesophilic temperatures (35°C).
- - Mixing systems (mechanical impellers or gas recirculation) to keep the sludge uniform.
- - Gas dome/collector at the top to harvest biogas.
- - Supernatant draw-off pipes to remove separated liquid.

UASB (Upflow Anaerobic Sludge Blanket)

- UASB is an anaerobic technology used not just for sludge, but for direct treatment of wastewater.
- Wastewater flows upwards through a dense 'blanket' of anaerobic granular sludge.
- The bacteria in the blanket consume the organics and produce biogas.
- Gas bubbles rise, providing natural mixing.
- A Gas-Liquid-Solid (GLS) separator at the top ensures sludge remains in the reactor while gas and clear effluent escape.

Biogas Utilization

- Biogas composition: 60-65% Methane (CH_4), 30-35% Carbon Dioxide (CO_2), trace H_2S.
- Methane is highly combustible and has significant calorific value.
- Uses at the treatment plant:
- - Burned in boilers to heat the digester itself.
- - Used in combined heat and power (CHP) engines to generate electricity for the plant.
- - Flared (burned off) safely if excess gas cannot be utilized.

Sludge Dewatering: The Need

- Digested sludge is now biologically stable (looks like black soil, smells earthy, not putrid).
- However, it is still mostly liquid (typically 95% water).
- Transporting liquid sludge to agricultural land or landfills is economically unfeasible.
- Dewatering is required to separate the solid fraction from the liquid fraction, reducing volume and transportation costs.

Sludge Drying Beds

- The simplest, oldest, and most common dewatering method in developing regions.
- Constructed as shallow rectangular beds with a porous bottom (layers of sand and gravel).
- Wet digested sludge is poured onto the bed to a depth of 20-30 cm.
- Dewatering occurs via two mechanisms:
- 1. Seepage: Water drains downwards through the sand/gravel into underdrain pipes.
- 2. Evaporation: Sun and wind dry the surface over several weeks.

Sludge Drying Beds: Operation and Output

- Drying time varies from 2 to 6 weeks depending on climate (fast in dry, hot weather; slow in monsoons).
- As it dries, the sludge cracks into blocks.
- Once dried to a solid 'cake' (usually 20-30% solid content), it is manually or mechanically removed.
- The dried sludge cake is rich in nutrients and is often used as a soil conditioner or fertilizer in agriculture.
- The liquid collected in the underdrains is highly polluted and is pumped back to the inlet of the treatment plant.

Summary

- Anaerobic digestion stabilizes volatile sludge without needing supplied oxygen.
- The process is a balance between acid-forming and methane-forming bacteria.
- Biogas (methane) is a valuable renewable energy byproduct.
- Digested sludge is biologically stable but must be dewatered.
- Sludge Drying beds offer a low-cost, natural method to dewater sludge before agricultural use.

Next Lecture: Disposal Methods

- With treatment complete, where does the clean effluent go?
- Next lecture covers Methods of Sewage Disposal.
- We will discuss disposal by dilution into water bodies.
- We will discuss disposal on land (sewage farming).
- We will look at standard effluent discharge criteria.

Methods of Sewage Disposal and Effluent Standards

Unit 8: Sewage Treatment and Disposal

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Agenda

- Need for Safe Disposal
- Disposal by Dilution (Water Bodies)
- Self-Purification of Streams
- Oxygen Sag Curve
- Disposal on Land (Sewage Farming)
- Sewage Sickness
- Effluent Discharge Standards

Need for Safe Disposal

- Even treated effluent contains some residual organics, nutrients (N, P), and microorganisms.
- Improper disposal can lead to:
- - Contamination of drinking water sources.
- - Fish kills due to oxygen depletion.
- - Eutrophication (algal blooms) in lakes.
- - Outbreaks of waterborne diseases.
- Disposal must be carefully planned to utilize nature's assimilative capacity without overwhelming it.

Method 1: Disposal by Dilution

- The most common method: discharging effluent into large natural bodies of water (rivers, lakes, oceans).
- Conditions favoring disposal by dilution:
- - The receiving water has a very large volume compared to the sewage flow (high dilution ratio).
- - The water body is not a source of drinking water downstream.
- - The receiving water has high dissolved oxygen (DO) levels.
- - Currents are strong enough to rapidly mix and disperse the effluent.

Self-Purification of Streams

- When organic matter is discharged into a river, a natural biological process begins.
- Aerobic bacteria in the river consume the organic matter, utilizing the river's Dissolved Oxygen (DO).
- Simultaneously, the river absorbs fresh oxygen from the atmosphere through the water surface (Reaeration).
- If Reaeration keeps pace with oxygen consumption (Deoxygenation), the river purifies itself without ecological damage.
- This natural recovery process is called 'Self-Purification'.

The Oxygen Sag Curve

- The DO level in a river drops downstream of the discharge point as bacteria consume the waste.
- It reaches a minimum point (critical DO) before gradually recovering as the waste is exhausted and reaeration dominates.
- Plotting this DO level along the length of the river creates the 'Oxygen Sag Curve'.
- Engineers use this curve to ensure the critical DO never drops below 4 mg/L, which is the minimum required for fish survival.

Method 2: Disposal on Land

- Also known as Effluent Irrigation or Sewage Farming.
- Treated sewage is applied to agricultural land.
- Advantages:
- \- The soil acts as a massive natural filter.
- \- The remaining nutrients (N, P, K) in the effluent act as free fertilizer, increasing crop yields.
- \- It provides a reliable source of irrigation water in arid regions.
- \- Prevents pollution of surface water bodies.

Conditions for Disposal on Land

- Not all land is suitable for sewage farming. Ideal conditions include:
- - Sandy or loamy soils with high permeability (allows water to drain).
- - Deep water table (prevents rapid contamination of groundwater).
- - Low rainfall region (soil isn't already saturated).
- - The effluent should not contain toxic industrial chemicals or heavy metals, which would accumulate in crops.

Sewage Sickness

- If sewage is applied continuously without allowing the soil to rest, the soil pores become clogged with organic matter.
- Oxygen can no longer penetrate the soil, turning the environment anaerobic.
- The soil turns black, foul odors are produced, and crops die.
- This condition is known as 'Sewage Sickness'.
- Prevention: Apply effluent intermittently, rotate crops, plow the land frequently, and avoid over-irrigation.

Effluent Discharge Standards

- Regulatory bodies (e.g., CPCB in India) mandate strict limits on effluent quality before disposal.
- These standards depend on the disposal destination.
- Why? To protect public health, aquatic life, and soil integrity.
- If a plant fails to meet these standards, it faces legal action, fines, or closure.
- Standard parameters monitored include: pH, BOD, COD, TSS (Total Suspended Solids), and Fecal Coliforms.

Typical Discharge Standards (Inland Surface Water)

- When discharging into a river or lake, the standards are stringent to protect aquatic life.
- General Standards (may vary by region):
- - pH: 5.5 to 9.0
- - Suspended Solids (TSS): ¡ 100 mg/L
- - BOD (3 days at 27°C): ¡ 30 mg/L
- - COD: ¡ 250 mg/L
- - Oil and Grease: ¡ 10 mg/L
- - Fecal Coliform: ¡ 1000 MPN/100ml

Typical Discharge Standards (Land for Irrigation)

- When discharging onto land for irrigation, the standards are slightly more relaxed for organics, as the soil provides further treatment.
- General Standards:
- - pH: 5.5 to 9.0
- - Suspended Solids (TSS): ¡ 200 mg/L
- - BOD: ¡ 100 mg/L
- Note: While BOD limits are relaxed, strict limits apply to heavy metals and toxic chemicals to prevent soil poisoning.

Summary

- Disposal by dilution relies on the natural self-purification capacity of large water bodies.
- The Oxygen Sag Curve models the DO drop and recovery in a river.
- Disposal on land recycles water and nutrients but requires careful management to prevent Sewage Sickness.
- Effluent discharge standards ensure that disposal practices do not harm the environment or public health.

Next Lecture: Low-Cost Sanitation

- Centralized sewerage systems are expensive and not feasible for rural or low-income urban areas.
- Next lecture covers Low-Cost Sanitation Systems.
- We will explore decentralized, on-site treatment options.
- Key topics: Pit latrines, Septic Tanks, and Imhoff Tanks.

Low-Cost Sanitation and Decentralized Systems

Unit 8: Sewage Treatment and Disposal

GTU Diploma Engineering

Water Supply Engineering

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Agenda

- The Need for Low-Cost Sanitation
- Pit Privies (Latrines)
- Aqua Privies
- Septic Tanks: Design and Working
- Effluent Disposal: Soak Pits and Dispersion Trenches
- Imhoff Tanks

The Need for Low-Cost Sanitation

- Centralized underground sewerage is capital-intensive and requires a reliable piped water supply to flush solids.
- In rural areas, isolated dwellings, or developing peri-urban slums, these conditions are rarely met.
- Open defecation poses severe public health risks (cholera, typhoid, hookworm).
- On-site (decentralized) sanitation provides a localized, affordable, and hygienic method to isolate human waste from the environment.
- Key principle: Treat and dispose of the waste right where it is generated.

Pit Privy (Pit Latrine)

- The simplest form of on-site sanitation.
- Consists of a hand-dug hole (pit) in the ground, covered by a slab with a drop hole, and surrounded by a superstructure for privacy.
- Depth is usually 2 to 3 meters.
- Liquids infiltrate into the surrounding soil; solids accumulate and decompose anaerobically in the pit.
- When the pit fills to within 0.5m of the top, it is covered with soil, and a new pit is dug (or the pit is emptied).

Improvements: VIP Latrine

- VIP = Ventilated Improved Pit Latrine.
- Solves the two main problems of basic pits: odors and flies.
- A tall vent pipe fitted with a fly screen at the top is added to the pit.
- Wind passing over the pipe creates an updraft, pulling fresh air down through the toilet hole and exhausting odors through the pipe.
- Flies attracted to the pit are drawn toward the light at the top of the vent pipe, get trapped by the screen, and die.

Aqua Privy

- An aqua privy features a watertight tank located immediately under the latrine floor.
- The drop pipe extends below the liquid level in the tank, creating a water seal.
- The water seal entirely prevents odors and insects from entering the superstructure.
- Solids digest anaerobically in the tank. The displaced liquid effluent overflows into a soak pit.
- Requires daily addition of water to maintain the water seal.

The Septic Tank: Overview

- The most common on-site treatment system for homes with piped water supply.
- A septic tank is a watertight, rectangular underground settling tank.
- It performs two functions simultaneously:
- 1. Sedimentation: Settles out heavy organics (sludge) and floats light organics (scum/grease).
- 2. Digestion: Anaerobic bacteria slowly break down the accumulated sludge at the bottom.
- The clarified effluent (which is still highly polluted) exits the tank for further soil treatment.

Septic Tank: Design Features

- Usually constructed of concrete or brickwork. Minimum width is 0.75m, minimum depth is 1.0m.
- Length to width ratio is generally 2:1 or 3:1.
- Detention time is designed for 12 to 36 hours (usually 24 hours).
- Inlet and outlet pipes are fitted with T-fittings or baffles.
- Baffles prevent incoming flow from stirring up the sludge and prevent floating scum from escaping into the outlet.

Septic Tank: Maintenance

- The anaerobic digestion process reduces sludge volume, but does not eliminate it.
- Over time, the sludge layer at the bottom and scum layer at the top will thicken.
- This reduces the effective volume of the clear zone, reducing detention time.
- Septic tanks must be de-sludged (pumped out by a vacuum truck) every 1 to 3 years.
- Failure to pump leads to solids washing out and destroying the soak pit.

Effluent Disposal: Soak Pits

- The effluent from a septic tank or aqua privy is septic, odorous, and contains pathogens. It cannot be discharged to open drains.
- A Soak Pit (Seepage Pit) is a covered, porous-walled chamber that allows effluent to slowly soak into the surrounding soil.
- Usually circular, lined with dry brick or stone masonry (open joints).
- The soil acts as a natural biological filter, providing secondary aerobic treatment as the liquid percolates down.
- Only suitable in permeable soils (sandy/loamy) with a deep water table.

Effluent Disposal: Dispersion Trenches

- If the soil is less permeable or the groundwater table is relatively high, soak pits cannot be used.
- Alternative: Dispersion Trenches (Drainfield or Leachfield).
- Effluent is distributed through a network of perforated pipes laid in shallow, gravel-filled trenches.
- This spreads the effluent over a much larger surface area than a single pit.
- The shallow placement utilizes the highly active aerobic bacteria present in topsoil for treatment.

Imhoff Tanks

- An improvement over the septic tank for larger communities or small towns.
- It is a two-story tank designed by Karl Imhoff.
- Upper Compartment: Acts strictly as a settling chamber (primary clarifier).
- Lower Compartment: Acts strictly as an anaerobic sludge digester.
- Solids settle in the upper chamber and slide through a slot into the lower chamber.
- Advantage: Biogas bubbles generated in the lower digester cannot enter the upper settling chamber, ensuring the sewage remains fresh (non-septic).

Summary

- Decentralized sanitation is vital for areas without centralized sewerage.
- VIP latrines and Aqua Privies offer simple, effective odor and fly control.
- Septic tanks provide primary settling and partial digestion but require regular de-sludging.
- Soak pits and dispersion trenches use the natural soil for secondary treatment of septic effluent.
- Imhoff tanks provide superior performance by physically separating the settling and digestion processes.

Unit 8 Conclusion

- This concludes Unit 8 on Sewage Treatment and Disposal.
- We have covered the entire journey: from measuring pollution (BOD), through Preliminary, Primary, and Secondary treatment.
- We learned about sludge handling and final safe disposal methods.
- Finally, we explored practical, low-cost decentralized alternatives.

Plumbing Tools, Pipes, and Fittings

Unit 9: House Plumbing

GTU Diploma Engineering

Water Supply Engineering

July 25, 2026

Agenda

- Introduction to House Plumbing
- Essential Plumbing Tools
- Types of Plumbing Pipes
- Common Pipe Fittings
- Selection Criteria for Pipes and Fittings
- Summary

Introduction to House Plumbing

- House plumbing involves the installation and maintenance of pipes, fixtures, and appliances for water supply and drainage.
- A proper plumbing system ensures the delivery of safe potable water and the sanitary removal of wastewater.
- Key requirements: No leakage, adequate pressure, prevention of backflow, and durability.
- It consists of two main subsystems: the water supply system (bringing fresh water in) and the drainage/vent system (taking wastewater out).

Essential Plumbing Tools: Measuring and Cutting

- Measuring Tape and Folding Rule: For accurate measurements of pipe lengths.
- Pipe Cutter: Provides clean, square cuts on copper, PVC, or steel pipes without deforming the pipe.
- Hacksaw: Used for cutting metal and plastic pipes when a pipe cutter is not suitable; requires filing to remove burrs.
- PVC Pipe Shears: Specifically designed for quick, clean cuts on plastic pipes up to 2 inches in diameter.

Essential Plumbing Tools: Gripping and Turning

- Pipe Wrench (Stillson Wrench): Has adjustable, toothed jaws designed to grip round metal pipes tightly when turned in one direction.
- Adjustable Wrench (Spanner): Used for hexagonal and square nuts and fittings; prevents rounding of the edges.
- Basin Wrench: A specialized tool with a long handle and swiveling jaw, used for reaching nuts securing faucets in tight spaces under sinks.
- Plier (Slip-Joint and Water Pump Pliers): Versatile tools for gripping pipes, nuts, and pulling wire or cotter pins.

Types of Plumbing Pipes: Metallic

- Galvanized Iron (GI) Pipes: Traditional pipes coated with zinc to prevent rust; heavy, prone to internal scaling and corrosion over time.
- Copper Pipes: Highly durable, biostatic (inhibits bacterial growth), and resistant to corrosion. Used for both hot and cold water but expensive.
- Cast Iron (CI) Pipes: Used primarily for drainage and waste venting; very heavy and sound-deadening.
- Stainless Steel Pipes: Used in areas requiring high corrosion resistance; rigid and expensive.

Types of Plumbing Pipes: Plastics (Polymers)

- Polyvinyl Chloride (PVC): Rigid, widely used for cold water supply and drainage. Not suitable for hot water.
- Chlorinated Polyvinyl Chloride (CPVC): Treated to withstand higher temperatures; used for both hot and cold water supply lines.
- Cross-linked Polyethylene (PEX): Flexible tubing that is easy to install, resistant to scale and chlorine. Ideal for retrofits and radiant heating.
- High-Density Polyethylene (HDPE): Extremely durable and flexible, commonly used for underground water mains and service connections.

Comparison of Pipe Materials I

Concept 1	Concept 2

Copper vs. CPVC for Water Supply

Copper: Lifespan 50+ years, handles high heat/pressure, susceptible to acidic water, requires soldering.

CPVC: Lifespan 30-50+ years, handles hot water, immune to galvanic corrosion, joined by solvent cement, can become brittle over time.

GI vs. PVC for Drainage

GI/CI: Heavy, difficult to install, blocks noise well, susceptible to rust (GI).

PVC: Lightweight, very easy to cut/join, smooth interior flow, transmits water noise more easily.

Common Pipe Fittings: Directional Changes

- Elbows (Bends): Used to change the direction of the pipe. Common angles are 90 degrees and 45 degrees.
- Street Elbows: Have one male end and one female end, allowing connection directly to another fitting without a short piece of pipe.
- Tees: T-shaped fittings used to split a line into two, or combine two lines into one. Has one inlet and two outlets at 90 degrees.
- Y-Fittings (Wyes): Used primarily in drainage systems to allow a smooth flow into the main line at a 45-degree angle, reducing turbulence.

Common Pipe Fittings: Connections and Transitions

- Couplings: Short fittings used to connect two straight pieces of pipe of the same diameter.
- Reducers: Used to connect a larger diameter pipe to a smaller diameter pipe, maintaining flow efficiency.
- Unions: Similar to couplings but designed to be easily disconnected without cutting the pipe. Essential for installing pumps and water heaters.
- Nipples: Short lengths of pipe threaded at both ends, used to connect two female fittings.

Common Pipe Fittings: Closures

- Caps: Fits over the end of a male pipe or fitting to stop the flow. Commonly used for future expansion points or testing.
- Plugs: Fits into a female fitting (threaded or socket) to close the line.
- Cleanouts: A fitting with a removable plug found in drainage systems, allowing access for a plumber's snake to clear blockages.
- Valves: Regulate or stop the flow of water (e.g., Gate valve, Ball valve, Check valve). While considered fittings, they have moving parts.

Summary of Tools and Materials

- Plumbing requires specialized tools for measuring, cutting, and gripping.
- Pipe materials have evolved from GI and Lead to Copper, CPVC, and PEX, balancing cost, durability, and ease of installation.
- Fittings (Elbows, Tees, Unions) are essential for directing flow, changing pipe sizes, and allowing future maintenance.
- Selecting the right combination of pipes and fittings is fundamental to a reliable, leak-free house plumbing system.

Next Lecture Preview

- Jointing methods for different types of pipes (Threading, Soldering, Solvent Welding).
- Introduction to Traps in plumbing.
- Types of traps (P-trap, S-trap, Gully trap) and their functions.
- The concept of water seal and trap failure.

Jointing Methods and Traps

Unit 9: House Plumbing

GTU Diploma Engineering

Water Supply Engineering

July 25, 2026

Agenda

- Importance of Proper Pipe Jointing
- Methods of Jointing (Threaded, Soldered, Solvent Weld, Flanged)
- Introduction to Plumbing Traps
- The Water Seal
- Types of Traps (P, S, Q, Gully, Intercepting)
- Summary

Importance of Proper Pipe Jointing

- A plumbing system is only as strong as its weakest joint.
- Improper joints lead to leaks, pressure loss, water damage to structures, and contamination of water supply.
- Joints must be completely watertight, and in the case of drainage, gastight.
- The method of jointing is dictated entirely by the pipe material (e.g., metal vs. plastic) and the specific application.

Jointing Methods: Threaded Joints

- Primarily used for Galvanized Iron (GI) pipes and some heavy plastic pipes.
- Process: Pipe ends are cut with a die to create external (male) threads, which screw into internal (female) threads of fittings.
- Sealing: Requires a sealing material like Teflon (PTFE) tape or pipe dope (joint compound) wrapped around the male threads to ensure a watertight seal.
- Advantages: Very strong, mechanical connection. Can be disassembled if needed.

Jointing Methods: Soldering (Sweating)

- The standard method for joining rigid Copper pipes.
- Process: Pipe and fitting are cleaned with emery cloth, coated with flux (paste), fitted together, and heated with a propane torch.
- Action: Solder (a metal alloy, typically lead-free) is applied to the joint. Capillary action draws the molten solder into the microscopic gap between the pipe and fitting.
- Result: A permanent, highly durable, leak-proof metallic bond.

Jointing Methods: Solvent Welding

- Used for plastic pipes like PVC, CPVC, and ABS.
- Process: The pipe and fitting are cleaned, often with a primer. Solvent cement is then applied to both surfaces.
- Action: The cement temporarily softens and dissolves the surface layer of the plastic. When pushed together, the two pieces chemically fuse.
- Result: The joint becomes a single piece of plastic, stronger than the pipe itself, once cured.

Jointing Methods: Flanged and Compression Joints

- Flanged Joints: Used for large diameter pipes or connecting to equipment like pumps. Pipes have flat flanges bolted together with a gasket in between for sealing.
- Compression Joints: Used for copper, PEX, or plastic without heat or glue. A nut compresses a brass or plastic ring (ferrule) against the pipe to create a seal.
- Push-Fit (Push-to-Connect) Fittings: Modern mechanical fittings where a stainless steel ring grips the pipe and an O-ring provides a seal (e.g., SharkBite).

Introduction to Traps

- A trap is a U-shaped or S-shaped fitting installed in the sanitary drainage system below or within a plumbing fixture.
- Primary Function: To retain a small quantity of wastewater after every use, forming a 'Water Seal'.
- Purpose of Water Seal: Prevents foul, toxic, and explosive sewer gases (like hydrogen sulfide and methane) from entering the building.
- It also catches heavy objects (like jewelry) and prevents them from entering the main sewer.

The Water Seal

- The water seal is the vertical depth of water between the crown weir and the dip of the trap.
- Depth: Typically ranges from 50 mm to 75 mm for standard fixtures. Deep seal traps may have 100 mm depth.
- Trap Failure (Loss of Seal) can occur due to:
- 1. Siphonage: Negative pressure in the drain pipe sucks the water out.
- 2. Evaporation: If a fixture is unused for a long time.
- 3. Back Pressure: Positive pressure blowing the seal out into the room.

Types of Traps: By Shape

- P-Trap: Shaped like the letter 'P'. Discharges into a horizontal pipe. The most common and most reliable trap used under sinks.
- S-Trap: Shaped like an 'S'. Discharges downwards into the floor. Prone to self-siphonage and is banned in many modern plumbing codes.
- Q-Trap: Similar to an S-trap but discharges at a 45-degree angle. Rarely used today.
- Bottle Trap: Has a vertical cylindrical shape, retaining water at the bottom. Used in modern washbasins for aesthetic reasons.

Types of Traps: By Application

- Floor Trap (Nahni Trap): Installed in floors of bathrooms, kitchens, and wash areas to collect surface wash water. Has a grating to keep out debris.
- Gully Trap: Placed outside the building to collect wastewater from sinks, baths, and rain pipes before connecting to the main sewer. Disconnects wastewater from foul sewer gases.
- Intercepting Trap: Provided at the junction of house sewer and municipal sewer. Prevents municipal sewer gases from entering the house drainage system.

Summary

- Jointing methods (Threading, Soldering, Solvent Welding, Compression) are specific to the pipe material and application.
- Proper jointing ensures leak-proof and structurally sound plumbing.
- Traps are essential U-shaped fittings that maintain a water seal.
- The water seal acts as a physical barrier against hazardous sewer gases.
- P-traps are standard for fixtures, while Gully and Intercepting traps provide macro-level protection for the building.

Next Lecture Preview

- Principles of designing a house drainage plan.
- Two-pipe and one-pipe drainage systems.
- General plumbing operations and maintenance.
- Safety precautions in plumbing works.

Drainage Plan, Operations, and Safety

Unit 9: House Plumbing

GTU Diploma Engineering

Water Supply Engineering

July 25, 2026

Agenda

- Principles of House Drainage
- Systems of Plumbing (Two-pipe, One-pipe, Single Stack)
- The Drainage Plan and Layout
- Routine Plumbing Operations and Maintenance
- Safety Precautions in Plumbing
- Unit 9 Summary

Principles of House Drainage

- The drainage system should remove wastewater and human excreta rapidly and efficiently.
- Pipes should be laid in straight lines as far as possible, with uniform gradients to ensure self-cleansing velocity.
- Inspection chambers (manholes) should be provided at every change of direction or gradient.
- The entire system must be well-ventilated to prevent the buildup of explosive or toxic gases and to protect trap water seals.

Systems of Plumbing: Two-Pipe System

- The most traditional and safest system.
- Consists of two separate vertical pipes (stacks):
- 1. Soil Pipe: Carries human waste from water closets (WCs).
- 2. Waste Pipe: Carries sullage (greywater) from baths, sinks, and basins.
- Both pipes have their own separate vent pipes, resulting in 4 vertical pipes overall in larger buildings.
- Waste pipe connects to the drain via a gully trap to separate it from soil gases.

Systems of Plumbing: One-Pipe System

- A streamlined system to reduce pipework.
- Soil and waste from all fixtures are discharged into a single vertical 'Soil and Waste Pipe'.
- All fixture traps are fully ventilated using a separate common vent pipe to prevent siphonage.
- Requires deep seal traps on all fixtures since soil and waste are mixed immediately.
- Reduces the number of vertical pipes from four to two (one main stack + one vent stack).

Systems of Plumbing: Single Stack System

- The most economical and modern system for certain building types.
- Uses only ONE vertical pipe which acts as both the soil/waste discharge and the vent.
- Relies strictly on limiting the length and slope of branch pipes to prevent trap siphonage, eliminating the need for a separate vent pipe.
- Requires strict adherence to design codes (e.g., maximum distance of fixture from the stack).

The Drainage Plan Layout

- A plumbing drawing or drainage plan indicates the exact routing of supply and drainage lines.
- Key elements shown: Location of fixtures, routing of horizontal drains, location of stacks (vertical pipes), inspection chambers, and connection to municipal sewer.
- Testing the System: Before concealing pipes in walls or trenches, they must be tested for leaks.
- Smoke Test or Peppermint Test is used to check for gas leaks in drainage pipes. Water test is used for underground drains.

Routine Plumbing Operations and Maintenance

- Clearing Blockages: Using a plunger, plumbing snake (auger), or hydro-jetting to clear clogs in traps and main lines.
- Repairing Leaks: Replacing worn-out washers or O-rings in faucets (taps), tightening compression nuts, or cutting and replacing a section of broken pipe.
- Winterization: Draining pipes in cold climates to prevent freezing and bursting.
- Checking Valves: Exercising main shut-off valves periodically to ensure they don't seize due to scaling.

Safety in Plumbing: Chemical and Biological Hazards

- Biological Hazards: Exposure to raw sewage, bacteria (E. coli), and viruses. Plumbers must wear heavy-duty gloves, eye protection, and ensure personal hygiene.
- Chemical Hazards: Exposure to strong drain cleaners (acids/alkalis), solvent cements, and fluxes. Work areas must be well-ventilated.
- Sewer Gases: Confined spaces like manholes can contain toxic hydrogen sulfide or explosive methane, displacing oxygen. Proper ventilation and gas detectors are required before entry.

Safety in Plumbing: Physical and Fire Hazards

- Fire Hazards: Using a propane torch for soldering near wooden studs. Always use a heat shield and have a fire extinguisher nearby.
- Eye and Hand Protection: Sparks from cutting tools, flying debris, and sharp pipe edges require safety goggles and cut-resistant gloves.
- Ergonomic Hazards: Working in awkward positions under sinks or lifting heavy cast iron pipes. Proper lifting techniques are essential.
- Electrical Safety: Mixing water and electricity is dangerous. Ensure power is shut off when working near electrical appliances like water heaters.

Comparison of Plumbing Systems

Concept 1	Concept 2
Two-Pipe System: 4 Pipes total, Excellent hygiene, High cost, High space requirement.	
One-Pipe System: 2 Pipes total, Good hygiene (fully vented), Medium cost, Medium space requirement.	
Single Stack System: 1 Pipe total, Requires precise design to prevent siphonage, Low cost, Low space requirement.	

Unit 9 Summary

- House plumbing is a vital engineering subsystem requiring specialized tools and materials (PEX, PVC, CPVC, Copper).
- Secure jointing methods and the implementation of traps (water seals) are fundamental to protecting public health inside a dwelling.
- Drainage plans must prioritize rapid waste removal and trap protection through proper venting.
- Plumbing operations carry biological, chemical, and physical risks; strict adherence to safety protocols is non-negotiable.

Next Lecture Preview

- We will begin Unit 10.
- Introduction to broader concepts in sanitary engineering and public health.
- Looking beyond the house to municipal infrastructure.

Maintenance Procedures, Causes of Trouble, and Cleaning

Unit 10: Maintenance of Sewage System

GTU Diploma Engineering

Water Supply Engineering

July 25, 2026

Agenda

- Importance of Sewer Maintenance
- Common Causes of Trouble in Sewers
- Routine and Preventive Maintenance Procedures
- Sewer Inspection Techniques
- Methods of Cleaning Sewers
- Flushing Operations

Importance of Sewer Maintenance

- Preventive maintenance avoids costly emergency repairs and sudden system failures.
- Ensures unhindered flow of sewage, preventing backflow into streets or basements.
- Reduces the generation of noxious or explosive sewer gases like Hydrogen Sulfide (H2S) and Methane (CH4).
- Extends the physical lifespan of the sewer infrastructure by preventing corrosion and structural damage.
- Protects public health by preventing the overflow of untreated wastewater into the environment.

Causes of Trouble: Structural Failures

- Pipe Cracking and Collapse: Caused by excessive surface loads, poor bedding, or shifting soil.
- Joint Failures: Improperly sealed joints can open up due to ground settlement, leading to leakage or infiltration.
- Corrosion: Crown corrosion in concrete pipes is caused by sulfuric acid formed from Hydrogen Sulfide (H2S) gas.
- Misalignment: Earth movements can cause pipes to shift out of alignment, creating dips or 'bellies' where solids settle.

Causes of Trouble: Blockages and Obstructions

- Fats, Oils, and Grease (FOG): Solidify when cooled, clinging to pipe walls and restricting flow.
- Root Intrusion: Tree roots seek moisture and nutrients, entering through tiny cracks or joints and growing into massive webs.
- Debris and Silt accumulation: Sand, grit, and street debris entering through catch basins or manholes.
- Foreign Objects: Rags, plastics, and non-biodegradable items inappropriately flushed down household drains.

Causes of Trouble: Infiltration and Inflow (I&I)

- Infiltration: Groundwater entering the sewer system through defective pipes, pipe joints, and manhole walls.
- Inflow: Surface runoff entering directly through manhole covers, cross-connections with storm drains, or roof downspouts.
- Impact: Surcharges the sewer lines beyond their design capacity, leading to overflows.
- Dilutes sewage, which increases the pumping and treatment costs at the wastewater treatment plant.

Maintenance Procedures: Routine Inspection

- Visual Inspection: Regularly checking manholes for flow conditions, odor, and structural integrity.
- Lamp Inspection: Shining a bright light from one manhole to another to check for a clear line of sight, indicating a straight and clear pipe.
- CCTV Inspection: Using remote-controlled closed-circuit television cameras to record the internal condition of pipes.
- Smoke Testing: Forcing non-toxic smoke into lines to identify sources of inflow and illegal connections (smoke will escape from illegal surface drains).

Maintenance Procedures: Preventive and Corrective

Concept 1	Concept 2

Preventive Maintenance: Scheduled activities to prevent failures. Includes periodic flushing, root chemical treatment, and regular pumping station checks.

Corrective Maintenance: Unscheduled activities to restore a failed system. Includes emergency unblocking, repairing collapsed pipes, and replacing broken manhole covers.

A good maintenance program should consist of 75-80% preventive and 20-25% corrective tasks.

Cleaning Sewers: Flushing Operations

- Objective: To remove accumulated silt, sand, and light organic matter by creating a high-velocity flow.
- Method: Water is suddenly released into the sewer from a fire hydrant, water tank, or an automatic flushing tank.
- Mechanism: The sudden surge of water creates a velocity greater than the self-cleansing velocity, scouring the invert.
- Limitation: Flushing is only effective for flat grades and small debris; it cannot remove hardened grease, roots, or heavy solid blockages.

Cleaning Sewers: Mechanical Cleaning (Rodding)

- Use of flexible steel rods pushed into the sewer to dislodge blockages.
- Various tools can be attached to the end of the rod: augers (for boring through grease), root saws (for cutting roots), and sand cups.
- Power Rodding machines use motors to rotate the rods, providing enough torque to cut through stubborn root masses.
- Particularly effective for clearing complete blockages in small to medium-diameter pipes.

Cleaning Sewers: High-Velocity Water Jetting

- Also known as Hydro-Jetting.
- Uses a high-pressure water pump, a hose, and a specialized nozzle.
- Water is pumped at 1000 to 3000 psi. The nozzle has rear-facing jets that propel the hose forward while scouring the pipe walls.
- As the hose is pulled back, the high-pressure water washes debris, grease, and silt back to the manhole where it is removed.
- Highly effective for grease removal and general preventative pipe washing.

Cleaning Sewers: Bucket Machines

- Used for removing heavy debris, sand, and gravel from large diameter sewers.
- Involves two powered winches set up over adjacent manholes.
- A cable is threaded through the sewer line connecting the two winches.
- A specialized bucket is pulled into the debris. Its jaws open to collect the debris and close when pulled backward, bringing the material to the surface.
- Usually preceded by rodding to thread the initial cable through.

Chemical Cleaning and Root Control

- Chemical Herbicides: Used to kill intrusive roots without harming the entire tree above ground.
- Application: Typically applied as a dense foam that fills the pipe, coating the roots completely.
- Grease Control: Bio-additives or chemical degreasers can be injected to break down hardened FOG.
- Odor Control: Addition of chemicals like hydrogen peroxide or chlorine to oxidize hydrogen sulfide and reduce foul odors.

Summary

- Sewer maintenance is critical to prevent blockages, overflows, and structural failures.
- Common troubles include FOG, root intrusion, structural cracking, and excessive Infiltration/Inflow.
- Inspection methods like CCTV and smoke testing help identify issues accurately.
- Cleaning techniques range from simple flushing to advanced high-velocity water jetting, power rodding, and bucket machines.
- A combination of mechanical and chemical methods provides the most comprehensive maintenance strategy.

Next Lecture Preview

- Maintenance Equipment and Selection
- Understanding exactly what machines to use for specific problems.
- Safety Measures in Sewer Maintenance
- Exploring confined space entry, gas detection, and Personal Protective Equipment (PPE).

Maintenance Equipment, Selection, and Safety Measures

Unit 10: Maintenance of Sewage System

GTU Diploma Engineering

Water Supply Engineering

July 25, 2026

Agenda

- Categories of Sewer Maintenance Equipment
- Selection Criteria for Equipment
- Hazards in Sewer Maintenance
- Confined Space Entry Protocols
- Gas Detection and Ventilation
- Personal Protective Equipment (PPE)
- Emergency Rescue and First Aid

Categories of Maintenance Equipment

- Hand Tools: Picks, shovels, manhole hooks, and hand-operated snakes for minor, accessible issues.
- Mechanical Tools: Power rodders and bucket machines for heavy blockages and grit removal.
- Hydraulic Equipment: High-velocity hydro-jetters and vacuum trucks (Vactor trucks) for washing and debris extraction.
- Inspection Equipment: CCTV crawlers, push cameras, and sonar equipment for submerged lines.
- Safety Equipment: Gas monitors, tripods, winches, harnesses, and ventilators.

Selection Criteria for Equipment

- Nature of the Blockage: Is it soft (grease/sludge) or hard (roots/debris)? Hydro-jets for grease, root saws/rodders for roots.
- Pipe Diameter: Small pipes (under 200mm) may only need push cameras and small rodders. Large interceptors require bucket machines and tractor CCTV.
- Pipe Material & Condition: High-pressure jetting might damage older, fragile clay or concrete pipes.
- Accessibility: Can a large vacuum truck reach the manhole? If in an easement or backyard, portable equipment is required.
- Cost and Availability: Balancing the capital cost of specialized machinery against the frequency of use.

Vacuum and Combination Trucks

- Combination Trucks (Combo Trucks) are the workhorses of modern sewer maintenance.
- They combine a high-pressure water jetter (to break up debris) and a powerful vacuum system (to suck up the loosened debris).
- Reduces manual labor significantly and keeps workers above ground, out of the hazardous sewer environment.
- Ideal for cleaning catch basins, lift stations, and clearing major main-line blockages.

Hazards in Sewer Maintenance

- Atmospheric Hazards: Toxic gases ($H2S$), explosive gases (Methane), and Oxygen deficiency.
- Biological Hazards: Exposure to raw sewage carrying pathogens like E. coli, Hepatitis A, and Tetanus.
- Physical Hazards: Slips, trips, falls into manholes, and engulfment by sudden surges of wastewater.
- Ergonomic & Mechanical: Heavy lifting (manhole covers), operating high-pressure machinery, and traffic hazards (working in roadways).

Atmospheric Hazards: The Silent Killers

- Hydrogen Sulfide (H_2S): Smells like rotten eggs at low levels, but paralyzes the olfactory nerves at high levels. Highly toxic and heavier than air (settles at the bottom).
- Methane (CH_4): Odorless, highly explosive, and can displace oxygen.
- Carbon Monoxide (CO): Odorless, toxic gas often from engine exhaust near the manhole.
- Oxygen Deficiency: Normal air is 20.9% oxygen. Levels below 19.5% are considered dangerous and can cause asphyxiation.

Confined Space Entry (CSE) Protocols

- Definition: A space large enough to enter, has limited entry/exit, and is not designed for continuous occupancy (e.g., Manholes, Pump Stations).
- Permit Required: A formal checklist must be completed and authorized before entry.
- Role Assignment: Requires an Entrant (person going in) and an Attendant/Top-man (person staying outside to monitor).
- Continuous Monitoring: Atmospheric conditions must be checked before entry and monitored continuously while work is ongoing.

Gas Detection and Ventilation

- Multi-Gas Monitors: Portable devices worn by workers that continuously measure O2, H2S, CO, and Lower Explosive Limit (LEL) for combustible gases.
- Pre-Entry Testing: The atmosphere must be tested at various depths (top, middle, bottom) before opening the cover entirely.
- Ventilation (Purging): Forced air blowers are used to introduce clean air into the manhole and expel hazardous gases before and during entry.
- The blower intake must be placed upwind and away from vehicle exhaust to avoid blowing CO into the manhole.

Personal Protective Equipment (PPE)

- Body Protection: Tyvek suits or waterproof waders to protect against sewage contact.
- Hand & Foot Protection: Heavy-duty rubber gloves (often worn over cut-resistant gloves) and steel-toed rubber boots.
- Head & Face: Hard hats, safety glasses, and sometimes full-face shields to protect against high-pressure spray back.
- Respiratory Protection: If ventilation is insufficient, Self-Contained Breathing Apparatus (SCBA) or supplied-air respirators are required.
- Visibility: High-visibility safety vests, especially when working near traffic.

Fall Protection and Retrieval Systems

- Full-Body Harness: Worn by the entrant at all times inside the confined space.
- Tripod and Winch: Set up over the manhole. The lifeline from the winch is attached to the D-ring on the worker's harness.
- Non-Entry Rescue: If the entrant collapses (e.g., from gas exposure), the attendant uses the winch to crank them out immediately.
- Prevents the attendant from becoming a secondary victim, which is a leading cause of confined space fatalities.

Traffic Control and Site Safety

- Manholes are frequently located in the center of busy streets.
- Proper Traffic Control Plans (TCP) must be implemented.
- Includes the use of advance warning signs, traffic cones, barricades, and sometimes flaggers.
- The work zone must provide a safe buffer space between moving vehicles and the open manhole.

Emergency Preparedness and Training

- Regular Training: Workers must be certified in confined space entry, CPR, and first aid.
- Vaccinations: Workers should have up-to-date vaccinations for Hepatitis A, Hepatitis B, Tetanus, and Polio.
- Emergency Action Plan (EAP): A clear protocol on who to call and what to do if an accident occurs.
- Equipment Maintenance: Safety equipment like gas monitors must be calibrated regularly (bump testing) to ensure accuracy.

Summary

- Equipment selection depends on the blockage type, pipe size, and location (e.g., combo trucks vs. hand rodders).
- Sewer maintenance presents severe atmospheric, biological, and physical hazards.
- Hydrogen Sulfide and Methane are deadly gases requiring continuous monitoring and forced ventilation.
- Confined Space Entry protocols dictate the use of permits, attendants, harnesses, and tripod retrieval systems.
- Comprehensive PPE and strict traffic control are mandatory to protect workers.

Course Conclusion

- This concludes Unit 10 and the core syllabus for Water Supply & Sanitary Engineering.
- We have traced the journey of water from its source, through treatment and distribution.
- And followed wastewater from collection, through appurtenances, to maintenance.
- Next steps: Comprehensive course review, exam preparation, and final assessments.

Introduction to Wastewater Recycling and Reuse

Unit 11: Recycling of wastewater and Solid Waste

GTU Diploma Engineering

Water Supply Engineering

July 25, 2026

Agenda

- Need for Wastewater Recycling
- Terminology: Reclaimed vs. Recycled Water
- Treatment Levels for Reuse
- Agricultural and Landscape Irrigation
- Industrial Water Reuse
- Urban Non-Potable and Potable Reuse
- Challenges in Wastewater Recycling

The Need for Wastewater Recycling

- Rapid urbanization and population growth place immense stress on finite freshwater resources.
- Climate change leads to unpredictable precipitation patterns and prolonged droughts.
- Discharging untreated or partially treated wastewater degrades receiving water bodies (eutrophication).
- Recycling wastewater provides a drought-resistant, reliable alternative water supply.

Terminology: Reclaimed, Recycled, and Reused Water

- Reclaimed Water: Wastewater that has been treated to meet specific water quality criteria with the intent of being used for beneficial purposes.
- Recycled Water: Often used synonymously with reclaimed water, though sometimes refers specifically to internal reuse within an industry.
- Direct Reuse: The use of reclaimed water that has been transported from a wastewater treatment plant to a reuse site without passing through a natural body of water.
- Indirect Reuse: Discharging reclaimed water into a natural water body (river, lake, aquifer) before abstracting it for use.

Treatment Levels Required for Reuse

- Primary Treatment: Usually insufficient for reuse due to high pathogen and suspended solids content.
- Secondary Treatment: Suitable for restricted agricultural irrigation (non-food crops) and some industrial cooling.
- Tertiary/Advanced Treatment: Involves filtration (sand, membrane) and high-level disinfection (UV, Chlorine, Ozone).
- Required for unrestricted agricultural irrigation, urban landscaping, and dual-pipe systems.

Agricultural and Landscape Irrigation

- Agriculture is the largest consumer of freshwater globally.
- Using reclaimed water for irrigation frees up high-quality potable water for domestic use.
- Nutrient Recovery: Treated wastewater often retains nitrogen and phosphorus, reducing the need for synthetic chemical fertilizers.
- Strict monitoring of heavy metals and pathogens (e.g., E. coli, Helminth eggs) is essential to protect soil and public health.

Industrial Water Reuse

- Industries utilize large volumes of water for cooling, washing, and processing.
- Cooling Towers: The most common industrial application for reclaimed water. Requires control of scaling (calcium, magnesium) and biological growth (biofouling).
- Boiler Feed Water: Requires highly treated water (often via Reverse Osmosis) to prevent scaling and corrosion at high temperatures.
- Zero Liquid Discharge (ZLD): Advanced industrial systems where 100% of wastewater is treated and reused internally, leaving only solid waste.

Urban Non-Potable Reuse

- Dual-Pipe Systems: Separate piping networks deliver potable water (clean, safe) and reclaimed water (purple pipes).
- Applications include toilet flushing, street washing, fire protection, and irrigating public parks and golf courses.
- Color Coding: Reclaimed water infrastructure is universally colored purple to prevent cross-connection with potable supplies.
- Requires stringent tertiary treatment to ensure public safety against accidental ingestion or aerosol inhalation.

Potable Reuse: Indirect vs. Direct I

Concept 1	Concept 2

Indirect Potable Reuse (IPR): Highly treated wastewater is blended with natural water sources (groundwater aquifers or surface reservoirs) before being treated again at a drinking water plant.

Environmental buffer provides additional natural treatment and public psychological reassurance.

Direct Potable Reuse (DPR): Advanced treated wastewater is introduced directly into the potable water distribution system or immediately upstream of a water treatment plant.

Requires extreme multi-barrier treatment (Microfiltration + RO + Advanced Oxidation Process).

Groundwater Recharge

- A form of Indirect Potable Reuse.
- Methods: Surface spreading basins (percolation) or direct injection wells.
- Soil Aquifer Treatment (SAT): As water percolates through the soil, physical filtration, chemical adsorption, and biological degradation naturally purify it.
- Prevents saltwater intrusion in coastal aquifers and replenishes depleted groundwater tables.

Technological Barriers in Advanced Treatment

- Contaminants of Emerging Concern (CECs): Pharmaceuticals, personal care products, and endocrine-disrupting chemicals (EDCs) are not fully removed by secondary treatment.
- Membrane Bioreactors (MBR): Combine biological treatment with micro/ultrafiltration for superior effluent quality.
- Advanced Oxidation Processes (AOP): Use ozone (O3) and hydrogen peroxide (H2O2) with UV light to destroy complex organic micro-pollutants.
- Reverse Osmosis (RO): Essential for removing dissolved salts and micro-pollutants but generates a concentrated brine stream.

Challenges and Public Perception

- The 'Yuck Factor': Psychological resistance from the public regarding the consumption of 'toilet-to-tap' water.
- Economic Costs: Advanced treatment facilities (RO, AOP) and dual distribution networks are highly capital-intensive and consume significant energy.
- Regulatory Frameworks: Lack of uniform international or national guidelines specifically for various reuse categories.
- Brine Disposal: RO and membrane processes produce highly concentrated brine that must be safely disposed of without harming the environment.

Summary

- Wastewater recycling is essential for sustainable water resource management.
- Applications range from agricultural and industrial to urban non-potable and even potable reuse.
- The level of treatment must strictly align with the intended use to protect public health and the environment.
- Advanced technologies like MBR, RO, and AOP are critical for high-end reuse.
- Overcoming public perception and high economic costs are the primary challenges.

Solid Waste Management: Sources, Classification, and Collection

Unit 11: Recycling of wastewater and Solid Waste

GTU Diploma Engineering

Water Supply Engineering

July 25, 2026

Agenda

- Introduction to Solid Waste Management (SWM)
- Sources of Solid Waste
- Classification of Solid Waste
- Physical and Chemical Characteristics
- Functional Elements of SWM
- Waste Segregation at Source
- Collection Systems and Equipment
- Transfer Stations and Transportation

Introduction to Solid Waste Management

- Solid Waste: Any discarded or abandoned materials (non-liquid) arising from domestic, commercial, industrial, and agricultural activities.
- Municipal Solid Waste (MSW): Primarily household waste (garbage and rubbish) alongside commercial and institutional waste collected by municipalities.
- Impact of Poor SWM: Clogged drains leading to flooding, proliferation of disease vectors (rats, mosquitoes), groundwater contamination (leachate), and air pollution.
- Objective of SWM: To control generation, storage, collection, transfer, processing, and disposal in a manner compliant with public health and environmental principles.

Sources of Solid Waste

- Residential: Single and multifamily dwellings (food waste, paper, plastics, glass).
- Commercial: Stores, hotels, restaurants, markets (corrugated cardboard, food waste, plastics, e-waste).
- Institutional: Schools, hospitals, government centers (paper, hazardous biomedical waste, cafeteria waste).
- Construction and Demolition (C&D): Road repair, building construction (wood, steel, concrete, dirt).
- Municipal Services: Street sweeping, landscaping, park maintenance (leaves, street dirt, branches).

Classification of Solid Waste

- Garbage: Putrescible (biodegradable) organic waste from the preparation, cooking, and serving of food. Decomposes rapidly and produces odors.
- Rubbish: Non-putrescible solid waste, both combustible (paper, wood, plastics) and non-combustible (glass, metals, ceramics).
- Ashes: Residue from the combustion of solid fuels for heating and cooking.
- Hazardous Waste: Wastes that pose a substantial danger immediately or over time (toxic, ignitable, corrosive, reactive). Requires specialized handling.

Physical Characteristics of MSW

- Density/Specific Weight: Crucial for assessing total mass and volume. Dictates the size and type of collection vehicles (e.g., use of compactor trucks).
- Moisture Content: Important for evaluating processing options like composting or incineration. Food waste typically has a high moisture content (50-70%).
- Particle Size and Distribution: Affects the porosity and permeability of compacted waste, influencing the design of mechanical separators and landfill gas/leachate movement.
- Field Capacity: The total amount of moisture that can be retained in a waste sample subject to the downward pull of gravity. Important for leachate generation calculations.

Chemical Characteristics of MSW

- Proximate Analysis: Determines moisture, volatile combustible matter, fixed carbon, and ash. Essential for evaluating combustion properties.
- Fusing Point of Ash: The temperature at which ash forms clinkers. Critical for incinerator design to prevent blockages.
- Ultimate Analysis (Elemental): Determines Carbon, Hydrogen, Oxygen, Nitrogen, Sulfur, and halogens. Used to calculate the carbon-to-nitrogen (C/N) ratio for composting.
- Energy Content (Calorific Value): Measured in kJ/kg using a bomb calorimeter. Determines the viability of waste-to-energy (WTE) projects.

Functional Elements of SWM

- 1. Waste Generation
- 2. Waste Handling and Segregation at Source
- 3. Collection
- 4. Separation, Processing, and Transformation
- 5. Transfer and Transport
- 6. Final Disposal

Waste Segregation at Source

- The most critical step for effective recycling and processing.
- Wet Waste (Biodegradable): Kitchen waste, vegetable peels, leftover food. Sent for composting or biomethanation.
- Dry Waste (Recyclable/Non-biodegradable): Paper, plastics, metal, glass. Sent for material recovery and recycling.
- Domestic Hazardous & E-waste: Batteries, paints, expired medicines, electronics. Require specialized safe disposal.
- Color-coded Bins: Green (Wet/Organic), Blue (Dry/Recyclables), Red/Black (Hazardous).

Concept 1	Concept 2

Hauled Container Systems (HCS): The containers used for storage are hauled to the processing/disposal site, emptied, and returned. Suitable for high waste generation points (markets, construction sites).

Stationary Container Systems (SCS): The containers used for storage remain at the point of generation. Waste is transferred into collection vehicles (e.g., compactor trucks). Used for residential and commercial collection.

Routing: Heuristic routing optimization is used to minimize travel distance, avoid dead-heading, and reduce fuel consumption.

Collection Equipment and Vehicles

- Handcarts and Tricycles: Used for door-to-door primary collection in narrow streets and dense urban areas.
- Light Commercial Vehicles (LCVs): Used for secondary collection and transport to transfer stations.
- Compactor Trucks: Hydraulically compact the waste inside the vehicle, increasing payload capacity by up to 3 times. Ideal for low-density MSW.
- Roll-on/Roll-off (Ro-Ro) Trucks: Used to haul large demountable containers from commercial areas or transfer stations.

Transfer Stations and Transportation

- Transfer Station: A centralized facility where waste is unloaded from smaller collection vehicles and re-loaded into larger, long-haul vehicles (trailers, trains).
- Purpose: Reduces transport costs when the disposal site is far (¿15-20 km) from the collection area.
- Operations: Often includes further compaction, baling, or preliminary material recovery to maximize the payload of the long-haul transport.
- Environmental Controls: Must be enclosed and equipped with odor control, dust suppression, and leachate collection systems.

Summary

- Solid Waste Management encompasses generation to final disposal, aiming to protect public health and the environment.
- Understanding waste sources and physical/chemical characteristics (density, moisture, C/N ratio, calorific value) is crucial for selecting processing methods.
- Source segregation (wet vs. dry) is the most critical step for effective waste recycling.
- Collection is the most expensive phase; optimizing vehicle types (HCS vs SCS) and routing is essential.
- Transfer stations consolidate waste for cost-effective long-haul transport to distant disposal sites.

Solid Waste Processing, Treatment, and Disposal

Unit 11: Recycling of wastewater and Solid Waste

GTU Diploma Engineering

Water Supply Engineering

July 25, 2026

Agenda

- Material Recovery Facilities (MRF) and Recycling
- Biological Processing: Composting
- Anaerobic Digestion (Biomethanation)
- Thermal Processing: Incineration
- Waste-to-Energy (WtE) Concepts
- Final Disposal: Sanitary Landfilling
- Landfill Gas and Leachate Management
- The Waste Management Hierarchy

The Waste Management Hierarchy

- An internationally recognized framework ranking waste management options based on environmental impact.
- 1. Prevention/Reduction (Most Preferred)
- 2. Reuse
- 3. Recycling / Composting
- 4. Energy Recovery (Incineration)
- 5. Disposal (Landfill) (Least Preferred)

Material Recovery Facilities (MRF) and Recycling

- MRF: A specialized plant that receives, separates, and prepares recyclable materials for end-user manufacturers.
- Unit Operations in MRFs:
- Size Reduction: Shredders and crushers.
- Screening: Trommel screens to separate by size.
- Magnetic Separation: Overband magnets for ferrous metals (iron/steel).
- Eddy Current Separators: Repel non-ferrous metals (like aluminum) for collection.
- Air Classifiers: Separate light materials (paper/plastic) from heavy materials (glass/stones).

Biological Processing: Composting

- Composting: The controlled, aerobic, biological decomposition of organic waste into a stable, humus-like product (compost).
- Ideal Conditions:
- C/N Ratio: 25:1 to 30:1. Carbon provides energy; Nitrogen is for microbial cell growth.
- Moisture Content: 50-60%. Too dry halts microbial action; too wet turns the process anaerobic (causing odors).
- Aeration: Regular turning or forced air to maintain oxygen levels.
- Temperature: Rises to 55-65°C (thermophilic phase), which is critical for destroying pathogens and weed seeds.

Composting Methods

Concept 1	Concept 2
Windrow Composting: Organic waste is formed into long, low piles (windrows) and periodically turned by mechanical equipment for aeration.	
Aerated Static Pile: Waste is mixed with bulking agents (like wood chips) and placed over perforated pipes. Air is blown or drawn through the pile; no turning is required.	
In-vessel Composting: Takes place inside enclosed drums or silos. Highly controlled environment (temperature, moisture, aeration), resulting in faster composting and superior odor control. High capital cost.	

Anaerobic Digestion (Biomethanation)

- Biomethanation: The decomposition of organic matter by microorganisms in the absence of oxygen.
- Products: Biogas (primarily Methane CH4 and Carbon Dioxide CO2) and digestate (nutrient-rich sludge).
- Process Stages: Hydrolysis -¿ Acidogenesis -¿ Acetogenesis -¿ Methanogenesis.
- Applications: Ideal for high-moisture organic waste (food waste, sewage sludge, animal manure).
- Energy Recovery: The methane produced is captured and burned to generate electricity or heat.

Thermal Processing: Incineration

- Incineration: Controlled combustion of solid waste in the presence of oxygen at high temperatures (850°C - 1000°C).
- Advantages: Drastically reduces waste volume (by 80-90%) and mass (by 70-80%). Destroys pathogens and toxic organics. Generates steam for electricity (Waste-to-Energy).
- Requirements: Waste must have a high net calorific value and low moisture content.
- Residues: Bottom ash (can sometimes be used in construction) and Fly ash (highly toxic, requires secure landfilling).

Air Pollution Control in Incineration

- A major challenge of incineration is the emission of toxic gases (NOx, SOx, HCl, Dioxins, and Furans) and particulate matter.
- Control Technologies:
- Electrostatic Precipitators (ESP) / Fabric Filters: Capture fly ash and particulate matter.
- Wet or Dry Scrubbers: Inject lime slurry to neutralize acid gases (SO2, HCl).
- Activated Carbon Injection: Adsorbs heavy metals (mercury) and highly toxic dioxins/furans.
- Strict temperature control (¿850°C for 2 seconds) is mandated to prevent the formation of dioxins.

Final Disposal: Sanitary Landfilling

- Sanitary Landfill: An engineered facility for the disposal of MSW, designed to minimize public health and environmental impacts.
- Unlike an 'open dump', a sanitary landfill isolates waste from the surrounding environment using highly engineered liner and cover systems.
- Site Selection Criteria: Adequate land area, hydrogeological isolation (impermeable natural clay), away from fault lines, floodplains, and airports (bird strike hazard).
- Daily Cover: A layer of soil (approx 15 cm) is applied over the compacted waste at the end of each day to prevent odors, fires, and access by vectors (rats, birds).

Landfill Liner and Leachate Management

- Leachate: Highly contaminated liquid generated as water percolates through the decomposing waste, extracting dissolved and suspended materials.
- Bottom Liner System: Prevents leachate from contaminating groundwater.
- Typically consists of a composite liner: a High-Density Polyethylene (HDPE) geomembrane placed over a thick layer of compacted, low-permeability clay.
- Leachate Collection: A network of perforated pipes laid in a gravel drainage layer above the liner collects leachate and pumps it out for wastewater treatment.

Landfill Gas (LFG) Management

- Decomposition of organic waste in the anaerobic depths of the landfill generates Landfill Gas (LFG).
- LFG Composition: Typically 50% Methane (CH4) and 50% Carbon Dioxide (CO2), plus trace volatile organic compounds.
- Hazards: Methane is explosive and a potent greenhouse gas (25x more impactful than CO2).
- Management: LFG must be extracted using vertical wells. It is then either flared (burned safely) or, preferably, conditioned and used to run turbines to generate electricity.

Summary

- Following the waste hierarchy, reduction and recycling (MRFs) are the most preferred management strategies.
- Organic fractions can be processed via composting (aerobic) or biomethanation (anaerobic) to recover nutrients and energy.
- Incineration provides significant volume reduction and energy recovery but requires strict air pollution control.
- Sanitary landfills are highly engineered facilities essential for final disposal, featuring liners, leachate collection, and gas management to protect the environment.