BALASORE COLLEGE OF ENGINEERING AND TECHNOLOGY
SERGARH, BALASORE

A

Lecture Notes

On

WATER SUPPLY AND SANITARY ENGINEERING

2nd Year **4th Semester**

BCET

Prepared by: JYOTISHANKAR RATH

Asst. Professor Civil Engineering Department

CHECKED BY

MODULE WISE DISTRIBUTION OF LOADS

Module	Chapter with title	Assigned Hour (as per BPUT)	Actual Session Needed	Range of Marks of Questions to be being asked (BPUT)
I	WATER SUPPLY	10	12	25-35
II	WATER QUALITY	12	13	30-35
III	WATER TREATMENT	10	13	25-30
IV	GENERATION AND COLLECTION OF WASTE WATER	08	12	20-25
TOTAL		**40**	**50**	**100**

SYLLABUS

Module-I

Quantity of water: Sources of water, Per capita demand, design period, population forecast, fluctuation in demand.

General requirement for water supply: Types of intakes, Pumping and Transportation of water.

Quality of water: Physical, chemical and biological characteristics of water and their significance, necessity of treatment, Drinking water standards

Module-II

Basic unit operations and unit processes for surface water treatment: Screening, Plain Sedimentation, Sedimentation aided with Coagulation, Filtration, Disinfection, Softening Miscellaneous treatments (principles only): Removal of colours, tastes and odours, removal of iron and manganese, fluoridation and defloridation, Ion exchange, electro-dialysis, RO

Module-III

Quantity and characteristics of wastewater, effluent discharge standards.

Domestic wastewater treatment: Primary treatment, Screening, Grit removal, Sedimentation, Sedimentation aided with coagulation. Secondary treatment: Basis of microbiology, Growth and food utilization, Suspended-culture systems, Attached-culture systems, Secondary clarification, Disinfections of effluents. Sludge treatment and disposal: Sludge characteristics, thickening, disposal

Module-IV

Solid waste management: Source, classification, characteristics, generation, collection, Storage and transport of MSW, MSW management, Waste minimization of MSW, Reuse and recycling, Biological & thermal treatment (principles only), land fill

Text and Reference Books:

1. Environmental Engineering (Volume I & II) by S. K. Garg-Khanna Publishers
2. Environmental Engineering (Volume I &II) by B. C. Punmia-Khanna Publishers
3. Environmental Engineering by H. S. Peavy, D.R. Rowe and G. Tchobanoglous, MGH.

MODULE-1

CHAPTER-1

SESSION-1

1.1 WATER SUPPLY

LEARNING OBJECTIVE

1.1.1 Introduction

1.1.2 Requirement for Water Suply

1.1.1 INTRODUCTION

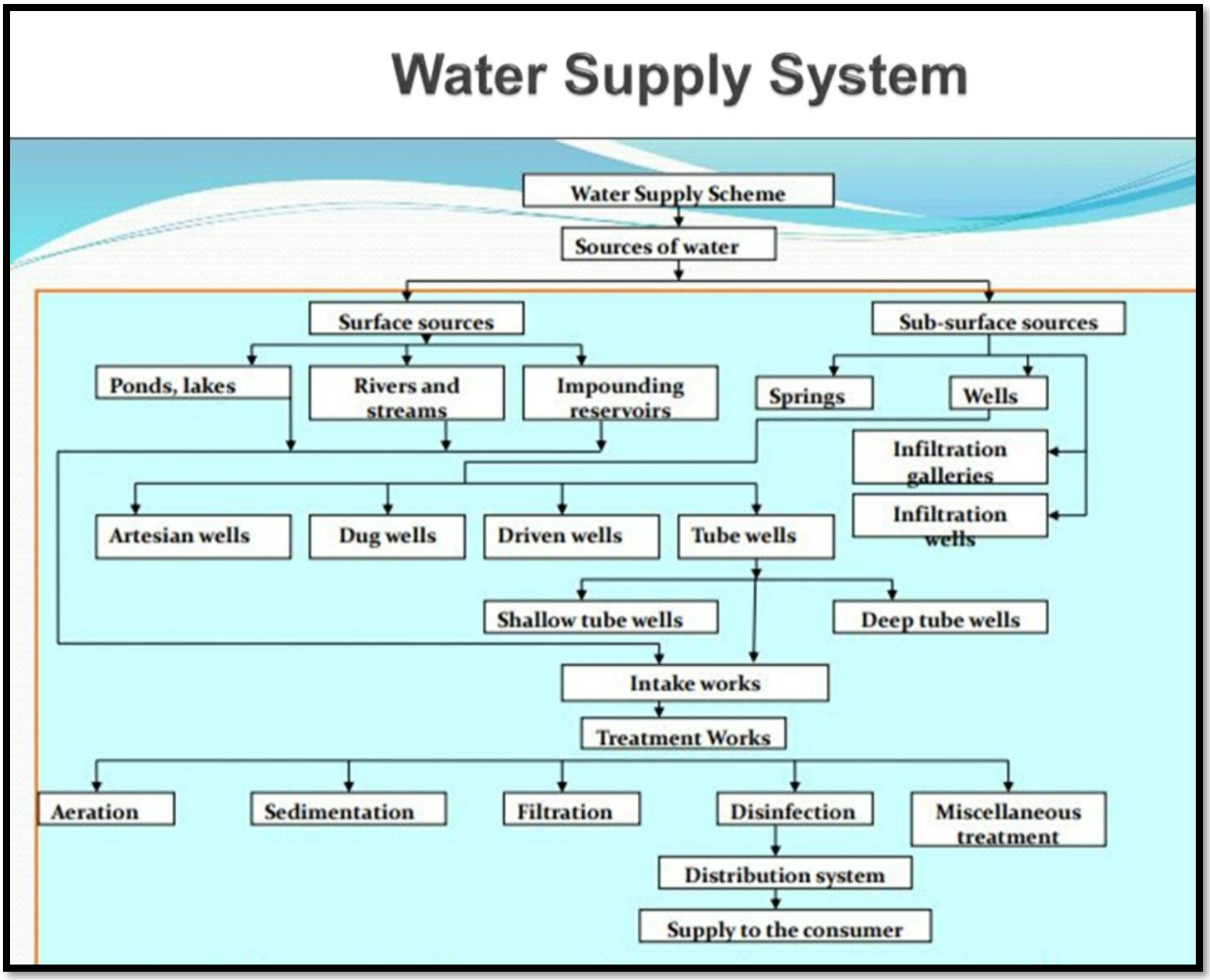
- Water is the essence of life, a fundamental resource that sustains all living beings on our planet. From quenching our thirst to facilitating agricultural production, supporting industries, and maintaining ecological balance, water is indispensable to human civilization.
- The branch of civil engineering which deals with the supply of water for various purposes e.g. domestic, industrial, commercial & public is called Water Supply Engineering.
- Water supply is the provision of water by public utilities, commercial organisations, community endeavours or by individuals, usually via a system of pumps and pipes. Public water supply systems are crucial to properly functioning societies. These systems are what supply drinking water to populations around the globe.
- Aspects of service quality include continuity of supply, water quality and water pressure. The institutional responsibility for water supply is arranged differently in different countries and regions (urban versus rural). It usually includes issues surrounding policy and regulation, service provision and standardization.

TYPES OF WATER SUPPLY SYSTEMS

- **Public Water Supply:** Managed by government or private entities, serving urban and suburban areas.
- **Rural Water Supply:** Often includes simpler systems like wells, rainwater collection, and community-managed systems.
- **Industrial Water Supply:** Systems designed to meet the specific needs of industrial processes, often requiring higher quantities and specialized treatment.

CHALLENGES IN WATER SUPPLY

1. **Water Scarcity:**
   - Limited availability due to climate change, overuse, and pollution.
2. **Infrastructure Aging:**
   - Many systems require significant upgrades and maintenance.
3. **Water Quality:**
   - Ensuring safe drinking water through effective treatment and monitoring.
4. **Access and Equity:**
   - Providing reliable water supply to underserved and remote areas.



1.1 WATER SUPPLY

LEARNING OBJECTIVE

1.1.2 Requirement for Water Suply

1.1.2 REQUIREMENT FOR WATER SUPLY

The general requirements of water supply encompass various aspects to ensure the delivery of safe, reliable, and sustainable water to communities. Here is a breakdown of these requirements:

1. **Quality**: Water supplied for consumption must meet regulatory standards for purity and safety. This involves thorough testing and treatment processes to remove contaminants and pathogens, ensuring that the water is potable and free from harmful substances.
2. **Quantity**: An adequate volume of water must be available to meet the needs of the population. This requires infrastructure capable of capturing, storing, treating, and distributing water efficiently, while also accounting for fluctuations in demand due to factors such as population growth, seasonal variations, and emergencies.
3. **Accessibility**: Water supply infrastructure should be accessible to all members of the community, regardless of socioeconomic status or geographical location. Efforts must be made to ensure equitable access, particularly for marginalized groups and underserved areas.
4. **Reliability**: Water supply systems must be reliable and resilient, capable of withstanding natural disasters, infrastructure failures, and other disruptions. Redundancies, backup systems, and emergency response plans are essential to minimize service interruptions and ensure continuity of supply.
5. **Affordability**: Water should be affordable for all, reflecting the principle of water as a human right. Pricing structures should consider the economic circumstances of consumers while also generating sufficient revenue to maintain and upgrade infrastructure, cover operational costs, and promote conservation.

6. **Sustainability**: Sustainable water management practices are vital to protect and preserve water resources for future generations. This includes promoting water conservation, reducing leakage and waste, implementing water reuse, and recycling initiatives, and adopting eco-friendly technologies.

7. **Regulatory Compliance**: Water supply systems must adhere to relevant regulations and standards set by governmental agencies or international organizations. Compliance ensures that water quality is maintained, public health is safeguarded, and environmental impacts are minimized.

8. **Community Engagement**: Engaging the community in water supply planning, decision-making, and management processes fosters transparency, accountability, and public trust. Education and outreach programs can also promote water conservation and sustainable usage habits among residents.

By addressing these general requirements, water supply systems can fulfil their mission of providing clean, safe, and reliable water to meet the needs of present and future generations.

CHAPTER-1

SESSION-3

1.1 WATER SUPPLY

LEARNING OBJECTIVE

1.1.3 Sources of Water

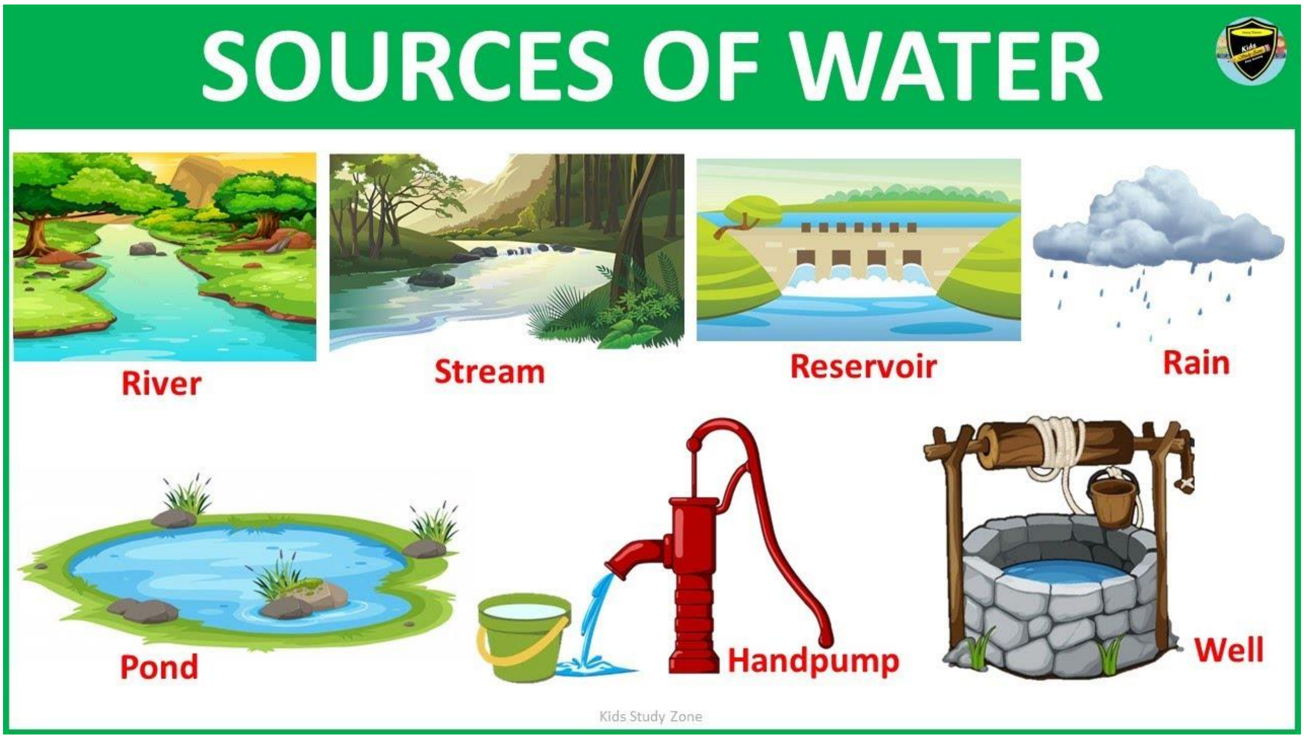
1.1.3 SOURCES OF WATER

Water is an essential part of our lives. We need water for the smooth functioning of lives. However, there is not much water left on the planet which is capable for consuming. The sources of water are also running out to a great extent. We must recognize these signs and learn how to restore these sources of water for a better future.

IMPORTANCE OF WATER SOURCES

- **Sustainability:** Ensuring a sustainable supply of water is critical for human survival, economic development, and environmental health.
- **Management:** Effective management of water sources involves balancing extraction with replenishment, protecting water quality, and considering the ecological impacts.

- **Adaptation:** With changing climate conditions, it is important to adapt water supply systems to ensure resilience against droughts, floods, and other climate-related events.



OCEAN WATER

- We know that oceans are a great source of water. However, what most people do not know is that while it contributes to 97% of the water, the water is not feasible to consume directly.
- The ocean water contains a large amount of salt and impurities. It requires several processes like desalination to make the water fit for consumption.
- Furthermore, we can also apply reverse osmosis as well. We can easily remove salt and the other particles using many ways. But this method is quite favourable.
- The saltwater goes through microscopic pores filters to eliminate any salt or microbes from it. However, it is a very expensive procedure due to the large energy required.
- Thus, we see that ocean water is surely in abundance. But it requires a lot of energy and capital to get filtered. Therefore, it is not easy to consume.

SURFACE WATER

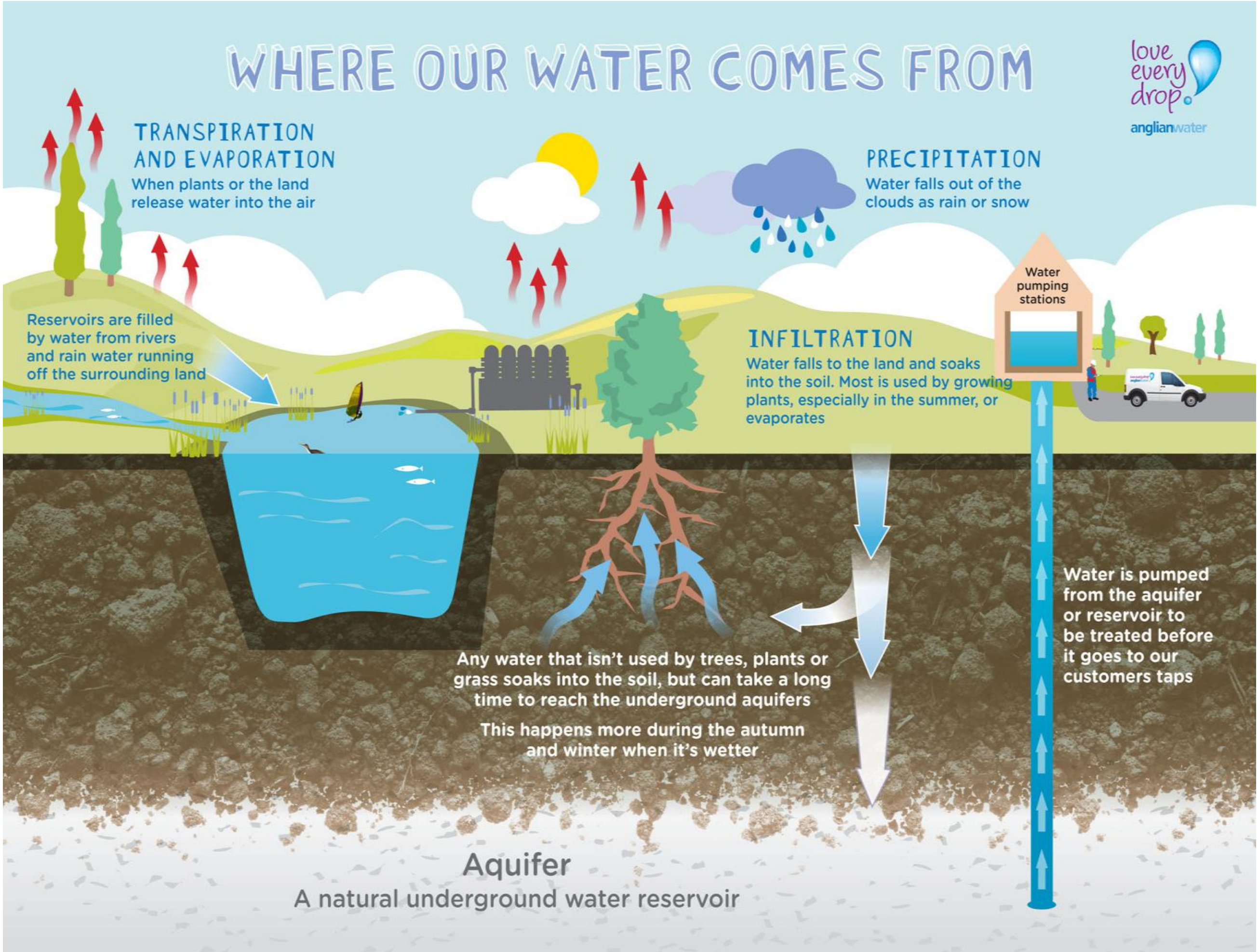
- Surface water is quite a broad term when we look at it. It consists of any above-ground water which gets collected. For instance, we have ponds, rivers, lakes, oceans and more.
- Surface water is the most used source of water. It accounts to at least 80 per cent of the water used by living beings.
- The underground aquifers also contribute to maintaining the level of surface water. While surface water is easily accessible and found in abundance, we have been misusing it for a long time now.
- The rivers and oceans are getting polluted due to religious practices and industrial waste. Therefore, we need to carefully this water as it will not last long.

GROUND WATER

- When we say groundwater, we mean the source of water which is found beneath the layer of soil. It exists in the soil and between rocks and other things. Groundwater contributes to 30% of water which we use in our daily lives.
- Nowadays, almost everyone is installing a submersible pump at their house. Moreover, pollution and seawater contamination has led to its depleting.
- It has indeed become a matter of concern because of overuse. If everyone keeps using it for personal purposes at this speed, the groundwater level will soon drop and we will not be able to recover it.

ICECAPS AND GLACIAL MELTING

- The ice caps and glaciers are great sources of water. However, the process of making it fit for consuming is too expensive. Nonetheless, these ice caps and glaciers have at least 70% of the water which we may consume.
- Moreover, these substances are very important for regulating the climate of the earth and its temperature. Therefore, we need to preserve them for a better future.



CHAPTER-1
SESSION-4

1.1 WATER SUPPLY
LEARNING OBJECTIVE
1.1.4 Quality of Water

1.1.4 QUALITY OF WATER

Water quality refers to chemical, physical and biological characteristics of water based on the standards of its usage. It is most frequently used by reference to a set of standards against which compliance, generally achieved through treatment of the water, can be assessed. The most common standards used to monitor and assess water quality convey the health of ecosystems, safety of human contact, extent of water pollution and condition of drinking water. Water quality has a significant impact on water supply and oftentimes determines supply options.

PHYSICAL CHARACTERISTICS:

1. **Turbidity:** Turbidity refers to the cloudiness or haziness of a fluid caused by large numbers of individual particles suspended within it. These particles can include sediment, silt, clay, microorganisms, or even pollutants. Turbidity is commonly measured in nephelometric turbidity units (NTU) and is an important parameter in assessing water quality. High turbidity levels can interfere with water treatment processes, impact aquatic ecosystems, and indicate the presence of contaminants. Monitoring and controlling turbidity are crucial for ensuring safe and clean water supplies for drinking, industrial use, and ecological health.
2. **Colour:** Dissolved organic matter from decaying vegetation or some inorganic materials may impart colour to the water. It can be measured by comparing the colour of water sample with other standard glass tubes containing solutions of different standard colour intensities. The standard unit of colour is that which is produced by one milligram of platinum cobalt dissolved in one litre of distilled water. The IS value for treated water is 5 to 25 cobalt units.
3. **Taste and Odour:** Odour depends on the contact of a stimulating substance with the appropriate human receptor cell. Most organic and some inorganic chemicals, originating from municipal or industrial wastes, contribute taste and odour to the water. Taste and odour can be expressed in terms of odour intensity or threshold values.

   A new method to estimate taste of water sample has been developed based on flavour known as 'Flavour Profile Analysis' (FPA). The character and intensity of taste and odour discloses the nature of pollution or the presence of microorganisms.
4. **Temperature:** The increase in temperature decreases palatability, because at elevated temperatures carbon dioxide and some other volatile gases are expelled. The ideal temperature of water for drinking purposes is *5 to 12 °C* - above 25 °C, water is not recommended for drinking.

CHEMICAL CHARACTERISTICS:

1. **pH:** pH value denotes the acidic or alkaline condition of water. It is expressed on a scale ranging from 0 to 14, which is the common logarithm of the reciprocal of the hydrogen ion concentration. The recommended pH range for treated drinking waters is *6.5 to 8.5*.

2. **Acidity:** The acidity of water is a measure of its capacity to neutralise bases. Acidity of water may be caused by the presence of uncombine carbon dioxide, mineral acids and salts of strong acids and weak bases. It is expressed as mg/L in terms of calcium carbonate. Acidity is nothing but representation of carbon dioxide or carbonic acids. Carbon dioxide causes corrosion in public water supply systems.

3. **Alkalinity:** The alkalinity of water is a measure of its capacity to neutralise acids. It is expressed as mg/L in terms of calcium carbonate. The various forms of alkalinity are (a) hydroxide alkalinity, (b) carbonate alkalinity, (c) hydroxide plus carbonate alkalinity, (d) carbonate plus bicarbonate alkalinity, and (e) bicarbonate alkalinity, which is useful mainly in water softening and boiler feed water processes. Alkalinity is an important parameter in evaluating the optimum coagulant dosage.

4. **Hardness:** If water consumes excessive soap to produce lather, it is said to be hard. Hardness is caused by divalent metallic cations. The principal hardness causing cations are calcium, magnesium, strontium, ferrous and manganese ions. The major anions associated with these cations are sulphates, carbonates, bicarbonates, chlorides, and nitrates.

   The total hardness of water is defined as the sum of calcium and magnesium concentrations, both expressed as calcium carbonate, in mg/L. Hardness are of two types, temporary or carbonate hardness and permanent or non-carbonate hardness. Temporary hardness is one in which bicarbonate and carbonate ion can be precipitated by prolonged boiling. Non-carbonate ions cannot be precipitated or removed by boiling, hence the term permanent hardness. IS value for drinking water is 300 mg/L as $CaCO_3$.

5. Chlorides

6. Sulphates

7. Iron

8. Solids

9. Nitrates

BIOLOGICAL CHARACTERISTICS:

Bacterial examination of water is very important, since it indicates the degree of pollution. Water polluted by sewage contain one or more species of disease producing pathogenic bacteria. Pathogenic organisms cause water borne diseases, and many non-pathogenic bacteria such as E. coli, a member of coliform group, also live in the intestinal tract of human beings. Coliform itself is not a harmful group but it has more resistance to adverse condition than any other group. So, if it is ensured to minimize the number of coliforms, the harmful species will be very less. So, coliform group serves as indicator of contamination of water with sewage and presence of pathogens.

The methods to estimate the bacterial quality of water are:

STANDARD PLATE COUNT TEST: In this test, the bacteria are made to grow as colonies, by inoculating a known volume of sample into a solidifiable nutrient medium (Nutrient Agar), which is poured in a Petridis. After incubating (35°C) for a specified period (24 hours), the colonies of bacteria (as spots) are counted. The bacterial density is expressed as number of colonies per 100 ml of sample.

MOST PROBABLE NUMBER: Most probable number is a number which represents the bacterial density which is most likely to be present. E. coli is used as indicator of pollution. E. coli ferment lactose with gas formation with 48 hours incubation at 35°C. Based on this E. coli density in a sample is estimated by multiple tube fermentation procedure, which consists of identification of E. coli in different dilution combination. MPN value is calculated as follows:

Five 10 ml (five dilution combination) tubes of a sample are tested for E. coli. If out of five only one gives positive test for E. Coli and all others negative. From the tables, MPN value for one positive and four negative results is read which is 2.2 in present case. The MPN value is expressed as 2.2 per 100 ml. These numbers are given by Maccardy based on the laws of statistics.

MEMBRANE FILTER TECHNIQUE: In this test a known volume of water sample is filtered through a membrane with opening less than 0.5 microns. The bacteria present in the sample will be retained upon the filter paper. The filter paper is put in contact of a suitable nutrient medium and kept in an incubator for 24 hours at 35°C. The bacteria will grow upon the nutrient medium and visible colonies are counted. Each colony represents one bacterium of the original sample. The bacterial count is expressed as number of colonies per 100 ml of sample.

1.1 WATER SUPPLY

LEARNING OBJECTIVE

1.1.5 Water Quantity Estimation

1.1.5 WATER QUANTITY ESTIMATION

The quantity of water required for municipal uses for which the water supply scheme must be designed requires following data:

1. Water consumption rate (Per Capita Demand in litres per day per head)

2. Population to be served.

QUANTITY= PER CAPITA DEMAND X POPULATION

WATER CONSUMPTION RATE

It is very difficult to precisely assess the quantity of water demanded by the public, since there are many variable factors affecting water consumption. The various types of water demand, which a city may have, may be broken into following classes:

Water Consumption for Various Purposes:

	Types of Consumption	Normal Range (lit/capita/day)	Average	%
1	Domestic Consumption	65-300	160	35
2	Industrial and Commercial Demand	45-450	135	30
3	Public Uses including Fire Demand	20-90	45	10
4	Losses and Waste	45-150	62	25

FIRE FIGHTING DEMAND:

The per capita fire demand is very less on an average basis but the rate at which the water is required is very large. The rate of fire demand is sometimes treated as a function of population and is worked out from following empirical formulae:

	Authority	Formulae (P in thousand)	Q for 1 lakh Population)
1	American Insurance Association	Q (L/min)=4637 √P (1-0.01 √P)	41760
2	Kuchling's Formula	Q (L/min)=3182 √P	31800
3	Freeman's Formula	Q (L/min)= 1136.5(P/5+10)	35050
4	Ministry of Urban Development Manual Formula	Q (kilo liters/d)=100 √P for P>50000	31623

FACTORS AFFECTING PER CAPITA DEMAND:

- Size of the city: Per capita demand for big cities is generally large as compared to that for smaller towns as big cities have sewered houses.
- Presence of industries.
- Climatic conditions.
- Habits of people and their economic status.
- Quality of water: If water is aesthetically & medically safe, the consumption will increase as people will not resort to private wells, etc.
- Pressure in the distribution system.
- Efficiency of water works administration: Leaks in water mains and services; and unauthorised use of water can be kept to a minimum by surveys.
- Cost of water.
- Policy of metering and charging method: Water tax is charged in two different ways: based on meter reading and because of certain fixed monthly rate.

FLUCTUATIONS IN RATE OF DEMAND:

- Average Daily Per Capita Demand = Quantity Required in 12 Months/ (365 x Population)
- If this average demand is supplied at all the times, it will not be sufficient to meet the fluctuations.

- ***Seasonal variation***: The demand peaks during summer. Firebreak outs are generally more in summer, increasing demand. So, there is seasonal variation.

- ***Daily variation*** depends on the activity. People draw out more water on Sundays and Festival days, thus increasing demand on these days.
- ***Hourly variations*** are very important as they have a wide range. During active household working hours i.e. from six to ten in the morning and four to eight in the evening, the bulk of the daily requirement is taken. During other hours the requirement is negligible. Moreover, if a fire breaks out, a huge quantity of water is required to be supplied during short duration, necessitating the need for a maximum rate of hourly supply.

So, an adequate quantity of water must be available to meet the peak demand. To meet all the fluctuations, the supply pipes, service reservoirs and distribution pipes must be properly proportioned. The water is supplied by pumping directly and the pumps and distribution system must be designed to meet the peak demand. The effect of monthly variation influences the design of storage reservoirs and the hourly variations influences the design of pumps and service reservoirs. As the population decreases, the fluctuation rate increases.

Maximum daily demand = 1.8 x average daily demand
Maximum hourly demand of maximum day i.e. Peak demand
= 1.5 x average hourly demand
= 1.5 x Maximum daily demand/24
= 1.5 x (1.8 x average daily demand)/24
= 2.7 x average daily demand/24
= 2.7 x annual average hourly demand

CHAPTER-1
SESSION-6,7

1.1 WATER SUPPLY

LEARNING OBJECTIVE
1.1.6 Water Quantity Estimation
1.1.7 Population Forecasting Method

1.1.6 WATER QUANTITY ESTIMATION

This quantity should be worked out with due provision for the estimated requirements of the future. The future period for which a provision is made in the water supply scheme is known as the **design period**.

Design period is estimated based on the following:

- ❖ Useful life of the component, considering obsolescence, wear, tear, etc.
- ❖ Expandability aspect.
- ❖ Anticipated rate of growth of population, including industrial, commercial developments & migration-immigration.
- ❖ Available resources.
- ❖ Performance of the system during initial period.

1.1.7 POPULATION FORECASTING METHODS

The various methods adopted for estimating future populations are given below. The method to be adopted for a particular case or for a particular city depends largely on the factors discussed in the methods, and the selection is left to the discretion and intelligence of the designer.

1. Arithmetic Increase Method

2. Geometric Increase Method

3. Incremental Increase Method

4. Decreasing Rate of Growth Method

5. Simple Graphical Method

6. Comparative Graphical Method

7. Ratio Method

8. Logistic Curve Method

POPULATION FORECAST BY DIFFERENT METHODS:

Problem 1: Predict the population for the years 1981, 1991, 1994, and 2001 from the following census figures of a town by different methods.

Year	1901	1911	1921	1931	1941	1951	1961	1971
Population: (thousands)	60	65	63	72	79	89	97	120

Solution:

Year	Population: (thousands)	Increment per Decade	Incremental Increase	Percentage Increment per Decade
1901	60	-	-	-
1911	65	+5	-	(5+60) x100=+8.33
1921	63	-2	-3	(2+65) x100=-3.07
1931	72	+9	+7	(9+63) x100=+14.28
1941	79	+7	-2	(7+72) x100=+9.72
1951	89	+10	+3	(10+79) x100=+12.66
1961	97	+8	-2	(8+89) x100=8.98
1971	120	+23	+15	(23+97) x100=+23.71
Net values	1	+60	+18	+74.61
Averages	-	8.57	3.0	10.66

ARITHMETICAL PROGRESSION METHOD:

$P_n = P + ni$

Average increases per decade = i = 8.57

Population for the years,

1981= population 1971 + ni, here n=1 decade

= 120 + 8.57 = 128.57

1991= population 1971 + ni, here n=2 decade

= 120 + 2 x 8.57 = 137.14

2001= population 1971 + ni, here n=3 decade

= 120 + 3 x 8.57 = 145.71

1994= population 1991 + (population 2001 - 1991) x 3/10

= 137.14 + (8.57) x 3/10 = 139.71

INCREMENTAL INCREASE METHOD:

Population for the years,

1981= population 1971 + average increase per decade + average incremental increase

= 120 + 8.57 + 3.0 = 131.57

1991= population 1981 + 11.57

= 131.57 + 11.57 = 143.14

2001= population 1991 + 11.57

= 143.14 + 11.57 = 154.71

1994= population 1991 + 11.57 x 3/10

= 143.14 + 3.47 = 146.61

GEOMETRIC PROGRESSION METHOD:

Average percentage increase per decade = 10.66

$P_n = P(1+i/100)^n$

Population for 1981 = Population 1971 x $(1+i/100)^n$

= 120 x (1+10.66/100), *i = 10.66, n = 1*

= 120 x 110.66/100 = 132.8

Population for 1991 = Population 1971 x $(1+i/100)^n$

= 120 x $(1+10.66/100)^2$, *i = 10.66, n = 2*

= 120 x 1.2245 = 146.95

Population for 2001 = Population 1971 x $(1+i/100)^n$

= 120 x $(1+10.66/100)^3$, *i = 10.66, n = 3*

= 120 x 1.355 = 162.60

Population for 1994 = 146.95 + (15.84 x 3/10) = 151.70

PROBLEM 2; The following data have been noted from the census department.

Year	Population
1940	8,000
1950	12,000
1960	17,000
1970	22,500

Answer by using Arithmetical Increase method:

Year	Population	Increase in population
1940	8,000	--------------
1950	12,000	4000
1960	17,000	5000
1970	22,500	5500
	Total	14,500
	Average	4,833

Solution:

Year	Population
1980	22,500 + 1* 4833 = 27,333
1990	27333 + 1 * 4833 = 32,166
2000	32166 + 1 * 4833 = 36,999

Answer by using Geometrical Increase Method:

Year	Population	Increase in population	Percentage increase in population
1940	8,000	---------	-----------
1950	12,000	4000	(4000/8000) *100 = 50.0%
1960	17,000	5000	(5000/12000) *100 = 41.7%
1970	22,500	5500	(5500/17000) *100 = 32.4%
Total		14,500	124.1
Average per decade		4,833	41.37

The population at the end of various decade will be as follows:

Year	Expected population
1980	22,500 +(41.37 / 100) * 22,500 =31,808
1990	31,808 + (41.37 / 100) * 31,808 = 44,967
2000	44,967 + (41.37 / 100) * 44,967 = 63570

Answer by using Incremental Increase Method:

Year	Population	Increase in Population	Incremental Increase
1940	8,000	-------	--------
1950	12,000	4000	--------
1960	17,000	5000	+1000
1970	22,500	5500	+500
Total		14,500	+1500
Average		4,833	+750

The population at the end of various decade will be as follows:

Year	Expected population
1980	22,500 + 1(4833 + 750) =28,083
1990	28,083 + 1(4833 + 750) = 33,666
2000	33,666 + 1(4833 + 750) =39,249

Answer by using Decreasing Rate Method:

Year	Population	Increase in Population	Percentage increase in population	Decrease in the % age increase
1940	8000	------	-----------	-------
1950	12000	4000	(4000/8000) *100 = 50	-------
1960	17000	5000	(5000/12000) *100= 41.7	+ 8.3
1970	22500	5500	(5500/17000) *100= 32.4	+ 9.3
Total		14500		17.6
Average		4833		8.8

The population at the end of various decade will be as follows:

Year	net %age increase in population	Expected Population
1980	32.4 – 8.8 = 23.6	22,500 + (23.6/100) *22,500 = 27,810
1990	23.6 – 8.8 = 14.8	27,810 + (14.8/100) *27,810 = 31,926
2000	14.8 – 8.8 = 6.0	31,926 + (6.0/100) *31,926 = 33,842

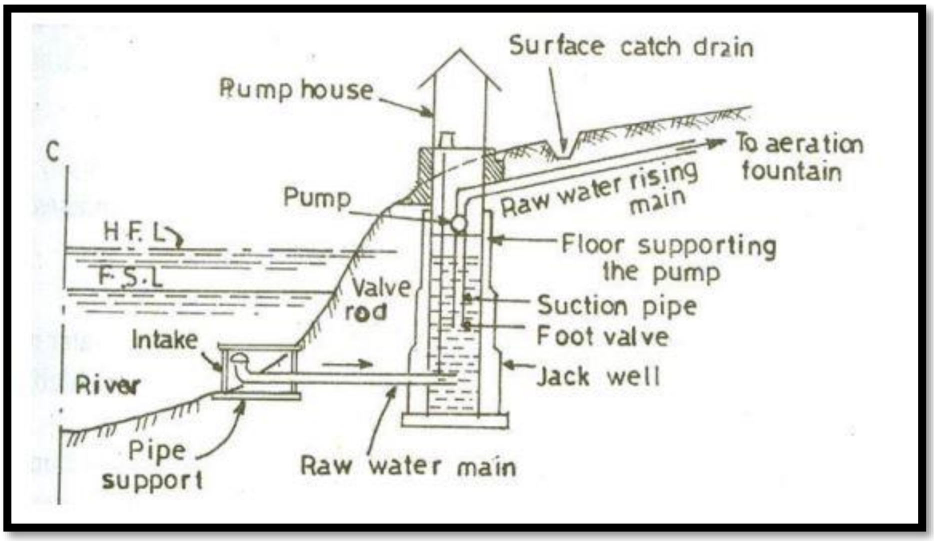
CHAPTER-1
SESSION-8,9

1.1 WATER SUPPLY

LEARNING OBJECTIVE
1.1.8 Intake Structure
1.1.9 Types of Intakes

1.1.8 INTAKE STRUCTURE

An intake structure is a facility used to collect water from a source (such as a river, lake, or reservoir) and convey it to the water treatment plant. The primary purpose of an intake structure is to ensure a continuous and reliable supply of water while minimizing the entry of debris, sediments, and other contaminants.



FACTORS GOVERNING LOCATION OF INTAKE:

1. As far as possible, the site should be near the treatment plant so that the cost of conveying water to the city is less.

2. The intake must be in the purer zone of the source to draw best quality water from the source, thereby reducing load on the treatment plant.

3. The intake must never be located at the downstream or in the vicinity of the point of disposal of wastewater.

4. The site should be such as to permit greater withdrawal of water, if required at a future date.

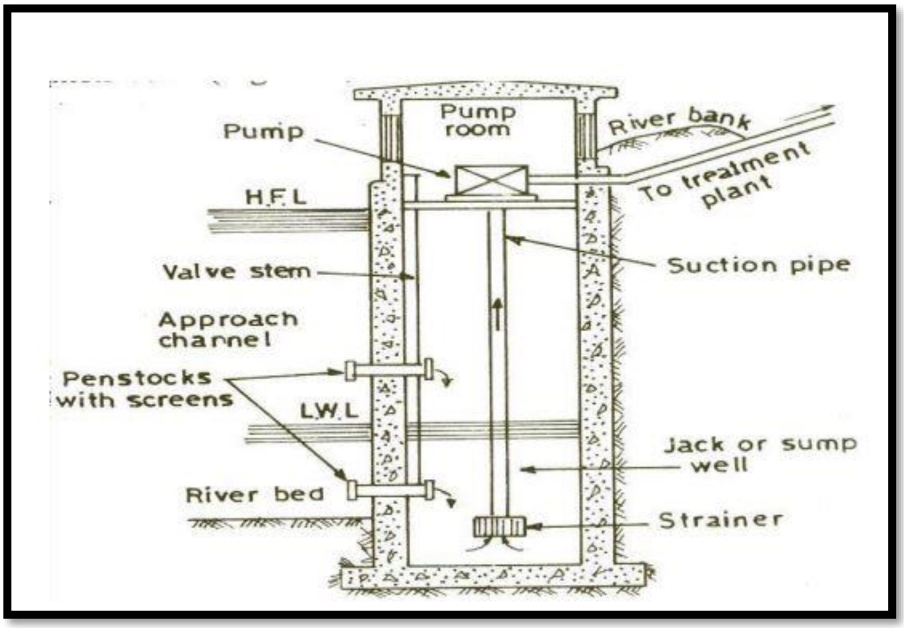
5. The intake must be located at a place from where it can draw water even during the driest period of the year.

6. The intake site should remain easily accessible during floods and should noy get flooded. Moreover, the flood waters should not be concentrated in the vicinity of the intake.

1.1.9 TYPES OF INTAKES

Intake structures can be classified based on their location, function, and design. The main types include:

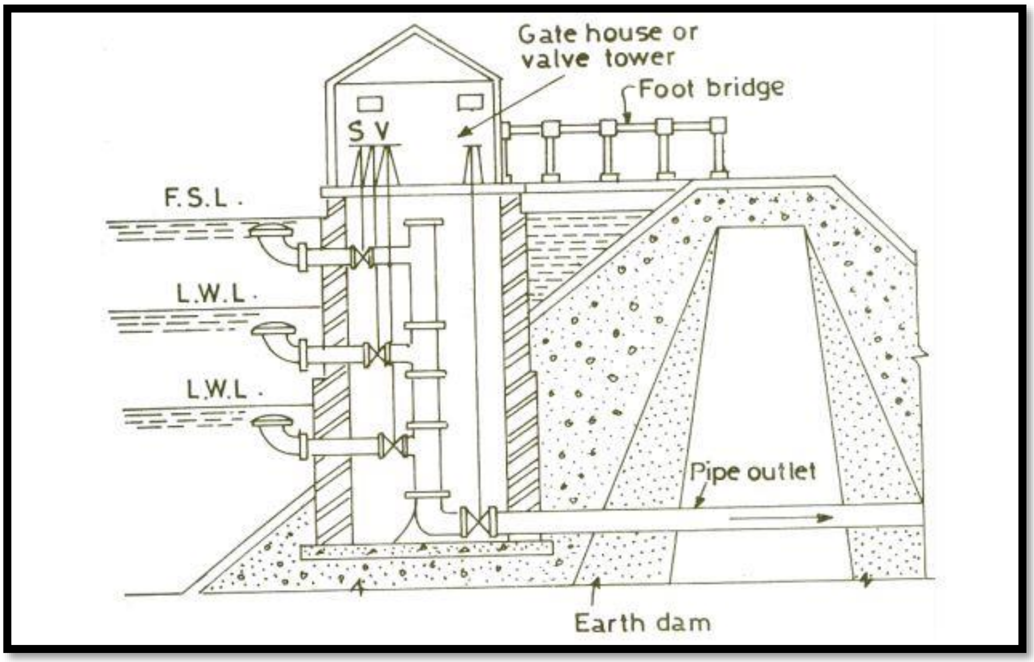
1. **RIVER INTAKE**



- Submerged Intake: Located below the water surface to minimize debris intake.
- Exposed Intake: Situated above the water surface; includes screens to filter out debris.

2. RESERVOIR INTAKE

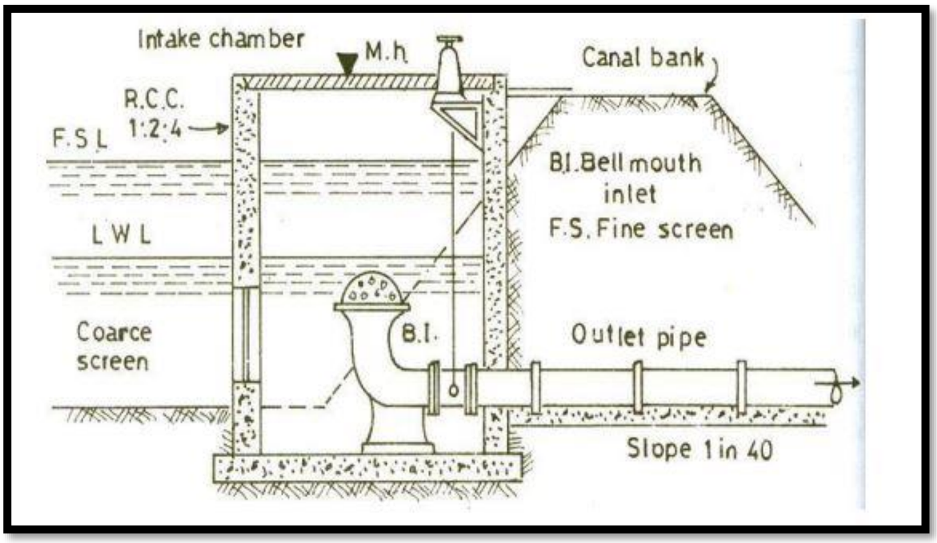
- Vertical Shaft Intake: A vertical pipe or shaft submerged in the reservoir, connected to a horizontal pipeline leading to the treatment plant.
- Intake Towers: Structures built within the reservoir, with multiple openings at different depths to access water of varying quality.



3. LAKE INTAKE

- Shoreline Intake: Constructed near the lake shore; can be either submerged or exposed.
- Offshore Intake: Located away from the shore to access cleaner water and avoid contamination.

4. **CANAL INTAKE**
    - Typically used in irrigation canals; consists of screens and gates to control water flow and prevent debris entry.



<u>DESIGN CONSIDERATIONS</u>

The design of intake structures must address several factors to ensure efficient operation and protection of the water supply:

1. Site Selection
    - Proximity to the water source and treatment plant.
    - Water quality and quantity at the intake location.
    - Environmental impact and potential for sedimentation or contamination.
2. Hydraulic Design
    - Sizing of intake pipes and channels to handle expected flow rates.
    - Provision of head loss and pressure requirements.
    - Consideration of flow velocity to minimize sediment and debris entry.
3. Screening and Debris Control
    - Use of course and fine screens to filter out debris, aquatic life, and sediments.

- Automated cleaning mechanisms to maintain screen efficiency.

4. Structural Design
    - Stability and durability of the intake structure against water currents, waves, and potential flooding.
    - Corrosion-resistant materials to ensure long-term operation.
5. Operational Flexibility
    - Multiple intakes or adjustable intake levels to access water of different qualities and avoid contamination.
    - Provision of gates or valves to control water flow and facilitate maintenance.
6. Environmental and Regulatory Compliance
    - Adherence to environmental regulations and standards.
    - Minimizing ecological impact on aquatic life and surrounding habitats.

CHAPTER-1

SESSION-10

1.1 WATER SUPPLY

LEARNING OBJECTIVE

1.1.10 Pumping

1.1.11 Pump Capacity

1.1.10 PUMP

A pump is a device, which converts mechanical energy into hydraulic energy. It lifts water from a lower to a higher level and delivers it at high pressure. Pumps are employed in water supply projects at various stages for following purposes:

1. To lift raw water from wells.

2. To deliver treated water to the consumer at desired pressure.

3. To supply pressured water for fire hydrants.

4. To boost up pressure in water mains.

5. To fill elevated overhead water tanks.

6. To backwash filters.

7. To pump chemical solutions, needed for water treatment.

CLASSIFICATION OF PUMPS:

Based on principle of operation, pumps may be classified as follows:

1. Displacement pumps (reciprocating, rotary)

2. Velocity pumps (centrifugal, turbine and jet pumps)

3. Buoyancy pumps (air lift pumps)

4. Impulse pumps (hydraulic rams)

1.1.11 PUMP CAPACITY

The capacity of a pump is a crucial parameter in the design and operation of water and wastewater systems. It refers to the volume of fluid that the pump can move per unit of time, typically measured in gallons per minute (GPM), litters per second (L/s), cubic meters per hour (m^3/h), etc.

The basic formula for calculating the capacity of a pump involves the flow rate and the head, combined with the pump's efficiency.

Problem: Determine the capacity of a pump required to move 3000 litters per minute (L/min) of water to a height of 20 meters. The pump efficiency is 75%.

Solution 1:

Given Data

Flow rate, Q=3000 L/min   Height (Head), H=20 m,

Efficiency, η=75%=0.75   Density of water, ρ=1000 kg/m3

Acceleration due to gravity, g=9.81 m/s2

Convert Flow Rate to Cubic Meters per Second (m^3/s)

$$Q = \frac{3000\,\mathrm{L/min}}{1000\,\mathrm{L/m^3}} \times \frac{1\,\mathrm{min}}{60\,\mathrm{s}} = \frac{3000}{1000 \times 60} = 0.05\,\mathrm{m^3/s}$$

The hydraulic power required to move the water is given by:

P(hydraulic)=Q×H×ρ×g

Substituting the given values:

P(hydraulic)=0.05 m3/s×20 m×1000 kg/m3×9.81 m/s2

P(hydraulic)=0.05×20×1000×9.81=9810 W=9.81 kW

The actual power required by the pump, considering its efficiency, is given by:

$$P_{\text{actual}} = \frac{P_{\text{hydraulic}}}{\eta}$$

Substituting the hydraulic power and efficiency,

$$P_{\text{actual}} = \frac{9810\,\text{W}}{0.75} = \frac{9810}{0.75} = 13080\,\text{W} = 13.08\,\text{kW}$$

Problem: A municipal water system needs to pump water from a reservoir to a water tower located 80 meters above the reservoir. The flow rate required is 1500 litters per minute, and the pump efficiency is expected to be 85%. Determine the minimum capacity of the pump required in horsepower (HP).

Problem: An irrigation system needs to pump water from a river to a farm located 150 meters away at a height of 10 meters above the river level. The flow rate required for irrigation is 2000 litters per minute, and the pump efficiency is 70%. Determine the power required by the pump in kilowatts (kW).

1.1 WATER SUPPLY

LEARNING OBJECTIVE

1.1.12 Water Distribution System

1.1.13 Hydraulic Design

1.1.12 WATER DISTRIBUTION SYSTEMS/ CONVEYANCE

The purpose of distribution system is to deliver water to consumer with appropriate quality, quantity, and pressure. Distribution system is used to describe collectively the facilities used to supply water from its source to the point of usage.

There are two stages in the transportation of water:

1. Conveyance of water from the source to the treatment plant.
2. Conveyance of treated water from treatment plant to the distribution system.

In the first stage water is transported by gravity or by pumping or by the combined action of both, depending upon the relative elevations of the treatment plant and the source of supply. In the second stage water transmission may be either by pumping into an overhead tank and then supplying by gravity or by pumping directly into the water-main for distribution.

FREE FLOW SYSTEM

- In this system, the surface of water in the conveying section flows freely due to gravity. In such a conduit the hydraulic gradient line coincides with the water surface and is parallel to the bed of the conduit.
- It is often necessary to construct very long conveying sections, to suit the slope of the existing ground. The sections used for free-flow are: Canals, flumes, grade aqueducts and grade tunnels.

PRESSURE SYSTEM

- In pressure conduits, which are closed conduits, the water flows under pressure above the atmospheric pressure. The bed or invert of the conduit in pressure flows is thus independent of the grade of the hydraulic gradient line and can, therefore, follow the natural available ground surface thus requiring lesser length of conduit.

- The pressure aqueducts may be in the form of closed pipes or closed aqueducts and tunnels called pressure aqueducts or pressure tunnels designed for the pressure likely to come on them. Due to their circular shapes, every pressure conduit is generally termed as a pressure pipe.
- When a pressure pipe drops beneath a valley, stream, or some other depression, it is called a depressed pipe or an inverted siphon.
- Depending upon the construction material, the pressure pipes are of following types: Cast iron, steel, R.C.C, hume steel, vitrified clay, asbestos cement, wrought iron, copper, brass and lead, plastic, and glass reinforced plastic pipes.

REQUIREMENTS OF GOOD DISTRIBUTION SYSTEM

1. Water quality should not get deteriorated in the distribution pipes.

2. It should be capable of supplying water at all the intended places with sufficient pressure head.

3. It should be capable of supplying the requisite amount of water during firefighting.

4. The layout should be such that no consumer would be without water supply, during the repair of any section of the system.

5. All the distribution pipes should be preferably laid one metre away or above the sewer lines.

6. It should be water-tight as to keep losses due to leakage to the minimum.

1.1 WATER SUPPLY

LEARNING OBJECTIVE

1.1.13 Hydraulic Design

1.1.13 HYDRAULIC DESIGN

❖ **MANNING'S EQUATION (FOR OPEN CHANNEL FLOW):**

$$\boxed{Q = \frac{1}{n} A R^{2/3} S^{1/2}}$$

Where:

- Q = Flow rate
- n = Manning's roughness coefficient
- A = Cross-sectional area of flow
- R = Hydraulic radius
- S = Slope of the channel

Problem: A rectangular channel is designed to carry stormwater runoff. The channel has a width of 2 meters and a depth of 1 meter. The Manning's roughness coefficient (n) for the channel is 0.015. If the slope of the channel is 0.001, determine the flow rate of water through the channel.

❖ **DARCY-WEISBACH EQUATION (FOR PIPE FLOW):**

$$\boxed{h_f = f \frac{L}{D} \frac{v^2}{2g}}$$

Where:

- hf = Head loss due to friction
- f = Darcy-Weisbach friction factor

- L = Length of pipe
- D = Diameter of pipe
- v = Fluid velocity
- g = Acceleration due to gravity

Problem: Water is flowing through a smooth, horizontal pipe with a diameter of 0.3 meters. The length of the pipe is 100 meters. If the flow rate is 0.05 m^3/s and the friction factor (f) is 0.02, determine the head loss due to friction.

Problem: Water flows through a 200-meter-long pipe with a diameter of 0.3 meters. The flow velocity is 1.5 m/s. Determine the head loss due to friction in the pipe.

PROBABLE QUESTIONS

1. Discuss the fundamental principles and general requirements essential for establishing a reliable and sustainable water supply system in urban and rural areas.
2. Explore the various sources of water available for human consumption, including surface water bodies such as rivers, lakes, and reservoirs, as well as groundwater aquifers.
3. Analyse the factors influencing the quality of water from different sources, including natural contaminants, anthropogenic pollutants, and microbial pathogens.
4. Evaluate the importance of water quality testing and monitoring programs in ensuring the safety and potability of drinking water supplies.
5. Describe the design considerations and operational challenges associated with intake structures for withdrawing water from surface water sources or groundwater wells.
6. Explain the role of screening and pre-treatment processes at intake structures to remove debris, sediments, and other particulate matter from raw water.
7. Discuss the principles of pumping systems used to lift water from intake structures or wells to treatment facilities or distribution networks, including pump selection, efficiency, and maintenance.
8. Explore the factors influencing the design and layout of water transmission and distribution pipelines, such as topography, hydraulic gradients, and population density.

9. Analyse the different types of pipes and materials used in water transportation networks, considering factors like durability, corrosion resistance, and cost-effectiveness.
10. Discuss the challenges associated with water loss and leakage in transmission and distribution pipelines, as well as strategies for leak detection, repair, and water conservation.
11. Evaluate the importance of hydraulic modelling and simulation tools in optimizing the design and operation of water distribution systems, including pressure management and flow balancing.
12. Explore the potential impacts of climate change and extreme weather events on water supply infrastructure and the resilience of water distribution networks.
13. Discuss the principles of water demand forecasting and management, including factors such as population growth, land use changes, and seasonal variations in water consumption.
14. Analyse the social, economic, and environmental implications of water supply projects, including issues of equity, access, affordability, and sustainability.
15. Describe the regulatory framework governing water supply systems, including standards for water quality, public health, and environmental protection.
16. Explore the role of community engagement and stakeholder participation in the planning, design, and management of water supply projects, emphasizing principles of equity, transparency, and accountability.
17. Discuss the integration of water supply infrastructure with other urban systems, such as wastewater treatment, stormwater management, and green infrastructure.
18. Analyse case studies of successful water supply projects from around the world, highlighting innovative technologies, financing mechanisms, and governance models.
19. Evaluate the potential for decentralized and alternative water supply solutions, such as rainwater harvesting, greywater recycling, and decentralized treatment systems, in addressing water scarcity and improving resilience.
20. Propose strategies for addressing the growing challenges of water scarcity, pollution, and aging infrastructure through integrated water resources management approaches that promote efficiency, sustainability, and adaptive capacity.

MODULE-2

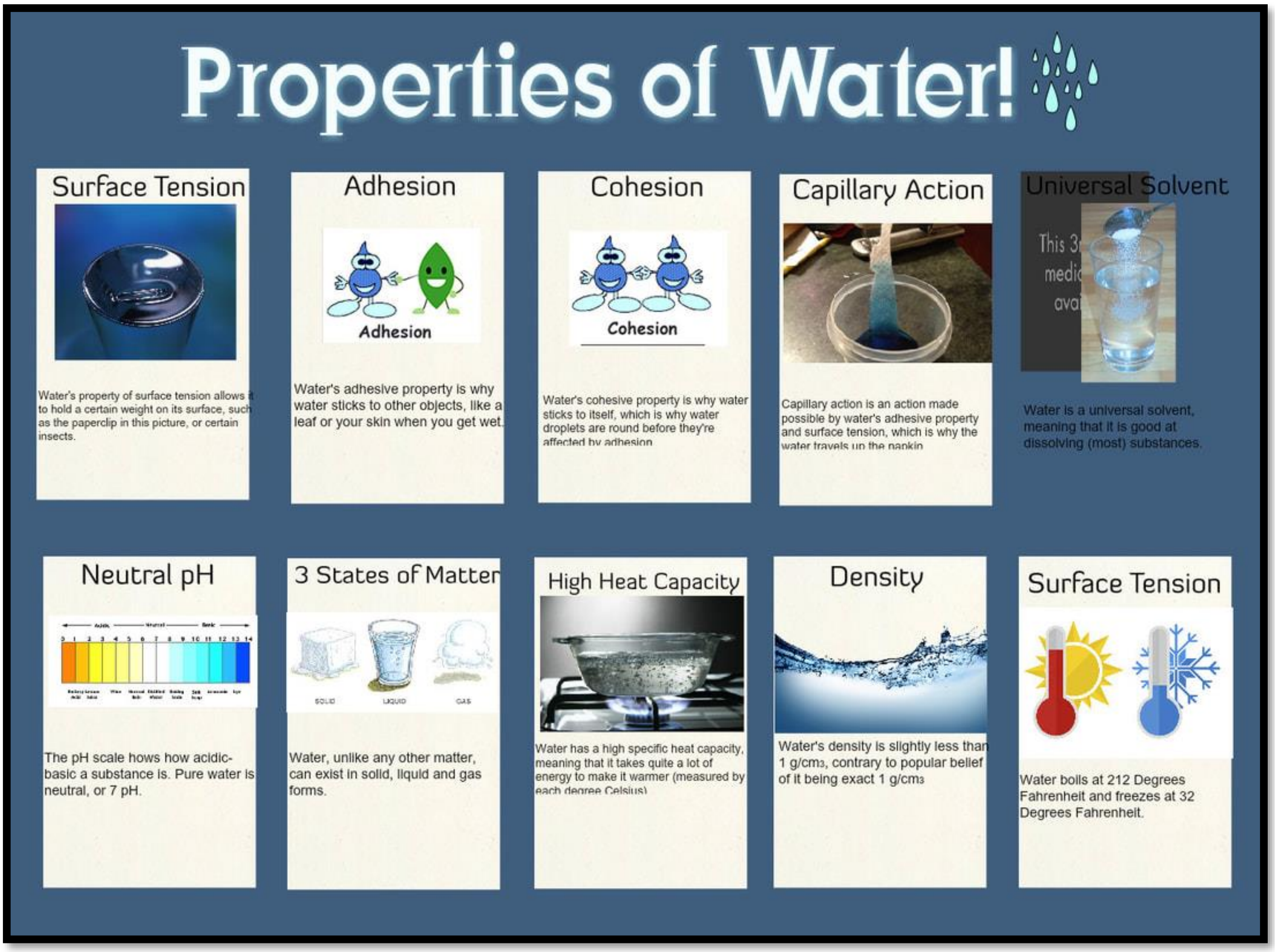
CHAPTER-1
SESSION-13

2.1 WATER QUALITY

LEARNING OBJECTIVE
2.1.1 Introduction
2.1.2 Characteristic of Water

2.1.1 INTRODUCTION

Water quality refers to the chemical, physical, and biological characteristics of water. It is a measure of the condition of water relative to the requirements of one or more biotic species and/or to any human need or purpose. Water quality can vary significantly from one location to another and can be influenced by natural processes as well as human activities.



2.1.2 CHARACTERSTICS OF WATER

PHYSICAL CHARACTERISTICS

Physical characteristics of water include properties that can be observed and measured without changing the chemical composition of the water.

- **Temperature**: Reflects the heat energy content of water. Significant changes can affect aquatic ecosystems and indicate pollution sources.
- **Turbidity**: Measures the clarity of water by assessing the presence of suspended particles. High turbidity can indicate soil erosion or pollution.
- **Colour**: Indicates the presence of dissolved substances or suspended particles. Unusual colours may signal pollution or natural processes.
- **Odor and Taste**: Reflect the presence of organic or inorganic compounds. Unpleasant Odors or tastes can indicate contamination.

SIGNIFICANCE

- Physical characteristics provide visual and sensory cues about water quality.
- They help identify potential sources of pollution and assess the aesthetic suitability of water for drinking, recreation, and aquatic habitats.

Water, a vital substance for all known forms of life, has several unique physical characteristics that make it indispensable. These characteristics are influenced by its molecular structure and hydrogen bonding. Here are the key physical characteristics of water:

1. POLARITY

- **Molecular Structure:** Water (H_2O) is a polar molecule, meaning it has a partial positive charge on one side (hydrogen atoms) and a partial negative charge on the other side (oxygen atom). This polarity allows water to form hydrogen bonds with other water molecules and with other polar substances.

2. DENSITY AND STATES

- **Density:** Water has a maximum density at 4°C (39.2°F). Unlike most substances, water expands upon freezing, making ice less dense than liquid water. This is why ice floats on water.
- **States of Matter:** Water naturally exists in three states: solid (ice), liquid (water), and gas (water vapor). The transition between these states (melting, freezing, evaporation, condensation) involves significant energy exchange.

3. SPECIFIC HEAT CAPACITY

- **High Specific Heat Capacity:** Water can absorb and store large amounts of heat with only a slight change in temperature. This high specific heat capacity helps moderate the Earth's climate and allows organisms to maintain stable internal temperatures.

4. THERMAL CONDUCTIVITY

- **Moderate Thermal Conductivity:** Water conducts heat better than many other liquids, which is important for heat distribution in natural water bodies and within living organisms.

5. SURFACE TENSION

- **High Surface Tension:** Due to hydrogen bonding, water molecules are strongly attracted to each other, resulting in high surface tension. This property allows water to form droplets and enables insects like water striders to walk on its surface.

6. VISCOSITY

- **Low Viscosity:** Water flows easily, which is crucial for its role in transportation of nutrients and waste in biological systems and in natural water cycles.

7. SOLVENT PROPERTIES

- **Universal Solvent:** Water's polarity makes it an excellent solvent, capable of dissolving a wide range of substances, including salts, sugars, acids, alkalis, and gases. This property is essential for biochemical reactions and nutrient transport.

8. TRANSPARENCY

- **Transparency:** Water is transparent to visible light, allowing sunlight to penetrate aquatic environments, which is vital for photosynthetic organisms.

9. COHESION AND ADHESION

- **Cohesion:** Water molecules stick to each other, leading to phenomena like surface tension and capillary action.
- **Adhesion:** Water molecules also stick to other substances, which helps in processes like capillary action where water can move against gravity in narrow spaces.

10. BOILING AND FREEZING POINTS

- **Boiling Point:** Water boils at 100°C (212°F) at standard atmospheric pressure. The boiling point decreases with altitude due to lower atmospheric pressure.
- **Freezing Point:** Water freezes at 0°C (32°F) at standard atmospheric pressure. The freezing point can be lowered by the presence of solutes, such as salt.

11. ELECTRICAL CONDUCTIVITY

- **Poor Conductor in Pure Form:** Pure water is a poor conductor of electricity. However, it becomes a good conductor when ions are dissolved in it, such as salts.

CHAPTER-1

SESSION-14

2.1 WATER QUALITY

LEARNING OBJECTIVE

2.1.3 Chemical Characteristics

2.1.3 CHEMICAL CHARACTERISTICS

Chemical characteristics of water involve the analysis of various substances dissolved or suspended in water.

- **pH**: Measures the acidity or alkalinity of water. pH affects the solubility of minerals and the effectiveness of treatment processes.

- **Dissolved Oxygen (DO)**: Represents the amount of oxygen dissolved in water. Essential for aquatic organisms, DO levels indicate the health of aquatic ecosystems.
- **Nutrients**: Include nitrogen, phosphorus, and other compounds essential for plant growth. Excessive nutrient levels can lead to eutrophication and algal blooms.
- **Heavy Metals**: Include substances like lead, mercury, and cadmium. Toxic at high concentrations, they can accumulate in aquatic organisms and pose health risks.

SIGNIFICANCE:

- Chemical characteristics provide insights into water composition, reactivity, and potential impacts on human health and the environment.
- They help assess water suitability for drinking, irrigation, industrial use, and aquatic life support.

Water (H_2O) is a simple yet incredibly versatile molecule with several important chemical characteristics. These characteristics arise from its molecular structure and the nature of the bonds it forms. Here are the key chemical characteristics of water:

1. MOLECULAR STRUCTURE AND BONDING

- **Molecular Composition:** Water consists of two hydrogen atoms covalently bonded to one oxygen atom. The molecular formula is H_2O.
- **Bond Angles and Shape:** The H-O-H bond angle in water is approximately 104.5°, giving it a bent shape. This shape contributes to its polarity.

2. POLARITY

- **Polar Molecule:** Water has a partial positive charge near the hydrogen atoms and a partial negative charge near the oxygen atom due to the difference in electronegativity between oxygen and hydrogen. This polarity enables water to interact with other polar molecules and ions, making it an excellent solvent.

3. HYDROGEN BONDING

- **Hydrogen Bonds:** The polarity of water allows it to form hydrogen bonds, which are weak bonds between the partially positive hydrogen atom of one water molecule and the partially negative oxygen atom of another water molecule.

These hydrogen bonds are responsible for many of water's unique properties, such as high boiling and melting points, high specific heat capacity, and surface tension.

4. SOLVENT PROPERTIES

- **Universal Solvent:** Water can dissolve a wide variety of substances, especially ionic and polar compounds. This is due to its polarity and ability to form hydrogen bonds with solutes. This property is crucial for biochemical reactions and processes in living organisms.
- **Dissociation of Salts:** When ionic compounds like salts dissolve in water, they dissociate into their constituent ions, which are stabilized by hydration shells of water molecules.

5. PH AND IONIZATION

- **Autoionization:** Water can self-ionize to a small extent, forming hydronium (H_3O^+) and hydroxide (OH^-) ions. This can be represented as: $2H2O \rightleftharpoons H3O{+}{+}OH{-}2H2O \rightleftharpoons H3O{+}{+}OH{-}$
- **pH Level:** Pure water has a neutral pH of 7 at 25°C, meaning the concentrations of H_3O^+ and OH^- are equal (1×10^{-7} M each). The pH scale measures the acidity or alkalinity of a solution, with lower values being acidic (higher H_3O^+ concentration) and higher values being basic (higher OH^- concentration).

6. CHEMICAL REACTIVITY

- **Reactivity:** Water is involved in many chemical reactions, including:
  - **Hydrolysis:** Water reacts with compounds to break chemical bonds, often splitting molecules into smaller units.
  - **Redox Reactions:** Water can act as both an oxidizing agent and a reducing agent in redox reactions.
- **Stability:** Water is generally chemically stable, but it can be decomposed into hydrogen and oxygen gases through electrolysis: $2H2O \rightarrow 2H2+O22H2O \rightarrow 2H2+O2$

7. AMPHOTERIC NATURE

- **Amphoteric Substance:** Water can act as both an acid and a base. As an acid, it can donate a proton (H^+), and as a base, it can accept a proton. This property is fundamental in many acid-base reactions and buffering systems.

8. COORDINATION CHEMISTRY

- **Ligand Properties:** Water molecules can act as ligands, donating lone pairs of electrons to metal ions to form coordination complexes. This is important in various biological systems and industrial processes.

9. THERMAL PROPERTIES

- **Heat of Vaporization:** Water has a high heat of vaporization, meaning it requires a lot of energy to convert from liquid to gas. This is due to strong hydrogen bonding.

- **Heat of Fusion:** Similarly, water has a high heat of fusion, requiring significant energy to change from solid (ice) to liquid.

10. ABSORPTION AND EMISSION OF LIGHT

- **Transparency and Absorption:** Water is transparent to visible light but absorbs infrared and ultraviolet light. This property is significant for aquatic ecosystems and the global heat balance.

CHAPTER-1

SESSION-15

2.1 WATER QUALITY

LEARNING OBJECTIVE

2.1.4 Biological Characteristics

2.1.4 BIOLOGICAL CHARACTERISTICS

Biological characteristics of water involve the presence and abundance of living organisms and indicators of biological activity.

- **Bacteria and Pathogens**: Include coliform bacteria, E. coli, and other microorganisms. Their presence indicates faecal contamination and poses health risks.

- **Aquatic Macroinvertebrates**: Include insects, crustaceans, and mollusks. Their diversity and abundance reflect the health of aquatic ecosystems.
- **Algae and Phytoplankton**: Photosynthetic organisms that form the base of aquatic food chains. Excessive growth can lead to water quality problems.

SIGNIFICANCE:

- Biological characteristics indicate ecosystem health, biodiversity, and the ecological functions of water bodies.
- They serve as indicators of pollution, habitat degradation, and potential risks to human and environmental health.

Water is essential for all forms of life, and its biological characteristics are key to understanding its role in biological systems. These characteristics include its involvement in biological processes, its role as a habitat, and its properties that support life. Here are the main biological characteristics of water:

1. SOLVENT FOR BIOCHEMICAL REACTIONS

- **Universal Solvent:** Water's polarity makes it an excellent solvent for a wide range of substances, including salts, sugars, acids, bases, and gases. This property is vital for biochemical reactions, as it allows reactants to dissolve and interact within cells.

2. MEDIUM FOR NUTRIENT TRANSPORT

- **Transport Medium:** In living organisms, water is the primary medium for transporting nutrients, waste products, and gases (like oxygen and carbon dioxide). In the human body, for example, blood plasma is mostly water and carries essential substances to and from cells.

3. PARTICIPATION IN METABOLIC PROCESSES

- **Hydrolysis and Dehydration Reactions:** Water is involved in hydrolysis reactions, where it breaks down complex molecules into simpler ones, and in dehydration synthesis, where it is removed to form bonds between molecules. These processes are crucial for metabolism.
- **Cellular Respiration:** Water is a product of cellular respiration, where glucose and oxygen are converted into carbon dioxide, water, and energy.

- **Photosynthesis:** In plants, water is a reactant in photosynthesis, where it is split into oxygen, protons, and electrons to produce glucose and oxygen.

4. REGULATION OF TEMPERATURE

- **Thermal Regulation:** Water has a high specific heat capacity, meaning it can absorb and store large amounts of heat with little temperature change. This property helps regulate temperature in living organisms and environments, providing a stable climate for biochemical processes.

5. HABITAT FOR AQUATIC LIFE

- **Aquatic Ecosystems:** Water provides a habitat for a vast array of organisms, from microscopic plankton to large marine mammals. Aquatic environments include oceans, rivers, lakes, and wetlands.

- **Dissolved Oxygen:** The solubility of oxygen in water is critical for the respiration of aquatic organisms. Dissolved oxygen levels affect the health and diversity of aquatic ecosystems.

6. STRUCTURAL ROLE

- **Cell Structure:** Water is a major component of cells, contributing to their structure and integrity. The cytoplasm, the fluid inside cells, is primarily water and provides a medium for organelles and molecules to function.

- **Turgor Pressure:** In plants, water within cells exerts turgor pressure against the cell walls, helping maintain rigidity and structural support.

7. WASTE REMOVAL

- **Excretion:** Water is essential for the excretion of waste products. In humans and animals, urine is mostly water and helps remove waste products from the body.

- **Detoxification:** Water aids in detoxifying the body by diluting and transporting harmful substances to be excreted.

8. HOMEOSTASIS

- **Maintaining Balance:** Water plays a crucial role in maintaining homeostasis, the stable internal environment required for optimal functioning of organisms. This includes regulating pH levels, electrolyte balance, and temperature.

9. REPRODUCTION AND DEVELOPMENT

- **Reproductive Fluids:** Water is a component of reproductive fluids, such as semen and amniotic fluid, providing a medium for the transport and protection of gametes and embryos.
- **Development:** Many organisms, especially amphibians and fish, rely on water for the early stages of their development. Water provides a protective environment for eggs and larvae.

10. BIOLOGICAL INTERACTIONS

- **Signal Transduction:** Water facilitates signal transduction in cells, allowing communication and coordination of biological processes. It helps transmit signals through soluble factors and receptor interactions.
- **Enzyme Activity:** The presence of water affects enzyme activity, which is crucial for catalysing biochemical reactions. Enzymes often require a specific hydration shell to function properly.

CHAPTER-1
SESSION-16,17

2.1 WATER QUALITY

LEARNING OBJECTIVE
2.1.5 Water Quality Criteria

2.1.5 WATER QUALITY CRITERIA

Water quality criteria are guidelines or standards set by regulatory agencies to define the desired quality of water for specific uses such as drinking water, recreational activities, aquatic life support, and agricultural purposes. These criteria help assess whether water bodies meet the necessary standards for their intended uses and guide management and regulatory decisions aimed at protecting and improving water quality. Here is an overview of water quality criteria:

COMPONENTS OF WATER QUALITY CRITERIA:

1. **Physical Characteristics**: Parameters such as temperature, turbidity, colour, Odor, and taste are considered to ensure water is aesthetically acceptable for various uses.

2. **Chemical Characteristics**: Chemical parameters include the presence and concentration of various substances such as nutrients (e.g., nitrogen, phosphorus), heavy metals (e.g., lead, mercury), organic compounds (e.g., pesticides, industrial chemicals), and disinfection byproducts. These criteria ensure water is safe for human consumption, supports aquatic life, and minimizes adverse environmental impacts.

3. **Biological Characteristics**: Biological criteria involve the presence and abundance of indicator organisms such as coliform bacteria, E. coli, and aquatic macroinvertebrates. These indicators help assess water quality in terms of contamination, ecosystem health, and suitability for recreational activities.

ESTABLISHMENT OF WATER QUALITY CRITERIA:

- **Scientific Research**: Water quality criteria are typically established based on scientific research, including laboratory studies, field investigations, and ecological assessments.
- **Risk Assessment**: Criteria are often derived by assessing the potential risks associated with exposure to certain contaminants and their effects on human health and the environment.
- **Stakeholder Input**: Input from stakeholders, including government agencies, environmental organizations, industry representatives, and the public, may also inform the development of water quality criteria.

TYPES OF WATER QUALITY CRITERIA:

1. **Primary Standards**: Primary standards are legally enforceable limits set to protect human health. Examples include maximum contaminant levels (MCLs) for drinking water contaminants established by regulatory agencies such as the U.S. Environmental Protection Agency (EPA).

2. **Secondary Standards**: Secondary standards are guidelines set to protect aesthetic qualities, taste, and Odor of water and to prevent nuisance issues. These standards are non-enforceable but provide recommendations for desirable water quality.

IMPLEMENTATION AND MONITORING:

- Once established, water quality criteria are implemented through regulatory programs and management strategies.
- Monitoring programs assess water quality against established criteria through regular sampling and analysis of key parameters.
- Regulatory agencies may enforce compliance with water quality criteria through permits, regulations, and enforcement actions.

REVISION AND UPDATES:

- Water quality criteria may be revised periodically based on new scientific research, emerging contaminants, changing environmental conditions, and evolving regulatory priorities.

CHAPTER-1
SESSION-18

2.1 WATER QUALITY

LEARNING OBJECTIVE
2.1.6 WATER BORNE DISEASES

2.1.6 WATER BORNE DISEASES

Waterborne diseases are illnesses caused by pathogenic microorganisms that are transmitted through contaminated water. These diseases can spread through ingestion of contaminated water, consumption of contaminated food, or contact with contaminated water during recreational activities. Here are some common waterborne diseases:

1. CHOLERA

- **Causative Agent**: Vibrio cholerae bacteria.
- **Transmission**: Ingestion of water or food contaminated with faecal matter containing the bacteria.
- **Symptoms**: Severe diarrhoea, vomiting, and dehydration. In severe cases, it can lead to death if untreated.
- **Prevention**: Improving sanitation and hygiene, access to clean drinking water, and vaccination.

2. TYPHOID FEVER

- **Causative Agent**: Salmonella Typhi bacteria.
- **Transmission**: Ingestion of water or food contaminated with faecal matter containing the bacteria.
- **Symptoms**: Prolonged fever, headache, abdominal pain, and gastrointestinal symptoms.
- **Prevention**: Sanitation and hygiene practices, access to clean drinking water, and vaccination.

3. HEPATITIS A

- **Causative Agent**: Hepatitis A virus (HAV).
- **Transmission**: Ingestion of water or food contaminated with faecal matter containing the virus.
- **Symptoms**: Fever, fatigue, nausea, abdominal pain, and jaundice.
- **Prevention**: Good hygiene practices, sanitation, and vaccination.

4. GIARDIASIS

- **Causative Agent**: Giardia intestinalis (Giardia lamblia) parasite.
- **Transmission**: Ingestion of water or food contaminated with Giardia cysts.
- **Symptoms**: Diarrhoea, abdominal cramps, bloating, and nausea.
- **Prevention**: Proper water treatment, filtration, and disinfection.

5. CRYPTOSPORIDIOSIS

- **Causative Agent**: Cryptosporidium parvum and Cryptosporidium hominis parasites.
- **Transmission**: Ingestion of water or food contaminated with Cryptosporidium oocysts.
- **Symptoms**: Watery diarrhoea, abdominal cramps, nausea, and vomiting.
- **Prevention**: Proper water treatment, filtration, and hygiene practices.

6. E. COLI INFECTION

- **Causative Agent**: Escherichia coli bacteria (certain strains).
- **Transmission**: Ingestion of water or food contaminated with faecal matter containing pathogenic E. coli strains.
- **Symptoms**: Diarrhoea (sometimes bloody), abdominal cramps, fever, and vomiting.
- **Prevention**: Good hygiene practices, proper food handling, and water treatment.

7. AMOEBIASIS

- **Causative Agent**: Entamoeba histolytica parasite.
- **Transmission**: Ingestion of water or food contaminated with Entamoeba cysts.
- **Symptoms**: Dysentery (bloody diarrhoea), abdominal pain, and weight loss.
- **Prevention**: Proper sanitation, clean water sources, and hygiene practices.

Waterborne diseases pose significant public health risks, particularly in areas with inadequate sanitation and limited access to clean drinking water. Prevention efforts focus on improving water quality, promoting hygiene practices, implementing sanitation measures, and providing access to safe drinking water and proper sanitation facilities. Additionally, public health education and awareness campaigns play a crucial role in preventing waterborne diseases and reducing their impact on communities.

CHAPTER-1

SESSION-19,20

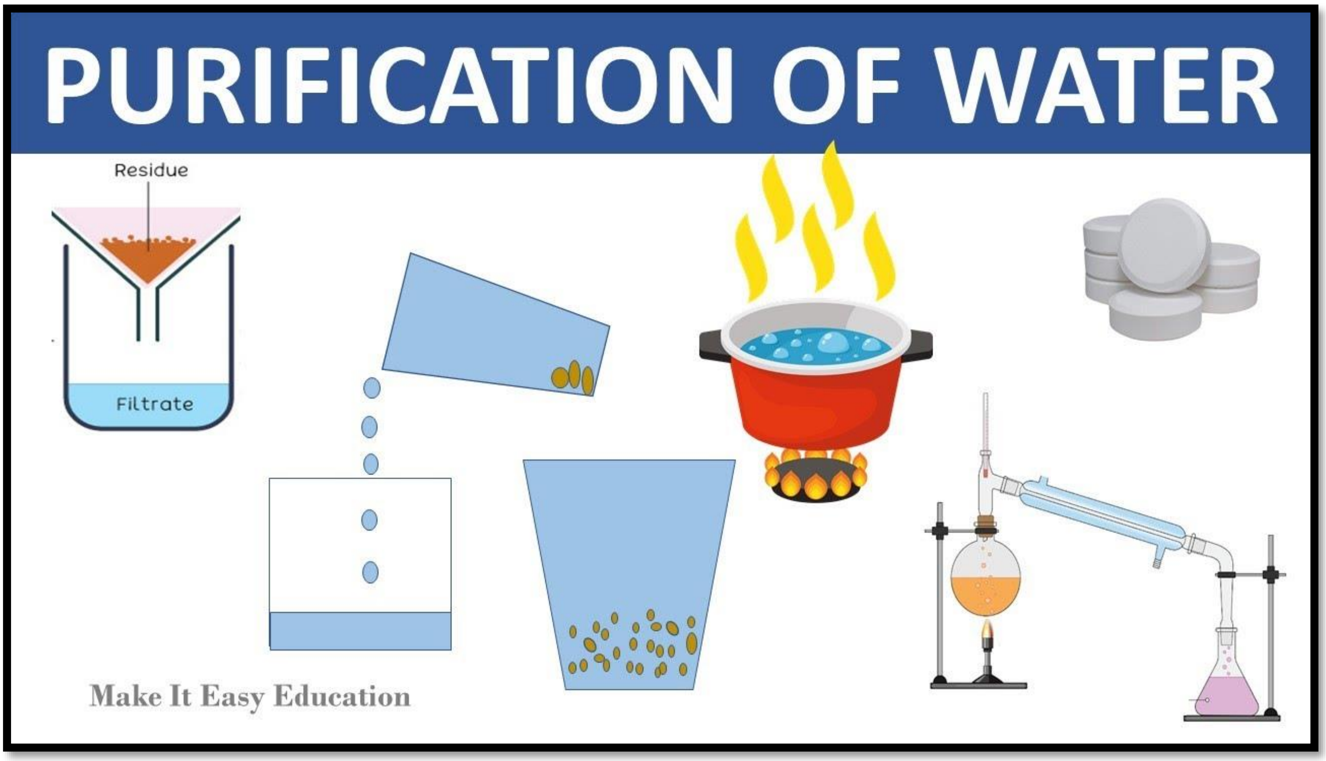
2.1 WATER QUALITY

LEARNING OBJECTIVE

2.1.7 Natural Purification of Water Sources

2.1.7 NATURAL PURIFICATION OF WATER SOURCES

Natural purification of water sources refers to the processes by which natural ecosystems cleanse and improve the quality of water. These processes occur through various physical, chemical, and biological mechanisms that help remove contaminants and restore water quality. Here are some key ways in which water sources are naturally purified:



1. **FILTRATION:**

- **Soil and Sediment Filtration**: As water percolates through soil and sediment layers, particles, pathogens, and pollutants are filtered out, improving water clarity, and reducing turbidity.
- **Aquatic Vegetation**: Aquatic plants and vegetation act as natural filters by trapping suspended solids, absorbing nutrients, and stabilizing sediments, thereby improving water quality.

2. **DILUTION:**

- **River Mixing**: Rivers and streams continuously mix and dilute pollutants as they flow downstream, reducing the concentration of contaminants and pathogens over time.
- **Groundwater Recharge**: Rainwater percolating through the soil replenishes groundwater reserves, diluting contaminants and promoting natural attenuation processes.

3. SEDIMENTATION:

- **Settling**: Suspended particles and sediments gradually settle to the bottom of water bodies, improving water clarity and removing particulate pollutants.
- **Natural Basins**: Wetlands, ponds, and lakes act as sedimentation basins, allowing particles and pollutants to settle out of the water column.

4. BIOLOGICAL PROCESSES:

- **Microbial Decomposition**: Microorganisms naturally present in water bodies break down organic matter and pollutants through biochemical processes, reducing their concentration and improving water quality.
- **Biological Uptake**: Aquatic organisms such as algae, bacteria, and aquatic plants absorb nutrients and pollutants from the water, helping to regulate nutrient levels and remove contaminants.

5. CHEMICAL REACTIONS:

- **Oxidation-Reduction**: Natural chemical reactions, such as oxidation-reduction processes, can transform pollutants into less harmful or inert substances, reducing their impact on water quality.
- **Precipitation**: Some pollutants may precipitate out of solution under certain conditions, forming insoluble compounds that settle out of the water column.

6. SUNLIGHT AND UV RADIATION:

- **Photolysis**: Exposure to sunlight and ultraviolet (UV) radiation can break down certain pollutants and disinfect water by destroying pathogens and microorganisms.

7. EROSION CONTROL:

- **Natural Vegetation**: Riparian vegetation and natural buffers along watercourses help prevent erosion, stabilize streambanks, and reduce sediment and nutrient runoff into water bodies.

Natural purification processes play a crucial role in maintaining the health and quality of water sources. Protecting and preserving natural ecosystems, such as wetlands, forests, and riparian areas, is essential for enhancing water quality and ensuring the availability of clean and safe drinking water for both humans and wildlife. Incorporating nature-based solutions into water resource management practices can help optimize natural purification processes and promote sustainable water management strategies.

PROBABLE QUESTIONS

1. Discuss the physical characteristics of water, including temperature, turbidity, colour, and Odor, and their significance in assessing water quality and suitability for various uses.
2. Explain the chemical characteristics of water, such as pH, dissolved oxygen, conductivity, and the concentrations of ions and contaminants, and their implications for aquatic ecosystems and human health.
3. Analyse the biological characteristics of water, including the presence of microorganisms, algae, and aquatic organisms, and their roles in nutrient cycling, food webs, and ecosystem dynamics.
4. Evaluate the significance of water quality criteria and standards established by regulatory agencies and international organizations for protecting public health, ecosystem integrity, and water resources sustainability.
5. Discuss the sources, pathways, and health impacts of waterborne diseases caused by pathogenic microorganisms, parasites, and toxins present in contaminated water sources.
6. Explore the mechanisms of transmission and control of waterborne diseases, including the role of sanitation, hygiene, water treatment, and public health interventions in preventing outbreaks and reducing morbidity and mortality.
7. Describe the epidemiology and public health implications of major waterborne diseases, such as cholera, typhoid fever, dysentery, hepatitis, and cryptosporidiosis, in different regions and populations.
8. Analyse the interactions between water quality, sanitation, and hygiene practices in determining the risk of waterborne disease transmission, emphasizing principles of integrated water resources management and One Health approaches.
9. Discuss the challenges and opportunities associated with monitoring and surveillance of waterborne diseases, including the use of epidemiological, environmental, and molecular tools for detection, tracking, and control.
10. Evaluate the effectiveness of different water treatment technologies and disinfection methods, such as chlorination, ultraviolet (UV) irradiation, ozonation, and membrane filtration, in removing pathogens and reducing microbial risks in drinking water.

11. Explore the concept of natural purification of water sources, including the roles of physical, chemical, and biological processes in attenuating contaminants, mitigating pollution, and enhancing water quality.
12. Describe the mechanisms of self-purification in natural water bodies, such as rivers, lakes, wetlands, and aquifers, including sedimentation, adsorption, microbial degradation, and nutrient cycling.
13. Analyse the impacts of human activities, land use changes, and pollution sources on the natural purification capacity of water sources, including nutrient enrichment, sedimentation, and toxic contamination.
14. Discuss the potential synergies and trade-offs between engineering-based and nature-based solutions for enhancing water quality and ecosystem resilience, considering factors such as cost-effectiveness, ecological integrity, and societal acceptance.
15. Evaluate case studies of successful restoration and conservation projects aimed at enhancing the natural purification capacity of water sources, including ecosystem-based approaches, green infrastructure, and sustainable land management practices.
16. Explore the role of watershed management, land use planning, and environmental regulations in protecting and restoring water quality, reducing nonpoint source pollution, and safeguarding drinking water supplies.
17. Discuss the principles of ecological engineering and bioremediation techniques for enhancing the self-purification capacity of contaminated water bodies, including the use of constructed wetlands, biofilters, and phytoremediation.
18. Analyse the socio-economic, cultural, and ethical dimensions of water quality management and conservation efforts, including considerations of equity, justice, and indigenous knowledge systems.
19. Propose strategies for addressing emerging challenges and future threats to water quality, such as climate change, urbanization, population growth, and industrialization, through interdisciplinary research, innovation, and policy reform.
20. Discuss the importance of public awareness, education, and community engagement in promoting water stewardship, sustainable consumption, and collective action for preserving and restoring the health of water ecosystems and human well-being.

MODULE-3

CHAPTER-1
SESSION-21

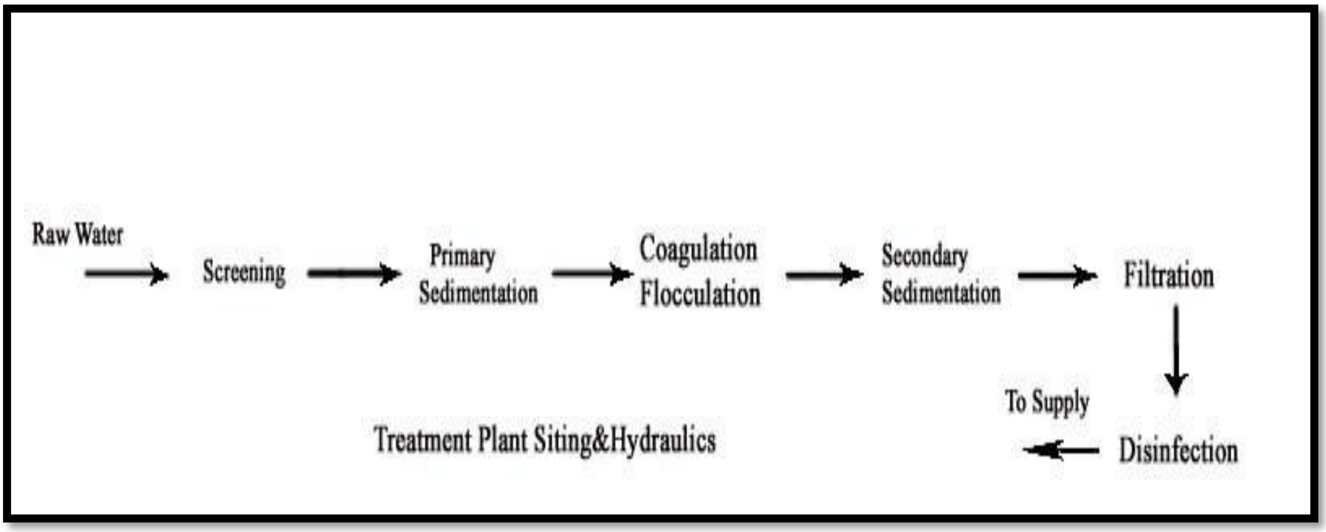
3.1 WATER TREATMENT

LEARNING OBJECTIVE

3.1.1 Introduction

3.1.1 INTRODUCTION

An engineered system of water treatment refers to a comprehensive, designed, and implemented set of processes and technologies that aim to improve the quality of water to make it suitable for specific uses such as drinking, industrial processes, medical applications, and safe return to the environment. These systems can be complex and varied, depending on the source of the water, the intended use, and the environmental regulations in place. Engineered water treatment systems are essential for ensuring the availability of clean and safe water for various applications. They integrate multiple physical, chemical, and biological processes to remove contaminants and achieve the desired water quality. Proper design, operation, and maintenance of these systems are crucial for their effectiveness and sustainability.



Depending upon the magnitude of treatment required, proper unit operations are selected and arranged in the proper sequential order for the purpose of modifying the quality of raw water to meet the desired standards. Indian Standards for drinking water are given in the table below.

Parameter	Desirable-Tolerable	*If no alternative source available, limit extended upto*
Physical		
Turbidity (NTU unit)	< 10	25
Colour (Hazen scale)	< 10	50
Taste and Odour	Un-objectionable	Un-objectionable
Chemical		
pH	7.0-8.5	6.5-9.2
Total Dissolved Solids mg/l	500-1500	3000
Total Hardness mg/l (as $CaCO_3$)	200-300	600
Chlorides mg/l (as Cl)	200-250	1000
Sulphates mg/l (as SO_4)	150-200	400
Fluorides mg/l (as F)	0.6-1.2	1.5
Nitrates mg/l (as NO_3)	45	45
Calcium mg/l (as Ca)	75	200
Iron mg/l (as Fe)	0.1-0.3	1.0

Unit treatment	Function (removal)
Aeration, chemicals use	Colour, Odour, Taste
Screening	Floating matter
Chemical methods	Iron, Manganese, etc.
Softening	Hardness
Sedimentation	Suspended matter
Coagulation	Suspended matter, a part of colloidal matter and bacteria
Filtration	Remaining colloidal dissolved matter, bacteria
Disinfection	Pathogenic bacteria, Organic matter and Reducing substances

Source	Treatment required
1. Ground water and spring water fairly free from contamination	No treatment or Chlorination
2. Ground water with chemicals, minerals and gases	Aeration, coagulation (if necessary), filtration and disinfection
3. Lakes, surface water reservoirs with less amount of pollution	Disinfection
4. Other surface waters such as rivers, canals and impounded reservoirs with a considerable amount of pollution	Complete treatment

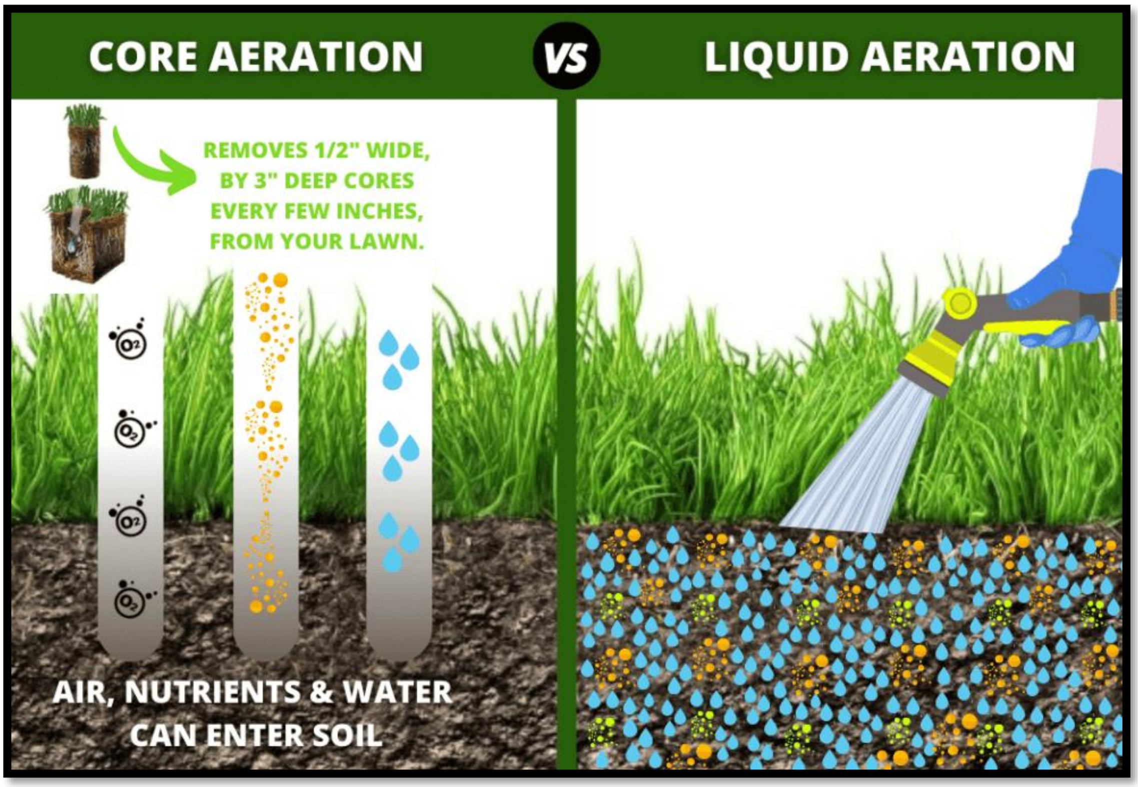
3.1 WATER TREATMENT

LEARNING OBJECTIVE

3.1.2 Aeration

3.1.2 AERATION

- Aeration removes odour and tastes due to volatile gases like hydrogen sulphide and due to algae and related organisms.
- Aeration also oxidise iron and manganese, increases dissolved oxygen content in water, removes CO2 and reduces corrosion and removes methane and other flammable gases.
- Principle of treatment underlines on the fact that volatile gases in water escape into atmosphere from the air-water interface and atmospheric oxygen takes their place in water, provided the water body can expose itself over a vast surface to the atmosphere. This process continues until an equilibrium is reached depending on the partial pressure of each specific gas in the atmosphere.



TYPES OF AERATORS

1. Gravity aerators
2. Fountain aerators
3. Diffused aerators
4. Mechanical aerators.

Gravity Aerators (Cascades): In gravity aerators, water is allowed to fall by gravity such that a large area of water is exposed to atmosphere, sometimes aided by turbulence.

Fountain Aerators: These are also known as spray aerators with special nozzles to produce a fine spray. Each nozzle is 2.5 to 4 cm diameter discharging about 18 to 36 l/h. Nozzle spacing should be such that each m3 of water has aerator area of 0.03 to 0.09 m2 for one hour.

Injection or Diffused Aerators: It consists of a tank with perforated pipes, tubes, or diffuser plates, fixed at the bottom to release fine air bubbles from compressor unit. The tank depth is kept as 3 to 4 m and tank width is within 1.5 times its depth. If depth is more, the diffusers must be placed at 3 to 4 m depth below water surface. Time of aeration is 10 to 30 min and 0.2 to 0.4 litres of air is required for 1 litre of water.

Mechanical Aerators: Mixing paddles as in flocculation are used. Paddles may be either submerged or at the surface.

USES OF AERATION OF LIQUIDS

- To smooth (laminate) the flow of tap water at the faucet.
- Production of aerated water or cola for drinking purposes.
- Secondary treatment of sewage or industrial wastewater through use of aerating mixers/diffusers.
- To increase the oxygen content of water used to house animals, such as aquarium fish or fish farm
- To increase oxygen content of wort (unfermented beer) or must (unfermented wine) to allow yeast to propagate and begin fermentation.
- To dispel other dissolved gases such as carbon dioxide or chlorine.
- In chemistry, to oxidise a compound dissolved or suspended in water.
- To induce mixing of a body of otherwise still water.

3.1 WATER TREATMENT

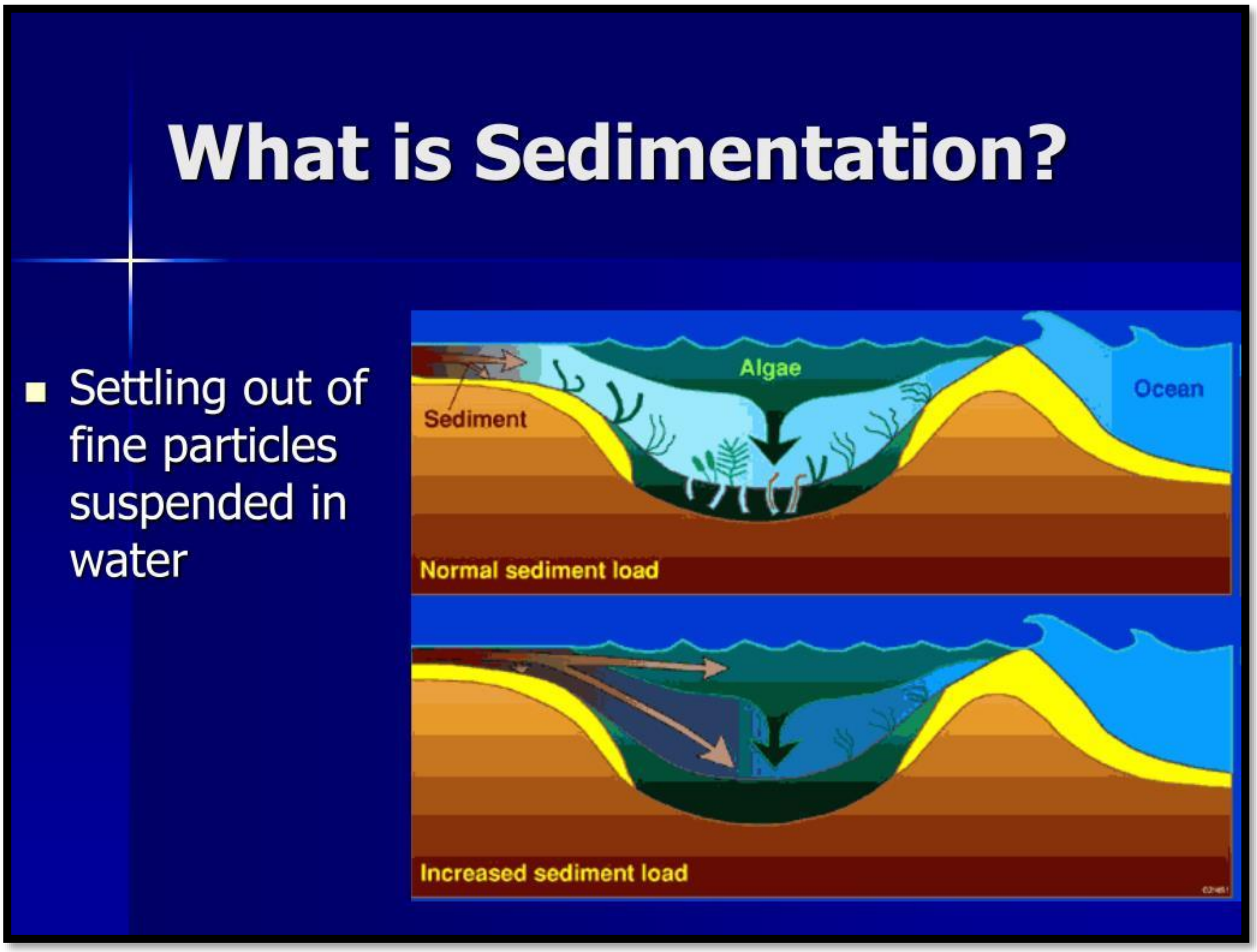
LEARNING OBJECTIVE

3.1.3 Sedimentation

3.1.3 SEDIMENTATION

Sedimentation is the process by which particles settle out of a fluid, typically water, due to the force of gravity. This process is fundamental in natural water systems, water and wastewater treatment, and various industrial applications. Solid liquid separation process in which a suspension is separated into two phases –

- Clarified supernatant leaving the top of the sedimentation tank (overflow).
- Concentrated sludge leaving the bottom of the sedimentation tank (underflow).



PURPOSE OF SETTLING

- To remove coarse dispersed phase.
- To remove coagulated and flocculated impurities.
- To remove precipitated impurities after chemical treatment.
- To settle the sludge (biomass) after activated sludge process / tricking filters.

PRINCIPLE OF SETTLING

- Suspended solids present in water having specific gravity greater than that of water tend to settle down by gravity as soon as the turbulence is retarded by offering storage.
- Basin in which the flow is retarded is called **settling tank**.
- Theoretical average time for which the water is detained in the settling tank is called the **detention period**.

TYPES OF SETTLING

Type I: **Discrete particle settling -** Particles settle individually without interaction with neighboring particles.
Type II: **Flocculent Particles** – Flocculation causes the particles to increase in mass and settle at a faster rate.
Type III: **Hindered or Zone settling** –The mass of particles tends to settle as a unit with individual particles remaining in fixed positions with respect to each other.
Type IV: **Compression** – The concentration of particles is so high that sedimentation can only occur through compaction of the structure.

A long rectangular settling tank can be divided into four different functional zones:
Inlet zone: Region in which the flow is uniformly distributed over the cross section such that the flow through settling zone follows horizontal path.
Settling zone: Settling occurs under quiescent conditions.
Outlet zone: Clarified effluent is collected and discharge through outlet weir.
Sludge zone: For collection of sludge below settling zone.

INLET AND OUTLET ARRANGEMENT

Inlet devices: Inlets shall be designed to distribute the water equally and at uniform velocities. A baffle should be constructed across the basin close to the inlet and should project several feet below the water surface to dissipate inlet velocities and provide uniform flow;

Outlet Devices: Outlet weirs or submerged orifices shall be designed to maintain velocities suitable for settling in the basin and to minimize short-circuiting. Weirs shall be adjustable, and at least equivalent in length to the perimeter of the tank. However, peripheral weirs are not acceptable as they tend to cause excessive short-circuiting.

WEIR OVERFLOW RATES

Large weir overflow rates result in excessive velocities at the outlet. These velocities extend backward into the settling zone, causing particles and flocs to be drawn into the outlet. Weir loadings are generally used up to 300 $m^3/d/m$. It may be necessary to provide special inboard weir designs as shown to lower the weir overflow rates.

CIRCULAR BASINS

- Circular settling basins have the same functional zones as the long rectangular basin, but the flow regime is different. When the flow enters at the centre and is baffled to flow radially towards the perimeter, the horizontal velocity of the water is continuously decreasing as the distance from the centre increases. Thus, the particle path in a circular basin is a parabola as opposed to the straight-line path in the long rectangular tank.
- Sludge removal mechanisms in circular tanks are simpler and require less maintenance.

3.1 WATER TREATMENT

LEARNING OBJECTIVE

3.1.4 Design Details

3.1.5 Sedimentation Tank Design

3.1.4 DESIGN DETAILS

1. Detention period: for plain sedimentation: 3 to 4 h, and for coagulated sedimentation: 2 to 2.5 h.
2. Velocity of flow: Not greater than 30 cm/min (horizontal flow).
3. Tank dimensions: L: B = 3 to 5:1. Generally L= 30 m (common) maximum 100 m. Breadth= 6 m to 10 m. Circular: Diameter not greater than 60 m. generally 20 to 40 m.
4. Depth 2.5 to 5.0 m (3 m).
5. Surface Overflow Rate: For plain sedimentation 12000 to 18000 L/d/m2 tank area; for thoroughly flocculated water 24000 to 30000 L/d/m2 tank area.
6. Slopes: Rectangular 1% towards inlet and circular 8%.

3.1.5 SEDIMENTATION TANK DESIGN

Problem: Design a rectangular sedimentation tank to treat 2.4 million litres of raw water per day. The detention period may be assumed to be 3 hours.

Solution: Raw water flow per day is 2.4×10^6 l. Detention period is 3h.

Volume of tank = Flow x Detention period = $2.4 \times 10^3 \times 3/24 = 300\ m^3$

Assume depth of tank = 3.0 m., Surface area = $300/3 = 100\ m^2$

L/B = 3 (assumed). L = 3B., $3B^2 = 100\ m^2$ i.e. B = 5.8 m

L = 3B = 5.8 X 3 = 17.4 m

Hence surface loading (Overflow rate) = $\frac{2.4 \times 10^6}{100} = 24{,}000\ l/d/m^2 < 40{,}000\ l/d/m^2$ (OK)

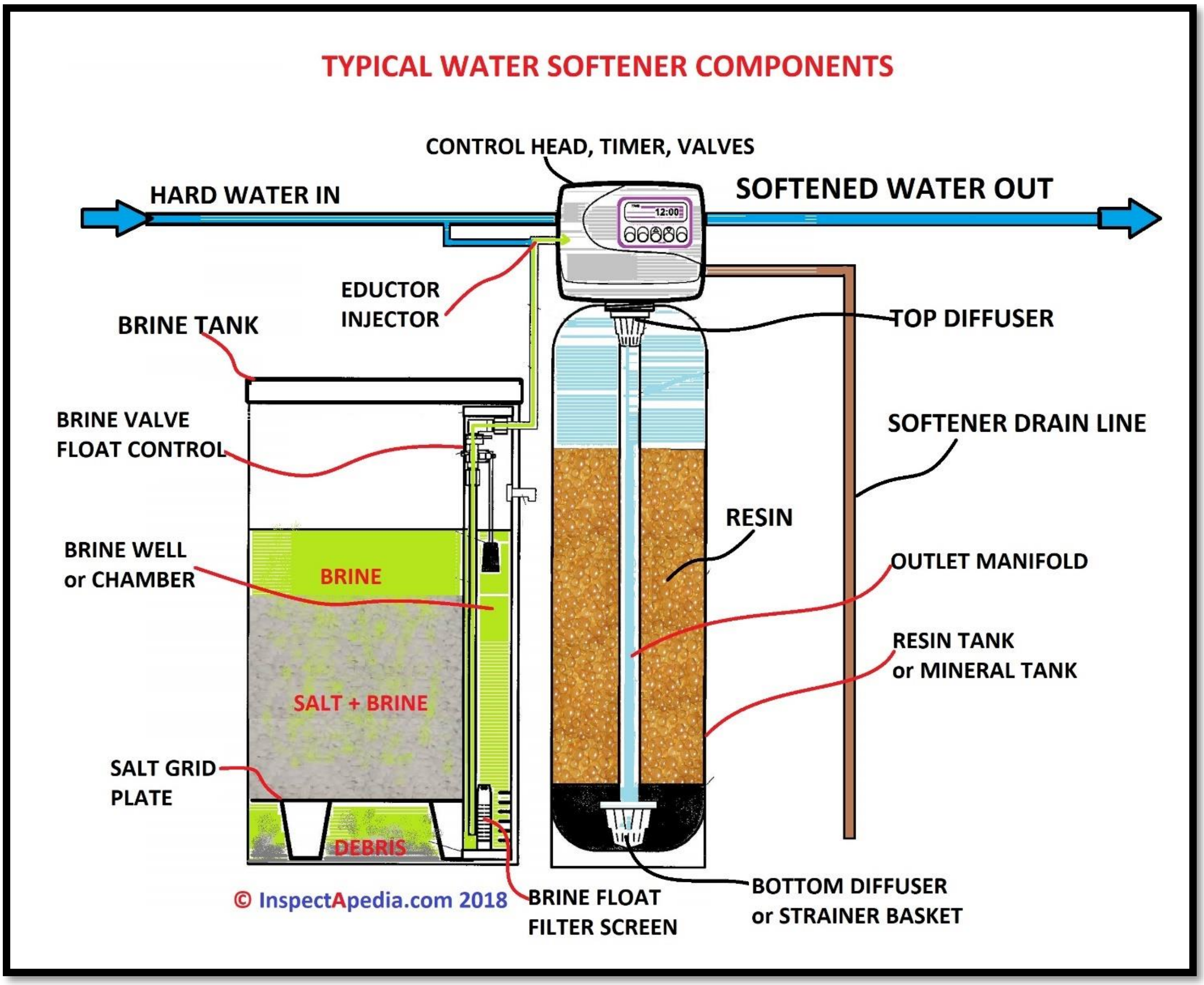
3.1 WATER TREATMENT

LEARNING OBJECTIVE
3.1.6 Softening

3.1.6 SOFTENING

Softening and coagulation are essential processes in water treatment designed to improve water quality by removing hardness, turbidity, and other impurities. Here is a detailed look at each process:

WATER SOFTENING



Water softening is the process of removing hardness-causing minerals, primarily calcium and magnesium, from water. Hard water can cause scale buildup in pipes, reduce the effectiveness of soaps and detergents, and damage appliances. The two main methods of water softening are:

1. ION EXCHANGE

- **Process:**
  - Hard water passes through a bed of ion exchange resin beads that are charged with sodium (or sometimes potassium) ions.
  - The resin beads exchange their sodium ions for calcium and magnesium ions in the water.
  - The softened water, now containing sodium instead of calcium and magnesium, exits the softener.
  - The resin is periodically regenerated using a salt (sodium chloride) solution to replace the exchanged sodium ions.
- **Advantages:**
  - Highly effective in removing hardness.
  - Can be automated and requires minimal maintenance once set up.
- **Disadvantages:**
  - Increases sodium content in treated water, which can be a concern for people on low-sodium diets.
  - Requires regular replenishment of salt for regeneration.

2. LIME SOFTENING

- **Process:**
  - Lime (calcium hydroxide) is added to hard water.
  - Lime reacts with bicarbonate hardness (calcium and magnesium bicarbonate) to form insoluble calcium carbonate and magnesium hydroxide, which precipitate out of the water.

- Additional chemicals like soda ash (sodium carbonate) can be added to remove non-bicarbonate hardness.
- The water is then clarified to remove the precipitated particles.

- **Advantages:**
  - Can treat large volumes of water.
  - Reduces both temporary and permanent hardness.
- **Disadvantages:**
  - Produces large amounts of sludge that require disposal.
  - Requires careful control of chemical dosing.

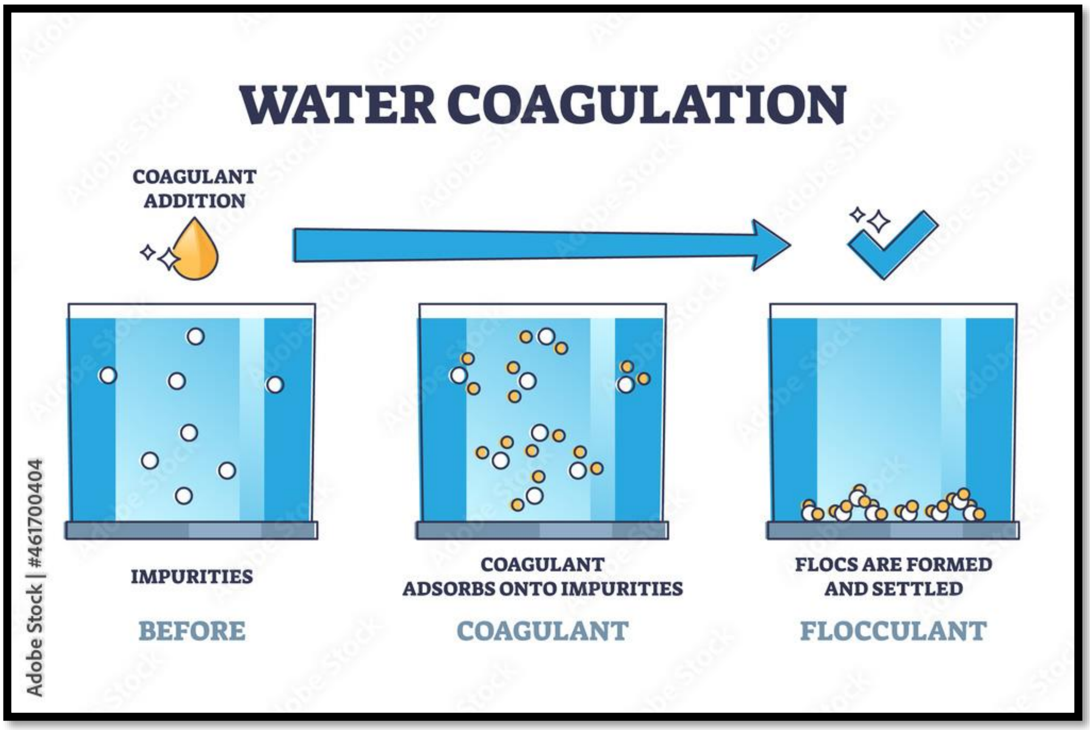
CHAPTER-1
SESSION-26

3.1 WATER TREATMENT

LEARNING OBJECTIVE

3.1.7 Coagulation

3.1.7 COAGULATION



Coagulation is the process of adding chemicals to water to destabilize and aggregate suspended particles, colloids, and dissolved substances into larger particles (flocs) that can be more easily removed by sedimentation or filtration. This is a crucial step in drinking water and wastewater treatment to improve water clarity and remove contaminants.

PROCESS OF COAGULATION

1. **Chemical Addition:**
    - Coagulants such as aluminium sulphate (alum), ferric chloride, or polyaluminum chloride are added to the water.
    - These chemicals neutralize the negative charges on particles, allowing them to come together and form larger aggregates.
2. **Rapid Mixing:**
    - The water is rapidly mixed to evenly distribute the coagulant and ensure thorough contact with the suspended particles.
3. **Flocculation:**
    - After rapid mixing, the water undergoes gentle, slow mixing to encourage the formation and growth of flocs.
    - Flocculants (polymers) may be added to enhance the floc formation process.
4. **Sedimentation/Filtration:**
    - The water is then sent to a sedimentation basin where the flocs settle out by gravity.
    - Further filtration can be used to remove any remaining flocs.

ADVANTAGES OF COAGULATION

- **Improves Water Quality:** Effectively removes turbidity, colour, organic matter, and microorganisms.
- **Enhances Filtration:** Pre-treatment with coagulation improves the performance and lifespan of filtration systems.

- **Versatility:** Can be used for a wide range of water qualities and treatment objectives.

Disadvantages of Coagulation

- **Chemical Handling:** Requires careful handling and storage of chemicals.
- **Sludge Production:** Generates sludge that needs to be properly managed and disposed of.
- **Operational Control:** Requires precise control of dosing and mixing conditions to achieve optimal results.

CHAPTER-1

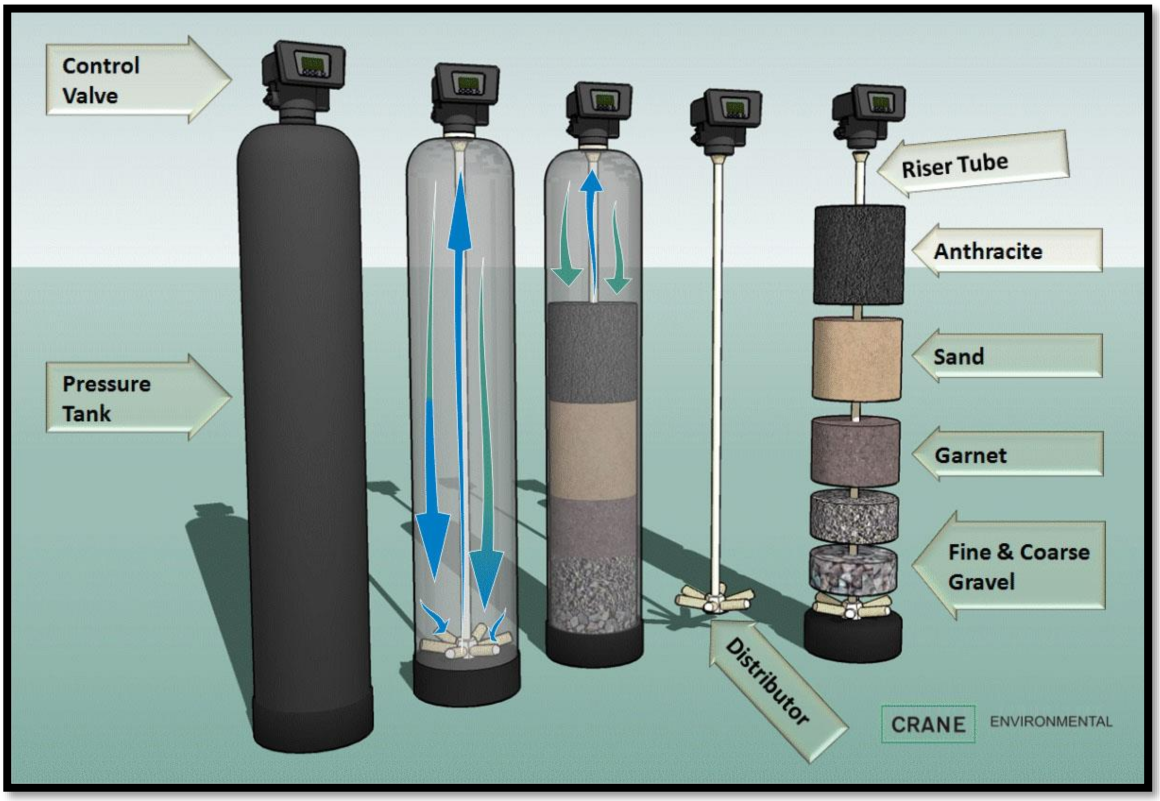
SESSION-27

3.1 WATER TREATMENT

LEARNING OBJECTIVE

3.1.8 Filtration

3.1.8 FILTRATION



The resultant water after sedimentation will not be pure, and may contain some very fine suspended particles and bacteria in it. To remove or to reduce the remaining impurities still further, the water is filtered through the beds of fine granular material, such as sand, etc. The process of passing the water through the beds of such granular materials is known as Filtration.

HOW FILTERS WORK: FILTRATION MECHANISMS

There are four basic filtration mechanisms:

SEDIMENTATION: The mechanism of sedimentation is due to force of gravity and the associate settling velocity of the particle, which causes it to cross the streamlines and reach the collector.

INTERCEPTION: Interception of particles is common for large particles. If a large enough particle follows the streamline, that lies very close to the media surface it will hit the media grain and be captured.

BROWNIAN DIFFUSION: Diffusion towards media granules occurs for very small particles, such as viruses. Particles move randomly about within the fluid, due to thermal gradients. This mechanism is only important for particles with diameters < 1 micron.

INERTIA: Attachment by inertia occurs when larger particles move fast enough to travel off their streamlines and bump into media grains.

FILTER MATERIALS

Sand: Sand, either fine or course, is generally used as filter media. The size of the sand is measured and expressed by the term called effective size. The effective size, i.e. D_{10} may be defined as the size of the sieve in mm through which ten percent of the sample of sand by weight will pass. The uniformity in size or degree of variations in sizes of particles is measured and expressed by the term called uniformity coefficient. The uniformity coefficient, i.e. (D_{60}/D_{10}) may be defined as the ratio of the sieve size in mm through which 60 percent of the sample of sand will pass, to the effective size of the sand.

Gravel: The layers of sand may be supported on gravel, which permits the filtered water to move freely to the under drains, and allows the wash water to move uniformly upwards.

Other materials: Instead of using sand, sometimes, anthrafilt is used as filter media. Anthrafilt is made from anthracite, which is a type of coal-stone that burns without smoke or flames. It is cheaper and has been able to give a high rate of filtration.

TYPES OF FILTERS

Slow sand filter: They consist of fine sand, supported by gravel. They capture particles near the surface of the bed and are usually cleaned by scraping away the top layer of sand that contains the particles.

Rapid-sand filter: They consist of larger sand grains supported by gravel and capture particles throughout the bed. They are cleaned by backwashing water through the bed to 'lift out' the particles.

Multimedia filters: They consist of two or more layers of different granular materials, with different densities. Usually, anthracite coal, sand, and gravel are used. The different layers combined may provide more versatile collection than a single sand layer. Because of the differences in densities, the layers stay neatly separated, even after backwashing.

CHAPTER-1

SESSION-28

3.1 WATER TREATMENT

LEARNING OBJECTIVE

3.1.9 Principle of Slow Sand Filter

3.1.10 Sand Filters Vs. Rapid Sand Filters

3.1.9 PRINCIPLES OF SLOW SAND FILTRATION

- In a slow sand filter impurities in the water are removed by a combination of processes: sedimentation, straining, adsorption, and chemical and bacteriological action.
- During the first few days, water is purified mainly by mechanical and physical-chemical processes. The resulting accumulation of sediment and organic matter forms a thin layer on the sand surface, which remains permeable and retains particles even smaller than the spaces between the sand grains.

- As this layer (referred to as "Schmutzdecke") develops, it becomes living quarters of vast numbers of micro-organisms which break down organic material retained from the water, converting it into water, carbon dioxide and other oxides.
- Most impurities, including bacteria and viruses, are removed from the raw water as it passes through the filter skin and the layer of filter bed sand just below. The purification mechanisms extend from the filter skin to approx. 0.3-0.4 m below the surface of the filter bed, gradually decreasing in activity at lower levels as the water becomes purified and contains less organic material.
- When the micro-organisms become well established, the filter will work efficiently and produce high quality effluent which is virtually free of disease carrying organisms and biodegradable organic matter. They are suitable for treating waters with low colours, low turbidities, and low bacterial contents.

3.1.9 SAND FILTERS VS. RAPID SAND FILTERS

- ***Base material:*** In SSF it varies from 3 to 65 mm in size and 30 to 75 cm in depth while in RSF it varies from 3 to 40 mm in size and its depth is slightly more, i.e. about 60 to 90 cm.
- ***Filter sand:*** In SSF the effective size ranges between 0.2 to 0.4 mm and uniformity coefficient between 1.8 to 2.5 or 3.0. In RSF the effective size ranges between 0.35 to 0.55 and uniformity coefficient between 1.2 to 1.8.
- ***Rate of filtration:*** In SSF it is small, such as 100 to 200 L/h/sq. of filter area while in RSF it is large, such as 3000 to 6000 L/h/sq. of filter area.
- ***Flexibility:*** SSF are not flexible for meeting variation in demand whereas RSF are quite flexible for meeting reasonable variations in demand.
- ***Post treatment required:*** Almost pure water is obtained from SSF. However, water may be disinfected slightly to make it completely safe. Disinfection is a must after RSF.
- ***Method of cleaning:*** Scrapping and removing of the top 1.5 to 3 cm thick layer is done to clean SSF. To clean RSF, sand is agitated and backwashed with or without compressed air.

- ***Loss of head:*** In case of SSF approx. 10 cm is the initial loss, and 0.8 to 1.2m is the final limit when cleaning is required. For RSF 0.3m is the initial loss, and 2.5 to 3.5m is the final limit when cleaning is required.

3.1 WATER TREATMENT

LEARNING OBJECTIVE

3.1.11 Rapid Sand Filter Design

3.1.11 RAPID SAND FILTER DESIGN

Problem: Design a rapid sand filter to treat 10 million litres of raw water per day allowing 0.5% of filtered water for backwashing. Half hour per day is used for backwashing. Assume necessary data.

Solution: Total filtered water = $\frac{10.05 \times 24 \times 10^6}{24 \times 23.5} = 0.42766$ Ml / h

Let the rate of filtration be 5000 l / h / m^2 of bed.

Area of filter = $\frac{10.05 \times 10^6}{23.5} \times \frac{1}{5000} = 85.5\ m^2$

Provide two units. Each bed area 85.5/2 = 42.77. L/B = 1.3; $1.3B^2 = 42.77$

B = 5.75 m; L = 5.75 x 1.3 = 7.5 m

Assume depth of sand = 50 to 75 cm.

Underdrainage system:

Total area of holes = 0.2 to 0.5% of bed area.

Assume 0.2% of bed area = $\frac{0.2}{100} \times 42.77 = 0.086\ m^2$

Area of lateral = 2 (Area of holes of lateral)

Area of manifold = 2 (Area of laterals)

So, area of manifold = 4 x area of holes = 4 x 0.086 = 0.344 = 0.35 m^2.

$\therefore$ Diameter of manifold = $(4x\ 0.35 /\pi)^{1/2}$ = 66 cm

Assume c/c of lateral = 30 cm. Total numbers = 7.5/ 0.3 = 25 on either side.

Length of lateral = 5.75/2 - 0.66/2 = 2.545 m.

C.S. area of lateral = 2 x area of perforations per lateral. Take dia of holes = 13 mm

Number of holes: $\frac{n\pi}{4} (1.3)^2 = 0.086 \times 10^4 = 860\ cm^2$

$\therefore n = \frac{4 \times 860}{\pi (1.3)^2} = 648$, say 650

Number of holes per lateral = 650/50 = 13

Area of perforations per lateral = 13 x $\pi (1.3)^2 /4$ = 17.24 cm^2

Spacing of holes = 2.545/13 = 19.5 cm.

C.S. area of lateral = 2 x area of perforations per lateral = 2 x 17.24 = 34.5 cm^2.

$\therefore$ Diameter of lateral = $(4 \times 34.5/\pi)^{1/2}$ = 6.63 cm

Check: Length of lateral $<$ 60 d = 60 x 6.63 = 3.98 m. l = 2.545 m (Hence acceptable).

Rising wash water velocity in bed = 50 cm/min.

Wash water discharge per bed = (0.5/60) x 5.75 x 7.5 = 0.36 m^3/s.

Velocity of flow through lateral = $\frac{0.36}{\text{Total lateral area}} = \frac{0.36 \times 10^{4}}{50 \times 34.5}$ = 2.08 m/s (ok)

Manifold velocity = $\frac{0.36}{0.345}$ = 1.04 m/s < 2.25 m/s (ok)

Wash water gutter

Discharge of wash water per bed = 0.36 m^3/s. Size of bed = 7.5 x 5.75 m.

Assume 3 troughs running lengthwise at 5.75/3 = 1.9 m c/c.

Discharge of each trough = Q/3 = 0.36/3 = 0.12 m^3/s.

$$Q = 1.71 \times b \times h^{3/2}$$

Assume b =0.3 m

$$h^{3/2} = \frac{0.12}{1.71 \times 0.3} = 0.234$$

$$\therefore\ h = 0.378 \text{ m} = 37.8 \text{ cm} = 40 \text{ cm}$$

= 40 + (free board) 5 cm = 45 cm; slope 1 in 40

Clear water reservoir for backwashing

For 4 h filter capacity, Capacity of tank = $\frac{4 \times 5000 \times 7.5 \times 5.75 \times 2}{1000}$ = 1725 m^3

Assume depth d = 5 m. Surface area = 1725/5 = 345 m^2

L/B = 2; $2B^2$ = 345; B = 13 m & L = 26 m.

Dia of inlet pipe coming from two filter = 50 cm.

Velocity <0.6 m/s. Diameter of wash water pipe to overhead tank = 67.5 cm.

Air compressor unit = 1000 l of air/ min/ m^2 bed area.

For 5 min, air required = 1000 x 5 x 7.5 x 5.77 x 2 = 4.32 m^3 of air.

3.1 WATER TREATMENT

LEARNING OBJECTIVE

3.1.12 Disinfection

3.1.12 DISINFECTION

The filtered water may normally contain some harmful disease producing bacteria in it. These bacteria must be killed to make the water safe for drinking. The process of killing these bacteria is known as Disinfection or Sterilization.

DISINFECTION KINETICS

When a single unit of microorganisms is exposed to a single unit of disinfectant, the reduction in microorganisms follows a first-order reaction.

$dN/dt=-kN$ $\quad$ $N=N_0e^{-kt}$

This equation is known as Chick's Law: -

N = number of microorganism (N_0 is initial number), k = disinfection constant

t = contact time

METHODS OF DISINFECTION

1. ***Boiling:*** The bacteria present in water can be destroyed by boiling it for a long time. However, it is not practically possible to boil huge amounts of water. Moreover, it cannot take care of future possible contaminations.
2. ***Treatment with Excess Lime:*** Lime is used in water treatment plant for softening. But if excess lime is added to the water, it can in addition, kill the bacteria also. Lime when added raises the pH value of water making it extremely alkaline. This extreme alkalinity has been found detrimental to the survival of bacteria. This method needs the removal of excess lime from the water before it can be supplied to the public. Treatment like recarbonation for lime removal should be used after disinfection.
3. ***Treatment with Ozone:*** Ozone readily breaks down into normal oxygen, and releases nascent oxygen. The nascent oxygen is a powerful oxidising agent and removes the organic matter as well as the bacteria from the water.
4. ***Chlorination:*** The germicidal action of chlorine is explained by the recent theory of *Enzymatic hypothesis*, according to which the chlorine enters the cell walls of bacteria and kill the enzymes which are essential for the metabolic processes of living organisms.

CHLORINE CHEMISTRY

Chlorine is added to the water supply in two ways. It is most often added as a gas, Cl_2(g). However, it also can be added as a salt, such as sodium hypochlorite (NaOCl) or bleach. Chlorine gas dissolves in water following Henry's Law.

$$Cl_{2(g)} \longrightarrow Cl_{2(aq)} \quad KH = 6.2 \times 10^{-2}$$

Once dissolved, the following reaction occurs forming hypochlorous acid (HOCl):

$$Cl_{2(aq)} + H_2O \longrightarrow HOCl + H^+ + Cl^-$$

Hypochlorous acid is a weak acid that dissociates to form hypochlorite ion (OCl-).

$$HOCl \longrightarrow OCl^- + H^+ \quad Ka = 3.2 \times 10^{-8}$$

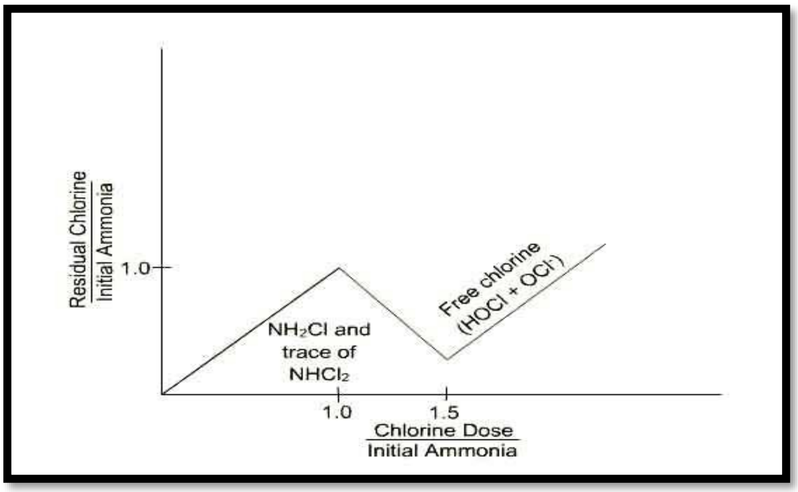
All forms of chlorine are measured as mg/L of Cl_2 (MW = 2 x 35.45 = 70.9 g/mol) Hypochlorous acid and hypochlorite ion compose what is called the free chlorine residual. These free chlorine compounds can react with many organic and inorganic compounds to form chlorinated compounds. If the products of these reactions possess oxidizing potential, they are considered the combined chlorine residual. A common compound in drinking water systems that reacts with chlorine to form combined residual is ammonia. Reactions between ammonia and chlorine form chloramines, which is mainly monochloramine (NH_2Cl), although some dichloramine ($NHCl_2$) and trichloramine (NCl_3) also can form. Many drinking water utilities use monochloramine as a disinfectant. If excess free chlorine exits once all ammonia nitrogen has been converted to monochloramine, chloramine species are oxidized through what is termed the breakpoint reactions. The overall reactions of free chlorine and nitrogen can be represented by two simplified reactions as follows: Monochloramine Formation Reaction. This reaction occurs rapidly when ammonia nitrogen is combined with free chlorine up to a molar ratio of 1:1.

$$HOCl + NH_3 \longrightarrow NH_2Cl + HOCl$$

Breakpoint Reaction: When excess free chlorine is added beyond the 1:1 initial molar ratio, monochloramine is removed as follows:

$$2NH_2Cl + HOCl \longrightarrow N_{2(g)} + 3H^+ + 3Cl^- + H_2O$$

The formation of chloramines and the breakpoint reaction create a unique relationship between chlorine dose and the amount and form of chlorine as illustrated below.



Free Chlorine, Chloramine, and Ammonia Nitrogen Reactions

3.1 WATER TREATMENT

LEARNING OBJECTIVE
3.1.13 Chlorine Demand
3.1.14 Water Distribution System

3.1.13 CHLORINE DEMAND

Free chlorine and chloramines readily react with a variety compounds, including organic substances, and inorganic substances like iron and manganese. The stoichiometry of chlorine reactions with organics can be represented as shown below:

HOCl:

$1/10C_5H_7O_2N + HOCl \longrightarrow 4/10CO_2 + 1/10HCO^{3-} + 1/10NH^{4+} + H^+ + Cl^- + 1/10H_2O$

OCl^-:

$1/10C_5H_7O_2N + OCl^- \longrightarrow 4/10CO_2 + 1/10HCO^{3-} + 1/10NH^{4+} + Cl^- + 1/10H_2O$

NH_2Cl:

$1/10C_5H_7O_2N + NH_2Cl + 9/10H_2O \longrightarrow 4/10CO_2 + 1/10HCO^{3-} + 11/10NH^{4+} + Cl^-$

Chlorine demand can be increased by oxidation reactions with inorganics, such as reduced iron at corrosion sites at the pipe wall. Possible reactions with all forms of chlorine and iron are as follows:

3.1.14 WATER DISTRIBUTION SYSTEMS

The purpose of distribution system is to deliver water to consumer with appropriate quality, quantity, and pressure. Distribution system is used to describe collectively the facilities used to supply water from its source to the point of usage.

REQUIREMENTS OF GOOD DISTRIBUTION SYSTEM

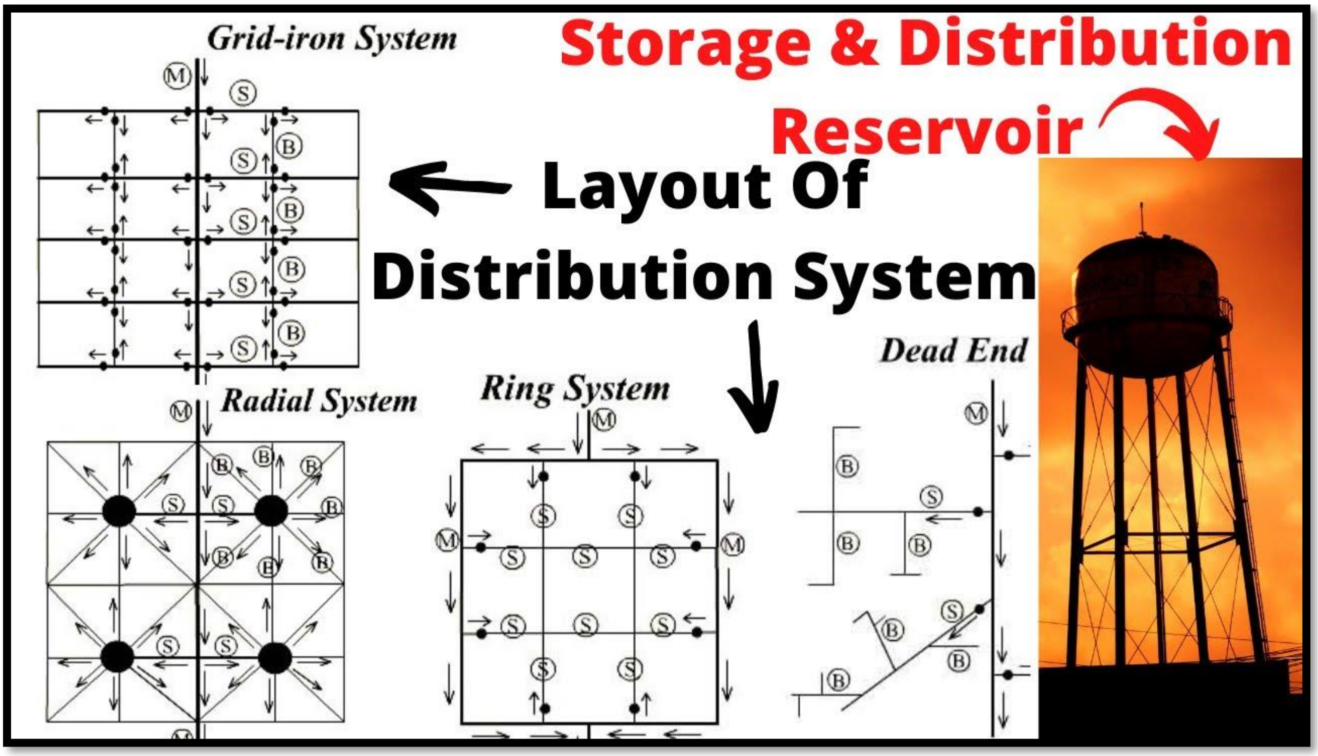
1. Water quality should not get deteriorated in the distribution pipes.

2. It should be capable of supplying water at all the intended places with sufficient pressure head.
3. It should be capable of supplying the requisite amount of water during firefighting.
4. The layout should be such that no consumer would be without water supply, during the repair of any section of the system.
5. All the distribution pipes should be preferably laid one metre away or above the sewer lines.
6. It should be water-tight as to keep losses due to leakage to the minimum.

LAYOUTS OF DISTRIBUTION NETWORK

The distribution pipes are generally laid below the road pavements, and as such their layouts generally follow the layouts of roads. There are, in general, four different types of pipe networks; any one of which either singly or in combinations, can be used for a particular place. They are:

Dead End System---Grid Iron System---Ring System---Radial System



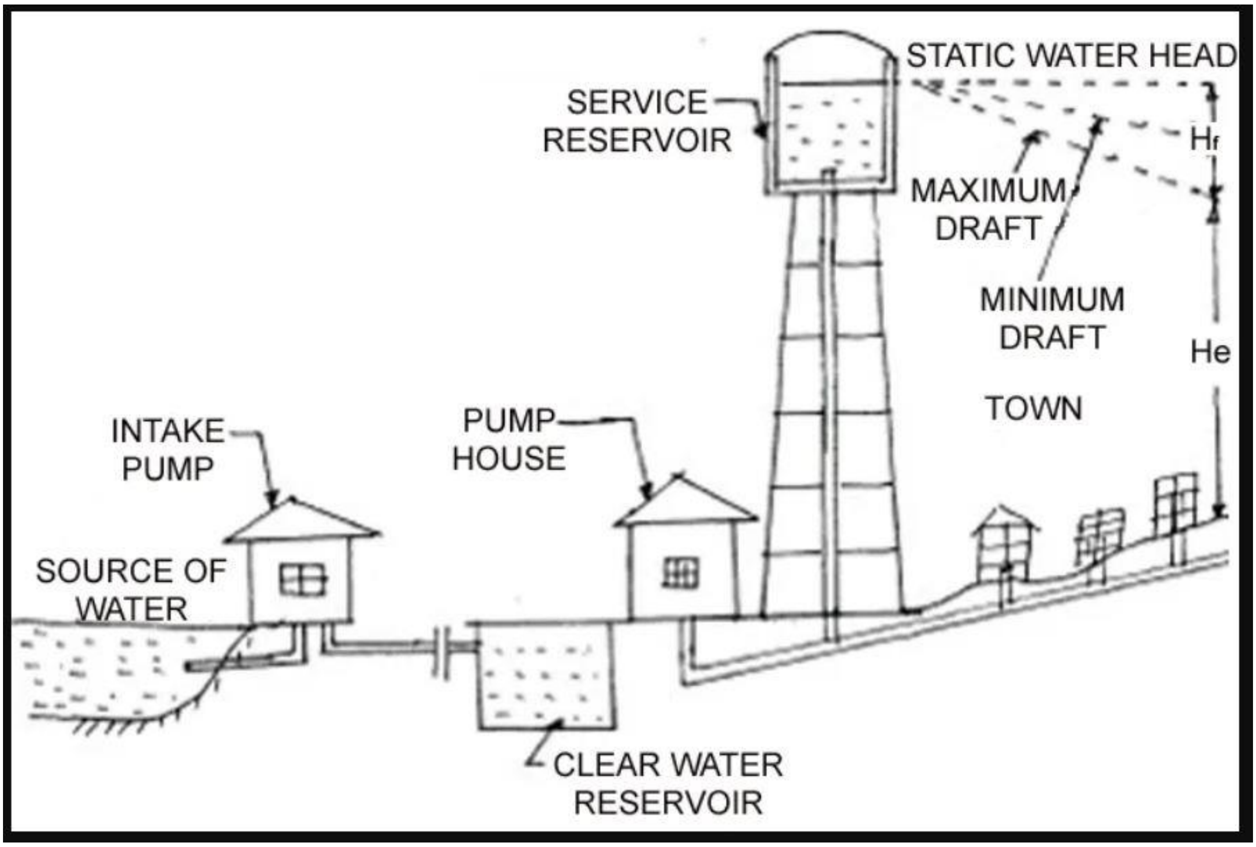
3.1 WATER TREATMENT

LEARNING OBJECTIVE

3.1.15 Distribution Reservoirs

3.1.15 DISTRIBUTION RESERVOIRS

Distribution reservoirs, also called service reservoirs, are the storage reservoirs, which store the treated water for supplying water during emergencies (such as during fires, repairs, etc.) and to help in absorbing the hourly fluctuations in the normal water demand.



FUNCTIONS OF DISTRIBUTION RESERVOIRS:

- to absorb the hourly variations in demand.
- to maintain constant pressure in the distribution mains.
- water stored can be supplied during emergencies.

LOCATION AND HEIGHT OF DISTRIBUTION RESERVOIRS:

- should be located as close as possible to the centre of demand.
- water level in the reservoir must be at a sufficient elevation to permit gravity flow at an adequate pressure.

TYPES OF RESERVOIRS

1. Underground reservoirs.
2. Small ground level reservoirs.
3. Large ground level reservoirs.
4. Overhead tanks.

STORAGE CAPACITY OF DISTRIBUTION RESERVOIRS

The total storage capacity of a distribution reservoir is the summation of:

1. ***Balancing Storage:*** The quantity of water required to be stored in the reservoir for equalising or balancing fluctuating demand against constant supply is known as the balancing storage (or equalising or operating storage). The balance storage can be worked out by mass curve method.
2. ***Breakdown Storage:*** The breakdown storage or often called emergency storage is the storage preserved to tide over the emergencies posed by the failure of pumps, electricity, or any other mechanism driving the pumps. A value of about 25% of the total storage capacity of reservoirs, or 1.5 to 2 times of the average hourly supply, may be considered as enough provision for accounting this storage.
3. ***Fire Storage:*** The third component of the total reservoir storage is the fire storage. This provision takes care of the requirements of water for extinguishing fires. A provision of 1 to 4 per person per day is sufficient to meet the requirement.

The total reservoir storage can finally be worked out by adding all the three storages.

PROBABLE QUESTIONS

1. Describe the principles and applications of aeration in water treatment, including its role in oxygenation, volatile organic compound removal, and control of taste and Odor issues in drinking water.
2. Discuss the design considerations and operational parameters for sedimentation processes in water treatment, including the removal of suspended solids, colloids, and flocs through settling and clarification.
3. Evaluate the mechanisms and benefits of water softening techniques, such as lime-soda ash softening, ion exchange, and membrane processes, in reducing hardness minerals (calcium and magnesium) and preventing scale formation in plumbing and appliances.
4. Explain the process of coagulation and flocculation in water treatment, including the use of chemical coagulants (e.g., aluminium sulphate, ferric chloride) and polymers to destabilize suspended particles and enhance their removal by sedimentation or filtration.
5. Analyse the design and operation of filtration systems for water treatment, including rapid sand filtration, multimedia filtration, and membrane filtration processes, in removing particulate matter, turbidity, and microbial pathogens from raw water.
6. Explore the principles and applications of adsorption processes, such as activated carbon adsorption and granular media filtration, in removing organic contaminants, taste and Odor compounds, and trace pollutants from water sources.
7. Discuss the mechanisms and benefits of ion exchange processes in water treatment, including the removal of dissolved ions (e.g., hardness, nitrate, arsenic) and trace metals through cation and anion exchange resins.
8. Evaluate the effectiveness and challenges of disinfection methods for water treatment, including chlorination, ozonation, UV irradiation, and advanced oxidation processes, in inactivating microbial pathogens and preventing waterborne diseases.
9. Explore the integration of multiple treatment processes (e.g., coagulation-flocculation-sedimentation-filtration) in conventional water treatment plants and advanced treatment systems for achieving specific water quality objectives and regulatory compliance.

10. Discuss the role of pre-treatment processes (e.g., screening, pre-chlorination, pH adjustment) in optimizing the performance and reliability of water treatment systems, including the protection of downstream processes and equipment from fouling and corrosion.
11. Analyse the factors influencing the selection and sizing of treatment units, including hydraulic loading rates, detention times, contactor configurations, and residence times, in meeting design criteria and performance standards.
12. Evaluate the operational and maintenance requirements of water treatment facilities, including process monitoring, chemical dosing, equipment inspection, and calibration, to ensure efficient and sustainable operation over time.
13. Discuss the challenges and opportunities associated with the implementation of decentralized and alternative water treatment technologies, such as point-of-use filters, solar disinfection, and community-scale treatment systems, in underserved and remote areas.
14. Explore the principles of risk assessment and management in water treatment, including the identification, prioritization, and mitigation of potential hazards, such as microbial contamination, chemical spills, and equipment failures.
15. Analyse case studies of successful water treatment projects from around the world, highlighting innovative technologies, adaptive strategies, and lessons learned in addressing local water quality challenges and improving public health outcomes.
16. Discuss the regulatory framework governing water treatment facilities, including permit requirements, effluent standards, monitoring and reporting obligations, and enforcement mechanisms, to ensure compliance with environmental regulations and public health objectives.
17. Explore the role of public education, community engagement, and stakeholder participation in water treatment decision-making processes, including transparency, accountability, and trust-building initiatives with affected populations.
18. Evaluate the environmental and social impacts of water treatment operations, including energy consumption, greenhouse gas emissions, chemical usage, waste generation, and land use changes, in assessing the sustainability of water supply systems.
19. Propose strategies for enhancing the resilience and adaptive capacity of water treatment infrastructure to climate change impacts, such as extreme weather

events, droughts, floods, and sea-level rise, through infrastructure upgrades, diversification of water sources, and emergency preparedness measures.

20. Discuss emerging trends and future directions in water treatment research and development, including nanotechnology, membrane innovation, electrochemical processes, and bioremediation techniques, in addressing emerging contaminants, water scarcity, and evolving regulatory requirements.
21. Describe the components and layout of a typical water distribution system, including source intakes, treatment plants, storage reservoirs, pumping stations, pipelines, valves, and distribution networks.
22. Discuss the principles of hydraulic design for water distribution systems, including flow analysis, pipe sizing, pressure requirements, and head loss calculations, to meet peak demand and fire protection needs.
23. Analyse the factors influencing the selection of pipe materials for water distribution networks, including cost, durability, corrosion resistance, hydraulic performance, and environmental sustainability.
24. Explore the design considerations and operational parameters for water storage facilities, such as elevated tanks, ground reservoirs, and underground cisterns, in maintaining system pressure, flow stability, and emergency storage capacity.
25. Discuss the principles of water distribution modelling and simulation, including network analysis, demand forecasting, and optimization techniques, in evaluating system performance, identifying vulnerabilities, and prioritizing infrastructure investments.
26. Evaluate the impacts of land use patterns, population growth, urbanization, and demographic changes on water demand projections and distribution system design criteria, including considerations of equity, access, and social vulnerability.
27. Discuss the challenges and opportunities associated with the integration of water distribution systems with other urban infrastructure networks, such as wastewater collection, stormwater management, and green infrastructure, in promoting resource efficiency and environmental resilience.
28. Analyse the role of water loss management programs in reducing non-revenue water (NRW) and improving system efficiency, including leak detection, pressure management, asset management, and metering technologies.

29. Explore the principles of water quality management in distribution systems, including disinfection, corrosion control, flushing programs, and cross-connection control, to ensure the safety and potability of drinking water supplies.
30. Discuss the regulatory requirements and standards governing the design, construction, operation, and maintenance of water distribution systems, including federal, state, and local regulations, as well as industry best practices and guidelines.
31. Evaluate the socio-economic, environmental, and public health impacts of water distribution infrastructure projects, including considerations of equity, affordability, environmental justice, and community resilience.
32. Explore the role of public participation, stakeholder engagement, and community partnerships in water distribution system planning, decision-making, and governance processes, including opportunities for citizen science, co-design, and collaborative monitoring initiatives.
33. Discuss the challenges and opportunities associated with the adoption of smart technologies, data analytics, and sensor networks for real-time monitoring, control, and optimization of water distribution systems, including considerations of privacy, cybersecurity, and data governance.
34. Analyse case studies of innovative water distribution projects and best practices from around the world, highlighting examples of sustainable design, technology integration, community engagement, and multi-sectoral collaboration.
35. Propose strategies for enhancing the resilience and adaptive capacity of water distribution systems to climate change impacts, such as extreme weather events, sea-level rise, droughts, and water quality fluctuations, through infrastructure upgrades, green infrastructure investments, and adaptive management approaches.
36. Explore the potential for decentralized and community-based approaches to water distribution, including rainwater harvesting, decentralized storage, local treatment, and alternative delivery systems, in addressing water scarcity, promoting water security, and building community resilience.
37. Discuss the importance of asset management planning, lifecycle costing, and risk-based decision-making in prioritizing investments, allocating resources, and optimizing the performance of water distribution infrastructure over time.
38. Evaluate the economic, financial, and institutional factors influencing the sustainability and affordability of water distribution services, including

considerations of revenue generation, cost recovery, tariff structures, and subsidies for low-income households.

39. Propose strategies for promoting water conservation, demand management, and behaviour change in water users through education, outreach, incentives, and pricing mechanisms, to reduce per capita consumption and mitigate pressure on distribution systems.
40. Discuss emerging trends and future directions in water distribution system design and management, including advances in materials science, sensor technology, automation, and artificial intelligence, in optimizing system performance, enhancing resilience, and promoting sustainable urban water management.

MODULE-4

CHAPTER-1

SESSION-33

4.1 GENERATION AND COLLECTION OF WASTE WATER

LEARNING OBJECTIVE

4.1.1 Introduction

4.1.2 Generation of Waste Water

4.1.1 INTRODUCTION

The generation of wastewater is an inevitable byproduct of human activities and industrial processes. Understanding its sources, characteristics, and the impacts on the environment and public health is essential for effective management and treatment. The generation of wastewater is a critical issue that requires comprehensive management to protect the environment and public health. Effective wastewater treatment and sustainable management practices are essential to mitigate the adverse impacts of wastewater and ensure the availability of clean water resources for future generations.

4.1.2 GENERATION OF WASTE WATER

Wastewater is generated from various sources, primarily categorized into domestic, industrial, agricultural, and stormwater. Each source contributes different types and quantities of wastewater, affecting its treatment and management.

1. **Domestic Wastewater:**
    - **Sources:** Residential areas including households, schools, offices, and hospitals.
    - **Components:** Contains human waste, food residues, soaps, detergents, and other household chemicals.
    - **Characteristics:** Typically high in organic matter, nutrients (like nitrogen and phosphorus), pathogens, and suspended solids.
2. **Industrial Wastewater:**
    - **Sources:** Factories, manufacturing plants, chemical processing units, mining activities, and more.
    - **Components:** Varies widely depending on the industry. Can include heavy metals, toxic chemicals, organic compounds, and high levels of biochemical oxygen demand (BOD) and chemical oxygen demand (COD).

   - **Characteristics:** Often requires specialized treatment due to potentially hazardous substances.
3. **Agricultural Wastewater:**
   - **Sources:** Farms, animal husbandry, and agricultural processing activities.
   - **Components:** Pesticides, fertilizers, animal waste, and runoff from irrigation.
   - **Characteristics:** High in nutrients, organic matter, and sometimes pathogens.
4. **Stormwater:**
   - **Sources:** Rainfall runoff from urban and rural areas, including streets, roofs, and other surfaces.
   - **Components:** Debris, oils, heavy metals, nutrients, and microorganisms.
   - **Characteristics:** Highly variable in composition and flow rates, often leading to the overflow of combined sewer systems.

CHAPTER-1

SESSION-34

4.1 GENERATION AND COLLECTION OF WASTE WATER

LEARNING OBJECTIVE

4.1.3 Collection of Waste Water

4.1.3 COLLECTION OF WASTE WATER

The collection of wastewater involves the conveyance of sewage from its source to treatment facilities. Effective collection systems are essential for maintaining public health and preventing environmental contamination.

1. **Sewer Systems:**
   - **Combined Sewers:** Collect both sanitary wastewater and stormwater in a single pipe system. While cost-effective, they can overflow during heavy rainfalls, leading to pollution.
   - **Separate Sewers:** Distinguish between sanitary sewage and stormwater, reducing the risk of overflows but requiring more infrastructure.

- **Components:** Pipes, manholes, pumping stations, and other infrastructure designed to transport wastewater efficiently.

2. **On-site Treatment and Septic Systems:**
    - **On-site Systems:** Used in rural or low-density areas where centralized sewer systems are impractical.
    - **Septic Tanks:** Treat domestic wastewater through biological decomposition and soil filtration. Require regular maintenance and proper siting to function effectively.
3. **Pumping Stations:**
    - **Purpose:** Used to lift wastewater from lower to higher elevations, ensuring it flows toward treatment facilities.
    - **Components:** Include pumps, power supplies, and control systems.
4. **Stormwater Management:**
    - **Retention Ponds:** Collect and hold stormwater runoff, allowing sediments to settle and reducing the flow rate into sewers.
    - **Green Infrastructure:** Includes rain gardens, green roofs, and permeable pavements designed to absorb and filter stormwater.

Challenges and Considerations

1. **Aging Infrastructure:**
    - Many urban areas face challenges with outdated and deteriorating sewer systems, leading to leaks, overflows, and inefficiencies.
2. **Climate Change:**
    - Increased frequency and intensity of storms can overwhelm existing wastewater systems, necessitating upgrades and more robust designs.
3. **Population Growth:**
    - Urbanization and population growth put additional pressure on wastewater collection and treatment systems, requiring expansion and modernization.
4. **Regulatory Compliance:**
    - Adherence to local, national, and international regulations regarding wastewater discharge and treatment standards is crucial for protecting public health and the environment.

LEARNING OBJECTIVE

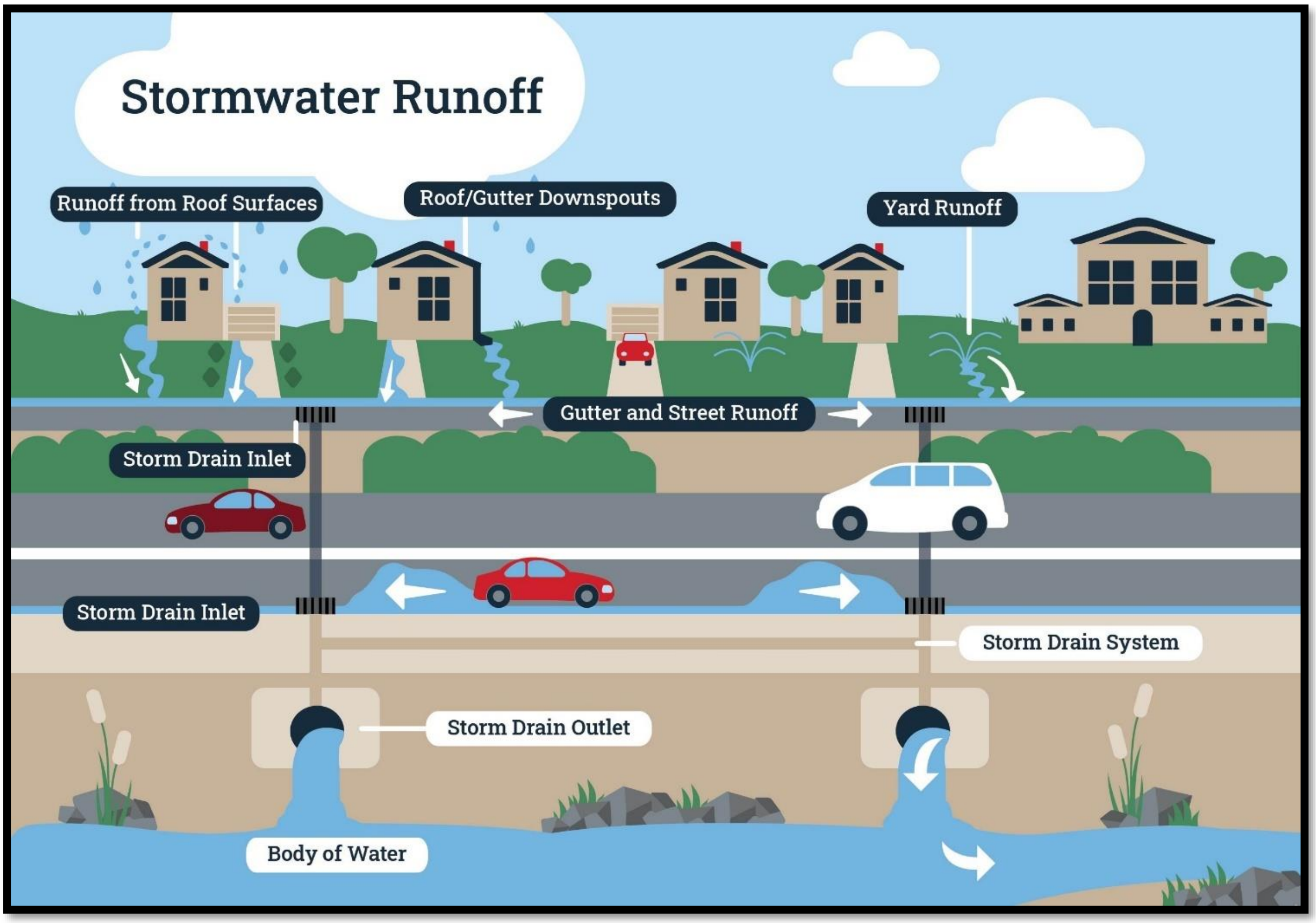
4.1.4 Strom and Combined Sewerage System

4.1.4 STROM AND COMBINED SEWERAGE SYSTEM

Sewerage systems are crucial for managing wastewater in urban and suburban areas. There are two primary types of sewerage systems: storm sewer systems and combined sewer systems. Each has distinct features, purposes, and challenges. Here is an overview of both systems:

STORM SEWER SYSTEM

A storm sewer system is designed to collect and transport rainwater, melted snow, and surface runoff from streets, sidewalks, roofs, and other surfaces directly to nearby water bodies such as rivers, lakes, or oceans.



COMPONENTS

- **Catch Basins:** Collect runoff from streets and other surfaces.
- **Storm Drains:** Channels that carry runoff from catch basins to larger storm sewers.
- **Storm Sewers:** Large pipes or open channels that transport runoff to discharge points.
- **Outfalls:** Points where stormwater is discharged into water bodies.

ADVANTAGES

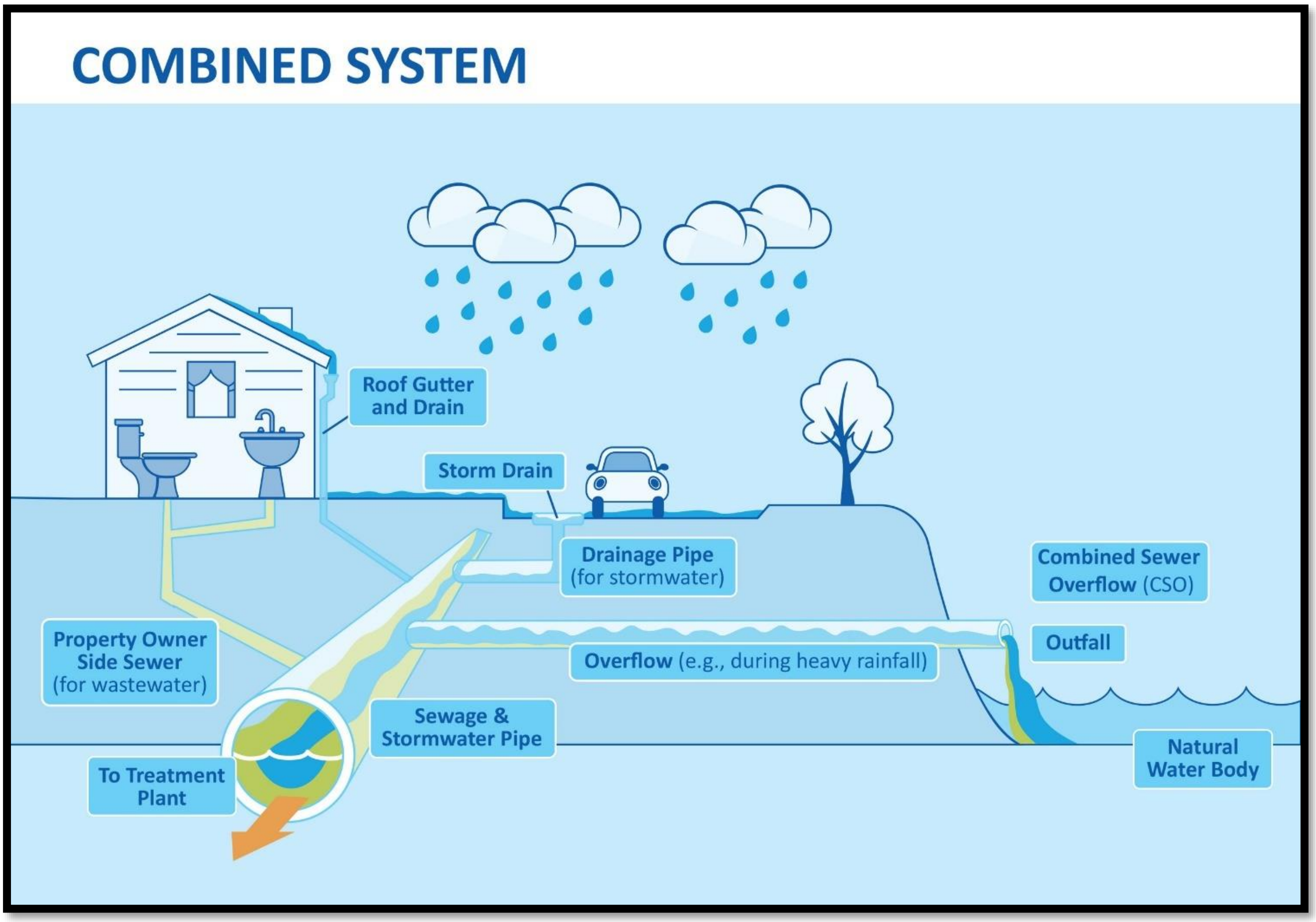
- **Flood Prevention:** Reduces the risk of flooding by quickly removing large volumes of runoff during heavy rains.
- **Separation of Flows:** Prevents the contamination of wastewater treatment plants with stormwater, reducing treatment loads and costs.

CHALLENGES

- **Pollution:** Stormwater can carry pollutants like oil, heavy metals, pesticides, and trash directly to water bodies without treatment.
- **Infrastructure Costs:** Construction and maintenance of separate storm sewer systems can be expensive.
- **Erosion:** High volumes of stormwater can cause erosion in natural waterways.

COMBINED SEWER SYSTEM

A combined sewer system (CSS) is designed to collect both wastewater (from homes, businesses, and industries) and stormwater runoff in a single pipe system. The combined flow is typically transported to a wastewater treatment plant before being discharged into a water body.



COMPONENTS

- **Combined Sewers:** Pipes that carry both sanitary wastewater and stormwater.
- **Interceptor Sewers:** Large sewers that receive flow from combined sewers and transport it to treatment plants.
- **Combined Sewer Overflow Outfalls:** Points where excess flow is discharged directly into water bodies during heavy rain events to prevent system overloads.

ADVANTAGES

- **Cost Efficiency:** Combining wastewater and stormwater in a single system can be more cost-effective, particularly in older cities where separate systems are not feasible.
- **Existing Infrastructure:** Utilizes existing infrastructure in older urban areas, reducing the need for extensive new construction.

CHALLENGES

- **Overflows:** During heavy rainfall, the capacity of combined sewer systems can be exceeded, resulting in combined sewer overflows (CSOs) that discharge untreated wastewater and stormwater into water bodies, posing significant environmental and public health risks.
- **Pollution Control:** Managing the quality of discharges during overflow events is challenging and often requires additional treatment or storage solutions.
- **Regulatory Compliance:** Meeting regulatory standards for water quality can be difficult, especially during overflow events.

MITIGATION STRATEGIES FOR COMBINED SEWER OVERFLOWS

1. **Green Infrastructure:**
   - **Permeable Pavement:** Allow water to infiltrate in ground, reducing runoff.
   - **Green Roofs:** Absorb rainwater and reduce the volume of runoff.
   - **Rain Gardens and Bioswales:** Natural landscapes designed to absorb and filter stormwater
2. **Storage Solutions:**
   - **Retention Basins:** Capture and temporarily store stormwater to prevent overflows.

- **Underground Storage Tanks:** Store excess combined flow during heavy rain events for later treatment.

3. **System Upgrades:**
   - **Sewer Separation:** Gradually converting combined systems to separate systems for stormwater and wastewater.
   - **Capacity Enhancements:** Increasing the capacity of existing sewer and treatment systems to handle larger volumes of combined flow.
4. **Advanced Treatment:**
   - **CSO Treatment Facilities:** Special facilities designed to treat overflow discharges before they reach water bodies.
   - **Disinfection:** Using chlorine, UV light, or ozone to reduce pathogen levels in overflow discharges.

CHAPTER-1

SESSION-36

4.1 GENERATION AND COLLECTION OF WASTE WATER

LEARNING OBJECTIVE

4.1.5 Quality of Waste Water

4.1.5 QUALITY OF WASTE WATER

The quality of wastewater varies significantly depending on its source, the types of pollutants it contains, and the level of treatment it undergoes. Assessing wastewater quality is crucial for determining the appropriate treatment methods and ensuring compliance with environmental regulations. Here are the key aspects to consider regarding the quality of wastewater:

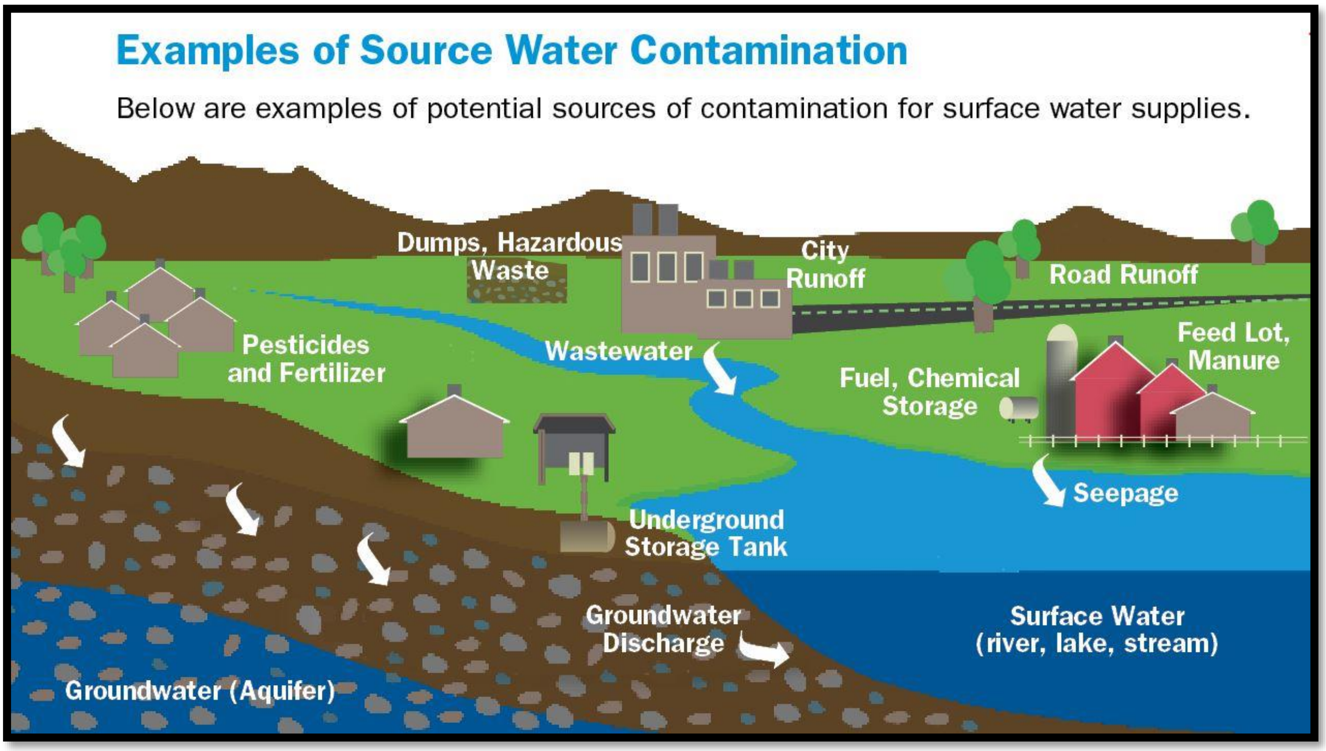
PARAMETERS AFFECTING WASTEWATER QUALITY

1. Physical Characteristics

2. Chemical Characteristics

3. Biological Characteristics

SOURCES OF WASTEWATER AND TYPICAL CONTAMINANTS



1. Domestic Wastewater

- **Greywater:** From sinks, showers, and laundry; contains soap, detergents, and food particles.
- **Blackwater:** From toilets; contains human waste, pathogens, and high organic content.

2. Industrial Wastewater

- **Manufacturing Processes:** Can contain a wide range of pollutants, including heavy metals, chemicals, and organic compounds.
- **Cooling Water:** Often discharged at elevated temperatures and may contain treatment chemicals.

3. Agricultural Wastewater

- **Runoff:** Contains fertilizers, pesticides, and animal waste.
- **Animal Farming:** High levels of organic matter, nutrients, and pathogens.

4. Stormwater Runoff

- **Urban Areas:** Carries pollutants like oil, heavy metals, and trash from streets and parking lots.
- **Rural Areas:** May carry soil particles, pesticides, and fertilizers.

MONITORING AND REGULATORY COMPLIANCE

1. Monitoring Programs

- **Regular Testing:** Ensures compliance with environmental regulations and standards.
- **Online Monitoring:** Uses sensors and automated systems to continuously track water quality parameters.

2. Regulations and Standards

- **EPA Guidelines (USA):** Establishes limits for contaminants in wastewater discharges.
- **European Union Directives:** Sets standards for wastewater treatment and discharge in member countries.
- **Local and National Regulations:** Vary by country and region, often requiring specific treatment processes and effluent quality standards.

CHAPTER-1

SESSION-37

4.1 GENERATION AND COLLECTION OF WASTE WATER

LEARNING OBJECTIVE

4.1.6 BOD and COD

4.1.6 BOD & COD

Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) are two important parameters used to measure the organic pollution levels in water bodies, particularly wastewater. While both are indicators of the amount of organic matter present, they measure different aspects and provide complementary information about water quality.

BIOCHEMICAL OXYGEN DEMAND (BOD)

Definition:

- BOD is the amount of dissolved oxygen consumed by microorganisms while decomposing organic matter in water over a specific period, usually five days at 20°C (BOD_5).

Significance:

- Indicator of Organic Pollution: BOD indicates the amount of biodegradable organic material present in water.
- Water Quality Assessment: It helps in assessing the level of pollution in water bodies and the effectiveness of wastewater treatment processes.
- Environmental Impact: High BOD levels can deplete dissolved oxygen in water, leading to adverse effects on aquatic life.

Measurement:

1. Sample Collection: Water samples are collected and stored in airtight containers to prevent oxygen loss.
2. Incubation: The samples are incubated at a constant temperature (usually 20°C) for five days in the dark to mimic natural conditions.
3. Dissolved Oxygen Measurement: The initial and final dissolved oxygen levels are measured using a dissolved oxygen meter. The difference between the initial and final readings represents the BOD.

CHEMICAL OXYGEN DEMAND (COD)

Definition:

- COD is the amount of oxygen required to chemically oxidize organic and inorganic compounds in water.

Significance:

- Measures Total Oxygen Demand: COD measures the total amount of oxygen required to oxidize all organic and inorganic substances present in water, regardless of their biodegradability.

- Rapid Assessment: It provides a quicker estimate of the pollution level compared to BOD.
- Environmental Impact: High COD levels indicate a high concentration of organic and inorganic substances that can exert oxygen demand in water bodies.

Measurement:

1. Sample Preparation: Water samples are mixed with a strong oxidizing agent, typically potassium dichromate, in an acidic medium.
2. Heating: The mixture is heated to facilitate the oxidation reaction.
3. Titration: After cooling, the remaining oxidizing agent is titrated with a reducing agent (e.g., ferrous ammonium sulphate) to determine the amount consumed. The difference in the volume of the titrant before and after the reaction indicates the COD.

COMPARISON AND APPLICATIONS:

BOD vs. COD:

- **Nature of Measurement:**
  - BOD measures the biological oxygen demand resulting from microbial decomposition.
  - COD measures the chemical oxygen demand resulting from the oxidation of organic and inorganic compounds.
- **Time Requirement:**
  - BOD analysis typically takes five days, while COD analysis can be completed within a few hours.
- **Scope:**
  - BOD measures only biodegradable organic matter, while COD measures both biodegradable and non-biodegradable substances.
- **Relevance:**
  - BOD is more relevant for assessing the impact of organic pollutants on aquatic ecosystems and the efficiency of biological treatment processes.

- COD provides a broader measure of the overall pollution level and is often used for rapid water quality assessment.

CHAPTER-1

SESSION-38

4.1 GENERATION AND COLLECTION OF WASTE WATER

LEARNING OBJECTIVE

4.1.7 Disposal of sewage effluents

4.1.7 DISPOSAL OF SEWAGE EFFLUENTS

Disposal of sewage effluents is a crucial aspect of wastewater management to prevent environmental pollution and protect public health. Here are several methods commonly used for sewage effluent disposal:

1. **Sewage Treatment Plants (STPs):** Many urban areas have sewage treatment plants where effluents undergo various treatment processes such as physical, chemical, and biological treatments to remove contaminants before discharge.
2. **Direct Discharge to Water Bodies:** Treated sewage effluents can be discharged directly into rivers, lakes, or oceans after meeting specific regulatory standards. This method requires careful monitoring to prevent water contamination.
3. **Land Application:** Treated effluents can be applied to agricultural lands as irrigation water or for fertilization purposes. This can be an effective method, provided the effluents are adequately treated to remove harmful pathogens and chemicals.
4. **Constructed Wetlands:** Constructed wetlands mimic natural wetland ecosystems and utilize plants and microorganisms to treat sewage effluents. This method can be cost-effective and environmentally friendly.
5. **Reclamation and Reuse:** Treated sewage effluents can be reclaimed and reused for non-potable purposes such as irrigation, industrial processes, and toilet flushing. This helps conserve freshwater resources and reduces the demand on potable water sources.
6. **Evaporation Ponds:** In arid regions, effluents can be disposed of in evaporation ponds where they are allowed to evaporate, leaving behind concentrated solids for further treatment or disposal.

7. **Deep Well Injection:** In some cases, treated effluents are injected deep underground into non-potable aquifers. This method requires careful site selection and monitoring to prevent groundwater contamination.

Each method has its advantages and limitations, and the selection of an appropriate disposal method depends on factors such as local regulations, available infrastructure, environmental considerations, and economic feasibility. Effective sewage effluent disposal requires a combination of proper treatment, monitoring, and regulatory oversight to minimize environmental impacts and protect public health.

CHAPTER-1

SESSION-39

4.1 GENERATION AND COLLECTION OF WASTE WATER

LEARNING OBJECTIVE

4.1.8 Design of Swears

4.1.8 DESIGN OF SEWERS

Designing sewers involves careful consideration of various factors to ensure efficient and effective conveyance of wastewater while minimizing environmental impacts. Here are the key aspects involved in the design of sewers:

1. **Hydraulic Design:** The hydraulic design of sewers involves determining the size, slope, and capacity of the sewer pipes to adequately convey the expected flow of wastewater. Factors such as peak flow rates, population growth projections, and rainfall patterns are considered to size the sewers appropriately.
2. **Slope and Alignment:** Sewers are typically designed with a slope to facilitate gravity flow of wastewater towards the treatment plant or disposal point. The alignment of sewers should minimize excavation and disruption to existing infrastructure while ensuring efficient flow.
3. **Pipe Materials:** The selection of pipe materials depends on factors such as soil conditions, corrosiveness of wastewater, and durability requirements. Common materials used for sewer pipes include vitrified clay, concrete, PVC, and HDPE (high-density polyethylene).

4. **Manholes and Access Points:** Manholes are installed along the sewer line to provide access for inspection, maintenance, and cleaning. The spacing and location of manholes should be determined based on accessibility requirements and hydraulic considerations.
5. **Inflow and Infiltration (I&I) Control:** Inflow and infiltration of stormwater into sewer systems can overload the treatment plant and cause sewer overflows. Design measures such as sealed manhole covers, infiltration barriers, and separate stormwater systems help control I&I.
6. **Pump Stations:** In areas where gravity flow is not feasible, pump stations are installed to lift wastewater to a higher elevation for further conveyance. The design of pump stations includes considerations such as pump capacity, head requirements, and backup systems for reliability.
7. **Regulatory Compliance:** Sewer design must comply with local regulations and standards related to wastewater discharge, environmental protection, and public health. Designers need to be familiar with applicable codes and guidelines to ensure regulatory compliance.
8. **Future Expansion and Maintenance:** Sewer systems should be designed with provisions for future expansion to accommodate population growth and urban development. Additionally, maintenance requirements such as access for cleaning and repair should be incorporated into the design.
9. **Sustainability Considerations:** Designing sustainable sewer systems involves minimizing energy consumption, reducing greenhouse gas emissions, and incorporating green infrastructure practices such as rain gardens and permeable pavement to manage stormwater runoff.

Overall, the design of sewers requires interdisciplinary expertise in hydraulics, civil engineering, environmental science, and urban planning to create resilient and sustainable wastewater infrastructure. Collaboration with stakeholders and community engagement are also essential for successful sewer design projects.

4.1 GENERATION AND COLLECTION OF WASTE WATER

LEARNING OBJECTIVE

4.1.9 Primary treatment of wastewater

4.1.9 PRIMARY TREATMENT OF WASTEWATER

Primary treatment of wastewater involves the physical separation of solids and liquids to reduce the pollutant load before further treatment. Here is an overview of the primary treatment processes:

1. **Screening:** The wastewater passes through screens or grates to remove large debris such as sticks, rags, plastics, and other solid objects. Screening prevents damage to pumps and equipment downstream and protects the treatment processes.
2. **Grit Removal:** After screening, the wastewater may undergo grit removal to separate sand, gravel, and other heavy particles. Grit removal prevents abrasion and damage to pumps, pipes, and equipment in subsequent treatment processes.
3. **Primary Sedimentation:** The wastewater flows into primary sedimentation tanks, also known as primary clarifiers or settling tanks. In these tanks, the flow velocity is reduced, allowing suspended solids and organic matter to settle to the bottom as sludge, while fats, oils, and grease (FOG) float to the surface and form a scum layer. The settled sludge is pumped out for further treatment, while the scum is skimmed off.
4. **Equalization:** In some wastewater treatment plants, equalization basins are used to homogenize flow and pollutant concentrations. This helps stabilize the treatment process and mitigate fluctuations in wastewater characteristics.
5. **Flow Measurement:** Flow measurement devices such as flow meters are often installed to monitor the flow rate of wastewater entering the treatment plant. Accurate flow measurement is essential for process control and optimization.

Primary treatment primarily focuses on the physical removal of solids and the initial separation of organic matter, reducing the biochemical oxygen demand (BOD) and suspended solids (SS) in the wastewater. While primary treatment alone is not sufficient to meet stringent discharge standards, it serves as a crucial first step in the wastewater treatment process, preparing the wastewater for further treatment processes such as secondary treatment (biological treatment) and tertiary treatment (advanced or final treatment).

4.1 GENERATION AND COLLECTION OF WASTE WATER

LEARNING OBJECTIVE

4.1.10 Secondary treatment of wastewater

4.1.10 SECONDARY TREATMENT OF WASTEWATER

Secondary treatment of wastewater involves the biological process of removing dissolved and suspended organic matter that remains after primary treatment. This step aims to further reduce the biochemical oxygen demand (BOD) and suspended solids (SS) to levels that meet regulatory standards for discharge into receiving water bodies. Here are the key processes involved in secondary treatment:

1. **Activated Sludge Process:** In this widely used method, wastewater is mixed with activated sludge—a microbial culture of aerobic microorganisms—in aeration tanks. Oxygen is supplied to support the growth of aerobic bacteria, which metabolize organic matter in the wastewater, converting it into carbon dioxide, water, and microbial biomass. After aeration, the wastewater-sludge mixture enters clarifiers where the activated sludge settles out, and the clarified water is discharged or subjected to further treatment.
2. **Trickling Filter Process:** In trickling filters, wastewater is distributed over a bed of rock, plastic media, or other support material. Aerobic microorganisms attached to the media consume organic matter as the wastewater trickles over them. The treated wastewater is collected at the bottom of the filter and sent to clarifiers for separation of solids. Trickling filters are known for their simplicity and effectiveness in treating wastewater with low-to-moderate organic loads.
3. **Rotating Biological Contactors (RBCs):** RBCs consist of multiple rotating discs partially submerged in wastewater. Microorganisms attached to the discs are exposed to alternating aerobic and anaerobic conditions as they rotate through

the wastewater. This promotes the biological breakdown of organic matter. Treated wastewater is separated from the biomass in clarifiers.

4. **Sequential Batch Reactors (SBRs):** SBRs are a variation of activated sludge systems where wastewater treatment occurs in batches rather than continuously. The process consists of alternating cycles of filling, aeration, settling, and decanting, all within a single reactor tank. SBRs offer flexibility and efficiency in wastewater treatment.
5. **Constructed Wetlands:** Constructed wetlands mimic natural wetland ecosystems and utilize plants, microorganisms, and soil to treat wastewater. Wastewater flows through shallow basins or channels planted with wetland vegetation, where physical, chemical, and biological processes remove contaminants. Constructed wetlands are particularly suitable for decentralized wastewater treatment and ecological restoration.

Secondary treatment significantly reduces the organic and microbial content of wastewater, making it safer for discharge into receiving water bodies or suitable for reuse in irrigation, industrial processes, or groundwater recharge. After secondary treatment, wastewater may undergo tertiary treatment for further polishing or disinfection before discharge.

CHAPTER-1

SESSION-42

4.1 GENERATION AND COLLECTION OF WASTE WATER

LEARNING OBJECTIVE

4.11.11 Tertiary treatment of wastewater

4.1.11 TERTIARY TREATMENT OF WASTEWATER

Tertiary treatment of wastewater is the final stage in the treatment process, aimed at further improving water quality beyond what is achieved through primary and secondary treatment. Tertiary treatment is typically employed to meet stringent regulatory standards for discharge into sensitive receiving water bodies or to prepare wastewater for reuse in non-potable applications. Here are some common methods used in tertiary treatment:

1. **Filtration:** Filtration processes such as sand filtration, multimedia filtration, or membrane filtration are used to remove fine suspended solids, residual organic matter, and microorganisms from wastewater. Filtration can effectively polish the effluent and achieve high-quality water suitable for discharge or reuse.
2. **Disinfection:** Disinfection is essential to eliminate pathogens and harmful microorganisms from wastewater before discharge or reuse. Common disinfection methods include chlorination, ultraviolet (UV) irradiation, ozonation, and chlorine dioxide treatment. Disinfection helps protect public health and prevent the spread of waterborne diseases.
3. **Nutrient Removal:** Nutrient removal is necessary to prevent eutrophication of receiving water bodies caused by excessive concentrations of nitrogen and phosphorus in wastewater effluent. Biological nutrient removal processes, such as enhanced biological phosphorus removal (EBPR) and simultaneous nitrification-denitrification, are employed to reduce nutrient levels to regulatory limits.
4. **Advanced Oxidation Processes (AOPs):** AOPs involve the use of powerful oxidizing agents such as ozone, hydrogen peroxide, or UV/hydrogen peroxide to degrade refractory organic compounds, pharmaceuticals, and emerging contaminants present in wastewater. AOPs can effectively degrade trace pollutants and improve water quality.
5. **Membrane Processes:** Membrane-based technologies such as reverse osmosis (RO), nanofiltration (NF), and ultrafiltration (UF) are used for advanced treatment and concentration of wastewater constituents. Membrane processes can remove dissolved solids, organic matter, and trace contaminants to produce high-quality effluent suitable for reuse or discharge.
6. **Adsorption:** Adsorption processes involve the use of activated carbon or other adsorbents to remove dissolved organic compounds, trace contaminants, and Odor-causing substances from wastewater. Adsorption is effective in polishing effluent and improving water quality.
7. **Ion Exchange:** Ion exchange processes can be used to remove specific ions or trace contaminants from wastewater by exchanging them with ions present on an exchange resin. Ion exchange is effective for selective removal of heavy metals, nutrients, and other contaminants.

Tertiary treatment plays a critical role in producing high-quality effluent that meets regulatory requirements for discharge or reuse in various applications, including irrigation, industrial processes, and environmental restoration. The selection of tertiary treatment methods depends on factors such as effluent quality goals, treatment objectives, site-specific conditions, and regulatory requirements.

4.1 GENERATION AND COLLECTION OF WASTE WATER

LEARNING OBJECTIVE

4.11.12 Wastewater Disposal Standard

4.1.12 WASTEWATER DISPOSAL STANDARD

Wastewater disposal standards, also known as effluent standards or discharge limits, are regulatory guidelines established by government agencies to protect public health and the environment by setting limits on the quality of wastewater that can be discharged into receiving water bodies or onto land. These standards typically specify maximum allowable concentrations of various pollutants, including organic matter, nutrients, pathogens, heavy metals, and other contaminants.

The specific wastewater disposal standards vary from country to country and may also differ at the regional or local level. They are often based on scientific research, risk assessment, and considerations of environmental impact. Here are some common components of wastewater disposal standards:

1. **Pollutant Concentrations:** Standards typically specify maximum allowable concentrations of pollutants in wastewater effluent, such as biochemical oxygen demand (BOD), total suspended solids (TSS), ammonia, phosphorus, nitrogen, heavy metals (e.g., lead, mercury, cadmium), pathogens (e.g., faecal coliforms), and specific organic compounds (e.g., pesticides, pharmaceuticals).
2. **Discharge Limits:** Wastewater disposal standards may include numerical limits on pollutant discharges, expressed as concentration values (e.g., milligrams per litter) or mass loadings (e.g., kilograms per day). These limits are designed to prevent water pollution and protect the quality of receiving water bodies, such as rivers, lakes, and coastal waters.
3. **Treatment Requirements:** Standards may specify the type and level of treatment required for different types of wastewater discharges, based on factors

such as the source of wastewater, its characteristics, and the sensitivity of the receiving environment. Treatment technologies and processes are selected to achieve compliance with effluent standards.

4. **Monitoring and Reporting:** Regulatory agencies often require wastewater dischargers to monitor their effluent quality regularly and report the results to demonstrate compliance with discharge limits. Monitoring may involve sampling and analysis of wastewater samples for various parameters, as well as maintaining records of operational data and treatment performance.
5. **Enforcement and Compliance:** Government agencies responsible for regulating wastewater disposal enforce compliance with effluent standards through inspections, audits, enforcement actions, and penalties for non-compliance. Regulatory authorities may issue permits or licenses to wastewater dischargers, specifying the conditions and requirements for discharge.

Wastewater disposal standards play a crucial role in protecting water quality, safeguarding public health, and preserving the integrity of aquatic ecosystems. They provide a regulatory framework for managing wastewater treatment and disposal activities, promoting sustainable development, and minimizing environmental impacts. Compliance with effluent standards is essential for ensuring responsible wastewater management and sustainable use of water resources.

PROBABLE QUESTIONS

1. Describe the sources and composition of wastewater generated in urban, suburban, and rural areas, including domestic, industrial, commercial, and institutional sources, and their implications for wastewater treatment and disposal.
2. Analyse the factors influencing the quantity and quality of wastewater generated, including population density, water use patterns, land use practices, industrial activities, and seasonal variations in precipitation and runoff.
3. Discuss the principles and challenges of wastewater collection systems, including gravity sewerage networks, pressure sewer systems, and vacuum sewer systems, in conveying sanitary waste and stormwater runoff to treatment facilities.
4. Evaluate the design considerations for sanitary sewer systems, including pipe materials, slope requirements, hydraulic capacity, flow velocities, and access points, to prevent blockages, backups, and overflows.

5. Explore the principles and practices of stormwater management, including green infrastructure, low impact development (LID) techniques, and sustainable drainage systems (SuDS), in reducing urban runoff, flood risk, and pollution of receiving waters.

6. Describe the differences between sanitary sewer systems, storm sewer systems, and combined sewerage systems in terms of design, function, and operation, including their respective roles in managing wastewater and stormwater runoff.
7. Analyse the challenges and risks associated with combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs), including water quality impacts, public health hazards, and regulatory compliance requirements.
8. Discuss the principles and practices of sewer separation and rehabilitation to mitigate CSOs and SSOs, including pipe lining, pipe bursting, sewer relining, and construction of separate stormwater detention and treatment facilities.
9. Evaluate the potential benefits and trade-offs of integrated urban water management approaches that promote the integration of sanitary, storm, and groundwater systems, such as decentralized wastewater treatment, water reuse, and aquifer recharge.
10. Propose strategies for enhancing the resilience and adaptive capacity of sewerage systems to climate change impacts, such as increased precipitation, sea-level rise, and extreme weather events, through infrastructure upgrades, green infrastructure investments, and adaptive management measures.

11. Discuss the methods and tools used to estimate the quantities of sanitary waste and stormwater generated in urban and rural areas, including population projections, water consumption data, rainfall records, and land use inventories.
12. Analyse the factors influencing the spatial and temporal distribution of sanitary waste and stormwater flows, including land topography, soil characteristics, vegetation cover, impervious surfaces, and drainage infrastructure.
13. Evaluate the impacts of urbanization, population growth, and climate change on the hydrological cycle, including alterations to precipitation patterns, runoff coefficients, streamflow regimes, and groundwater recharge rates.
14. Discuss the challenges and opportunities associated with managing peak flows of sanitary waste and stormwater during extreme weather events, including strategies for flood risk reduction, storm surge protection, and emergency response planning.

15. Describe the design criteria and standards for sewerage systems, including pipe diameter, slope, capacity, and alignment, as well as construction materials, joint types, and bedding requirements.
16. Analyse the principles and methods of hydraulic design for sewer networks, including open channel flow calculations, Manning's equation, Hazen-Williams formula, and computer modelling techniques, to optimize pipe sizing and layout.
17. Evaluate the structural design considerations for sewer pipes, manholes, junctions, and appurtenances, including factors such as soil loadings, traffic loads, groundwater pressures, and seismic forces, to ensure system integrity and durability.
18. Discuss the principles of sewerage system maintenance and operation, including inspection, cleaning, flushing, and rehabilitation techniques, to prevent blockages, leaks, collapses, and infiltration/exfiltration issues.
19. Explore the challenges and opportunities associated with the design and implementation of sustainable sewerage systems, including decentralized treatment technologies, rainwater harvesting, greywater reuse, and water-sensitive urban design (WSUD) approaches.
20. Propose strategies for enhancing the efficiency, reliability, and resilience of sewerage systems through innovation, collaboration, and adaptive management practices, including asset management planning, performance benchmarking, and stakeholder engagement initiatives.

21. Describe the objectives and processes of primary treatment of wastewater, including screening, grit removal, sedimentation, and primary clarification, in reducing suspended solids, grit, and floating debris prior to biological treatment.
22. Discuss the principles and applications of secondary treatment processes, such as activated sludge, trickling filters, rotating biological contactors (RBCs), and membrane bioreactors (MBRs), in removing organic pollutants, nutrients, and pathogens from wastewater.
23. Analyse the factors influencing the selection and design of secondary treatment systems, including influent characteristics, effluent requirements, treatment efficiency, energy consumption, and lifecycle costs.
24. Evaluate the benefits and challenges of tertiary treatment processes, including filtration, adsorption, disinfection, and advanced oxidation, in polishing wastewater effluent to meet specific water quality standards and reuse criteria.

25. Explore the principles and applications of advanced wastewater treatment technologies, such as membrane filtration, reverse osmosis, ultraviolet (UV) disinfection, and ozonation, in achieving high-quality effluent for non-potable reuse applications.
26. Describe the regulatory framework governing wastewater disposal standards and effluent discharge limits, including federal, state, and local regulations, as well as international guidelines and best management practices.
27. Analyse the environmental and public health implications of wastewater discharges to surface waters, including nutrient enrichment, eutrophication, aquatic habitat degradation, and waterborne disease transmission.
28. Discuss the challenges and opportunities associated with wastewater reuse and recycling initiatives, including indirect potable reuse, industrial reuse, agricultural irrigation, and landscape irrigation, in reducing freshwater demand and promoting sustainable water management practices.
29. Evaluate the role of water quality monitoring, sampling, and reporting programs in ensuring compliance with wastewater disposal standards, including the use of performance metrics, enforcement mechanisms, and public transparency initiatives.
30. Propose strategies for enhancing wastewater treatment and disposal practices to meet emerging regulatory requirements, address evolving water quality concerns, and promote ecosystem protection and human health outcomes.

MODULE-5

CHAPTER-1
SESSION-43

5.1 BASIC OF MICROBIOLOGY

LEARNING OBJECTIVE
5.1.1 Introduction

5.1.1 INTRODUCTION

Microbiology is the branch of biology that deals with the study of microorganisms, which are microscopic organisms such as bacteria, viruses, fungi, algae, and protozoa. In water treatment, microbiology plays a crucial role in ensuring the safety and quality of drinking water by monitoring and controlling microbial contaminants. Here are some basics of microbiology in water treatment:

1. **Microbial Contaminants:** Water sources can be contaminated with various microorganisms, including bacteria, viruses, protozoa, and fungi. These contaminants can pose health risks if consumed, causing waterborne diseases such as diarrhoea, cholera, typhoid fever, and gastroenteritis.
2. **Microbial Testing:** Microbiological testing of water samples is performed to detect and quantify microbial contaminants. Common tests include the analysis of indicator organisms such as coliform bacteria (e.g., Escherichia coli) and faecal indicator bacteria (e.g., total coliforms, faecal coliforms) to assess water quality and the presence of potential pathogens.
3. **Waterborne Pathogens:** Pathogenic microorganisms present in water sources can originate from human and animal faecal contamination, sewage discharge, agricultural runoff, and environmental sources. Waterborne pathogens include bacteria (e.g., Salmonella, Campylobacter), viruses (e.g., Norovirus, Hepatitis A virus), protozoa (e.g., Giardia, Cryptosporidium), and helminths (parasitic worms).
4. **Water Treatment Processes:** Water treatment plants employ various physical, chemical, and biological processes to remove microbial contaminants and ensure the safety of drinking water. Common treatment processes include:

- **Coagulation and Flocculation:** Chemical coagulants such as aluminium sulphate (alum) or ferric chloride are added to water to destabilize suspended particles and facilitate their removal through sedimentation and filtration.
- **Filtration:** Water passes through granular media filters (e.g., sand, anthracite) to remove suspended solids, turbidity, and microbial contaminants.
- **Disinfection:** Chemical disinfectants such as chlorine, chloramine, ozone, or UV irradiation are used to kill or inactivate microbial pathogens present in water. Disinfection is the final step in water treatment and provides a barrier against waterborne diseases.
- **Advanced Treatment:** Additional treatment processes such as membrane filtration, activated carbon adsorption, and advanced oxidation are employed to remove trace contaminants, disinfection byproducts, and emerging pathogens from water.

5. **Monitoring and Compliance:** Regulatory agencies establish water quality standards and guidelines for microbial contaminants in drinking water to protect public health. Water utilities are required to monitor water quality regularly, conduct microbial testing, and ensure compliance with regulatory standards for microbial contaminants.
6. **Public Health Protection:** Effective water treatment and microbial control are essential for safeguarding public health and preventing waterborne disease outbreaks. Proper sanitation, hygiene practices, and maintenance of water infrastructure are also critical for ensuring the safety of drinking water supplies.

Microbiology in water treatment involves the interdisciplinary application of microbiological principles, water chemistry, engineering, and public health to ensure the provision of safe and potable drinking water to communities.

5.1 BASIC OF MICROBIOLOGY

LEARNING OBJECTIVE
5.1.2 Biological wastewater treatment system
5.1.3 ASP

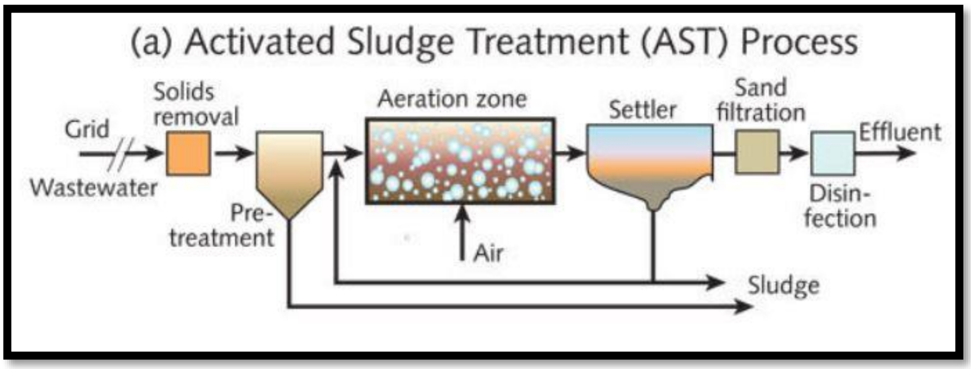
5.1.2 BIOLOGICAL WASTEWATER TREATMENT SYSTEM

Biological wastewater treatment systems utilize microorganisms to degrade organic pollutants and remove nutrients from wastewater. These systems harness the metabolic activities of bacteria, archaea, fungi, algae, and protozoa to break down organic matter, convert nutrients, and reduce the pollutant load in wastewater. Here are the key components and processes of biological wastewater treatment systems:

1. Activated Sludge Process (ASP)
2. Trickling Filter Process
3. Rotating Biological Contactors (RBCs)
4. Sequencing Batch Reactors (SBRs)
5. Constructed Wetlands
6. Anaerobic Digestion

Biological wastewater treatment systems are effective in removing organic pollutants, reducing nutrient concentrations (e.g., nitrogen and phosphorus), and improving the quality of treated wastewater for discharge into receiving water bodies or reuse in non-potable applications. These systems are environmentally sustainable, cost-effective, and can be tailored to specific wastewater characteristics and treatment objectives

5.1.3 ASP



The Activated Sludge Process (ASP) is a biological wastewater treatment method widely used in municipal and industrial wastewater treatment plants. It involves the use of microbial communities to degrade organic pollutants and remove nutrients from wastewater. Here is a detailed overview of the ASP:

1. **Primary Treatment:** The ASP typically follows primary treatment processes such as screening and sedimentation to remove large solids and grit from the wastewater. Primary treated wastewater, often referred to as primary effluent, enters the ASP for further treatment.
2. **Aeration Tank:** The heart of the ASP is the aeration tank, also known as the biological reactor or oxidation ditch. In the aeration tank, the primary effluent is mixed with a culture of microorganisms known as activated sludge. The microorganisms include bacteria, fungi, protozoa, and other organisms capable of metabolizing organic matter.
3. **Aeration:** Oxygen is supplied to the aeration tank to support the growth of aerobic microorganisms. Aeration is typically achieved using mechanical aerators, diffusers, or surface aerators. The dissolved oxygen concentration in the aeration tank is maintained at levels that promote the aerobic degradation of organic pollutants.
4. **Microbial Metabolism:** The microorganisms in the activated sludge metabolize organic matter in the wastewater as a source of energy and carbon. They utilize organic compounds such as sugars, proteins, and fats as substrates, breaking them down into simpler compounds such as carbon dioxide, water, and microbial biomass.
5. **Biological Reactions:** Several biological reactions occur during ASP, including:
    - **Hydrolysis:** Complex organic compounds are hydrolysed into simpler molecules by extracellular enzymes produced by microorganisms.
    - **Aerobic Oxidation:** Aerobic bacteria oxidize organic molecules, releasing energy for their growth and reproduction.
    - **Nitrification:** Ammonium (NH_4^+) is converted to nitrite (NO_2^-) and then to nitrate (NO_3^-) by nitrifying bacteria (Nitrosomonas and Nitrobacter).

- **Denitrification:** Nitrate is converted to nitrogen gas (N_2) by denitrifying bacteria under anaerobic conditions, reducing nitrogen levels in the effluent.
- **Phosphorus Removal:** Some microorganisms can accumulate phosphorus within their cells, facilitating its removal from the wastewater.

6. **Mixed Liquor:** The mixture of wastewater and activated sludge in the aeration tank is known as mixed liquor. The mixed liquor contains suspended solids, microbial biomass, and dissolved compounds undergoing biological treatment.
7. **Settling and Separation:** After aeration, the mixed liquor flows to clarifiers or sedimentation tanks where the suspended solids settle out by gravity. The settled sludge, known as return activated sludge (RAS), is recycled back to the aeration tank to maintain the population of microorganisms. The clarified effluent, known as secondary effluent, is discharged, or subjected to further treatment.
8. **Disinfection:** The secondary effluent may undergo disinfection using chemical disinfectants (e.g., chlorine, ozone) or physical methods (e.g., UV irradiation) to inactivate remaining pathogens and ensure the safety of the treated wastewater.
9. **Sludge Management:** Excess activated sludge generated during ASP is periodically wasted from the system and sent to sludge treatment processes such as digestion, dewatering, and drying for further treatment or disposal.

The Activated Sludge Process is a highly efficient and versatile method for treating wastewater, capable of achieving high removal efficiencies for organic pollutants, nutrients, and pathogens. It can be tailored to specific treatment objectives and operational conditions, making it suitable for a wide range of wastewater treatment applications. However, proper operation and maintenance are essential to ensure optimal performance and compliance with regulatory standards.

5.1 BASIC OF MICROBIOLOGY

LEARNING OBJECTIVE

5.1.4 Trickling filter

5.1.4 TRICKLING FILTER

A trickling filter is a biological wastewater treatment system that utilizes attached growth microorganisms to remove organic matter and pollutants from wastewater. It consists of a bed of media (typically rock, gravel, or synthetic material) over which wastewater is distributed and allowed to trickle down through the media. Here is a detailed overview of the trickling filter process:

1. **Media Bed:** The trickling filter is filled with a bed of porous media, such as rock or synthetic material, which provides a surface area for the attachment and growth of microbial biofilm. The media bed is typically several feet thick and may be contained within a tank or open structure.
2. **Distribution System:** Wastewater is evenly distributed over the surface of the media bed using a distribution system, such as spray nozzles, rotating arms, or perforated pipes. The distribution system ensures uniform wetting of the media and efficient contact between wastewater and microbial biofilm.
3. **Trickling Filtration:** Wastewater trickles down through the media bed by gravity, flowing over the surface of the media and meeting the microbial biofilm attached to the media particles. As the wastewater passes through the media, organic pollutants are absorbed and degraded by the microbial community.
4. **Microbial Biofilm:** Attached growth microorganisms, including bacteria, fungi, and protozoa, form a biofilm on the surface of the media particles. The biofilm provides a habitat for microbial communities, which metabolize organic matter and convert it into simpler compounds through biological processes such as aerobic respiration and fermentation.
5. **Aeration:** Oxygen is supplied to the trickling filter through natural aeration or forced aeration systems to support aerobic microbial activity. Adequate oxygen availability is essential for the growth and activity of aerobic bacteria responsible for organic matter degradation.

6. **Nutrient Removal:** In addition to organic matter removal, trickling filters can also remove nutrients such as nitrogen and phosphorus through microbial uptake and assimilation. Nitrogen removal occurs through nitrification and denitrification processes, while phosphorus removal may occur through microbial uptake and precipitation.
7. **Effluent Collection:** Treated wastewater, known as effluent, percolates through the media bed and is collected at the bottom of the trickling filter. The effluent typically contains reduced concentrations of organic matter, suspended solids, and pollutants compared to the influent wastewater.
8. **Clarification:** The effluent from the trickling filter may undergo further clarification in settling tanks or clarifiers to remove any remaining suspended solids and biomass. Clarification helps improve the quality of the treated effluent before discharge or further treatment.
9. **Maintenance:** Regular maintenance of trickling filters is essential to ensure optimal performance and microbial activity. This may include media cleaning, biofilm management, inspection of distribution systems, and monitoring of influent and effluent quality parameters.

Trickling filters are effective, cost-efficient, and environmentally sustainable wastewater treatment systems suitable for small to medium-sized treatment plants, decentralized applications, and upgrades of existing treatment facilities. They offer advantages such as low energy consumption, simplicity of operation, and robustness against hydraulic and organic load fluctuations. However, proper design, operation, and maintenance are essential to achieve desired treatment objectives and regulatory compliance

5.1.5 ANAEROBIC PROCESSES

Anaerobic processes in water treatment are biological treatment methods that occur in the absence of oxygen. These processes utilize anaerobic microorganisms to degrade organic pollutants and remove nutrients from wastewater. Anaerobic treatment can be applied to various types of wastewaters, including municipal wastewater, industrial effluents, and agricultural runoff. Here are some key anaerobic processes used in water treatment:

1. **Anaerobic Digestion:** Anaerobic digestion is a biological process in which organic matter is decomposed by anaerobic microorganisms in the absence of oxygen. It is commonly used for the treatment of sludge generated in wastewater treatment plants, as well as organic waste from food processing, agriculture, and other industries. In anaerobic digesters, organic waste undergoes microbial degradation, producing methane (biogas), carbon dioxide, water, and stabilized biosolids. Biogas produced during anaerobic digestion can be captured and used as a renewable energy source for heating, electricity generation, or transportation.
2. **Anaerobic Lagoon:** Anaerobic lagoons, also known as anaerobic ponds or biodigesters, are shallow, earthen basins used for the treatment of organic wastewater. Wastewater is directed into the lagoon, where it undergoes anaerobic digestion by indigenous anaerobic microorganisms naturally present in the environment. Anaerobic lagoons provide an environment conducive to microbial activity, with limited mixing and aeration. They are commonly used in agricultural operations, food processing plants, and decentralized wastewater treatment systems.

3. **Anaerobic Hybrid Reactor:** Anaerobic hybrid reactors combine anaerobic and aerobic treatment processes within a single reactor system to achieve enhanced treatment efficiency. The reactor consists of an anaerobic zone followed by an

aerobic zone, allowing for sequential treatment of organic matter under both anaerobic and aerobic conditions. Anaerobic hybrid reactors are used for the treatment of high-strength organic wastewater, industrial effluents, and landfill leachate.

4. **Anaerobic Membrane Bioreactor (AnMBR):** An anaerobic membrane bioreactor is a combination of anaerobic digestion and membrane filtration technologies for wastewater treatment. Anaerobic microorganisms degrade organic matter in the absence of oxygen, while membranes retain suspended solids and biomass, producing a high-quality effluent. AnMBRs offer advantages such as reduced footprint, energy savings, and minimal sludge production compared to conventional aerobic membrane bioreactors.
5. **Anaerobic Fluidized Bed Reactor (AFBR):** An anaerobic fluidized bed reactor utilizes a bed of granular media to support microbial biofilm growth and enhance anaerobic digestion. Wastewater is continuously circulated through the reactor, causing the media particles to become fluidized and creating a highly efficient mixing environment. Anaerobic bacteria attach to the media surface and degrade organic pollutants in the wastewater. AFBRs offer advantages such as high treatment efficiency, compact design, and reduced sludge production.

Anaerobic processes in water treatment offer several advantages, including energy recovery, reduced sludge production, and lower operating costs compared to aerobic treatment methods. However, they require careful control of operating conditions, such as temperature, pH, and hydraulic retention time, to optimize microbial activity and treatment performance. Additionally, anaerobic processes may not be suitable for the removal of certain pollutants, such as nutrients and refractory organic compounds, which may require additional treatment steps.

CHAPTER-1

SESSION-48

5.1.6 SLUDGE DIGESTION

Sludge digestion is a biological process used in wastewater treatment to stabilize and reduce the organic content of sludge, resulting in the production of methane (biogas) and stabilized biosolids. The process involves the decomposition of organic matter by anaerobic microorganisms in the absence of oxygen. Here is a detailed overview of sludge digestion:

1. **Sludge Collection:** Sludge is collected from various stages of the wastewater treatment process, including primary sedimentation tanks, secondary clarifiers, and sludge dewatering facilities. The collected sludge may contain organic matter, pathogens, and other contaminants removed during the treatment process.
2. **Anaerobic Digesters:** Sludge digestion typically takes place in anaerobic digesters, which are sealed tanks or reactors designed to create anaerobic conditions suitable for microbial activity. Anaerobic digesters may be cylindrical, rectangular, or spherical in shape, with various configurations and mixing mechanisms to promote efficient digestion.
3. **Sludge Conditioning:** Before digestion, sludge may undergo conditioning processes to improve its dewaterability and microbial activity. Conditioning methods may include chemical addition (e.g., lime stabilization, polymer addition), thermal treatment (e.g., pasteurization), or mechanical pretreatment (e.g., grinding, thickening).
4. **Loading and Mixing:** Sludge is loaded into the anaerobic digester, where it is mixed with recycled sludge (return activated sludge) and inoculated with anaerobic microorganisms. Mixing is essential to ensure uniform distribution of sludge and maintain optimal conditions for microbial activity, including temperature, pH, and nutrient availability.

5. **Microbial Activity:** Anaerobic microorganisms, primarily bacteria and archaea, metabolize organic matter in the sludge as a source of energy and carbon. The

microbial community includes acid-forming bacteria, acetogenic bacteria, and methanogenic archaea, each playing a specific role in the digestion process. Organic compounds such as proteins, carbohydrates, and lipids are hydrolysed, fermented, and converted into simpler compounds such as volatile fatty acids (VFAs), acetate, hydrogen, and carbon dioxide.

6. **Methane Production:** Methanogenic archaea metabolize VFAs and other organic acids to produce methane (CH4) and carbon dioxide (CO2) through a series of biochemical reactions. Methane production is a key characteristic of anaerobic digestion and results in the formation of biogas, a mixture of methane, carbon dioxide, and trace gases. Biogas can be collected and utilized as a renewable energy source for heating, electricity generation, or transportation.
7. **Digestion Phases:** Anaerobic digestion typically occurs in several phases, including:
   - **Hydrolysis:** Complex organic compounds are hydrolysed into simpler molecules by extracellular enzymes produced by acid-forming bacteria.
   - **Acidogenesis:** Fermentative bacteria metabolize organic compounds, producing VFAs, hydrogen, and other intermediate products.
   - **Acetogenesis:** Acetogenic bacteria convert VFAs and hydrogen into acetate and other short-chain fatty acids.
   - **Methanogenesis:** Methanogenic archaea produce methane and carbon dioxide from acetate, hydrogen, and carbon dioxide.
8. **Digestion Performance:** Anaerobic digestion performance is influenced by various factors, including temperature, pH, hydraulic retention time (HRT), organic loading rate (OLR), and digester configuration. Optimal operating conditions are essential to maximize methane production, minimize digester instability, and achieve effective sludge stabilization.
9. **Digestate Handling:** After digestion, the digested sludge, known as digested biosolids or digestate, undergoes further processing to remove excess water and prepare it for disposal or reuse. Digested biosolids may be dewatered using mechanical methods (e.g., centrifugation, belt presses) and then disposed of in landfills, incinerated, or beneficially reused as soil conditioner or fertilizer.

Sludge digestion is a critical component of wastewater treatment systems, providing sustainable management of sludge generated during the treatment process while recovering energy and producing stabilized biosolids for disposal or beneficial reuse.

Proper operation and maintenance of anaerobic digesters are essential to ensure efficient digestion performance, minimize Odors, and comply with environmental regulations.

CHAPTER-1

SESSION-49

5.1 BASIC OF MICROBIOLOGY

LEARNING OBJECTIVE

5.1.7 Disposal of sludge

5.1.7 DISPOSAL OF SLUDGE

The disposal of sludge, also known as biosolids, is an essential aspect of wastewater treatment operations. Sludge disposal aims to manage the residual solids generated during the treatment process in an environmentally responsible manner while adhering to regulatory requirements. Here are several common methods for sludge disposal:

1. **Land Application:** Sludge can be beneficially reused as a soil amendment or fertilizer through land application. Treated biosolids are applied to agricultural land, forests, or reclaimed sites to improve soil fertility, structure, and moisture retention. Land application provides a sustainable solution for sludge disposal, enhances soil health, and reduces the need for chemical fertilizers. However, careful management is required to prevent potential risks associated with nutrient runoff, pathogens, and heavy metals.
2. **Incorporation into Compost:** Sludge can be mixed with organic materials such as yard waste, food scraps, or agricultural residues to produce compost. Composting is a natural process that involves the decomposition of organic matter by microorganisms under aerobic conditions. The resulting compost can be used as a soil conditioner, potting mix, or landscaping material, providing a valuable product from sludge disposal.
3. **Thermal Treatment:** Sludge can be thermally treated through processes such as incineration, pyrolysis, or gasification to reduce volume, stabilize organic matter, and destroy pathogens. Incineration involves the combustion of sludge at high temperatures to generate heat and energy, while pyrolysis and gasification convert sludge into biochar, syngas, or other renewable energy products. Thermal

treatment offers effective sludge reduction and pathogen destruction but may require significant energy input and emission control measures.

4. **Anaerobic Digestion:** Sludge can undergo anaerobic digestion to produce biogas (methane) and stabilized biosolids. Anaerobic digestion is a biological process that occurs in the absence of oxygen, where microorganisms metabolize organic matter in sludge, producing methane as a byproduct. The biogas can be captured and utilized as a renewable energy source, while the digested biosolids can be dewatered and disposed of or beneficially reused.
5. **Landfill Disposal:** Sludge that cannot be beneficially reused or treated through other methods may be disposed of in sanitary landfills. Landfill disposal involves the containment and burial of sludge in engineered landfills designed to prevent environmental contamination and minimize Odor emissions. Landfill disposal is typically considered a last resort due to space constraints, environmental concerns, and regulatory restrictions.
6. **Deep Ocean Disposal:** In some regions, sludge may be disposed of in deep ocean waters under strict regulatory controls. Deep ocean disposal involves the offshore discharge of treated sludge into deep-sea trenches or designated disposal sites, where it is diluted and dispersed by ocean currents. Deep ocean disposal is controversial due to potential ecological impacts and regulatory limitations.

The selection of sludge disposal methods depends on various factors, including regulatory requirements, environmental considerations, treatment objectives, cost-effectiveness, and available infrastructure. Integrated sludge management approaches that combine multiple disposal methods, such as land application coupled with thermal treatment or composting, may offer sustainable solutions for sludge disposal while maximizing resource recovery and minimizing environmental impact.

CHAPTER-1

SESSION-50

5.1 BASIC OF MICROBIOLOGY

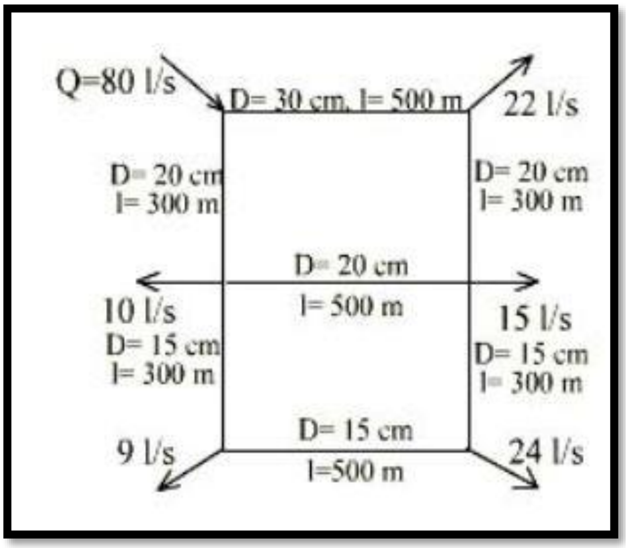
LEARNING OBJECTIVE

5.1.8 Waste water treatment unit

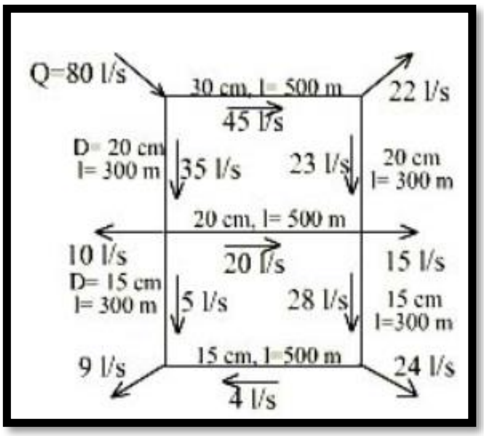
5.1.8 WASTE WATER TREATMENT UNIT

Flow in Pipes of a Distribution Network by Hardy Cross Method

Problem: Calculate the head losses and the corrected flows in the various pipes of a distribution network as shown in figure. The diameters and the lengths of the pipes used are given against each pipe. Compute corrected flows after one correction.



Solution: First, the magnitudes as well as the directions of the possible flows in each pipe are assumed keeping in consideration the law of continuity at each junction. The two closed loops, ABCD and CDEF are then analysed by Hardy Cross method as per tables 1 & 2 respectively, and the corrected flows are computed.



Consider loop ABCD

Pipe	Assumed flow		Dia of pipe		Length of pipe (m)	$K = \frac{L}{470\ d^{4.87}}$	$Q_a^{1.85}$	$H_L = K.Q_a^{1.85}$	$\lvert H_L/Q_a \rvert$
	in l/sec	in cumecs	d in m	$d^{4.87}$					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
AB	(+) 43	+0.043	0.30	$2.85\ X10^{-3}$	500	373	$3\ X10^{-3}$	+1.12	26
BC	(+) 23	+0.023	0.20	$3.95\ X10^{-4}$	300	1615	$9.4\ X10^{-4}$	+1.52	66
CD	(-) 20	-0.020	0.20	$3.95\ X10^{-4}$	500	2690	$7.2\ X10^{-4}$	-1.94	97
DA	(-) 35	-0.035	0.20	$3.95\ X10^{-4}$	300	1615	$2\ X10^{-3}$	-3.23	92
Σ								-2.53	281

* $H_L = (Q_a^{1.85} L)/(0.094 \times 100^{1.85}\ X\ d^{4.87})$

or $K.Q_a^{1.85} = (Q_a^{1.85} L)/(470\ X\ d^{4.87})$

or $K = (L)/(470\ X\ d^{4.87})$

For loop ABCD, we have d =-SH_L / x.S lH_L/Q_al

=(-) -2.53/(1.85 X 281) cumecs

=(-) (-2.53 X 1000)/(1.85 X 281) l/s

=4.86 l/s =5 l/s (say)

Hence, corrected flows after first correction are:

Pipe	AB	BC	CD	DA
Corrected flows after first correction in l/s	+ 48	+ 28	- 15	- 30

Consider loop DCFE

Pipe	Assumed flow		Dia of pipe		Length of pipe (m)	$K = \frac{L}{470\ d^{4.87}}$	$Q_a^{1.85}$	$H_L = K.Q_a^{1.85}$	$\lvert H_L/Q_a \rvert$
	in l/sec	in cumecs	d in m	$d^{4.87}$					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
DC	(+) 20	+0.020	0.20	3.95×10^{-4}	500	2690	7.2×10^{-4}	+1.94	97
CF	(+) 28	+0.028	0.15	9.7×10^{-5}	300	6580	1.34×10^{-3}	+8.80	314
FE	(-) 8	-0.008	0.15	9.7×10^{-5}	500	10940	1.34×10^{-4}	-1.47	184
ED	(-) 5	-0.005	0.15	9.7×10^{-5}	300	6580	5.6×10^{-5}	-0.37	74
Σ								+8.9	669

For loop ABCD, we have d =-SH_L / x.S lH_L/Q_al

=(-) +8.9/(1.85 X 669) cumecs

=(-) (+8.9 X 1000)/(1.85 X 669)) l/s

= -7.2 l/s

Hence, corrected flows after first correction are:

Pipe	DC	CF	FE	ED
Corrected flows after first correction in l/s	+ 12.8	+ 20.8	- 15.2	- 12.2

5.1 BASIC OF MICROBIOLOGY

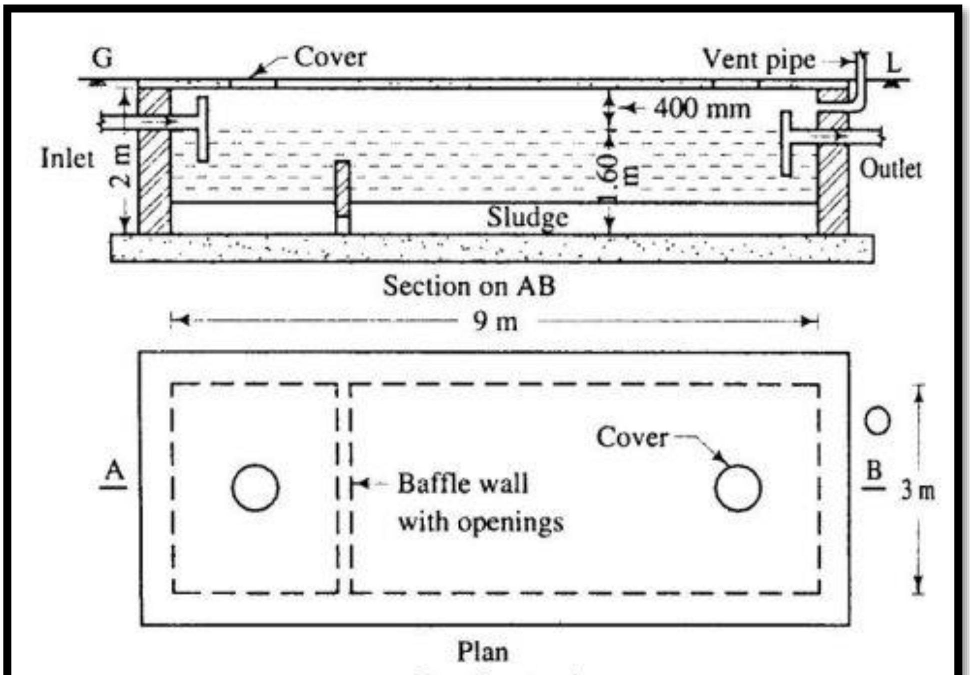
LEARNING OBJECTIVE

5.1.9 Waste water treatment unit

5.1.9 WASTE WATER TREATMENT UNIT

SEPTIC TANK

Septic tank is based on the principle of sedimentation of sewage and digestion of sludge. In this tank the sewage is detained for some period. During this detention period, the sewage is decomposed by anaerobic bacteria and the sludge is deposited at the bottom (as sedimentation tank). The digestion of sludge is carried out by the anaerobic bacteria (as digestion tank). The effluent is clear and it is discharged into the soak pit constructed at a suitable place.



Septic tank

USES: The septic tank is suitable for the towns where it is not possible to establish the water carriage system. It is provided in residential buildings, hostels, hotels, hospitals, schools, colleges, etc.

CONSTRUCTIONAL FEATURES: Fig shows a septic tank. The following are the constructional features of septic tank:

(i) It is a rectangular tank constructed with brick masonry over concrete foundation. The length is usually 3 times the breadth.

(ii) The liquid depth varies from 100-180 cm.

(iii) A free board of 30-50-cm is provided above the liquid level.

(iv) The inlet pipe and outlet pipe consist of ‗T ‘or ‗elbow ‘which are submerged to a depth of about 25cm below the liquid level

(v) The outlet level is about 15cm lower than the inlet level.

(vi) The inside surface of tank should be plastered and finished with neat cement polish to make it complete watertight.

(vii) For smaller tank single baffle wall should be provided. But for larger tank two baffles should be provided near both the ends.

(viii) The top of the baffle should be at least 15cm above the liquid level.

(ix) Openings should be provided near the bottom of the baffle for the flow of effluent from first chamber to second chamber. Sometimes, hanging baffles may be provided.

(x) R.C.C. slab with manhole is provided at the top of the tank.

(xi) Ventilation pipe is provided for the removal of foul gas.

WORKING OF SEPTIC TANK: The fresh sewage from the latrines enters the first chamber directly where the scum start floating at the beginning. Within few days, the anaerobic bacteria decompose the scum and sludge is formed which is settled down at the bottom of the tank, and it is digested further by those bacteria. The effluent from the first chamber flows to the second chamber through the opening in the baffle wall and finally disposed of to the soak pit. During the decomposition, the gases like carbon dioxide, methane and hydrogen sulphide are formed which are released through the vent pipe. Due to the deposition of sludge, the capacity of the tank goes on reducing gradually. So, the tank should be cleared every year, or at some reasonable period. 5. Design Aspects: Following are the design aspects of the septic tanks:

(i) Capacity: The volume of septic tank is decided by taking into consideration the quantity of flow and detention period. It can also be designed on per capita basis which varies from 60- 110 litres person to be served by the septic tank. The pace for sludge is kept usually at the rate of 15 to 45 litres per capita per year.

(ii) Detention Period: The detention period varies from 12 to 72 hours, the common being 24 hours.

(iii) Freeboard: This should be about 400mm to 600mm.

(iv) Shape: The septic tanks are generally rectangular in shape. The ratio of length to width is about 2 to 4.

SOAK PIT/ SOAK TRENCH

FUNCTION: The function of soak pit is to receive effluent from the septic tank and disperse the liquid to the surrounding soil through the openings provided at the wall and through the bottom. The soak pit should not be constructed very near to an open well or tube well. Constructional Features: The following are the constructional features of the soak pit:

(i) The soak pit is constructed with brick masonry in the shape of a square or circle. The depth varies from 3-5m. But the depth depends upon the water table of the locality. It should be remembered that the depth should not be taken below the water table.

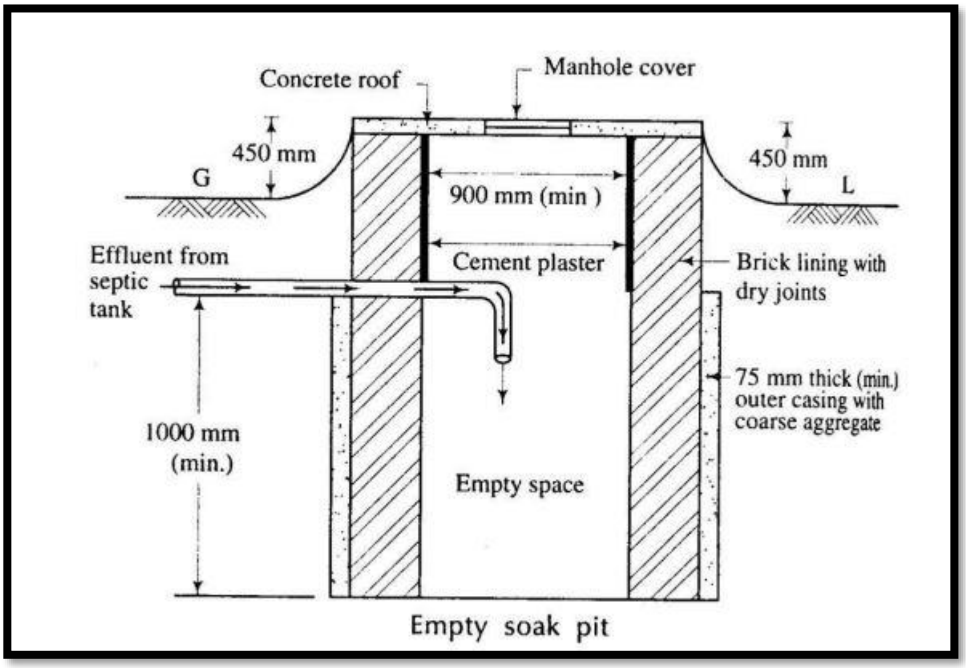
(ii) The diameter of the pit depends on the volume of effluent and number of users. However, the diameter varies from1-2m.

(iii) Openings are provided on the wall of the pit, as shown in fig. The bottom is kept open so that the water can be absorbed by the surrounding soil.

(iv) The pit may be hollow or filled up with brick bats and brick khoa.

(v) Sometimes, a packing of coarse sand (15 cm thick) is provided around the pit to increase the percolating capacity of the soil.

(vi) If the soaking capacity of the pit is destroyed, it should be cleaned and filling materials may be replaced.



CHAPTER-1
SESSION-53

5.1 BASIC OF MICROBIOLOGY

LEARNING OBJECTIVE

5.1.10 Design Problem

5.1.10 DESIGN OF SEPTIC TANK AND SOAK PIT PROBLEM

Design a septic tank having the following data;

(i) Number of users-200
(ii) Rate of water supply -150 lit/head/day
(iii) Detention period-18 hours

(iv) Percolating capacity of filter media= 1250 lit/m3

Also find the diameter of the soak pit. Assume reasonable data, if required.

Solution:

Considering that the whole quantity of water comes as sewage,

Flow of sewage per day = 200 X 150 = 30000 lits

Detention Period is 18 hours.

So , Tank capacity = $\frac{30,000 \times 18}{24}$ = 22,500 lits

Assuming sludge storage capacity at the rate of 20 lits/person/year.

Volume of sludge = 200 X 20

= 4000 lits.

∴ Tank capacity = 22,500+4000

= 26,500 lits.

Considering 20% provision for future extension.

Extra volume = 26,500 X 0.2 = 5,300 lits.

Total volume of tank = 26,500+5,300

= 31,800 lits

= 32,000 lits(say)

=32 m^3 [1m^3 = 1000 lits]

Considering, the effective depth of liquid as 1.5m.

Cross-sectional area = $\frac{32}{1.5}$ = 20.6 m^2.

Let, width $= b$

and length $= 3b$

$$b \text{ X } 3b = 20.6$$

or $3b^2 = 20.6$

$\therefore$ $b = 3.0\text{m (say)}$

$\therefore$ Length $= 3 \text{ X}3 = 9$ m.

Considering free board as 0.5m.

Overall depth = 1.5+0.5= 2m.

Therefore, the size of septic tank is 9mx3mx2m.

Size of Soak well

Volume of soak well $= \frac{32 \text{ X } 1000}{1250} = 25.6 \text{ m}^3$

Problem: Design a septic tank for a household with 5 members. Assume the per capita wastewater generation is 120 litters per day. The septic tank should have a retention time of 24 hours, and an additional 50% volume should be added for sludge and scum accumulation. The depth of the tank is to be 1.5 meters.

PROBABLE QUESTIONS

1. Explain the fundamental principles of microbiology as they relate to water and wastewater treatment, including the classification and characteristics of microorganisms, microbial metabolism, and growth kinetics.
2. Discuss the roles of bacteria, viruses, protozoa, and fungi in waterborne diseases, microbial contamination of water sources, and the biodegradation of organic pollutants in wastewater treatment processes.
3. Analyse the factors influencing microbial growth and activity in water and wastewater environments, including temperature, pH, dissolved oxygen, nutrients, and toxicants.

4. Describe the principles and processes of aerobic biological wastewater treatment, including the activated sludge process, extended aeration, sequencing batch reactors (SBRs), and membrane bioreactors (MBRs), in removing organic matter, nutrients, and pathogens from wastewater.
5. Discuss the design, operation, and performance of activated sludge systems, including process kinetics, sludge age, mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), and sludge settling characteristics.
6. Evaluate the advantages and limitations of trickling filter and rotating biological contactor (RBC) systems in aerobic wastewater treatment, including process efficiency, land requirements, hydraulic loading rates, and media characteristics.
7. Analyse the mechanisms and applications of anaerobic biological wastewater treatment processes, including conventional anaerobic digesters, high-rate anaerobic reactors (e.g., UASB, EGSB), and anaerobic membrane bioreactors (AnMBRs), in producing biogas and stabilizing organic sludge.
8. Discuss the factors influencing the performance of anaerobic digestion processes, including substrate composition, temperature, pH, hydraulic retention time (HRT), and alkalinity, in maximizing biogas production and methane yield.
9. Explore the principles and practices of sludge digestion and handling in wastewater treatment plants, including thickening, stabilization, dewatering, and disposal options (e.g., land application, landfilling, incineration, composting).
10. Evaluate the environmental and economic implications of different sludge management strategies, including energy recovery, nutrient recycling, greenhouse gas emissions, and regulatory compliance requirements.

11. Describe the regulatory requirements and best management practices for the disposal of treated effluent and sludge from wastewater treatment plants, including effluent discharge standards, biosolids regulations, and environmental permitting requirements.
12. Analyse the environmental impacts of effluent discharge to surface waters, including nutrient enrichment, dissolved oxygen depletion, toxicity, and habitat degradation, as well as the potential risks to human health and aquatic ecosystems.
13. Discuss the principles and practices of effluent reuse and recycling in water-stressed regions, including agricultural irrigation, landscape irrigation, industrial

process water, and groundwater recharge, to mitigate freshwater scarcity and promote sustainable water management.

14. Evaluate the challenges and opportunities associated with sludge disposal and reuse options, including land application, composting, soil amendment, energy recovery, and beneficial use projects, in maximizing resource recovery and minimizing environmental impacts.

15. Propose solutions to design problems related to water distribution systems, including hydraulic analysis, pipe sizing, pressure management, and network optimization, to meet peak demand, fire protection requirements, and water quality objectives.
16. Analyse the hydraulic and structural design considerations for sewerage systems, including gravity sewer networks, pressure sewer systems, and combined sewer systems, in conveying sanitary waste and stormwater runoff to treatment facilities.
17. Discuss the design criteria and performance standards for water treatment units, such as coagulation-flocculation-sedimentation processes, filtration systems, disinfection units, and membrane technologies, to meet drinking water quality standards and public health objectives.
18. Evaluate the design parameters and operational requirements for wastewater treatment units, including biological reactors, clarifiers, sludge dewatering units, and disinfection systems, in achieving effluent quality targets and regulatory compliance.
19. Propose solutions to design problems related to sludge digestion processes, including reactor sizing, loading rates, retention times, and process optimization strategies, to maximize biogas production, solids reduction, and pathogen destruction.
20. Discuss the integration of advanced technologies, innovative practices, and sustainable design principles in the planning, design, and operation of water and wastewater treatment facilities, including energy efficiency, resource recovery, and resilience to climate change impacts