Lecture Notes

on

Environmental Engineering (MCMC3001)

3rd Year Civil, Electrical, Mechanical, Computer Science Engineering

Module 1: Water

By

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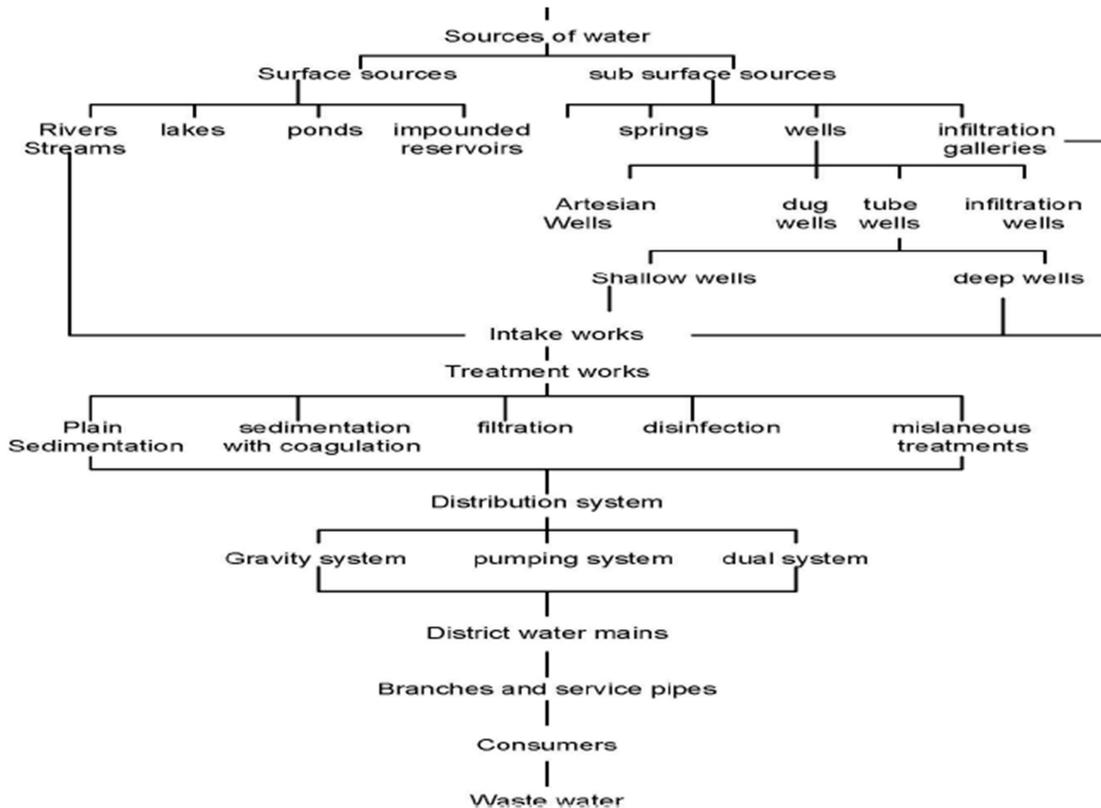
MODULE 1

Water

Water is a transparent, odourless and tasteless liquid essential for life and a major component of Earth's hydrosphere.

It is chemically represented as H_2O.

It exists in three states: solid (ice), liquid, and gas (water vapour or steam).

It is vital for all forms of life.

Sources of Water

1. **Surface sources**, such as

      a. Ponds and lakes

      b. Streams and rivers

      c. Storage reservoirs

      d. Oceans, generally not used for water supplies, at present.

2. **Sub-surface sources or underground sources**, such as

    a. Springs

    b. Infiltration wells

    c. Wells and Tube-wells

A large natural depression or hollow formed in the earth's surface, which gets filled with water is called a **lake**. The surface runoff from the catchment area contributing to a lake enters the lake through small natural streams. The ground water may also enter a lake through springs. The quantity of water available from a lake depends upon its size, catchment area, annual rainfall and geological formations.

A **pond** is a man-made body of standing water smaller than a lake. The ponds are formed by digging of ground and they are filled up with water in rainy season.

A stream or a **river** is a natural channel which carries surface runoff received by it from its catchment or drainage basin. It also carries the ground water flow added to it and the runoff resulting from the melted snow.

The **ocean** water being highly saline it cannot be used for water supply unless the excessive salt content of the water is removed. The process of removing salt from water is known as **desalination** and the salt free water so obtained is known as fresh water

Storage reservoirs store the excess water that flows in the river during the periods of high flows for use during the periods of low flows or droughts.

The **ocean** water being highly saline it cannot be used for water supply unless the excessive salt content of the water is removed. The process of removing salt from water is known as desalination and the salt free water so obtained is known as fresh water

Springs are vital source of freshwater, formed when groundwater naturally flows to the Earth's surface. They act as a crucial part of the water cycle, feeding rivers, lakes and wetlands and are often the source of major rivers.

Gravity Springs: These are the most common type, where water flows due to gravity pulling it downhill. They are often found on hillsides or slopes.

Artesian springs: These springs occur when groundwater is under pressure within a confined aquifer and is released through a crack or opening in the overlying layer.)

Wells and tube wells are vital sources of groundwater, particularly in areas where surface water sources are scarce or unreliable. Open wells are dug manually, with a relatively wider diameter and shallower depth compared to tube wells. Tube wells, also known as borewells, are drilled into the ground using specialized equipment, resulting in a deeper and narrower well compared to open wells.

An **infiltration gallery** is a horizontal or nearly horizontal tunnel usually rectangular in cross-section and having permeable boundaries so that groundwater can infiltrate into the same, and hence it is also sometimes known as horizontal well. It is generally provided in highly permeable aquifers with high water table so that adequate head is available for gravity flow of groundwater into the gallery. Constructed at shallow depth 3-5m along the bank of river. The openings are covered with graded gravel to prevent entry of fine sand particles into the gallery. The gallery is laid at a slope and the water collected in the gallery is led to a sump from where it is pumped out and supplied to consumers after necessary treatment.

Infiltration wells are the shallow wells constructed in series along the banks of a river to collect the water seeping through the banks of the river. The wells are closed at top and open at bottom. These wells are constructed of brick masonry with open joints. The water infiltrates through the bottom of these wells and as it has to pass through sand bed it gets purified to some extent

Water quality

Water quality refers to the physical, chemical, and biological characteristics of water that determine its suitability for a specific use, such as drinking, recreation, or supporting aquatic life. It's assessed based on a set of standards and parameters, and it's crucial for maintaining healthy ecosystems and human well-being.

Key aspects of water quality:

- **Physical characteristics:**

    These include turbidity, taste & odour, temperature, colour, conductivity, the amount of solids.

- **Chemical characteristics:**

These involve measuring pH, hardness, dissolved oxygen, other dissolved gases, the presence of various ions (like nitrates, sulfates), and potentially harmful substances like heavy metals or organic pollutants.

- **Biological characteristics:**

    This includes assessing the presence and abundance of microorganisms (bacteria, viruses, etc.), algae, and other aquatic organisms.

Turbidity:

Turbidity refers to the cloudiness or haziness of water caused by suspended particles. High turbidity can make it difficult to see through the water and can interfere with filtration processes.

Colour:

Water colour can be influenced by the presence of minerals, organic matter or even industrial waste.

Taste and Odour:

Taste and odour can indicate the presence of pollutants or decaying organic matter.

Temperature:

Water temperature affects the solubility of gases, the metabolism of aquatic organisms and the distribution of species.

Conductivity:

Conductivity measures the ability of water to conduct an electrical current, which is related to the concentration of dissolved ions.

pH

- It is defined as the negative logarithm of hydrogen ion concentration in water. It is the measure of degree of acidity or alkalinity of water.
- It is measure on pH scale, which varies from 0 to 14.
- At PH = 7 water is neutral.

    PH=0 to 7 water is acidic.

    PH= 7 to 14 water is alkaline.

Acidity

- It is the capacity of substance to neutralize hydroxyl ion OH⁻(basics). It is due to the presence of minerals and dissolution of carbon dioxide.
- Usually dissolved carbon dioxide (CO_2) is the major acidic component present in the unpolluted surface water.

Alkalinity

- Alkalinity of water is a measure of its capacity to neutralize acids, i.e. to absorb hydrogen ions
- Alkalinity is dependent on the presence of certain chemicals in the water, such as bicarbonates, carbonates, and hydroxides.
- Alkalinity cause by CO_3^{2-} is called carbonate alkalinity.
  Alkalinity cause by HCO3- is called bicarbonate alkalinity.
  Alkalinity cause by OH⁻is called caustic alkalinity.

Hardness

- Hardness is defined as concentration of metallic cations in solution.
- Multivalent metallic cations most abundant in natural water is calcium, magnesium.
- Other ions which lead to hardness are Fe2+, Mn2+, but are found in much smaller quantities and hence for all practical purpose hardness is represented by the sum of Ca2+ & Mg2+ ions.
- Hardness of water can be classified into two types
    1. Temporary Hardness
    2. Permanent Hardness
- **Temporary Hardness of water:** The presence of magnesium and calcium carbonates in water makes it temporarily hard. In this case, the hardness in water can be removed by boiling the water & adding lime.
  When we boil water, the soluble salts of $Mg(HCO_3)2$ are converted to $Mg(OH)_2$, which is insoluble, and hence gets precipitated and removed. After filtration, the water we get is soft water.
- **Permanent Hardness of water:** when the soluble salts of magnesium and calcium are present in the form of chlorides and sulphates in water, we call it permanent hardness because this hardness cannot be removed by boiling.
  We can remove this hardness by lime soda and zeolite process.

Dissolved gases

- CH_4 known for its explosive tendency
- H_2S impart bad taste and odour
- CO_2 indicates biological activity, impart bad taste and water becomes corrosive
- Dissolved oxygen should be in the range of 5-10ppm.

Biochemical oxygen demand (BOD)

- The amount or demand of oxygen that is required for the complete decomposition of biodegradable organic matter.

  Limit for BOD value is nil.

Presence of nitrogen related compound

Nitrogen is present in the form of Free Ammonia, Organic Ammonia (Albuminoid), Nitrite, Nitrate

Water quality issues

Water quality is affected by various sources of pollution, both natural and human-induced. Water quality issues encompass a range of problems related to the physical, chemical, and biological characteristics of water, rendering it unsafe or unsuitable for intended uses. These issues can stem from various sources, including industrial and agricultural activities, natural factors, and inadequate water treatment. Common problems include contamination by pathogens, chemicals, excess nutrients, and sediment, leading to potential health risks and ecological damage.

Types of Water Quality Issues:

- **Biological Contamination:**

  Presence of harmful bacteria, viruses, and other microorganisms in water, often originating from sewage, animal waste, or wildlife.

- **Chemical Pollution:**

  Introduction of toxic chemicals, heavy metals, pesticides, and industrial byproducts into water sources.

- **Nutrient Pollution:**

  Excessive amounts of nutrients like nitrogen and phosphorus, primarily from agricultural runoff and wastewater, leading to eutrophication and harmful algal blooms.

- **Sediment Pollution:**

    Suspended particles like silt and clay clouding the water, impacting aquatic life and increasing water treatment costs.

- **Thermal Pollution:**

    Discharge of heated water from industrial processes, altering water temperatures and affecting aquatic ecosystems.

- **Microplastics:**

    Tiny plastic particles contaminating water sources, potentially impacting human and animal health.

- **Radioactive Contamination:**

    Introduction of radioactive materials into water bodies, posing serious health risks.

    Causes of Water Quality Issues:

- **Industrial Discharge:**

    Untreated or inadequately treated wastewater from factories, including toxic chemicals and heavy metals.

- **Agricultural Runoff:**

    Pesticides, fertilizers, and animal waste from farms contaminating surface and groundwater.

Water Quality Indices (WQIs)

Water Quality Indices (WQIs) gives the overall quality of water in a single and easy-to-understand value, It summarizes complex water quality data. They are calculated by combining several water quality parameters and their respective weights, providing a clear indication of water suitability for different uses i.e. drinking or irrigation.

WQIs aim to simplify complex water quality data into a single, easy-to-understand number or rating.

Components of WQIs**:**

They typically involve selecting relevant water quality parameters, assigning them sub-indices based on their concentrations, and then aggregating these sub-indices using weighting factors.

Applications:

WQIs are used to:

- Assess the overall quality of water sources.

- Compare water quality at different locations or times.

- Inform decision-making related to water management and pollution control.

- Communicate water quality information to the public and policymakers.

Common Parameters:

WQIs often consider parameters like dissolved oxygen (DO), biological oxygen demand (BOD), pH, coliform counts, conductivity, and various chemical concentrations.

Calculation Methods:

Different methods exist for calculating WQIs, including the use of mathematical models and statistical techniques.

Limitations:

WQIs have limitations, and it's important to consider the specific context and limitations of the chosen method when interpreting the results.

Water supply system

A water supply system essentially consists of three key components: the source, treatment and distribution. The source provides the raw water, which can be obtained from surface or groundwater sources. This raw water then undergoes treatment to remove impurities and make it safe for consumption. Finally, the treated water is distributed to users through a network of pipes and related infrastructure.

Components of water supply system
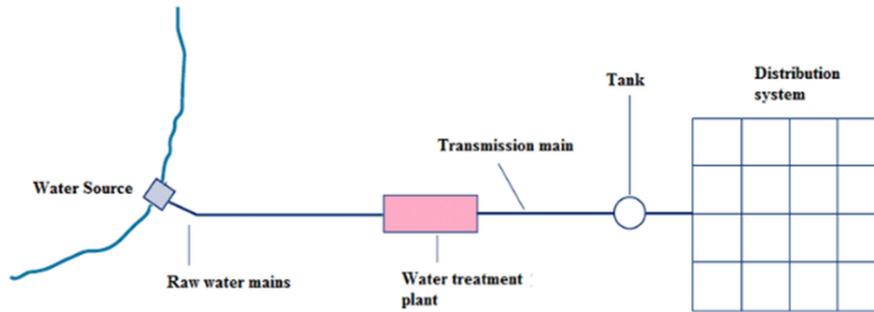
1. Water Source:

- **Surface Water:** Rivers, lakes, reservoirs, and streams are common surface water sources.

- **Groundwater:** Wells and aquifers provide access to water stored underground.

- **Other Sources:** Seawater desalination is also a potential source in some regions.

2. Treatment:

- **Intake Works:**

  It includes structures like pumps, canals and pipelines that move water from the source to the treatment plant.

- **Treatment Facilities:**

  Processes like screening, coagulation, flocculation, sedimentation, filtration, disinfection etc are used to remove contaminants.

3. Distribution:

- **Transmission Mains:** Large diameter pipes that carry water from the treatment plant to storage facilities or distribution zones.

- **Distribution Mains:** Smaller pipes that branch off from transmission mains to deliver water to neighbourhoods and individual properties.

- **Service Laterals:** Pipes connecting the distribution mains to individual service connections at homes and businesses.

- **Storage Facilities:** Reservoirs and tanks that store treated water and regulate pressure.

- **Pumping Stations:** Used to pressurize and move water through the system, especially when gravity alone is not sufficient.

- **Valves:** Used to control flow, isolate sections for maintenance and regulate pressure.

- **Fire Hydrants:** Provide access to water for fire fighting purposes.

Various valves used in W/S systems

We can control the liquid flow with the help of a valve. It is done by different methods such as closing, opening or blocking various passages in a pipe system. So this device can control the flow and pressure in a system.

Various types of valves are used in water supply systems to control, regulate, and direct the flow of water. Common types include gate valves, globe valves, ball valves, butterfly valves, and check valves, each serving a specific purpose.

1. Gate Valves:

Primarily used for slow and full open/close control, stopping or starting the flow of water.

2. Globe Valves:

Used for both regulating and throttling flow (precise flow control).

3. Ball Valves:

Commonly used for quick on/off control, but also capable of throttling.

4. Butterfly valves: a quarter-turn rotational valve with a disc that rotates to control fluid (liquid, gas, slurry) flow in a pipe, acting like a butterfly's wings

4. Check Valves:

Non-return or one-way valve, lets fluids (liquids/gases) flow in only one direction, prevent backflow of water in the system.

Need for planned water supply schemes

Planned water supply schemes are necessary for public health, sanitation, economic growth etc. by providing adequate quantity of water ensuring safe and reliable for drinking, cooking, and hygiene, reducing waterborne diseases, promoting industry and preventing pollution. It addresses challenges like population growth, water scarcity, water contamination (like fluoride/arsenic etc.), high cost through integrated infrastructure and management.

Types of demand

- Domestic Water demand
- Industrial water demand

- Institution and commercial water demand
- Demand for public uses
- Fire demand
- Water required compensating losses in wastes and thefts

Domestic Water demand

- It includes water required for drinking, cooking, bathing, lawn sprinkling, gardening etc.
- Minimum domestic consumption with full flushing system as per IS 1172-1993

    = 135 l/h/d for weaker section & LIG colony

    = 200 l/h/d for town & city

    = 340 l/h/d for developed and effluent country like USA

- Total domestic water demand = total design population × per capita domestic consumption
- Total domestic water consumption = 50-60% of total water consumption

Minimum Annual Average Domestic Water Consumption for LIG colonies and weaker sections in towns and cities of India (IS 1172-1993)

Sl No	Different Uses	Consumption in l/h/d
1	Drinking	5
2	Cooking	5
3	Bathing	55
4	Cloth washing	20
5	Utensils washing	10
6	House cleaning	10
7	Flushing of water closets	30
Total		135

Minimum Annual Average Domestic Water Consumption for towns and cities of India with full flushing system (IS 1172-1993)

Sl No	Different Uses	Consumption in l/h/d
1	Drinking	5
2	Cooking	5
3	Bathing	75
4	Cloth washing	25
5	Utensils washing	15
6	House cleaning	15
7	Lawn watering and gardening	15
8	Flushing of water closets	30
Total		200

Industrial water demand

- **It means water demand of various industries** existing in the city or going to be started in near future for which water supply has been planned.
- Such quantity varies with type and number of industries present in the city
- In Industrial cities, per capita water requirement → 450 l/h/d

Institutional and commercial water demand

- Water is required for various institutions i.e. colleges. Schools, hospitals, restaurants, hotels, offices, railway stations and factories
- It varies with the type and number of institutions as well as commercial establishment along with nature of city.
- Average per capita demand for Institutional and commercial water requirement → 20-50 l/h/d

Demand for public uses

- It means water required for public utility purposes i.e. washing & sprinkling n roads, watering of public parks, use of public fountains, gardening etc.

- It should not more than 5% of total consumption in India.
- An amount of 10 l/h/d is added for this purpose.

Fire demand

- Fires generally break out in industrial & thickly populated areas & fire fighting squads are generally maintained to throw water over the fire at high speed.
- Fire hydrants are generally fitted in water mains at about 100-150 apart & fire fighting pumps are immediately connected to them as soon as fire breaks out.
- Minimum water pressure available at fire hydrants should be 100-150 kN/m2 (10-15m of water head) & should be maintained even after 4-5 hrs of constant use of fire hydrants.
- In a moderate fire breakout, 3 jet streams are simultaneously thrown from each hydrant

     -one on burning property

     -other two on adjacent property on either side of burning property

- Discharge of each stream @ 1100l/min

Empirical formulas for calculating rate of fire demand

- **National board of fire under writer's formula**

  For central congested high valued city

  $Q = 4637\sqrt{P}[1\text{-}0.01\sqrt{P}]$ If $P \leq 200000$

- **Kuichling's formula**

  $Q = 3182\sqrt{P}$

  Q = amount of water required in lit/min

  P = population in thousands

- **Freeman's formula**

  $Q = 1136[(P/10)+10]$

- **Buston's formula**

  $Q = 5663\sqrt{P}$

Agricultural water Demand

- Agricultural water demand refers to the total amount of water needed to support farming activities, including irrigation, livestock watering, and other uses within the agricultural sector.

- It encompasses the water required for irrigation, crop production, animal husbandry, and other related processes.
- Essentially, it's the volume of water that farmers and agricultural operations require to sustain their activities and produce food and other agricultural products.

Design period

- The number of years for which design of waterworks have been done is known as design period

- It should not be too long or too short

- It varies from 20-50 years

- Mostly waterworks are designed for 20-30 years which is fairly good

Sl No	Component	Design period (Yrs)
1	Clear water service reservoir	15
2	Conveying pipes for raw water & clear water	30
3	Distribution system	30
4	Electric motors and pumps	15
5	Infiltration works	30
6	Storage reservoirs	50
7	Water treatment units	15

Water Distribution System

- After complete treatment of water, it becomes necessary to distribute it to a number of houses, estates, industries and public places by means of a network of distribution system. The distribution system consists of pipes of various sizes, valves, meters, pumps, distribution reservoirs, hydrants, stand posts etc.
- The pipe lines carry the water to each and every street, road.
- Valves control the flow of water through the pipes.
- Meters provided to measure the quantity of water consumed by individual as well as by town.

- Hydrants provided to connect the water to the fire-fighting equipment's during fire.
- Service connections done to connect the individual building with the water line passing through the streets.
- Pumps provided to pump the water to the elevated service reservoirs or directly in the water mains to obtain the required pressure in the pipe lines.

Layouts of Distribution System

There are 4 different types/layouts of water distribution systems, as mentioned below:

1. Dead End System

2. Radial System

3. Grid Iron System

4. Ring System

Dead End System:

•It is suitable for old towns and cities having no definite pattern of roads

Advantages:

•Relatively cheap.

•Determination of discharges and pressure easier due to less number of valves.

Disadvantages:

•Due to many dead ends, stagnation of water occurs in pipes.

Dead End or Tree System

M : Main Pipe
B : Branch
S : Sub Mains
• : Cut off Valves
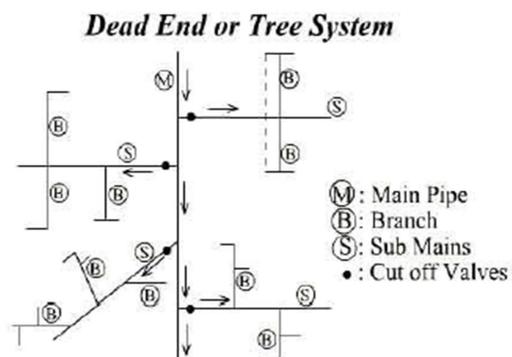
Grid Iron System:

•It is suitable for cities with rectangular layout, where the water mains and branches are laid in rectangles.
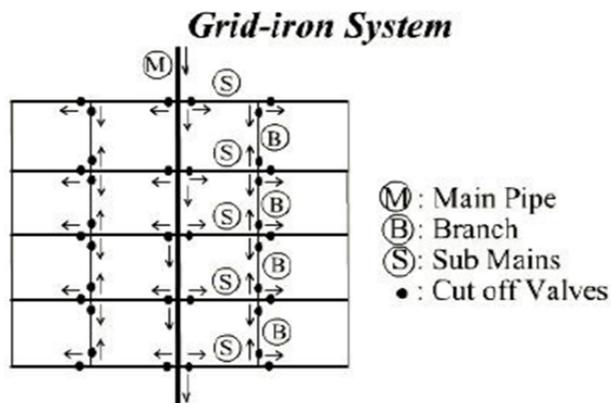
Advantages:

•Water is kept in good circulation due to the absence of dead ends.

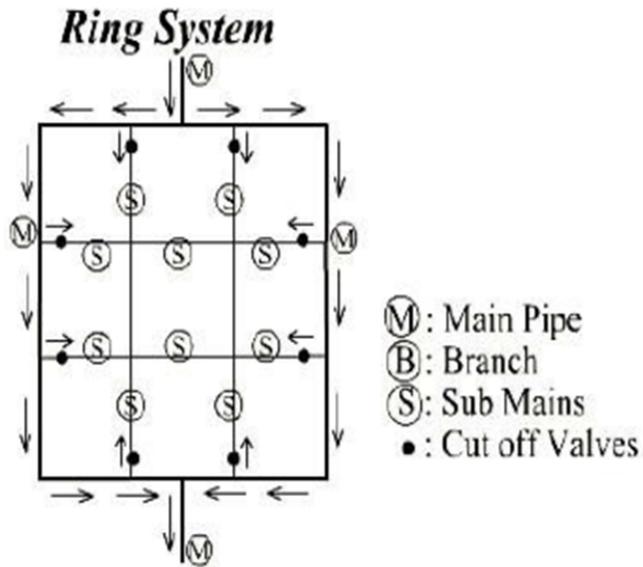•In the cases of a breakdown in some section, water is available from some other direction.

Disadvantages

•Exact calculation of sizes of pipes is not possible due to provision of valves on all branches.

Ring System:

- The supply main is laid all along the peripheral roads and sub mains branch out from the mains. Thus, this system also follows the grid iron system with the flow pattern similar in character to that of dead end system. So, determination of the size of pipes is easy.

- Advantages:

- Water can be supplied to any point from at least two directions.

Grid-iron System

Ⓜ : Main Pipe
Ⓑ : Branch
Ⓢ : Sub Mains
• : Cut off Valves

Ring System

M: Main Pipe
B: Branch
S: Sub Mains
• : Cut off Valves

Radial System:

- The area is divided into different zones. The water is pumped into the distribution reservoir kept in the middle of each zone and the supply pipes are laid radially ending towards the periphery.

Advantages:

- It gives quick service.

- Calculation of pipe sizes is easy.

Radial System

● : Distribution Reservoirs
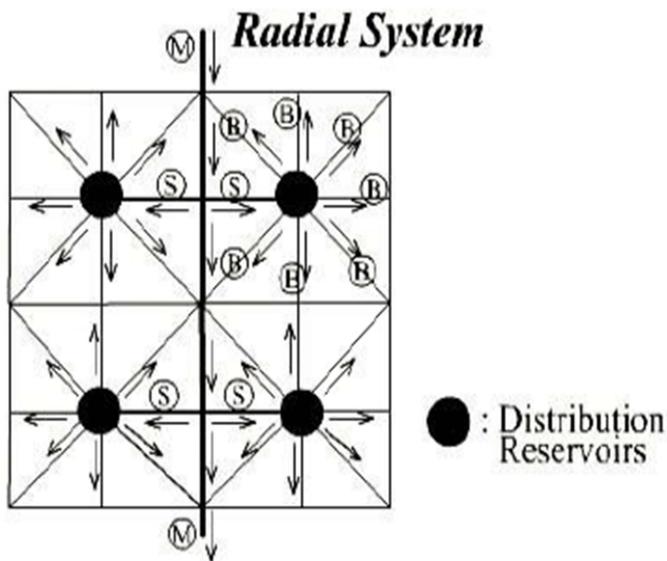
Methods of distribution

Depending upon the topography of the town, the water may be distributed by

1. Plumbing system

2. Gravity system

3. Combine of pumping and gravity (dual system)

1. Pumping system

• The treated water is directly pumped into distribution mains without storing in high level reservoirs. High lift pumps are provided for forcing water into main pipe.

• Since the water is fluctuating the pumps have to operate at various rates during the whole day. A continuous attendance is required at the pumping station to regulate the flow by running only the required number of pump out of total number of pump install.

Pumping system can supply the required quantity of water for fire fighting by running all pumps including standby. The system is costly and its use should be discouraged as far as possible.


Pumping System
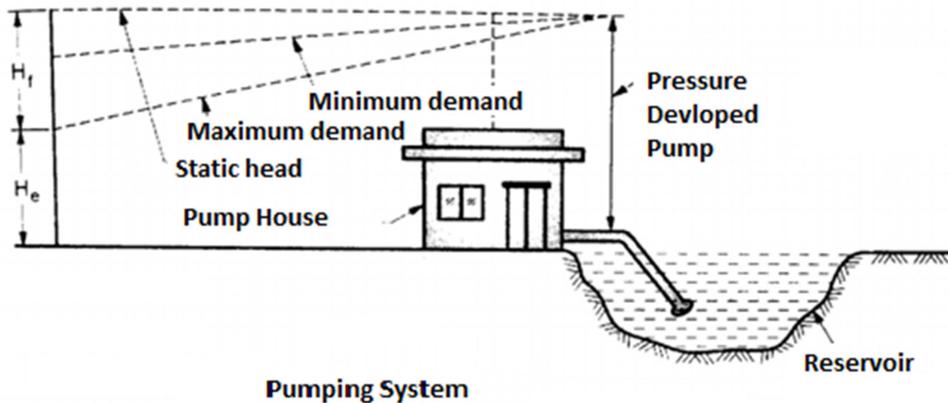
Advantages

- Large quantity of water available in case of fire.
- Suitable for any type of topography.

Disadvantages

- Sufficient water required.
- Not economical.
- More losses and wastage.

2. Gravity system

• In this system the gravity force is used in distribution water from high level source to low level zone consumers.

• This eliminates pumping altogether. The method is economical reliable and required less maintenance. For proper working of the system the difference of head available between

• Service reservoir and low level zone should be sufficient to develop enough pressure at consumers tap. The method also minimises wastage and leakages.

Gravity System
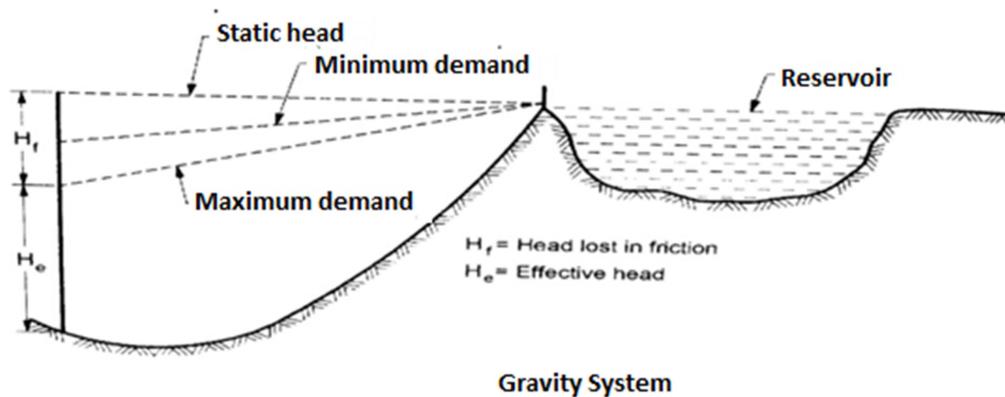
Advantages

- Simple and economical.

- Less maintenance.

- Less leakage and wastage.

- Reduction in pipe sizes.

Disadvantages

- Not suitable if source is not a sufficient elevation to cause flow under gravity.

- Cannot provide high pressure for fire demand.

3. Combined of gravity and pumping system

In this system the water after treatment is pumped and stored in the elevated services reservoir (ESR) according to the supply hours the store water supply to the public by gravity.

Advantages

- The system is economical, efficient and reliable and adopted practically everywhere.

- Pumping at constant rate increases efficiency.

- Special supervision is not required.

- Fire demand efficiently met with.

- Water is available even during failure of pump and power.

Combine Gravity and Pumping system
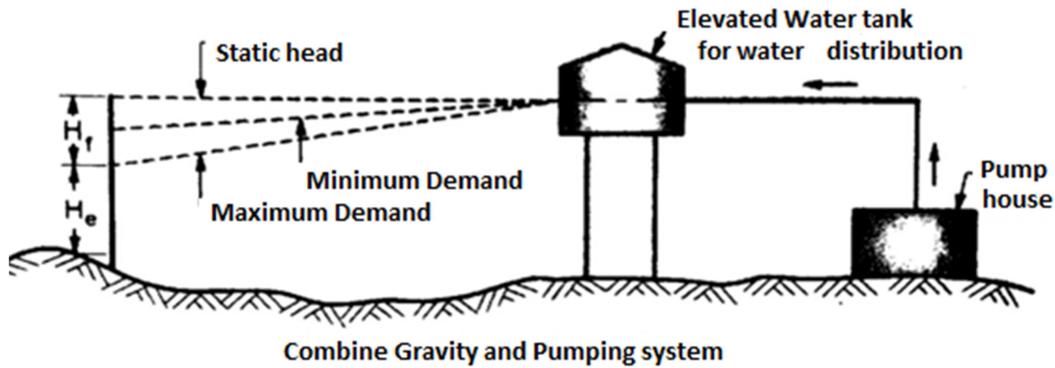
Water treatment

A typical water treatment process cleans raw water through several stages:

Pretreatment i.e. screening, aeration etc.

Primary treatment i.e. Coagulation & flocculation (adding chemicals to clump particles), sedimentation (settling heavy clumps),

Secondary treatment i.e. filtration (passing water through filters)

Disinfection (killing pathogens with chlorine or UV light).

Additional steps like pH adjustment, softening, or fluoridation may occur before the water is distributed for safe drinking.
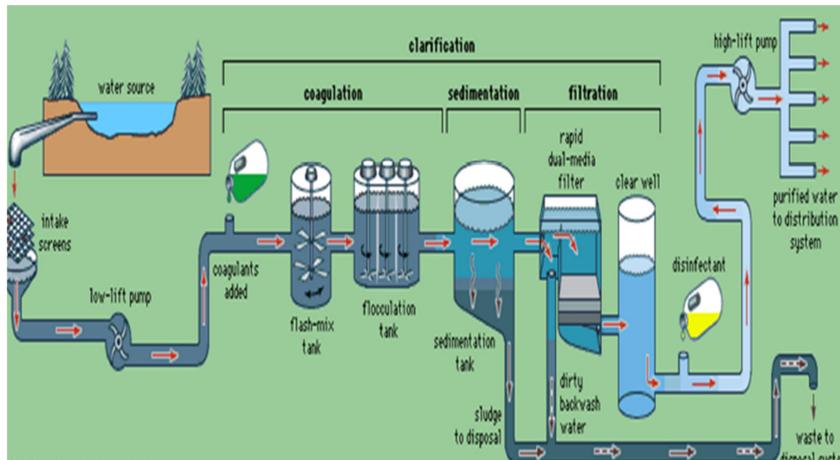
Screening (for the removal of large floating and suspended materials).

- Mostly used at intake site

Aeration (for the oxidation of iron and manganese, removal of dissolved gasses and VOCs).

- Optional unit, and may not be provided if target impurities are not present in water

Sedimentation (for the removal of suspended sediments of specific gravity >1).

- Sedimentation in water treatment is a physical process which uses gravity to remove suspended solids like sand, silt and organic matter from water in large tanks (clarifiers/settling tanks) by allowing them to settle at the bottom, forming sludge, which clarifies the water

- Plain (or primary) sedimentation may not be provided, as in most cases, settling units are provided after coagulation and flocculation for chemical assisted settling.

- In many conventional water treatment systems settling unit is combined with flocculation unit, named as clariflocculator.

Purpose

- Removes turbidity (cloudiness) and larger suspended solids.

- Reduces the burden on filtration and disinfection stages.

- Improves overall water clarity and quality.
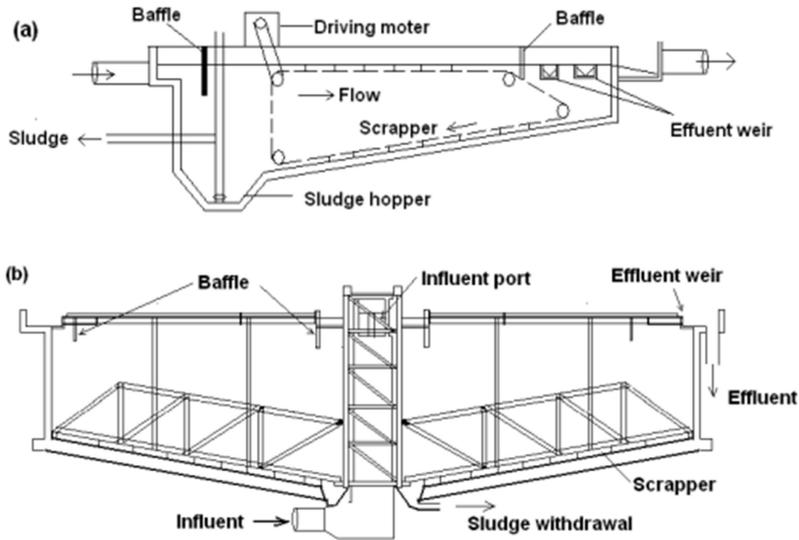
(a) Rectangular and (b) Circular primary sedimentation tank

Coagulation and flocculation

- The **coagulation process** in water treatment is the addition of special chemicals (coagulants) to raw water to neutralize the electrical charges of tiny, suspended particles, causing them to clump together into larger masses called **flocs**. This makes the impurities heavy enough to be removed from the water by settling or filtration.

- Successive steps are involved intended to overcome the forces stabilizing the fine suspended or colloidal particles, allowing particle collision and growth of floc.
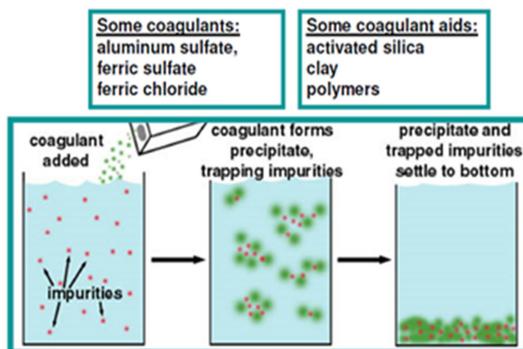

(a) Coagulation steps   **(b) Jar test apparatus**

Optimum dose of coagulant: Jar Test

The optimum dose are usually determined by a *Jar Test.* A typical Jar Test apparatus consists of four to six beakers of 1-2 L volume. with stirrers (4 to 6) provided with paddles. The paddles can be rotated with varying speed with the help of a motor and regulator. Samples will be taken in jars or beakers and varying dose of coagulant will be added simultaneously to all the jars. The dose, which gives the least turbidity, is taken as the optimum coagulant dose.

Filtration

After water passes through coagulantion and Flocculation Basin, it is treated in Sedimentation Basin for the removal of flocs. Alternately, after passing through Flash Mixer, it may be sent through Clariflocculator (for flocculation and Clarification). After water comes out of clarifier (settling basin), it has lost most of the suspended and colloidal particles, however, usually it still contains very fines sediments and some micro-flocs (as clarifier may not remove all suspended particles and flocs with 100% efficiency). Therefore, water is passed through sand or multimedia filters for the removal of left-over suspended solids and micro-flocs (which is known as filtration process). It can be done by slow sand filter and rapid sand filter.
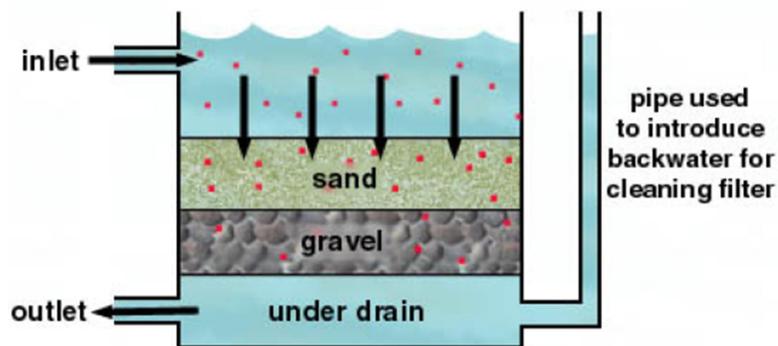
Filtration

Disinfection

Water is disinfected before it makes its way to the distribution system. Disinfection removes disease-causing bacteria, viruses, and parasites. Chlorine is better known to help in the disinfection of water. It includes oxidizing agents that instantly remove all the bacteria in water.

Advanced treatments

Adsorption traps pollutants (like organics, chlorine) onto a solid surface (e.g., activated carbon). Pollutants (adsorbate) stick to the surface of a porous solid (adsorbent) like activated carbon, removing them from water.

Ion Exchange swaps unwanted ions (e.g., hardness minerals) with desired ones on resin beads (e.g., sodium) for softening or demineralization. An ionic resin exchanges its loaded ions (like Na^+) for unwanted ions (like Ca^{2+}, Mg^{2+}) in the water, softening it or demineralizing it. It is used for water softening (removing hardness), demineralization, producing high-purity water.

Membrane Processes (like RO, UF) physically filter contaminants using semipermeable barriers. Water is forced through a semipermeable membrane, physically separating particles, ions, or molecules based on size and charge. It includes Microfiltration (MF), Ultrafiltration (UF), Nanofiltration (NF), Reverse Osmosis (RO).