Water Supply Systems

PDH: 3.0 Hours

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1. Introduction

The course presents the Introduction, Water Cycle, Watershed, Water Supply System Components, Water Supply Sources, Water Quality, Water Quantity, Distribution Systems, Water Quality Standards, Health Effects, Aesthetic Effects, Planning and Management of Water Supply Systems. This course is suggested for civil engineers, environmental engineers, and water and wastewater treatment plant managers and operators.

In this course we will define and elaborate on water cycle, watershed, elements of water supply systems, distribution systems, effects on health and environment, as well as the planning and management of water supply systems. We will solve a few problems to show the use of Darcy-Weisback equation, Hazen William's Nomogram and energy equation to estimate the head loss and pressure at a certain point in a distribution system.

2. Learning Objectives

Upon successful completion of this course, the participants will be able to:

- define and describe water cycle and watershed;
- define public water system, wholesome water, and potable water;
- describe the basic elements of water supply system and the main sources of water supply;
- interpret the water collection system, basics of water treatment, and distribution systems;
- design the overhead storage tanks;
- estimate the pressure at different parts in the distribution system using energy equations.

3. Water Cycle

Water is in constant circulation, powered by the energy from sunlight and gravity in a natural process called the hydrologic cycle. Water evaporates from the ocean and land surfaces, is held temporarily as vapour in the atmosphere, and falls back to Earth's surface as precipitation. Surface water is the residue of precipitation and melted snow, called runoff. Where the average rate of precipitation exceeds the rate at which runoff seeps into the soil, evaporates, or is absorbed by vegetation, bodies of surface water such as streams, rivers, and lakes are formed. Water that infiltrates Earth's surface becomes groundwater, slowly seeping downward into extensive layers of porous soil and rock called aquifers. Under the pull of gravity, groundwater flows slowly and steadily through the aquifer. In low areas it emerges in springs and streams. Both surface water and groundwater eventually return to the ocean, where evaporation replenishes the supply of atmospheric water vapour. Winds carry the moist air over land, precipitation occurs, and the hydrologic cycle continues.

Global distribution of water

Water is present in abundant quantities on and under Earth's surface, about 97% of the water on earth is salt water in the ocean. Of the 3% of water that is fresh water, 2% is frozen in ice caps and only 1% is usable as liquid fresh water. The usable 1% of water is used by organisms as liquid water or water vapor found in lakes, rivers, streams, ponds, in the ground water, and as vapor in the atmosphere. Most of Earth's estimated 1.4 billion cubic km (326 million cubic miles) of water is in the oceans or frozen in polar ice caps and glaciers. Ocean water contains about 35 grams per litre (4.5 ounces per gallon) of dissolved minerals or salts, making it unfit for drinking and for most industrial or agricultural uses.

There is ample fresh water—water containing less than 3 grams of salts per litre, or less than one-eighth ounce of salts per gallon—to satisfy all human needs. It is not always available, though, at the times and places it is needed, and it is not uniformly distributed over the globe, sometimes resulting in water scarcity for susceptible communities. In many locations the availability of good-quality water is further reduced because of urban development, industrial growth, and environmental pollution.

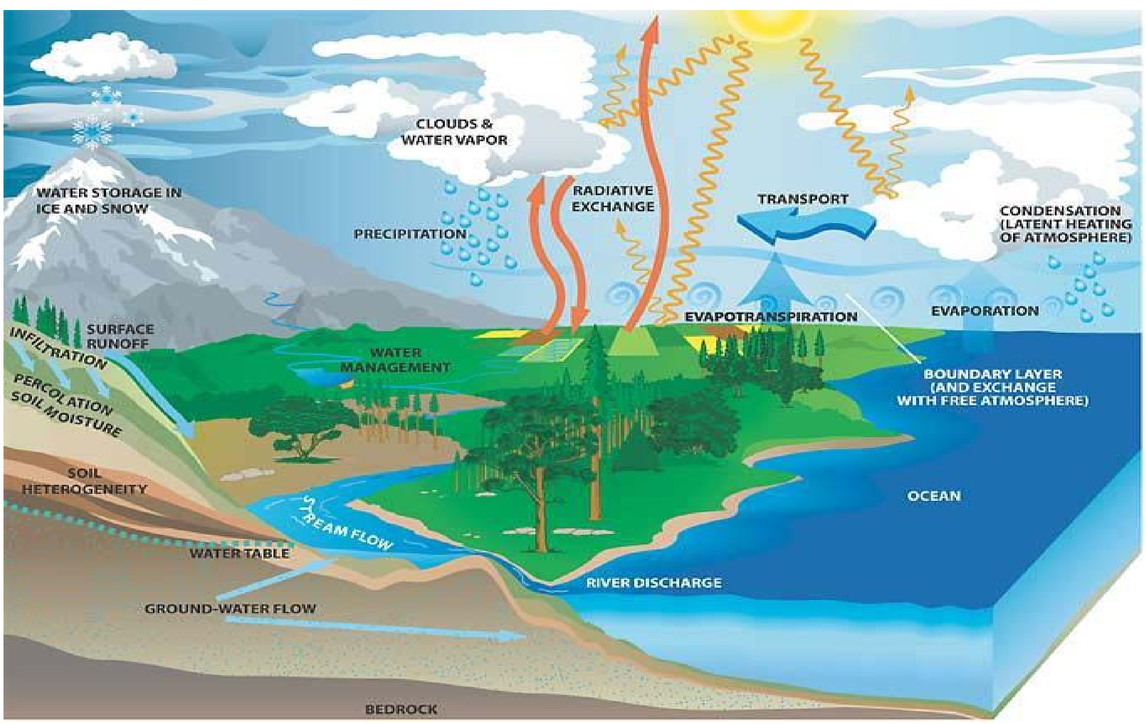


Figure 1: Water Cycle

The six major processes in the water cycle are

- **Precipitation –** water from the clouds fall to earth rain, snow, hail or sleet

- **Surface Runoff –** water on the surface of the land that flows downhill into bodies of water such as streams, rivers, ponds, and lakes
- **Infiltration** – rain water soaks into the ground through soil and rock layers under the soil with some remaining underground as groundwater
- **Evaporation –** liquid water changes to a gaseous state as water vapor
- **Transpiration –** water that has been absorbed by plants will evaporate through the leaves as water vapor
- **Condensation –** water vapor is changed into a liquid Water vapors join dust particles to form clouds

4. Watershed

A **watershed or drainage basin** is an area of land where water from rain and melting snow or ice drains downhill into a body of water, such as a river, lake, reservoir , wetland. A **watershed or drainage basin** is an area of land where water from rain and melting snow or ice drains downhill into a body of water, such as a river, lake, reservoir , wetland.

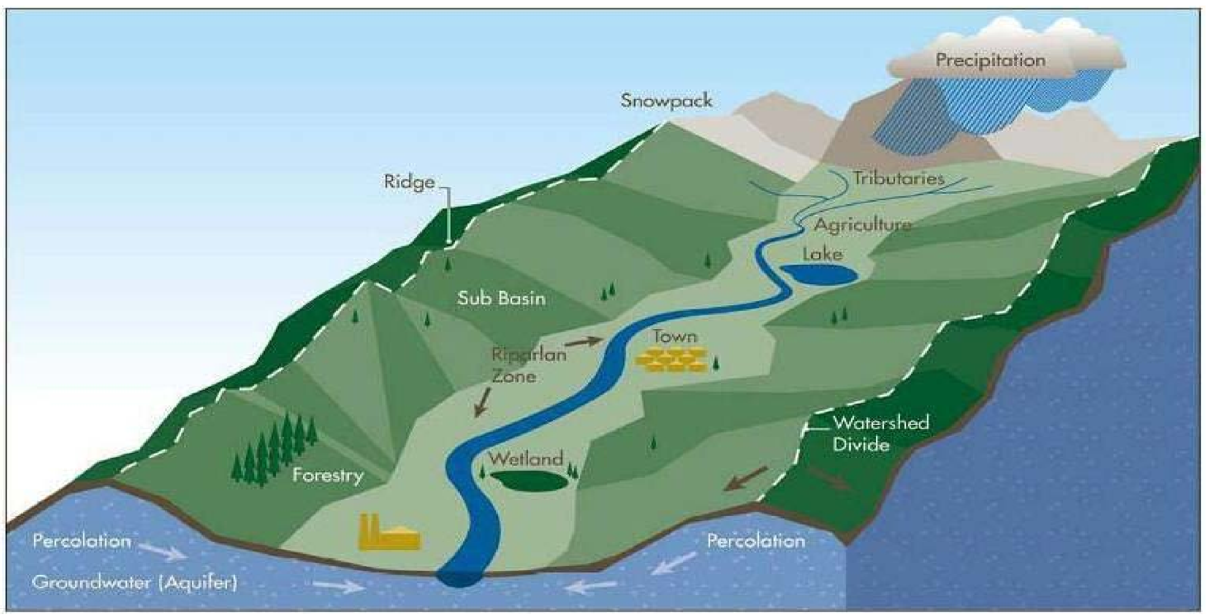


Figure 2: View of Watershed

Watershed surface water management plans are implemented to reduce flooding, improve water quality, and enhance stream and wetland habitat. Land usage and water treatment methods are important in maintaining water quality in the watershed. Sources of water pollution may include **point source pollution** from a clearly identifiable location or **nonpoint source pollution** that comes from many different places. Sources of pollution usually fall into four main categories – industrial, residential, commercial, and environmental.

- Some types of pollution may include
  - ✓ organic pollution – decomposition of living organisms and their bi-products.

- ✓ inorganic pollution – dissolved and suspended solids as silt, salts, and minerals.
- ✓ toxic pollution – heavy medals and other chemical compounds that are lethal to organisms.
- ✓ thermal pollution – waste heat from industrial and power generation processes.

5. Historical Development of Water Supply Systems

Water was an important factor in the location of the earliest settled communities, and the evolution of public water supply systems is tied directly to the growth of cities. In the development of water resources beyond their natural condition in rivers, lakes, and springs, the digging of shallow wells was probably the earliest innovation. As the need for water increased and tools were developed, wells were made deeper. Brick-lined wells were built by city dwellers in the Indus River basin as early as 2500 BCE, and wells almost 500 metres (more than 1,600 feet) deep are known to have been used in ancient China.

Construction of *qanāt*s, slightly sloping tunnels driven into hillsides that contained groundwater, probably originated in ancient Persia about 700 BCE. From the hillsides the water was conveyed by gravity in open channels to nearby towns or cities. The use of *qanāt*s became widespread throughout the region, and some are still in existence. Until 1933 the Iranian capital city, Tehrān, drew its entire water supply from a system of *qanāt*s.

Source: https://www.britannica.com/technology/water-supply-system

The need to channel water supplies from distant sources was an outcome of the growth of urban communities. Among the most notable of ancient water-conveyance systems are the aqueducts built between 312 BCE and 455 CE throughout the Roman Empire. Some of these impressive works are still in existence. The writings of Sextus Julius Frontinus (who was appointed superintendent of Roman aqueducts in 97 CE) provide information about the design and construction of the 11 major aqueducts that supplied Rome itself. Extending from a distant spring-fed area, a lake, or a river, a typical Roman aqueduct included a series of underground and aboveground channels. The longest was the Aqua Marcia, built in 144 BCE. Its source was about 37 km (23 miles) from Rome. The aqueduct itself was 92 km (57 miles) long, however, because it had to meander along land contours in order to maintain a steady flow of water. For about 80 km (50 miles) the aqueduct was underground in a covered trench, and only for the last 11 km (7 miles) was it carried aboveground on an arcade. In fact, most of the combined length of the aqueducts supplying Rome (about 420 km [260 miles]) was built as covered trenches or tunnels. When crossing a valley, aqueducts were supported by arcades comprising one or more levels of massive granite piers and impressive arches.

Source: https://www.britannica.com/technology/water-supply-system

5.1 Objectives

The broad objectives underlying any water supply system are to:

- supply safe and wholesome water to consumers;
- supply water in adequate quantity; and
- make water easily available to consumers so as to encourage personal and household cleanliness.

Wholesome water → water which is unpolluted, free from toxic substances as well as excessive amounts of mineral and organic matter that may impair the water quality.

5.2 Elements of Water Supply Systems

The first step in the design of a water supply system is the determination of quantity of water that will be required with the provision for the estimated requirements of the future. Next a reliable **source** that will provide required water throughout the year, finally a **collection system**, a **treatment plant**, and a **distribution system** must be provided.

- The essential elements of a water supply system are:
  - ✓ Source of supply;
  - ✓ Collection system;
  - ✓ Treatment system; and
  - ✓ Distribution system.

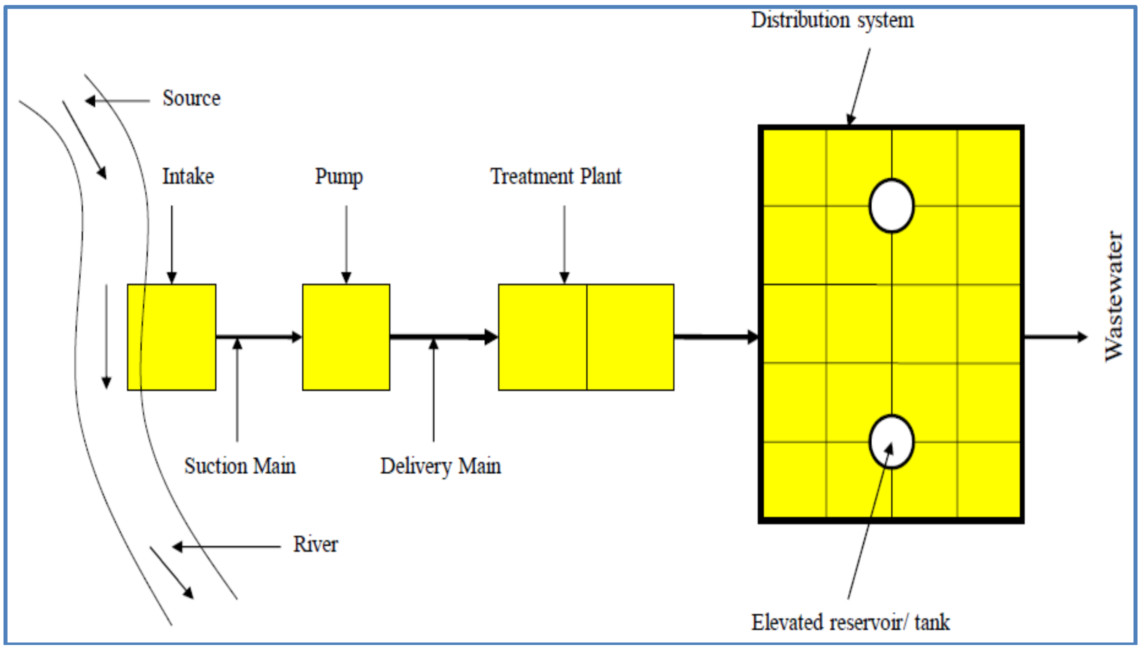


Figure 3: Elements of water supply systems

Source of Supply

- All waters come in the form of precipitation. It is evaporated from the ocean, condenses to form clouds and finally precipitates over land.
- As water falls in the form of rain, snow, sleet, or hail, it acts as a vacuum cleaner picking up all the dusts and dirt particles in the atmosphere.
- When water hits the ground, a portion of it runs off across the surface of the ground and a portion sinks into the ground.
- Therefore, the major source of supply is of two types:
  - ✓ **Surface water supply; and**

- ✓ **Ground water supply.**
- – **Minor source – Rain water**

- **Surface Water Supply**
  - ✓ The water running across the surface of the ground is designated as surface water. It picks up many substances as it flows back to the ocean like microorganisms, organic matter, minerals, and other polluting substances.
  - ✓ Surface water supply is usually obtained from streams, rivers, lakes, ponds, reservoirs, irrigation canals, and oceans.
  - ✓ Since surface water is very likely to be polluted, it needs extensive treatment.

- **Ground Water Supply**
  - ✓ The surface water which seeps into the ground is designated as **groundwater** or **sub-surface water**.
  - ✓ It travels through the surface layer of the earth, it picks up some minerals and a few organic solution.
  - ✓ The microorganisms and particulate matter find themselves being filtered out in the upper layers.
  - ✓ Thus, groundwater taken from deep aquifers are free from microorganisms and contain relatively low concentration of minerals and organic contaminants.
  - ✓ **Springs**, **wells**, **infiltration wells**, and **infiltration galleries** form the chief ground water supply.
  - ✓ Since groundwater is unlikely to be polluted, it needs less or sometimes no treatment.

- **Suitability of Sources with Regards to <u>Quantity</u>**
  - – The surface water source should have enough water to provide water throughout the year. Usually surface water are abundant.
  - – However, suitability of surface water source should be determined based on the water availability in the worst dry season in last 20-25 years.
  - – In terms of groundwater sources, the quantity of water available is usually less than that in the case of surface water sources.

- A hydrogeological study may be performed to find out the available groundwater (GW) to withdraw in an aquifer.
- The GW supplies withdrawn from deep aquifer are more constant in their yield and hence more reliable.

- **Suitability of Sources with Regards to <u>Quality</u>**
  - Impurities in water normally are in two types, **<u>suspended</u>** and **<u>dissolved</u>**.
  - The surface waters are characterized by the suspended impurities whereas **GW** are free from suspended matter, but are likely to contain a large amount of dissolved impurities, which they gather during travel in the underground strata comprising rocks and minerals.
  - The suspended matter often contains the **pathogenic** (i.e., disease producing) bacteria. As a result, surface waters are not considered to be safe for drinking without the necessary treatment.
  - GW are comparatively safer and fit for drinking purpose with a minor or sometimes no treatment.

- **Choice of a Source for Water Supply**
  - The main considerations are:
    - ✓ **Location of source;**
    - ✓ **Quantity of water available;**
    - ✓ **Quality of water;** and
    - ✓ **Cost of entire scheme.**
  - The quantity of water available should be sufficient to cater for the needs of the community regarding domestic service, industrial demands, fire fighting requirements, schools, hospitals, other public uses.
  - The quantity of water supplied should also include the design requirements, which means the calculated quantity would be somewhat higher than the bare needs.
  - The quality of water available should be **wholesome, safe**, and **free from pollutants of any kind**.
  - The health of the public should in no way be endangered due to epidemics associated with water-borne diseases.

- The quantity and quality of water are prime considerations in selection of any source of supply.
- The cost considerations regarding the development and operation of water supply are also significant.
- The water from the source can be collected to the treatment plant by gravity flow or by pumping.
- The cost would, naturally, be less for gravity flow. The cost would also depend on distance between source and distribution system.
- The cost should be reasonable and be repaid at the end of design period, which is usually **20 to 30** years.

▪ **Collection System**

- The collection system is a sort of engineering works designed to convey water from a source to the treatment system.
- The essential units of a collection system are:
  - ✓ Intake
  - ✓ Intake main
  - ✓ Aqueduct or transmission main; and
  - ✓ Pumping station.
- **Intake:**
  - ✓ An intake is device or a structure placed in a surface water source to facilitate the withdrawal of water from the source and discharge into an intake conduit or pipe (**Intake main**) through which it will flow into water-works system.
  - ✓ Types of intake structures consist of intake towers, submerged intakes, intake pipes or conduits, movable intake and shore intakes.
  - ✓ Intake should be so located and designed that the possibility of interference with the supply is minimized to the greatest possible extent.
  - ✓ Where uncertainty of continuous serviceability exists intakes should be **duplicated**.
- The following factors must be considered in locating and designing intakes:

- Location of the best quality of water available;
- Possibility of wide fluctuations of water levels;
- Characteristics of intake surrounding, i.e., depth of water, character of river bottom, navigation requirements, effects of waves, currents, floods, and storms upon the intake structures and in scouring the river bed and banks;
- Formation of shoals and bars;
- Possible sources of pollution; and
- Provision for excluding possible floating materials like logs and vegetation.

– Intake Main and transmission Main:

- The pipeline from the source to the treatment plant (suction main in Figure 3) is known as intake main and transmission main.
- The size of the pipeline is determined by the volume of water to be delivered and the pressure or the head of water.
- The design of the pipeline is governed by the principles of engineering economics, perhaps to a great extent than any other part of the water supply system.

– Pumping Station:

- A pumping station is essential for pumping water from the source through the intake to allow water to flow by gravity through the transmission main to the treatment plant.
- *The details of pumping station is out of the scope of the lecture and the course*.

- **Treatment Plant**

  ✓ Treatment plant is an essential element of a water supply system **to treat water for making it palatable**.

  ✓ In case of surface waters, the treatment procedure may involve the removal of turbidity, color, taste, odor, and bacteria.

- ✓ Groundwater from wells may need to be treated to reduce hardness, iron, corrosive qualities, and sometimes bacteria.
- ✓ The methods used for treatment include screening, sedimentation, treatment with chemicals, filtration through sand beds, and disinfection to kill microorganisms.

- **Distribution System**
  - The distribution system is necessary to deliver water to the individual consumer in the required quantity and under satisfactory pressure.
  - The distribution system is often a major investment of community water supply system. This includes:
    - ✓ Various pipes that convey the water to consumers;
    - ✓ Storage reservoirs/tanks that are provided to aid the distribution of water;
    - ✓ Pumps and necessary equipment; and
    - ✓ Fire hydrants, valves, meters, and other appurtenances.

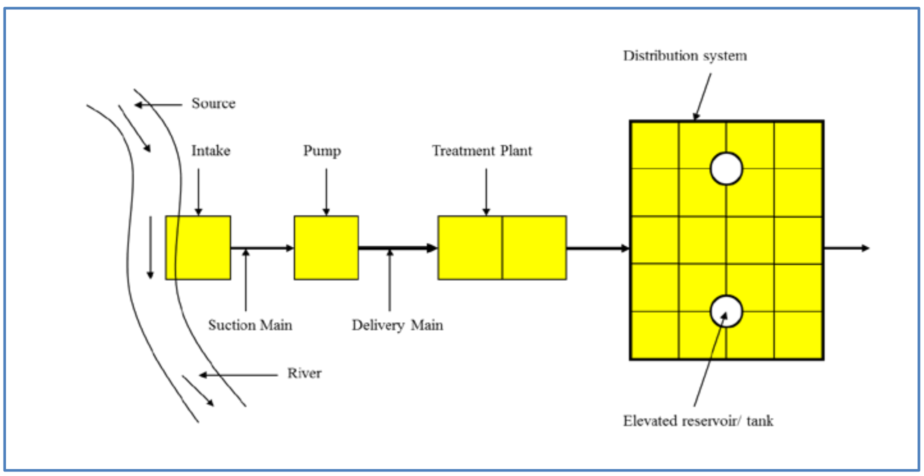


Figure 3: Repeat

- **Classification of Distribution System**
  - There are three general methods or systems for providing satisfactory water pressure in the distribution pipes, namely:
    - ✓ ***gravity system***,
    - ✓ ***system with direct pumping***, and
    - ✓ ***the system with pumping and storage*****.**

- **Gravity system:**
  - ✓ This system is adopted where the source of supply such as a lake, or an impounding reservoir, is at a sufficient elevation with respect to the city in order to produce adequate pressures for fire and domestic services.
  - ✓ This method, evidently, is the safest and most reliable.

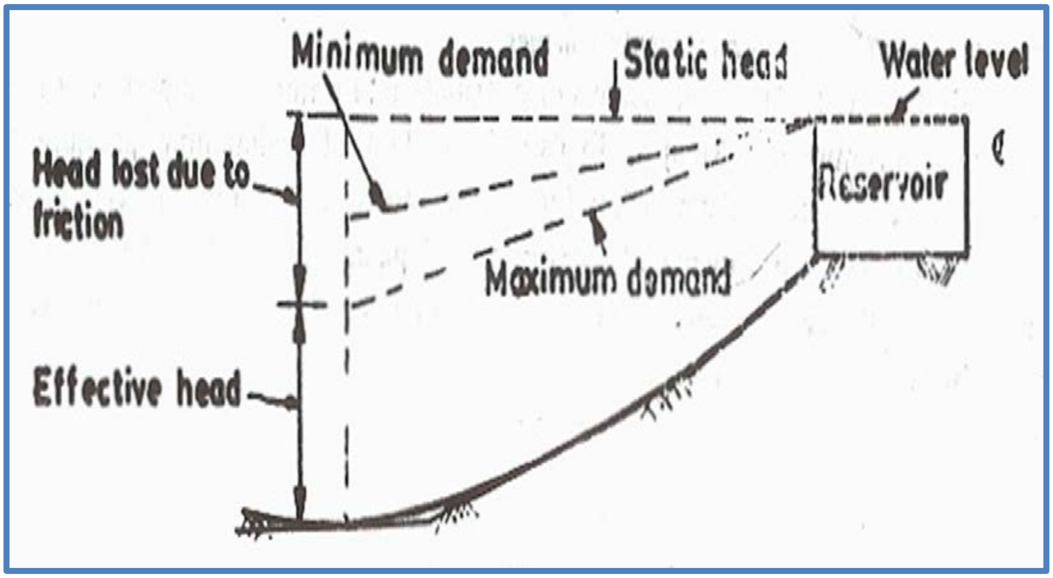


Figure 4: Gravity distribution system

- **System with direct pumping:**
  - ✓ In this method, the water is directly pumped to the mains. Consumption is the only outlet.
  - ✓ This method is least desirable, a failure in the power supply means breakdown of the system.
  - ✓ Also, pressures in the main vary with the consumption, so that under varying consumption, several pumps may be required to conform to the supply, adding to the cost.

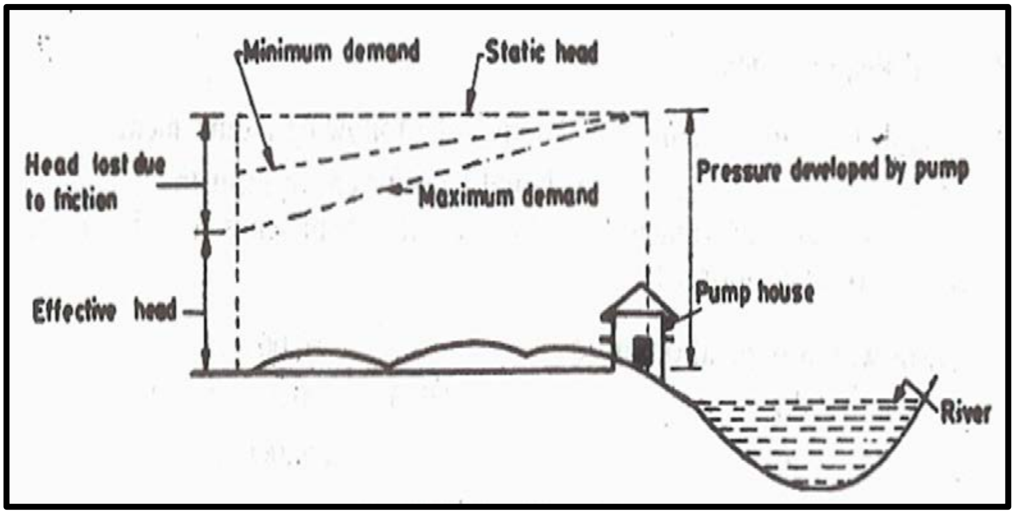


Figure 5: Direct pumping distribution system

- **System with pumping and storage (Duel):**
  - ✓ This is also called direct-indirect or dual system. In this system, when the demand rate exceeds the pumping rate, the flow into the distribution system is both from the pumping station as well as the elevated reservoir.
  - ✓ When, the reverse condition exists, i.e. pumping rate exceeds demand rate, the excess water is stored in the reservoir.
  - ✓ This system, obviously, is the most economical and reliable. It provides for a uniform rate of pumping.
  - ✓ The pumps can be operated at their rated capacities, resulting in higher efficiency and economy of operation.
  - ✓ Also, the water stored serves as a reserve to take care of fire demands and pump breakdowns.

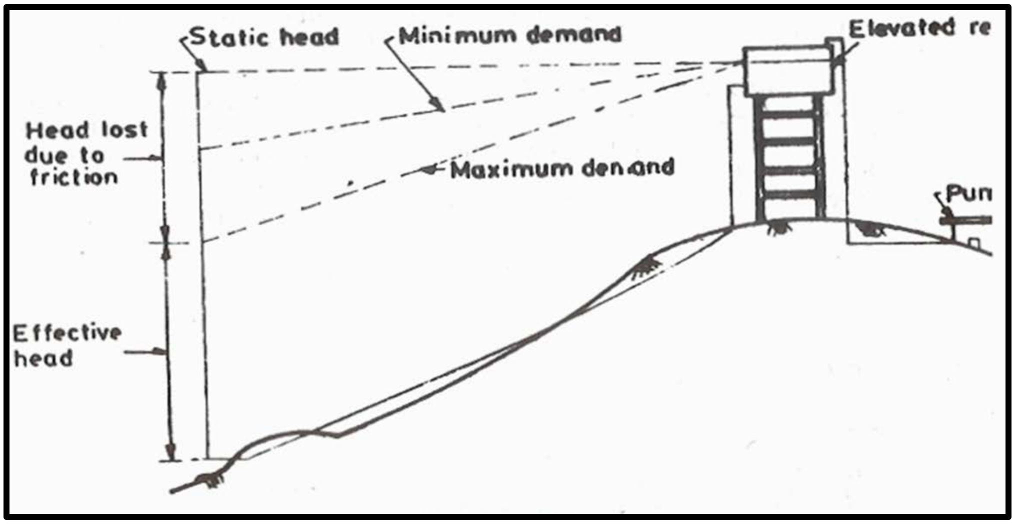


Figure 6: Pumping and storage distribution system

- **Distribution System – Method of Supply**
  - **Intermittent supply** i.e., for a few fixed hours of the day, for example 5:00 am to 11:00 am and 3:00 pm and 9:00 pm
  - **Continuous supply** i.e., for 24 hours in a day.
  - **Disadvantages of intermittent supply:**
    - ✓ Consumers are compelled to store water for use during non-supply hours.
    - ✓ The unused water of storage tanks is most likely to be thrown out to be replaced during the supply hours, by fresh supply. Evidently, this is wastage of water.
    - ✓ In case of fire breaks out during non-supply hours, considerable damage would have resulted before the supply could be turned on and fire extinguished.
    - ✓ During the non-supply hours, the pressures in the distribution system may fall below the atmospheric pressures, causing partial vacuum, sucking in air or other harmful gases from the sewers running close-by and resulting a possible contamination of water supply.

- **Pressure Requirements in the Distribution Pipes**
  - For domestic purposes → **50 to 60** psi (with a minimum of **20** psi and a maximum of **120** psi). AWWA recommends a static pressure of **75** psi through a system.
  - For fire hose – **80 to 100** psi.

- **Distribution Reservoirs**
  - These reservoirs (**overhead water tank**) are used to provide storage of treated water to meet the requirements of the consumers during high demand and when the demand cannot be met by direct pumping and also to provide fire storage and stabilize pressures in the distribution system.
  - The reservoirs may be steel or concrete. They may be cylindrical, rectangular, or square.
  - The reservoirs should be located as close to the center of use as possible for even distribution.
  - The water level in the reservoir must be high enough to allow gravity flow at satisfactory pressure to the pipe system it serves.

- **Types of Reservoirs**
  - The storage reservoirs (overhead water tank) are commonly built up in four different types:
    - R.C. C. tank on R.C.C staging;
    - Steel tank on brick tower;
    - Steel tank on steel staging; and
    - Pre-stressed steel tank on steel staging.
  - Accessories of an reservoir:
    - Inlet and outlet pipes fitted with bell-mouth
    - Overflow and washout pipes combined with valve control;
    - Ladder and manhole for cleaning and inspection;
    - Water level indicator; and
    - Ventilators and lightning arrestors.

- **Most Economic Dimension of a Cylindrical Reservoir/Tank:**
  - The dimensions of a tank can be determined by applying the simple principle of calculus, maxima and minima.

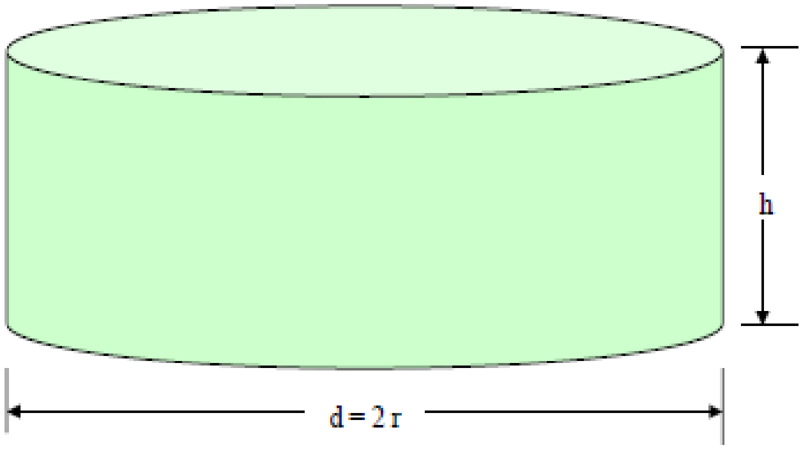


Figure 7: Cylindrical overhead storage tank

– Since the tank is cylindrical, minimum surface area that will be required to hold a constant volume of water by the condition of maxima and minima will be the economic size.

– Assuming floor thickness is equal to the wall thickness;

$A = A_1 + A_2$
where, A_1 = Area of the base; A_2 = Area of the shell surface; A = Total surface area
$A = \pi r^2 + 2\pi rh$
$\forall$ = volume of the tank = $\pi r^2 h$

$$\therefore h = \frac{\forall}{\pi r^2}$$

$$A = \pi r^2 + 2\pi r \frac{\forall}{\pi r^2} = \pi r^2 + \frac{2\forall}{r}$$

Differentiating both sides with respect to ***r***.

$$\frac{dA}{dr} = \pi \frac{d}{dr}(r^2) + 2\forall \frac{d}{dr}(r^{-1})$$

$$= \pi.2r^{2-1} + 2\forall(-1)r^{-1-1} = 2\pi r - \frac{2\forall}{r^2} \quad \left[\because \tfrac{d}{dx}x^n = nx^{n-1}\right]$$

– From the condition of maxima and minima,

$$\frac{dA}{dr} = 0$$

$$\therefore 2\pi r - \frac{2\forall}{r^2} = 0$$

$$or\ 2\pi r = \frac{2\forall}{r^2} = \frac{2\pi r^2 h}{r^2} = 2\pi h$$

$$or\ r = h$$

Hence, for economical dimension of a cylindrical tank, radius (r) must be equal to the height (h).

Example 1: Calculate the economic dimension of a cylindrical tank for a capacity of 100,000 gallons (1 ft^3 = 7.481 gallons).

Example 1 Solution:

Solutions:					
Given: $\forall$ =	100,000	gallons =	100000 gallons x 1 cft / 7.48 gallon =	13368.98	cft.
For economic dimension, r = h					
$\forall = \pi r^2 h = \pi h^3$	$\therefore\ h = \sqrt[3]{\frac{\forall}{\pi}} =$		(13368.98/3.14159)^(1/3)) =	16.21	ft.
diameter, d = 2r = 2h =	2 x 16.21 =	32.41	ft.	Therefore, tank diameter = 32.41 ft. and height = 16.21 ft.	

- **Distribution Pipe System**
  - The basic requirements of distribution pipe systems are adequate strength and maximum corrosion resistance.
  - Cast iron, concrete, asbestos-cement, PVC (Polyvinyl chloride), and G.I. (galvanized iron) are available in smaller sizes, while steel, HDPE (High Density Polyethylene), and R.C.C. (Reinforced Cement Concrete) pipes are available in larger sizes.
  - The pipe system comprises of four units:
    - The supply main;
    - The sub-mains;
    - Minor distributors; and
    - Valves.

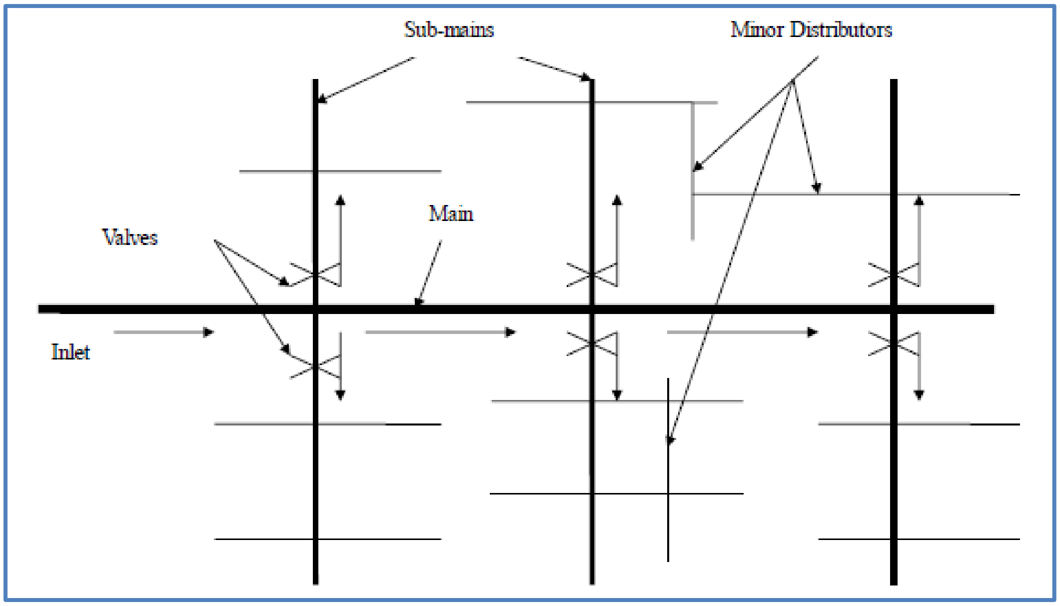


Figure 8: Component of the pipe system (Dean End System)

- The supply main or just main is the direct conveyor of water from the pumping plant or the gravity conduit to the sub-mains. It should be sufficient in size to carry the flow.
- The sub-mains are the secondary feeders connected to either side may be placed at about 1,000 ft apart and should be of sufficient size to discharge domestic supply and fire flow.
- The minor distributors or branches make up the grid iron of the pipes and supply water to the fire hydrants and service pipes of the residences and other buildings.
- For fire services, minimum diameter of pipe should be ***6 inch*** and for domestic service alone ***4 inch*** and less.
- Valves are needed to operate and control the pipe system. These should be sufficient in number and suitably located.

- **Layout of Distribution System**
  - There are 4 types of distribution system depending on the methods of layout of the pipe system. These are:
    - ✓ **Dead End System** (Figure 8)
    - ✓ **Grid Iron System** (Figure 9)
    - ✓ **Circle or Ring System** (Figure 10); and

- ✓ **Radial system** (Figure 11).

– **Dead End System:** It comprises of a supply main from the service reservoir and laid along the main road, with sub-mains running at right angles to it in both directions and laid along other roads joining the main road (Figure 3).

The minor distributions run from the sub-mains laid along the streets and connect buildings and houses.

– This system is suitable for old town or cities which have been irregularly developed having no definite pattern of roads and streets.

– **Its advantages are:**

- It is relatively cheap and the diameter of pipes are smaller as they serve only a limited population;
- It is easy to determine the discharge and pressure at any point in the system; and
- By suitably locating fewer valves, water supply can be so regulated that by closing any valve, a section of the system can be cut out for repairs without affecting the rest.

– **Its disadvantages are:**

- Each pipe has a dead end and where water becomes stagnant and sediments accumulate requiring the provision of blow-off or drain valves to remove the sediments;
- Due to dead-ends, contamination of water may occur; and
- A large district is to be cut out when repairs have to be made in main or sub-mains.

– **Grid Iron System:**

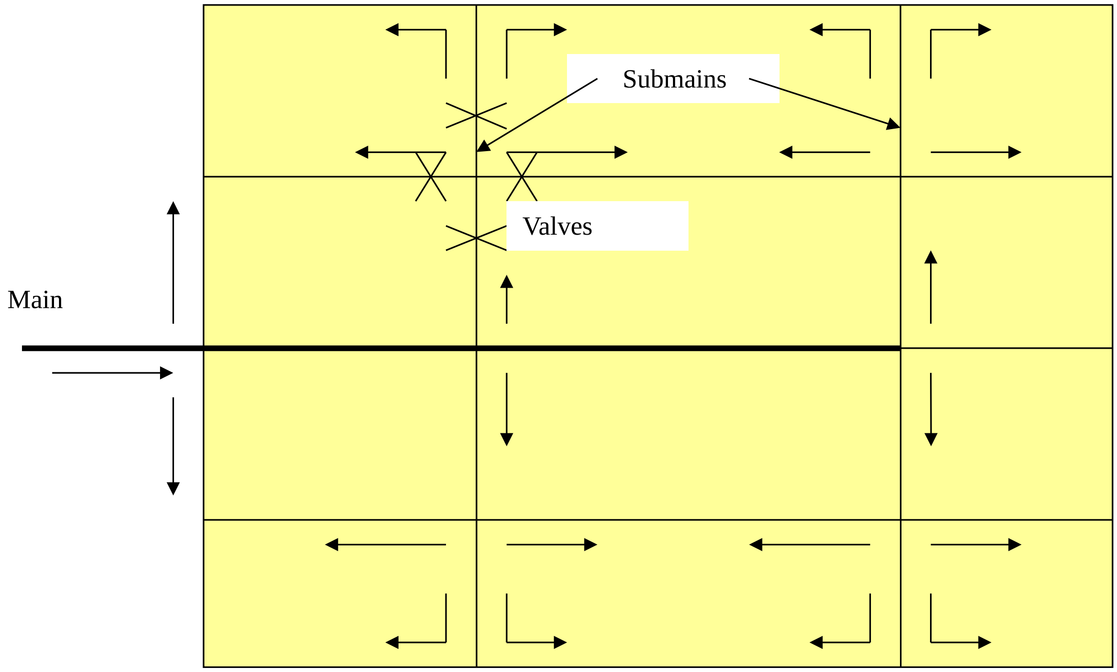


Figure 9: Grid Iron System

– It is an improvement over the Dead End System, by connecting the ends of various sub-mains so as to eliminate the dead ends. The water the circulates freely throughout the system.

– Such a system is very useful for a city laid out on a rectangular plan.

– **Its advantages are:**

  - Avoidance of any stagnation due to circulating continually;
  - In case of fire, water is available from all directions; and
  - Absence of the discontinuity of water supply anywhere in the system in the event of any repair-work to a main or sub-main, water being easily available from another main or sub-main.

– **Its disadvantages are:**

  - It requires the provision of a very large number of valves, at every junction of two roads, 4 valves are required.
  - Exact calculations of pressure and diameter of pipe is difficult; and
  - Longer pipes required, hence it is expensive.

– **Circle or Ring System:**

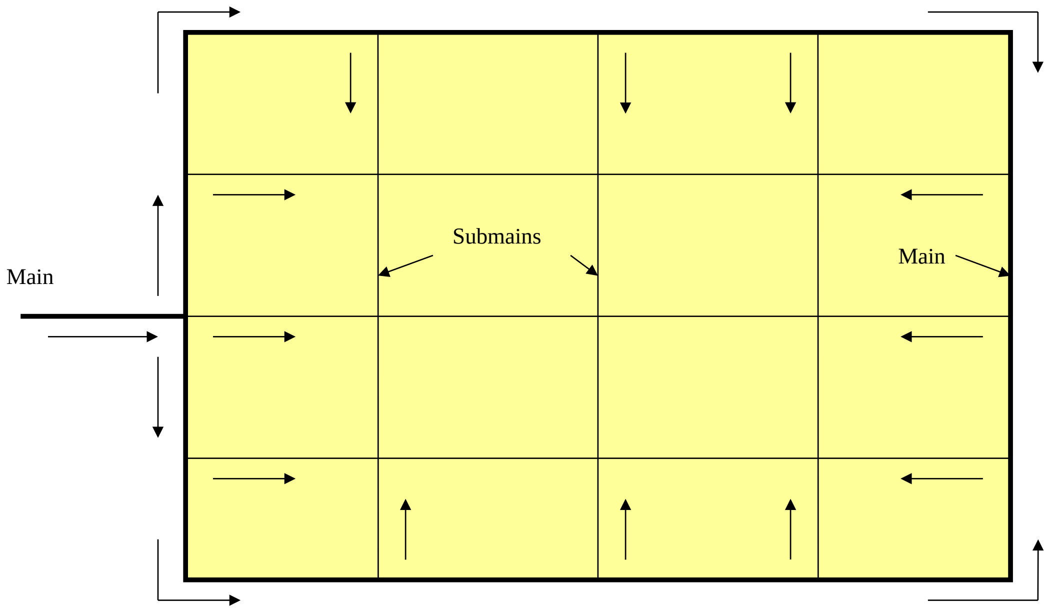


Figure 10: Ring System

– This consists of cutting the entire district into circular or rectangular blocks and then laying the mains along the peripheral roads with sub-mains branching out from the mains and running on the inner roads and streets.

– Thus, this system also follows the Grid Iron pattern with the difference that the flow pattern is now similar in character of the Dead End System. That makes the determination of discharge or size of pipe easier.

– Also, water can be supplied to any point from at least two directions.

– **Its advantages are:**

- Every point receives supply from two directions;
- During breakdown, water can be supplied from other pipelines;
- In case of fire, water is available from all directions;
- Design of pipes is easy

– **Its disadvantages are:**

- Larger number of pipes are required.

– **Radial System:**

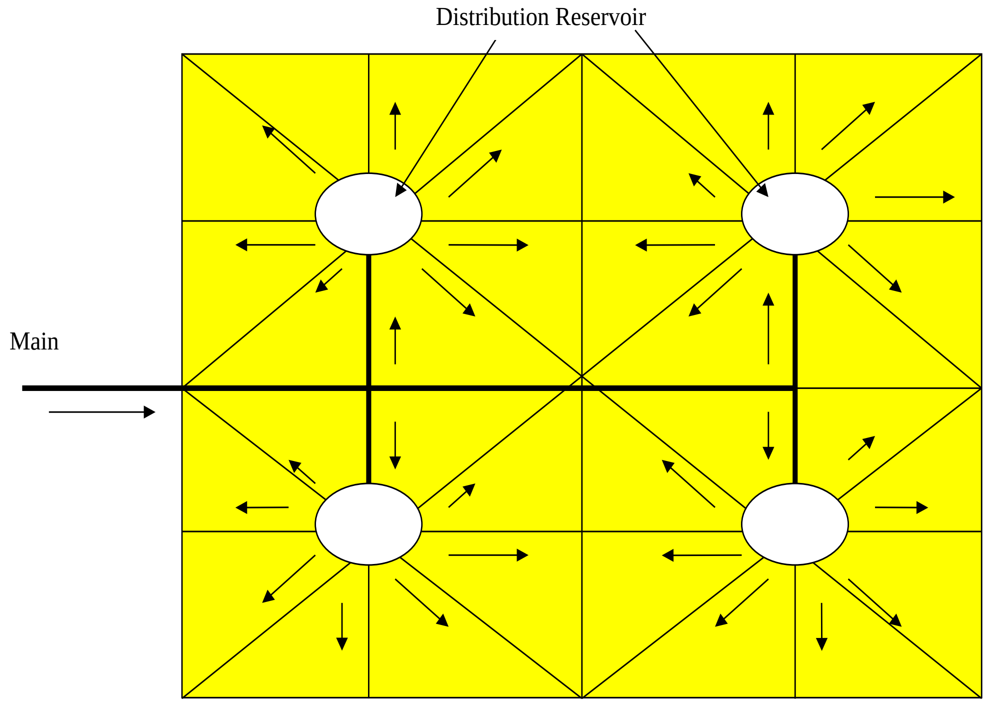


Figure 11: Radial System

– This system is the reverse instead of from the system.

– The entire district/community is divided into a number of distribution zones.

– The distribution reservoir is placed in the center of each zone.

– The supply pipes are laid radially away towards the periphery.

– **Its advantages are:**

  - Calculation of pipe sizes is easy; and
  - Quick service.

– **Its disadvantages are**:

  - There is no apparent disadvantage of this system.

- **Design of Distribution System**

  – **Factors to be considered in the design of a distribution system are:**

- Type of flow – whether continuous or intermittent;
- Method of distribution – whether by gravity or by pumping;
- Probable future demand based on perspective increase in population. This also includes industrial demand as well as the firefighting requirements;
- Period to be considered to be the life of the pipes used. The system should be designed anticipating the future for the condition that will obtain near the end of the time when the amounts set aside for depreciation would have returned the first cost; and
- The flow-formulae used in the design;

– The principle involved in the design is to assume the pipe size and then to work out the terminal pressure heads which could be made available at the end of each pipe section after allowing for the loss of pressure head in the pipe section when discharging the peak flow. The peak flow in the pipes is taken as ***3 time the average daily flow***.

– Factors causing loss of pressure head include pipe size, rate of flow, and friction. Usually, losses due to friction of the pipes are considered.

– The available pressure heads as calculated are checked up to see if they correspond to the permissible residual pressure heads. If not, the pipe size is changed and the system is reinvestigated until satisfactory conditions are obtained.

– The design procedure can be outlined as follows:

- Prepared a contoured plan of the city or town, locating on it the positions of districts or distribution zones with their population, service reservoirs, pumping stations, main roads and streets, existing main lines and other similar features. A small scale (say 1:10,000) may be used.
- Prepared detailed map of each district or distribution zone, showing, in addition to the aforesaid information for a particular district or distribution zone, location of all principal and minor streets. The tentative alignment of all mains, sub-mains, and braches as well as positions of valves and other appurtenances should be marked. Probable population to be served by each section of pipeline should be indicated in a bigger scale (say 1:2,000).

- Estimate the rate of demand for all purposes including the fire-demand and determine the quantity (average daily flow) flowing in each section of the pipe length. Multiply with 3 to get the daily maximum demand.
- Assume pipe sizes. The velocity of the flow varies 3 to 4 ft/sec.
- Find loss of pressure head in the pipe line due to friction. Hazen-Williams formula, as it is available as Nomograph can be used. Alternately, friction-flow formula can be used as indicated below **(Darcy-Weisbach** Equation):

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

where, h_f = friction head loss; f = friction factor (0.01); L = pipe length; D = internal diameter of the pipe; v = velocity through the pipe; and g = acceleration due to gravity.

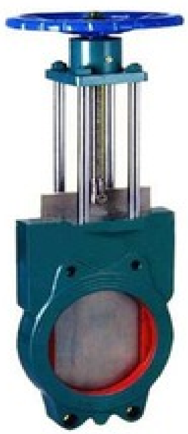
- Determine the available terminal pressure-heads. Starting from the service reservoir of the pumping station where the total pressure-head is known, the pressure-head at the end of any line would be determined by allowing for the frictional loss of head and any rise or fall due to slope of the pipeline and the ground levels.
  - In case of difference between the available terminal pressure-head and the permissible pressure-head, revised the assumed pipe size.

- **Analysis of Distribution System**
  - Frequently, it becomes necessary to analyze a given distribution system in order to determine through a quick and approximate check, the pressures and flows available in any section of the system and to suggest ways to improve upon the same, if found inadequate. The followings are the methods used to analyze the distribution system:
    - Equivalent Pipe Method
      - Pipes in series
      - Pipes in parallel
    - Method of Sections
    - Hardy-Cross Method

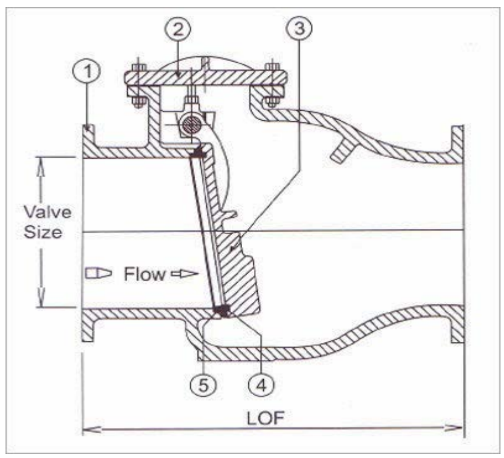
- **Appurtenances in the Distribution System**
  - The various appurtenances commonly used in a distribution system are:

- Valves
  - ✓ Sluice valve (also called gate or stop valve);
  - ✓ Reflux valve (also called check or non-return valve);
  - ✓ Scour valve (also called washout/drain valve);
  - ✓ Air-Relief valve;
  - ✓ Pressure relieve valve (also called safety or blow-off valves).
- Hydrants; and
- Meters

– **Valves**



(a)



(b)

Figure 12: Valves (a) Sluice and (b) Reflux valves

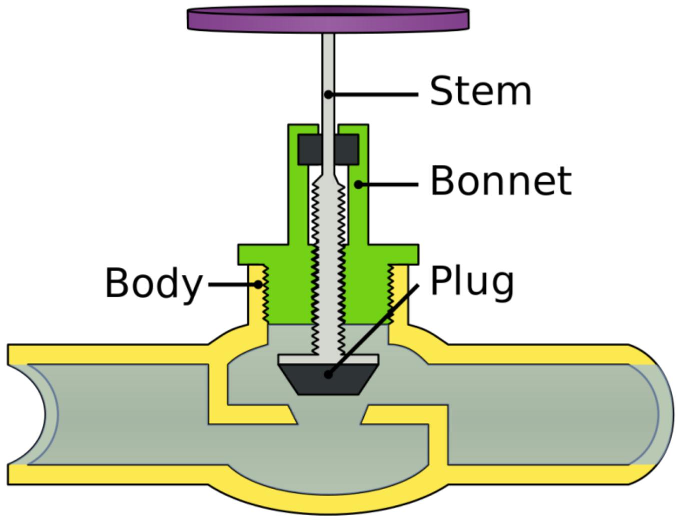


Figure 13: Air-Relief valve

– **Fire Hydrant**

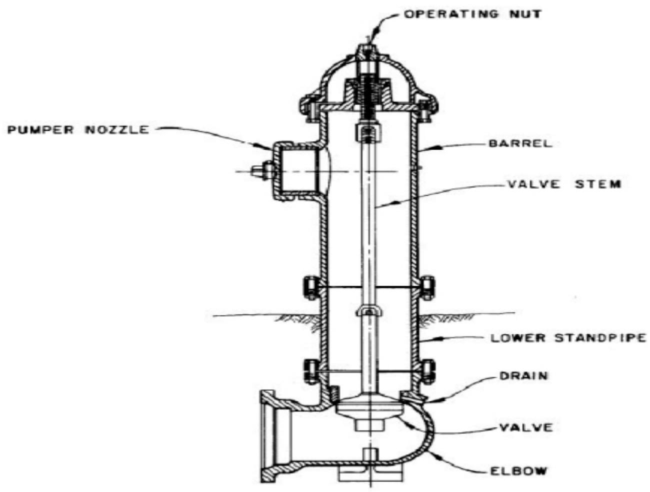


Figure 14: Fire Hydrant

Example 2: Based on the layout of the water supply system, how much pressure in psi will be available at the faucet of the 2nd floor of the residential building as show in Figure 15? Do you think that the pressure is enough for the building? Consider flow through the delivery pipe, $Q = 2.5$ cfs and diameter of the pipe, $D = 4$ inch. Ignore the minor pressure losses and use the following formulae to calculate the major pressure losses.

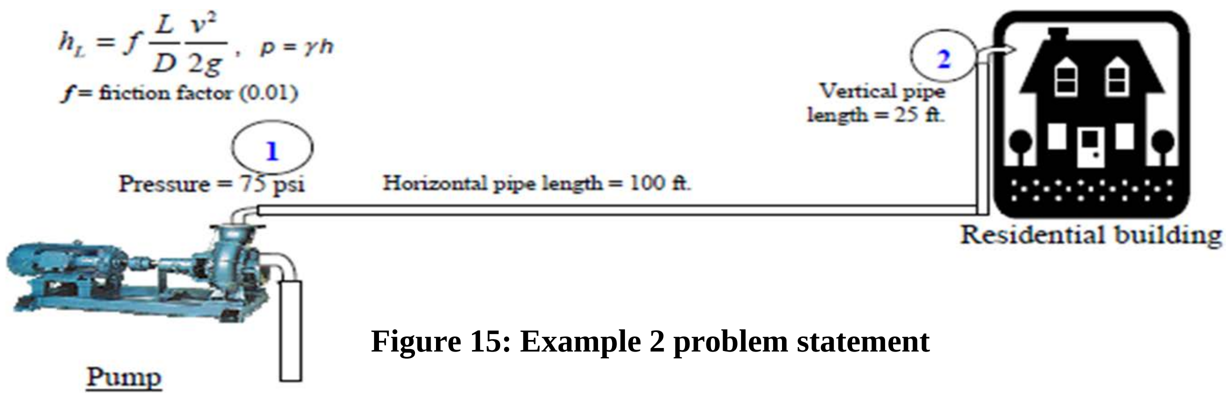


Figure 15: Example 2 problem statement

Example 2: Solutions

Given:							
Q =	2.5	cfs			For water, γ =	62.4	lb/cft
D =	4	inch =	0.333	ft			
P_1 =	75	psi =	10800	psf	Friction factor, f	0.010	(given, if not given, find it using Moody's diagram)
Pipe length, L =	125	ft.			g =	32.2	ft./s^2
Horizontal =	100	ft.					
Verical =	25	ft.					
Using energy equation between (1) and (2)	$\frac{p_1}{\gamma}+\frac{v_1^2}{2g}+z_1+h_p=\frac{p_2}{\gamma}+\frac{v_2^2}{2g}+z_2+h_t+h_L$						
Here, P_1 =	75	psi =	10800	psf			
$v_1 = v_2 = v$ =	Q/A =	2.5/(3.14159x0.333^2/4) =			28.65	ft/s	
h_p =	0.00	ft.					
h_t =	0.00	ft.					
z_1 =	0.00	ft.					
z_2 =	25.00	ft.					
Since, minor losses are ignored, $h_L = h_f = f\frac{L}{D}\frac{v^2}{2g}$					= 0.01 (125/0.333)(28.65^2/2x32.2) =	47.79	ft.
$p_2=\gamma\left[\frac{p_1}{\gamma}+\frac{v_1^2}{2g}+z_1+h_p-\frac{v_2^2}{2g}-z_2-h_t-h_L\right]$					= 62.4[10800/62.4 + 0 + 0 - 25 - 0 - 47.79]		
				=	6257.95	psf	
				=	43.46	psi	Ans.
Comments:	The faucet pressure at the 2nd floor is less than recommeded pressure, 50-60 psi.						

Note: If the friction factor ***f***, is not given, it can be found from Moody's diagram.

Example 3: If the pressure at the building is not within the recommended range (50-60 psi) for example 2, what should be the initial adjusted pressure at the pump to provide the recommended pressure of 56 psi at the building. Show your detail calculations for full credit. Use γ = 62.4 lb/ft^3 for water.

Example 3: Solutions

Solutions:		Assuming unit weight of water, γ =	62.4	lb/ft^3			
Given,	Pressure at point 1, P_1 =		75	psi =	10,800	psf	
	Presure at the faucet (at point 2), P_2 =		43.46	psi =	6,258	psf	
	Pressure to be at the faucet (point 2) =		56	psi =	8,064	psf	
	Flow rate through the pipe, Q =		2.5	ft^3/s			
Pressure required at point 1, P_1 =	75 + (56 - 43.46) =		87.54	psi =	12,606	psf	
Additional pressure head required, h = additional pressure	(12606 -10800) lb/ft^2 / 62.4 lb/ft^3 =				28.9	ft.	
Additional pwer required = γQh =	62.4 lb/ft^3 x 2.5 ft^3/s x 28.94 ft =		4,515	lb.ft/s x 1 hp / 550 lb.ft/s =	8.21	hp	ANS.

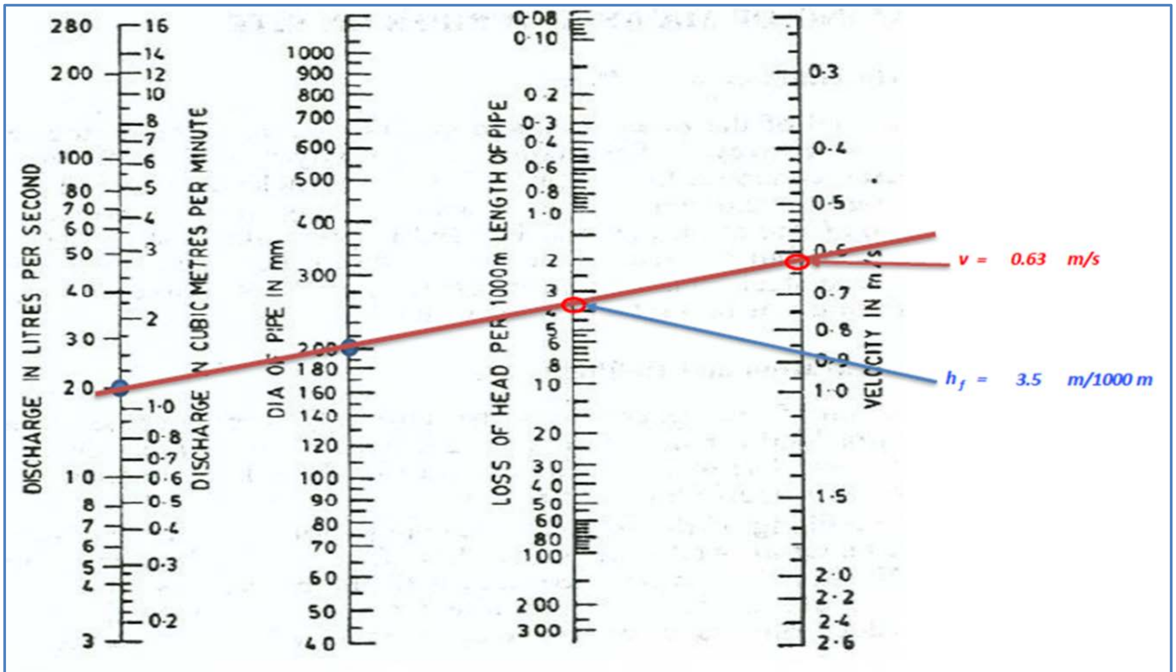
Example 4: Find the total friction loss and velocity of flow in 200 mm diameter G.I. pipe discharging 20 L/s in a total length of 300 m using Hazen William Nomogram.

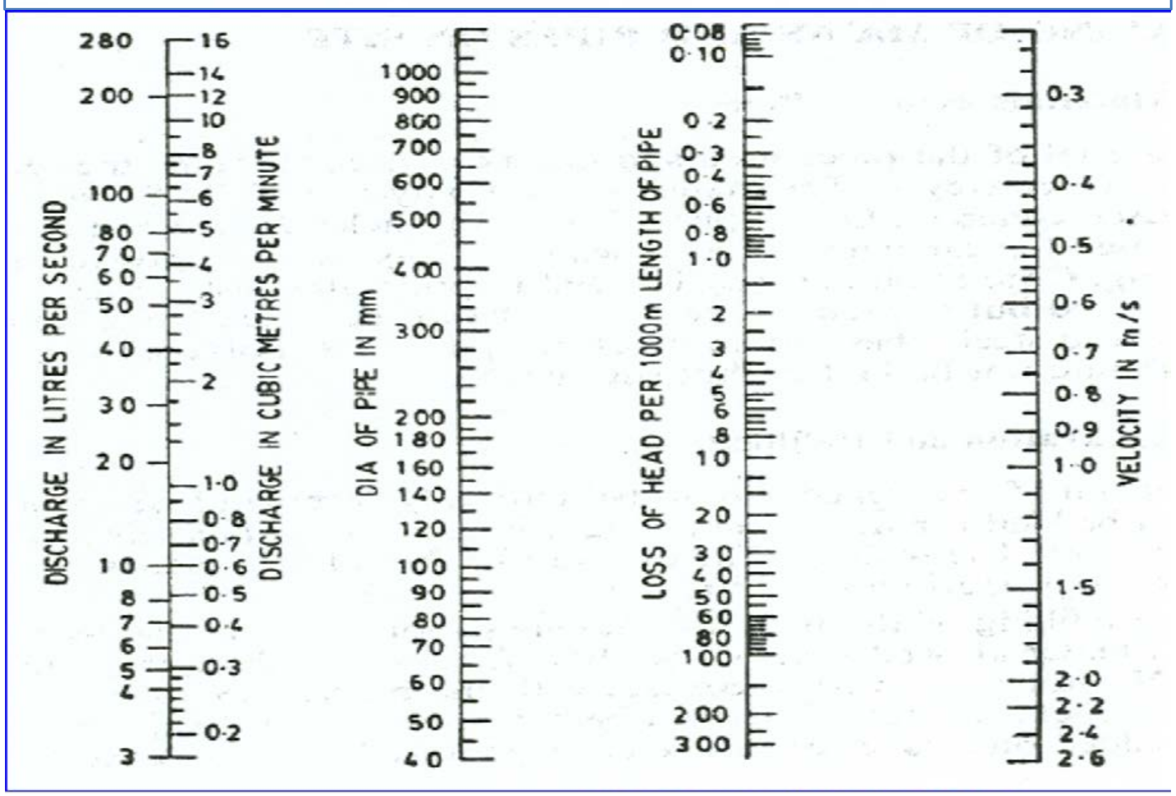
Example 4: Solutions

Given: Q =	20	L/s, D =	200	mm Length, L =	300	m		
From the Nomogram, the frictional loss =					3.5	m /1000 m	Velocity, v = 0.63	m/s
The total friction loss in 300 m length pipe = (3.5/1000)x300 =						1.05	m Ans.	

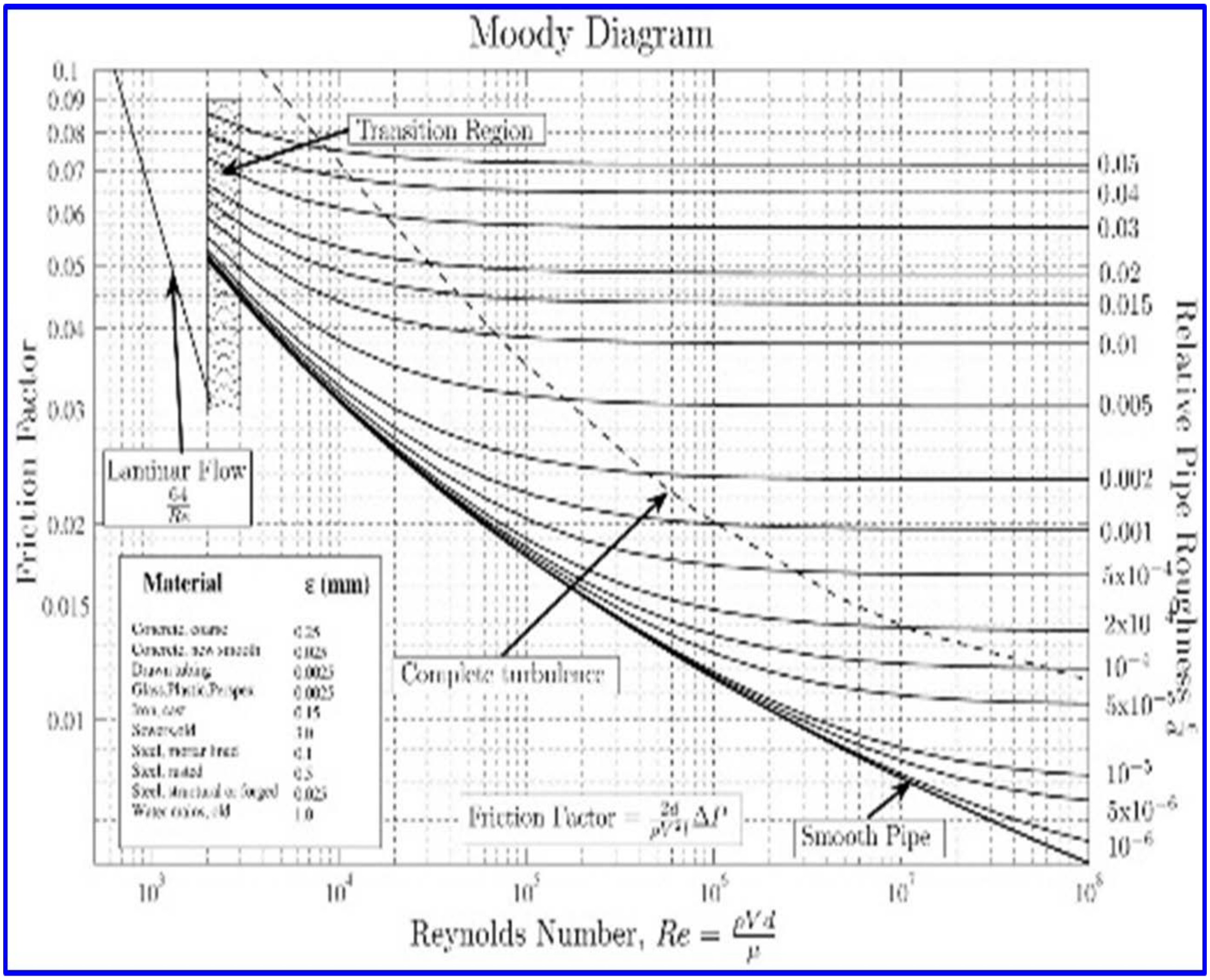
The nomogram use is shown in next slide. Two points: one at 20 L/S (1st line) and the other at 200 mm diameter (2nd line)were selected, then a straight line was drawn. The values for loss was taken from 3rd line and velocity from 4th line.

Example 4: Solutions-cont'd





Nomogram for pipe design



Moody's Diagram

If the friction factor ***f***, is not given, it can be found from Moody's diagram as shown above.

6. Health Concerns

Five general types of impurities are of public health concern. These are organic chemicals, inorganic chemicals, turbidity, microorganisms, and radioactive substances. Organic contaminants include various pesticides, industrial solvents, and trihalomethanes such as chloroform. Inorganic contaminants of major concern include arsenic, nitrate, fluoride, and toxic metals such as lead and mercury. All these substances can harm human health when present above certain concentrations in drinking water. A low concentration of fluoride, however, has been proved to promote dental health. Some communities add fluoride to their water for this purpose.

Turbidity refers to cloudiness caused by very small particles of silt, clay, and other substances suspended in water. Even a slight degree of turbidity in drinking water is objectionable to most people. Turbidity also interferes with disinfection by creating a possible shield for pathogenic organisms. Groundwater normally has very low turbidity, because of the natural filtration that occurs as it percolates through the soil. Surface waters, though, are often high in turbidity.

The most important microbiological measure of drinking-water quality is a group of bacteria called coliforms. Coliform bacteria normally are not pathogenic, but they are always present in the intestinal tract of humans and are excreted in very large numbers with human waste. Water contaminated with human waste always contains coliforms, and it is also likely to contain pathogens excreted by infected individuals in the community. Since it is easier to test for the presence of coliforms rather than for specific types of pathogens, coliforms are used as indicator organisms for measuring the biological quality of water. If coliforms are not found in the water, it can be assumed that the water is also free of pathogens. The coliform count thus reflects the chance of pathogens being present; the lower the coliform count, the less likely it is that pathogens are in the water.

Radioactive materials from natural as well as industrial sources can be harmful water contaminants. Wastes from uranium mining, nuclear power plants, and medical research are possible pollutants. Strontium-90 and tritium are radioactive contaminants that have been found in water as a result of nuclear weapons testing. Naturally occurring substances such as radium and radon gas are found in some groundwater sources. The danger from dissolved radon gas arises not from drinking the water but from breathing the gas after it is released into the air.

7. Aesthetic Concerns

Color, taste, and odor are physical characteristics of drinking water that are important for aesthetic reasons rather than for health reasons. Color in water may be caused by decaying leaves or by algae, giving it a brownish yellow hue. Taste and odor may be caused by naturally occurring dissolved organics or gases. Some well-water supplies, for example, have a rotten-egg odor that is caused by hydrogen sulfide gas. Chemical impurities associated with the aesthetic quality of drinking water include iron, manganese, copper, zinc, and chloride. Dissolved metals impart a bitter taste to water and may stain laundry and plumbing fixtures. Excessive chlorides give the water an objectionable salty taste.

8. Water Quality Standards

Water quality standards set limits on the concentrations of impurities allowed in water. Standards also affect the selection of raw water sources and the choice of treatment processes. The development of water quality standards began in the United States in the early 20th century. Since that time, the total number of regulated contaminants has increased as toxicological knowledge and analytical measurement techniques have improved. Modern testing methods now allow the detection of contaminants in extremely low concentrations—as low as one part contaminant per one billion parts water or even, in some cases, per one trillion parts water. Water quality standards are continually evolving, usually becoming more stringent. As a result, the number of regulated contaminants increases over time, and their allowable concentrations in water are lowered.

Drinking-water regulations in the United States include two types of standards: primary and secondary. Primary standards are designed to protect public health, whereas secondary standards are based on aesthetic factors rather than on health effects. Primary standards specify maximum contaminant levels for many chemical, microbiological, and radiological parameters of water quality. They reflect the best available scientific and engineering judgment and take into account exposure from other sources in the environment and from foods. Turbidity is also included in the primary standards because of its tendency to interfere with disinfection. Secondary standards are guidelines or suggested maximum levels of color, taste, odor, hardness, corrosiveness, and certain other factors.

9. Municipal Water Consumption

Water consumption in a community is characterized by several types of demand, including domestic, public, commercial, and industrial uses. Domestic demand includes water for drinking, cooking, washing, laundering, and other household functions. Public demand includes water for fire protection, street cleaning, and use in schools and other public buildings. Commercial and industrial demands include water for stores, offices, hotels, laundries, restaurants, and most manufacturing plants. There is usually a wide variation in total water demand among different communities. This variation depends on population, geographic location, climate, the extent of local commercial and industrial activity, and the cost of water.

Water use or demand is expressed numerically by average daily consumption per capita (per person). In the United States the average is approximately 380 litres (100 gallons) per capita per day for domestic and public needs. Overall, the average total demand is about 680 litres (180 gallons) per capita per day, when commercial and industrial water uses are included. (These figures do not include withdrawals from freshwater sources for such purposes as crop irrigation or cooling operations at electric power-generating facilities.) Water consumption in some developing countries may average as little as 15 litres (4 gallons) per capita per day. The world average is estimated to be approximately 60 litres (16 gallons) per person per day.

In any community, water demand varies on a seasonal, daily, and hourly basis. On a hot summer day, for example, it is not unusual for total water consumption to be as much as 200 percent of the average demand. The peak demands in residential areas usually occur in the morning and early evening hours (just before and after the normal workday). Water demands in commercial and industrial districts, though, are usually uniform during the work day. Minimum water demands typically occur in the very early or predawn morning hours. Civil and environmental engineers must carefully study each community's water use patterns in order to design efficient pumping and distribution systems.

10. Planning of Water Supply Systems

The planning of water supply systems involves the evaluation of the ability of an existing or proposed Water source to meet all anticipated water demands and potential fire flows in a safe and dependable manner. Planning is based on the future system needs and the forecasted growth over the design period. It also considers possible renovations or capital improvements for water treatment facilities and water storage. The goal of planning is to provide residents and businesses in a city with safe, affordable, high quality potable water for daily consumption and fire demand.

In general the following are the items that need to be done in planning a water supply system:

- Estimation of the future population of the community and study the local conditions to determine the quantity of water that must be provided;
- Location of a reliable source of water of adequate quantity and quality;
- Design of a suitable intake (for surface water source only) and collections system;
- Provision for the necessary storage of water and design of works required to deliver the water from its source to the community;
- Determination of the physical, chemical, and biological characteristics of the water;
- Design of various units of treatment plant;
- Design of a distribution system, including distribution reservoirs, pumping station, elevated storage, layout and location of fire hydrants;
- Provision for the establishment of an organization which will maintain and operate the supply, distribution, treatment facilities, and billings.

11. Management of Water Supply Systems

Water supply system is a complex issue. After all, water is a force to be reckoned with – physically, socially and financially. Your clients depend on it, which means you need to be able to depend on their network. You need to optimally design and redesign networks while still maintaining the correct hydraulic coverage, facilitate self-cleaning functions and reduce your build costs by millions. You must maintain your assets, reduce non-revenue water and manage downtime, all while making sure that your business processes keep up with evolving needs.

12. Summary

In this course we defined and elaborated on water cycle, watershed, elements of water supply systems, distribution systems, effects on health and environment, as well as the planning and management of water supply systems. We also solved a few problems to show the use of Darcy-Weisback equation, Hazen William's Nomogram and energy equation to estimate the head loss and pressure at a certain point in a distribution system.

13. References

1. Internet open source.
2. Personal work experience.

+++++++++++++++ **The End** ++++++++++++++

Any questions please contact the instructor at makarim@juno.com

QUIZ for Water Supply Systems

1. The broad objectives underlying any water supply system are to:
a. supply **safe** and **wholesome water** to consumers
b. supply water in adequate quantity
c. make water easily available to consumers to encourage personal and household cleanliness
d. all of the above
e. none of the above

2. The essential elements of a water supply system are:
a. Source of supply
b. Collection system
c. Treatment system
d. Distribution system
e. All of the above
f. None of the above

3. Two potential sources of water supply are:
a. Surface water and rainwater
b. Groundwater and rainwater
c. Surface water and Ground water
d. All of the above
e. None of the above

4. Suitability of surface water source should be determined based on the water availability in the worst dry season in last ______ to _______ years.
a. 10 to 20
b. 20 to 25
c. 25 to 30
d. 30 to 50

5. Impurities in water normally are in two types and these are:
a. suspended and dissolved
b. suspended and colloidal
c. colloidal and dissolved
d. ionized and dissolved

6. Surface water supply is usually obtained from streams, rivers, lakes, ponds, reservoirs, irrigation canals, and oceans.
a. True
b. False

7. Springs, wells, infiltration wells, and infiltration galleries form the chief surface water supply.
a. True
b. False

8. Streams, rivers, lakes, ponds, reservoirs, irrigation canals, and oceans form the chief groundwater supply.
a. True
b. False

9. Springs, wells, infiltration wells, and infiltration galleries form the chief groundwater supply.
a. True
b. False

10. The surface waters are characterized by the ______________ impurities whereas groundwater are free from ___________ matter, but are likely to contain a large amount of _____________ impurities, which they gather during travel in the underground strata comprising rocks and minerals.
a. suspended, suspended, dissolved
b. suspended, dissolved, suspended
c. suspended, dissolved, dissolved
d. suspended, colloidal, dissolved

11. The suspended matter often contains the ________________ bacteria. As a result, surface waters are not considered to be safe for drinking without the necessary treatment.
a. pathogenic
b. aerobic
c. anaerobic
d. facultative
e. none of the above

12. The main considerations to choose a source of water supply are:
a. Location of source
b. Quantity of water available
c. Quality of water
d. Cost of entire scheme
e. a and b
f. a, b, c, and d

13. The quality of water available from a water supply source should NOT be **wholesome, safe**, and **free from pollutants of any kind**.
a. True
b. False

14. The water from the source can be collected to the treatment plant by ___________ flow or by _____________.
a. gravity or pumping
b. gravity or overhead storage
c. storage or storage
d. all of the above
e. none of the above

15. The cost should be reasonable and be repaid at the end of design period, which is usually ______ to _______ years.
a. 10 to 20
b. 20 to 30
c. 30 to 40
d. 40 to 50

16. The essential units of a water collection system are:
a. Intake
b. Intake main
c. Aqueduct or transmission main
d. Pumping station
e. All of the above
f. None of the above

17. Where uncertainty of continuous serviceability exists intakes should be _____________.
a. triplicated
b. duplicated
c. a and b
d. all of the above
e. none of the above

18. A pumping station is NOT essential for pumping water from the source through the intake to allow water to flow by gravity through the transmission main to the treatment plant.
a. True
*b. False

19. Treatment plant is NOT an essential element of a water supply system to treat water for making it palatable.
a. True
b. False

20. The methods used for treatment include screening, sedimentation, treatment with chemicals, filtration through sand beds, and disinfection to kill microorganisms.
a. I do agree with it
b. I don’t agree with it

21. In case of surface waters, the treatment procedure may involve the removal of turbidity, color, taste, odor, and bacteria.
a. I do agree with it
b. I don't agree with it

22. Groundwater from wells may NOT need to be treated to reduce hardness, iron, corrosive qualities, and sometimes bacteria.
a. I do agree with it
b. I don't agree with it

23. ____________ system is least desirable, a failure in the power supply means breakdown of the system.
a. direct pumping
b. pumping and storage
c. only storage
d. a and b

24. ___________ system, obviously, is the most economical and reliable. It provides for a uniform rate of pumping.
a. direct pumping
b. pumping and storage
c. only storage
d. a and b

25. The methods water supply to consumers are ______________ and ____________________.
a. intermittent and continuous
b. pumping and storage
c. a and b
d. all of the above
e. none of the above

26. For domestic purposes, a pressure range of _______ to ______ psi (with a minimum of 20 psi and a maximum of 120 psi) is necessary. AWWA recommends a static pressure of ___________ psi through a system. For fire hose a pressure range of ________ to _________ psi is necessary.
a. 50 to 60 psi; 75 psi; 80 to 100 psi
b. 50 to 60 psi; 95 psi; 85 to 105 psi
c. 50 to 70 psi; 75 psi; 80 to 100 psi
d. 40 to 50 psi; 75 psi; 80 to 100 psi

27. The overhead water tanks or reservoirs are used to provide storage of treated water to meet the requirements of the consumers during high demand and when the demand cannot be met by direct pumping and also to provide fire storage and stabilize pressures in the distribution system.
a. True
b. False

28. The basic requirements of distribution pipe systems are _________ __________ and _____________ __________________ _________________.
a. pipe size and maximum strength requirements
b. adequate strength and maximum corrosion resistance
c. all of the above
d. none of the above

29. The distribution pipe system comprises of four units and these are: ___________ __________ __________ _____________
a. The supply main; The sub-mains; Minor distributors; and Valves
b. Pumps, valves, connections, joints
c. all of the above
d. none of the above

30. For fire services, minimum diameter of pipe should be _________ ***inch*** and for domestic service alone _______ ***inch*** and less.
a. 6 and 4
b. 8 and 6
c. 6 and 6
d. 4 and 4

31.There are 4 types of distribution system depending on the methods of layout of the pipe system and these are:
a. Dead End System
b. Grid Iron System
c. Circle or Ring System
d. Radial system
e. All of the above
f. None of the above

32. In Circle or Ring System the main advantages are: (a) every point receives supply from _______ directions, (b) during breakdown, water can be supplied from other ____________.
a. two; pipelines
b. three; pipelines
c. five; pipelines
d. four; pipelines

33. The factors causing loss of pressure head in the distribution system include pipe size, rate of flow, and friction. Usually, losses due to friction of the pipes are considered.
a. True
b. False

34. Factors to be considered in the design of a distribution system are: __________ and __________.
a. type of flow and method of distribution
b. continuous and intermittent
c. gravity and pumping
d. pipe and overhead storage tank