EWCE 331
Water Supply Engineering

Lecture 1

Instructor

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Department of EWCE, MIST

Lecture outline

Surface Water Supply Scheme

Topics	References
• **Surface water collection units** • **Water treatment units**	**1. A Text Book of Water Supply Engineering** Authors: M. A. Aziz 1st ed., Hafiz Book Center **3. Water Supply and Sanitation** Authors: M. Feroz Ahmed, Md. Mujibur Rahman 1st ed., ITN-BUET **3. Water and Environmental Engineering** Authors: M. Habibur Rahman, Abdullah Al-Muyeed 1st ed., ITN-BUET

Public Water Supply



- Public water supply refers to water withdrawn by public and private water suppliers and delivered to users.
- Public water suppliers provide water to domestic, commercial and industrial users.
- Provides water to at least 25 people or has a minimum of 15 service connections.

Objectives of Public Water Supply

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



Elements of Public Water Supply

1. Source of supply
2. Collection system
3. Treatment or purification plant
4. Distribution system

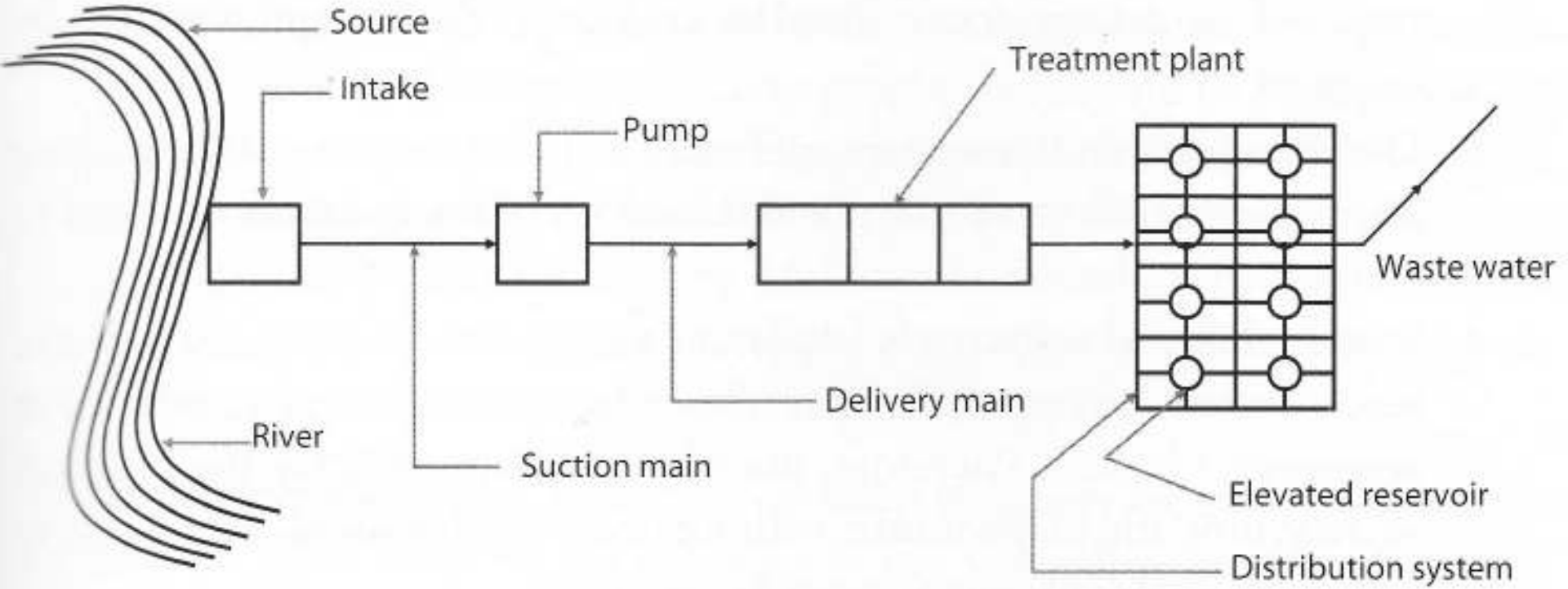
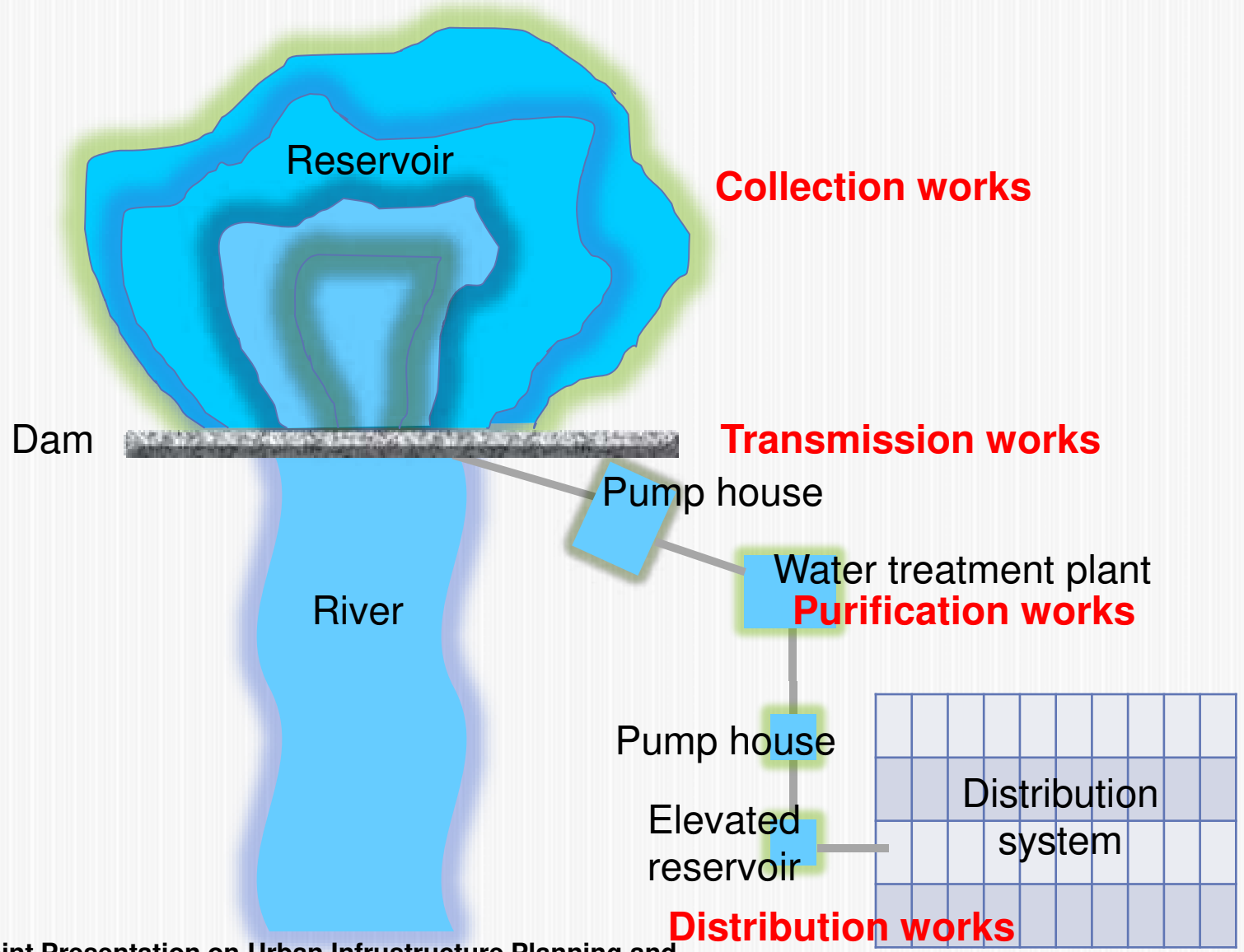


Figure 1.21: Essential Elements of Water supply System

Surface Water Supply Scheme



Source: Powerpoint Presentation on Urban Infrustructure Planning and Mgt, PG URBAN PLANNING, Civil Engineering Department, M.Tech. (Urban Planning), Sardar Vallabhbhai National Institute of Technology, Surat

Surface Water Collection System

- Collection system is a sort of engineering works designed to convey water from a source to a treatment plant.

- Essential units in a collection system are:
  (a) Intake
  (b) Intake main (conduit)
  (c) Aqueduct or transmission main
  (d) Pumping station

Surface Water Collection System Units

1. Intake

- An intake is a device or a structure placed in a surface water source to permit the withdrawal of water from the source and its discharge into an intake conduit or pipe (intake main).

- From the intake main the water will then flow into the water-works system.

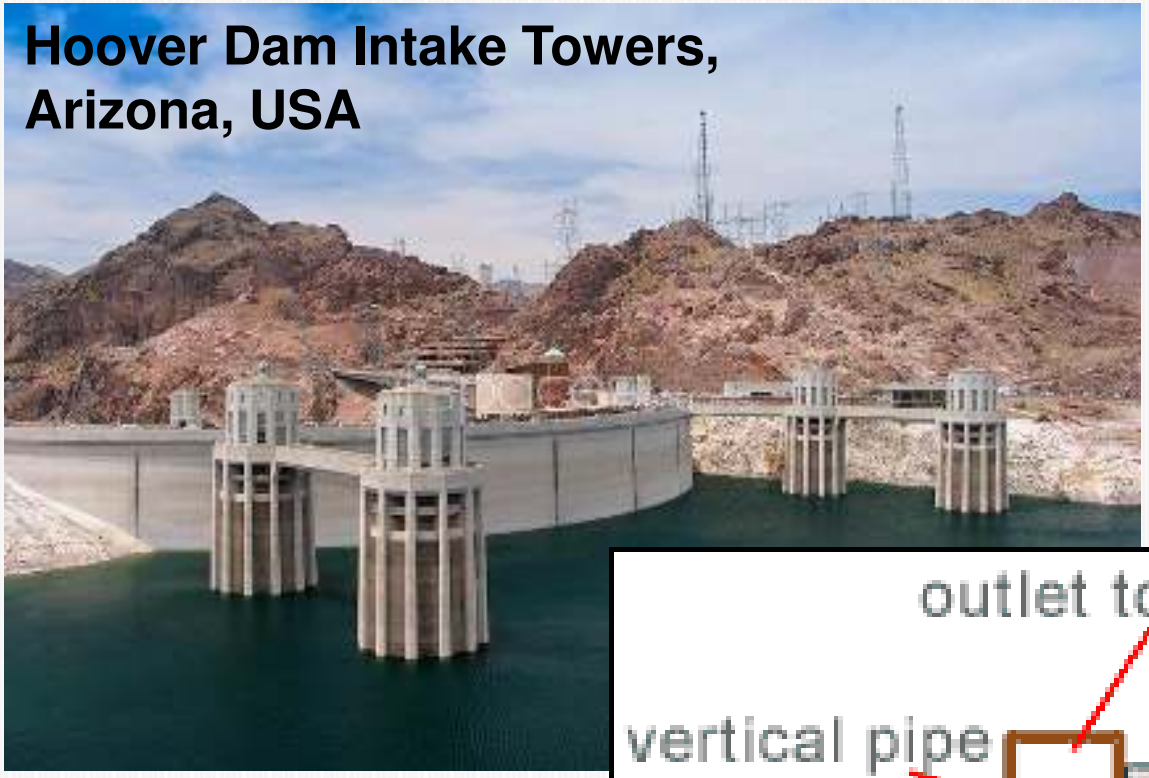
- Intakes are generally consist of opening protected by a strainer or grating through which the water enters the intake main.

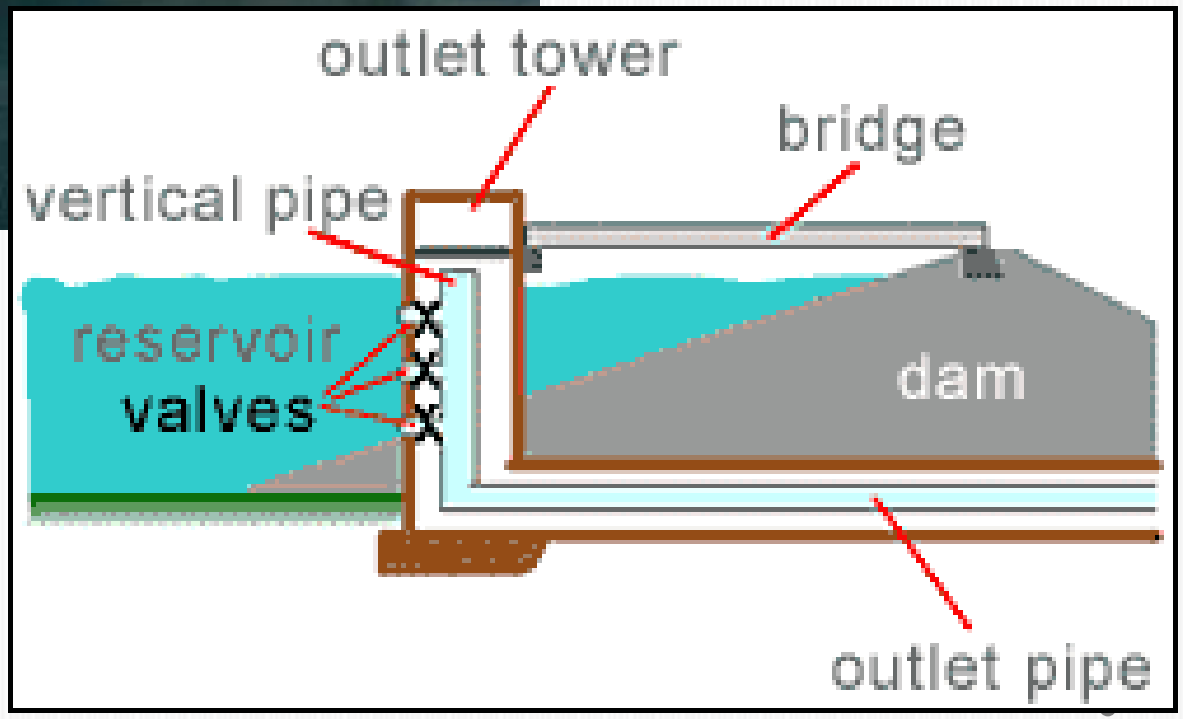
Surface Water Collection System Units

1. Intake

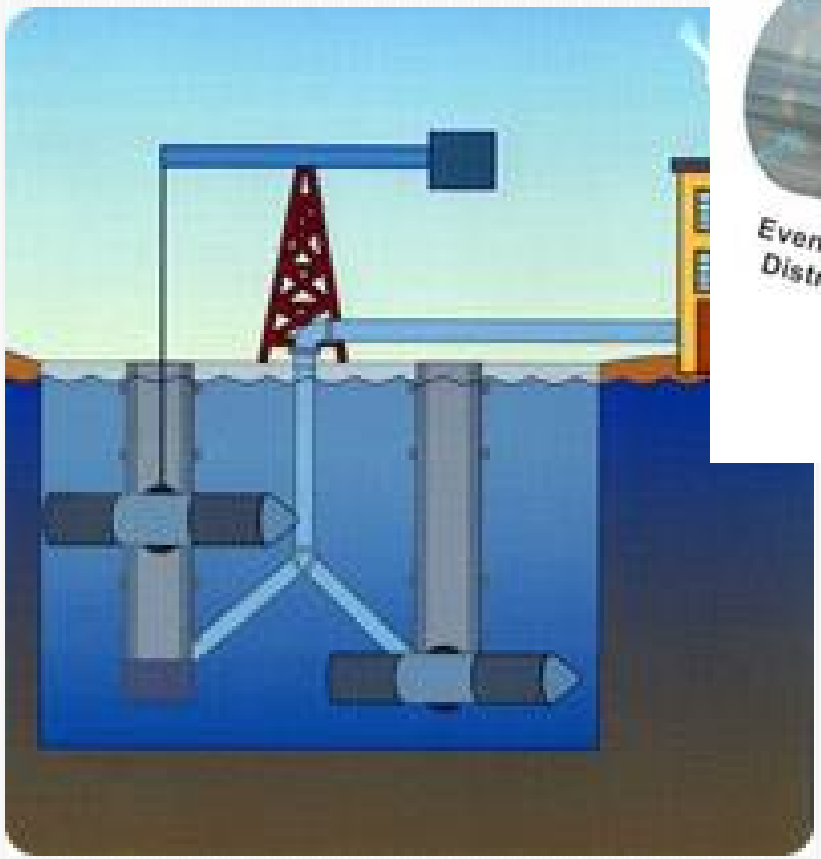
- Types of intake structures consist of –
  - ✓ Intake towers
  - ✓ Submerged intakes
  - ✓ Intake pipes or conduits
  - ✓ Movable intakes
  - ✓ Shore intakes

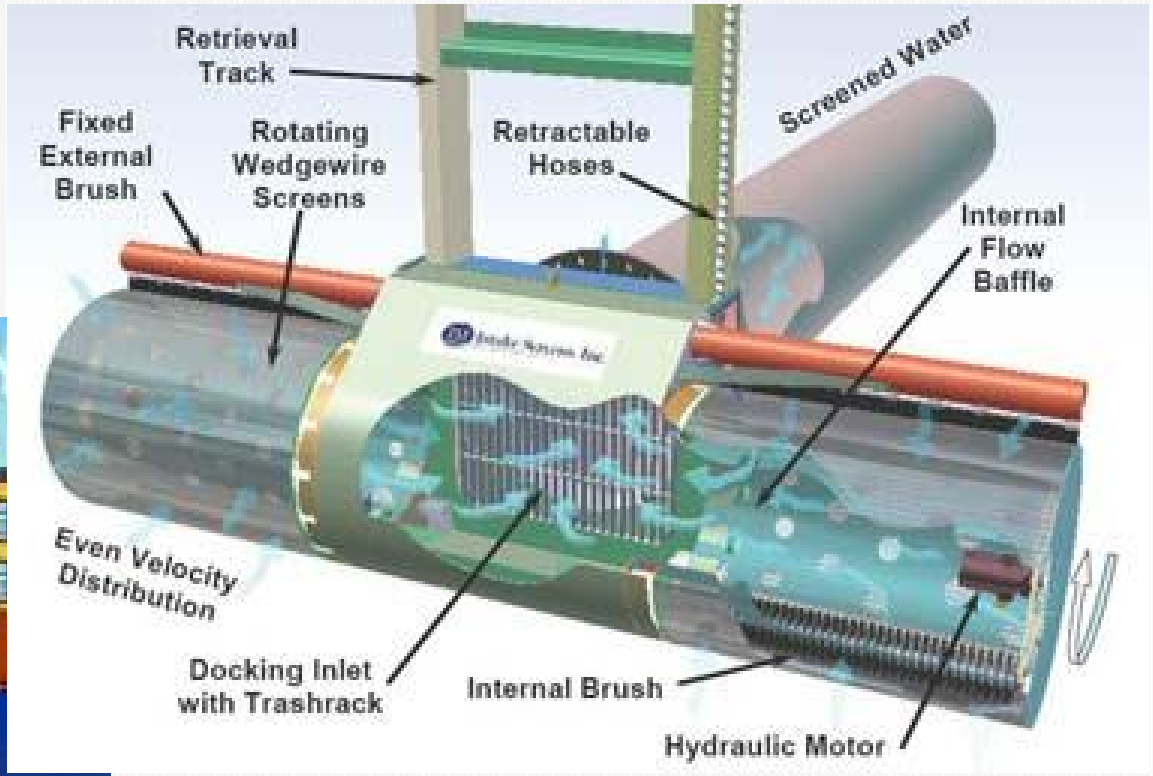
Surface Water Collection Units – **Intake Towers**





Surface Water Collection Units – **Submerged Intake**





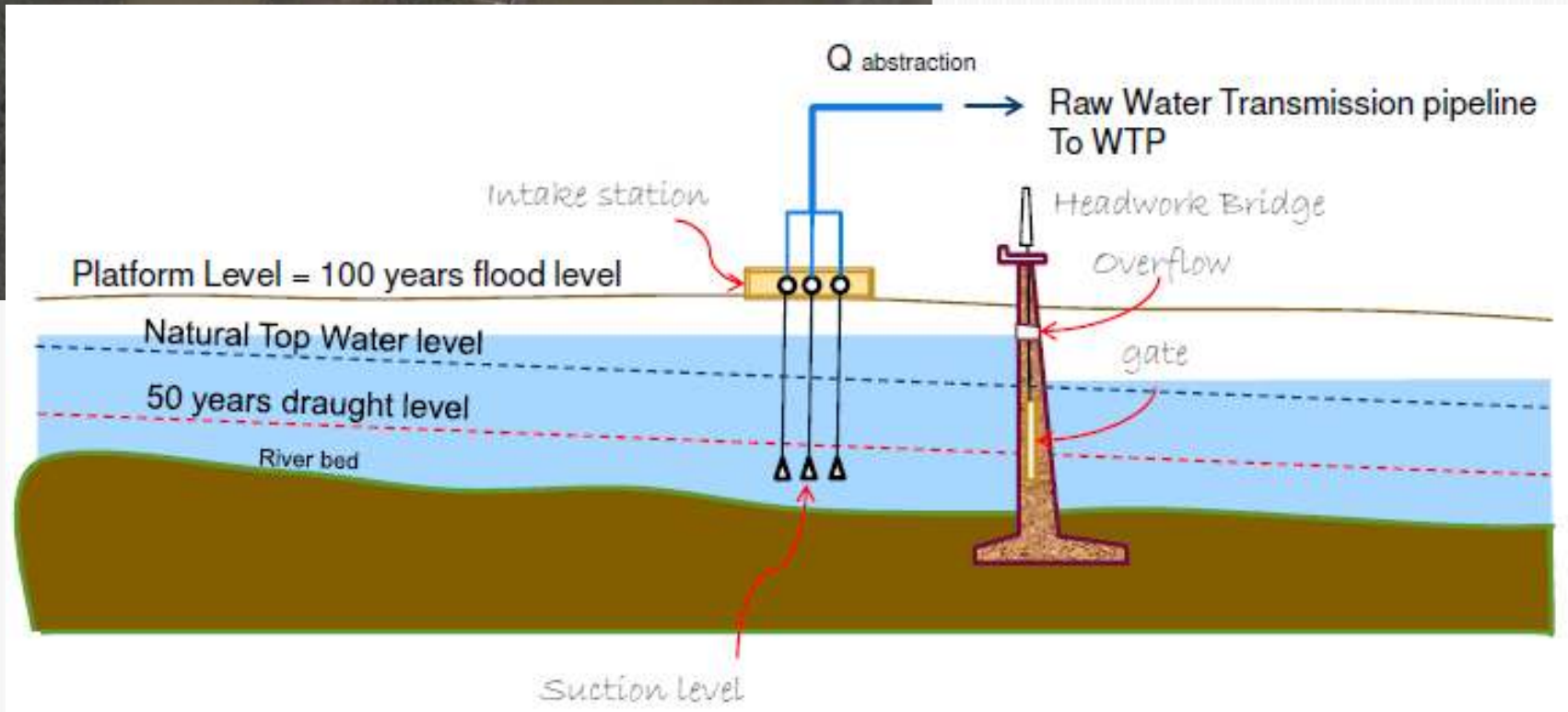
Surface Water Collection Units – **Movable Intake**



Movable weir with intake screen, Japan

Surface Water Collection Units – **Intake Structure**





Surface Water Collection System Units - **Intake**

Consideration for designing and locating the intake structures -

- The source of supply must be considered including the wide fluctuation in water level.
- Intake surroundings should be considered. For example depth of water around intake.
- Characteristics of bottom, navigation requirements, the effect of floods and storm to the structure and scouring in the bottom are also considered.

Surface Water Collection System Units - **Intake**

Consideration for designing and locating the intake structures -

- The location with respect to the sources of pollution is also considered.
- The frequency of floating materials such as ice, vegetation is considered.
- Intake capacity must be large enough to meet the requirement of design discharge.

Type of Intakes for Water Collection

According to type of source

- River Intake
- Canal Intake
- Reservoir Intake
- Lake Intake

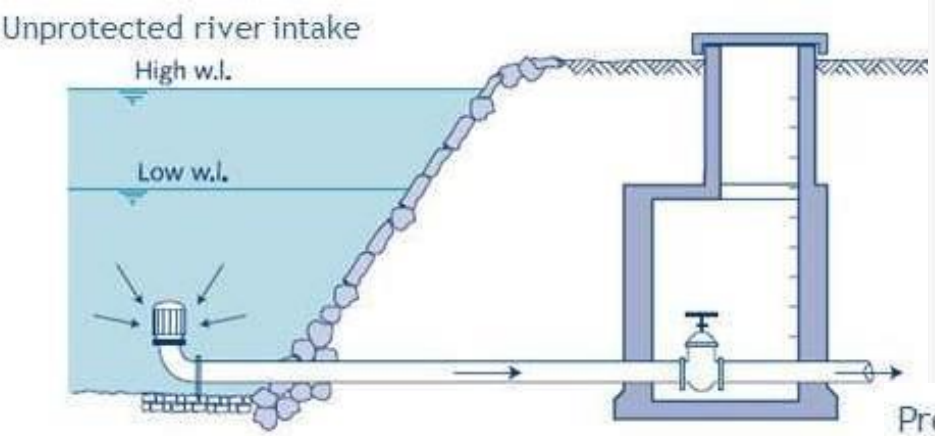
According to position of Intake

- Submerged Intake
- Exposed Intake

According to presence of water in the intake tower

- Wet Intake
- Dry Intake

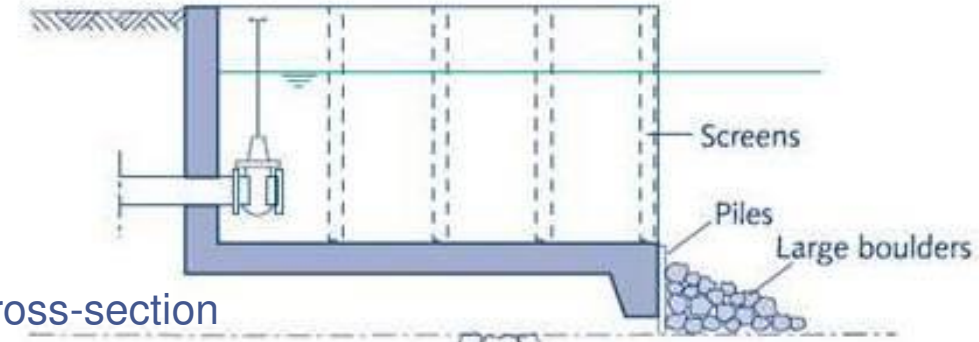
Intakes for Water Collection



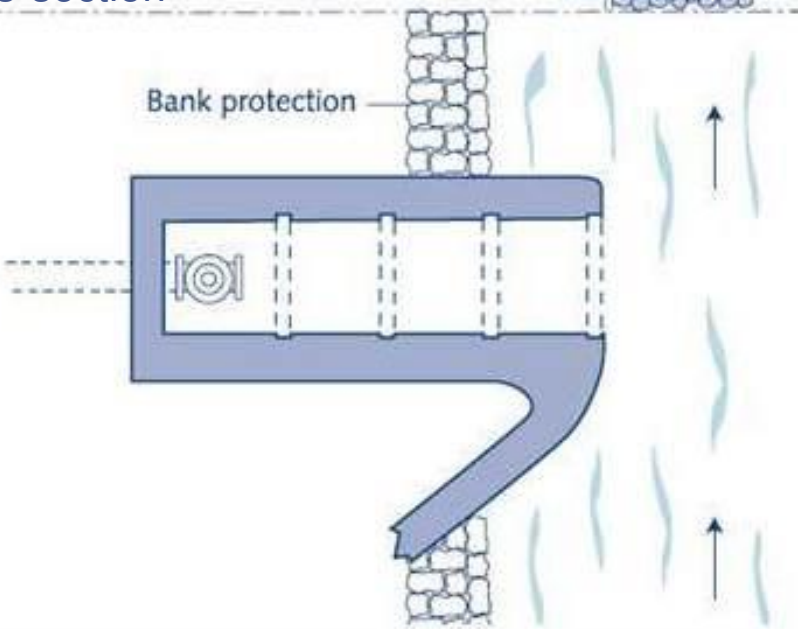
Protected river intake



Trash Rack/ Screen



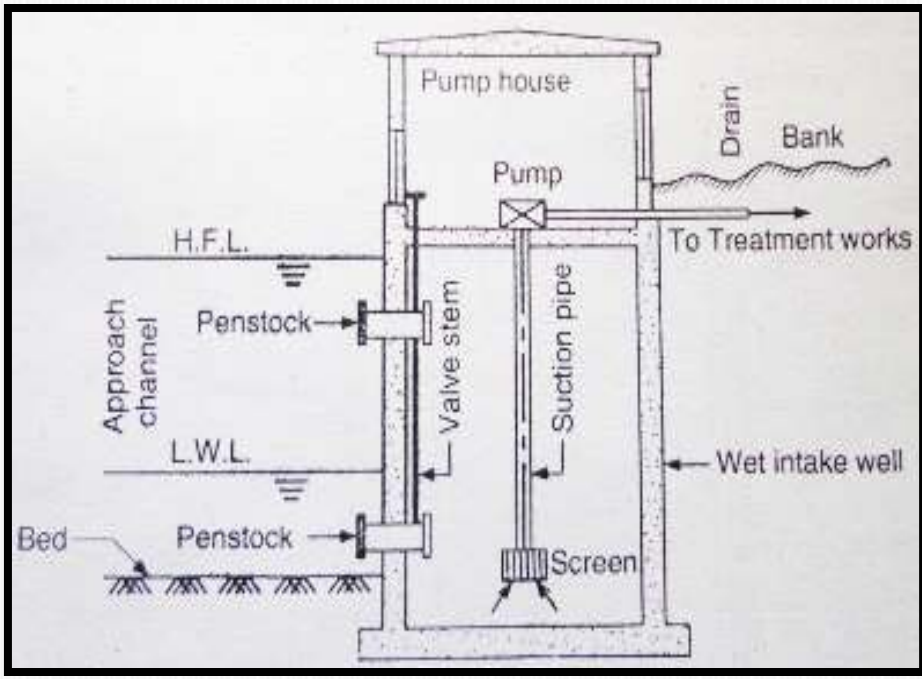
Cross-section



Plan

Intakes for Water Collection – River Intakes

- River Intakes are constructed well upstream from points of discharge of sewage and industrial wastes.
- They are located sufficiently inside the river so that necessary demand of water can be met in all the seasons of the year.
- Preferable locations will have deep water, stable river bottom and favorable water quality.
- Locations will have protection against floods, debris and river traffic.

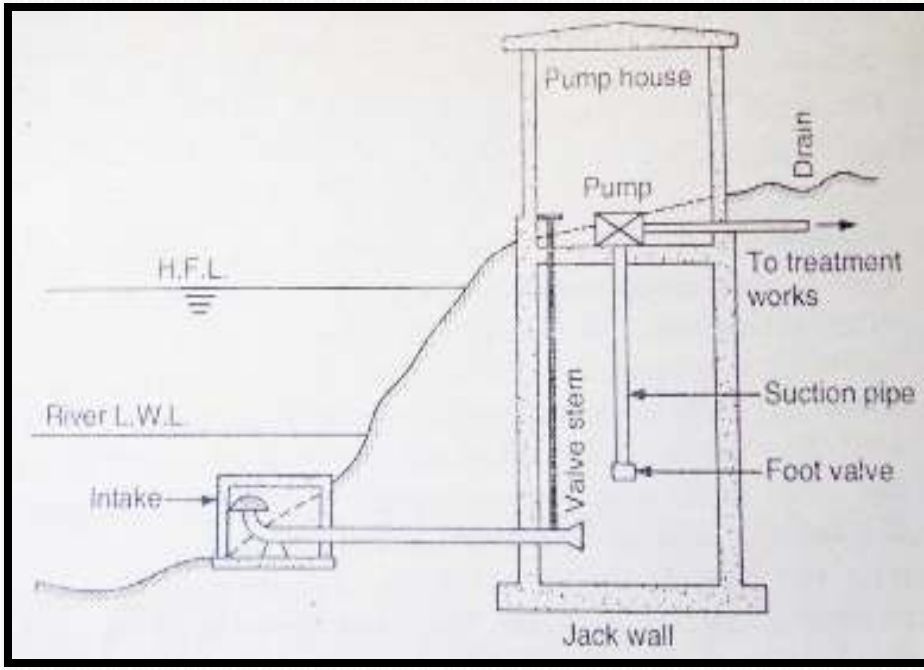


Intakes for Water Collection – River Intakes

- For fluctuating river beds, intakes are mounted on carriages, that are able to move up and down on a free water surface.

- The intake tower permits the entry of water through several entry ports located at various levels to cope with fluctuations in the water levels during different seasons.

- This are also called as **penstocks.** The penstocks are covered with suitable design screens to prevent entry of floating impurities.



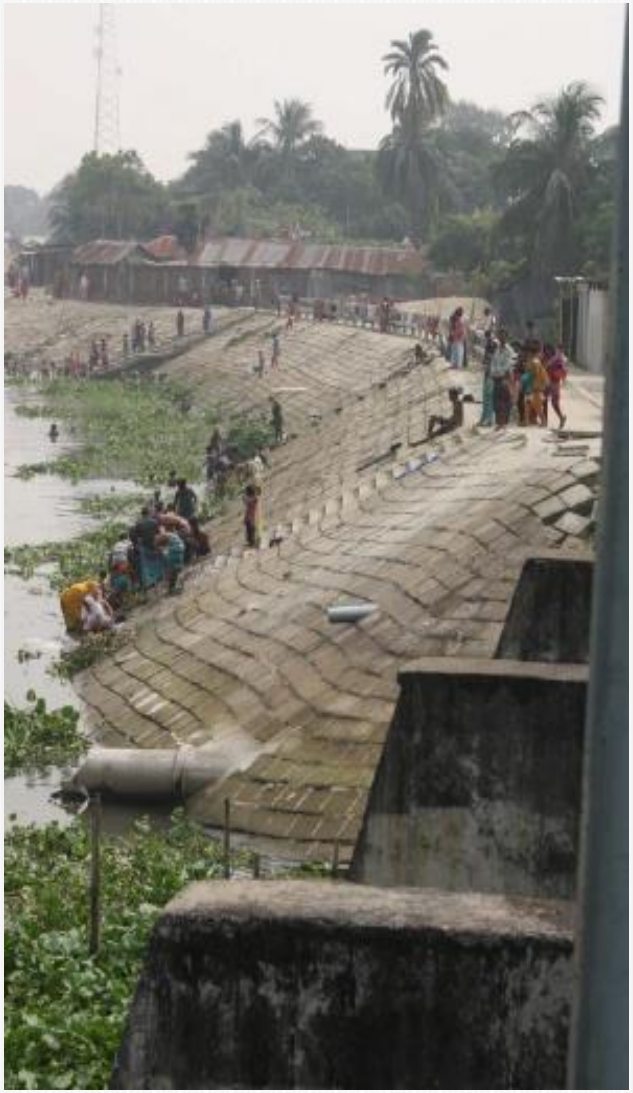
Sharulia Intake Station, SWTP, DWASA, Dhaka





Bar Screens on the outside

Sharulia Intake Station, SWTP, DWASA



River training works to protect the banks besides the intake



Additional screens before pumping

Sharulia Intake Station, SWTP, DWASA



Sluice gates to control the flow



Inside the pump station

Sharulia Intake Station, SWTP, DWASA



Water is pumped and discharged to WASA conveyance canal



WASA conveyance canal

Intakes for Water Collection – Reservoir Intake

- It is constructed when the flow in the river is not guaranteed throughout the year.
- A dam is constructed across the river to store the water in the reservoir so formed.
- Sited with due reference to sources of pollution, prevailing winds and surface currents.
- Reservoir intakes lie closer to bank in the deepest part of the reservoir.

Intakes for Water Collection – Reservoir Intake

- Reservoir Intakes essentially consist of an Intake tower constructed on the slope of Dam.
- The location of the intake tower should be such that the Intake can draw water in sufficient quantity even in the driest period.
- Intake pipes are fixed at different levels, so as to draw water near the surface in all variations of water levels.

Intakes for Water Collection – Reservoir Intake

- Intake towers are separately constructed in case of earthen dams.

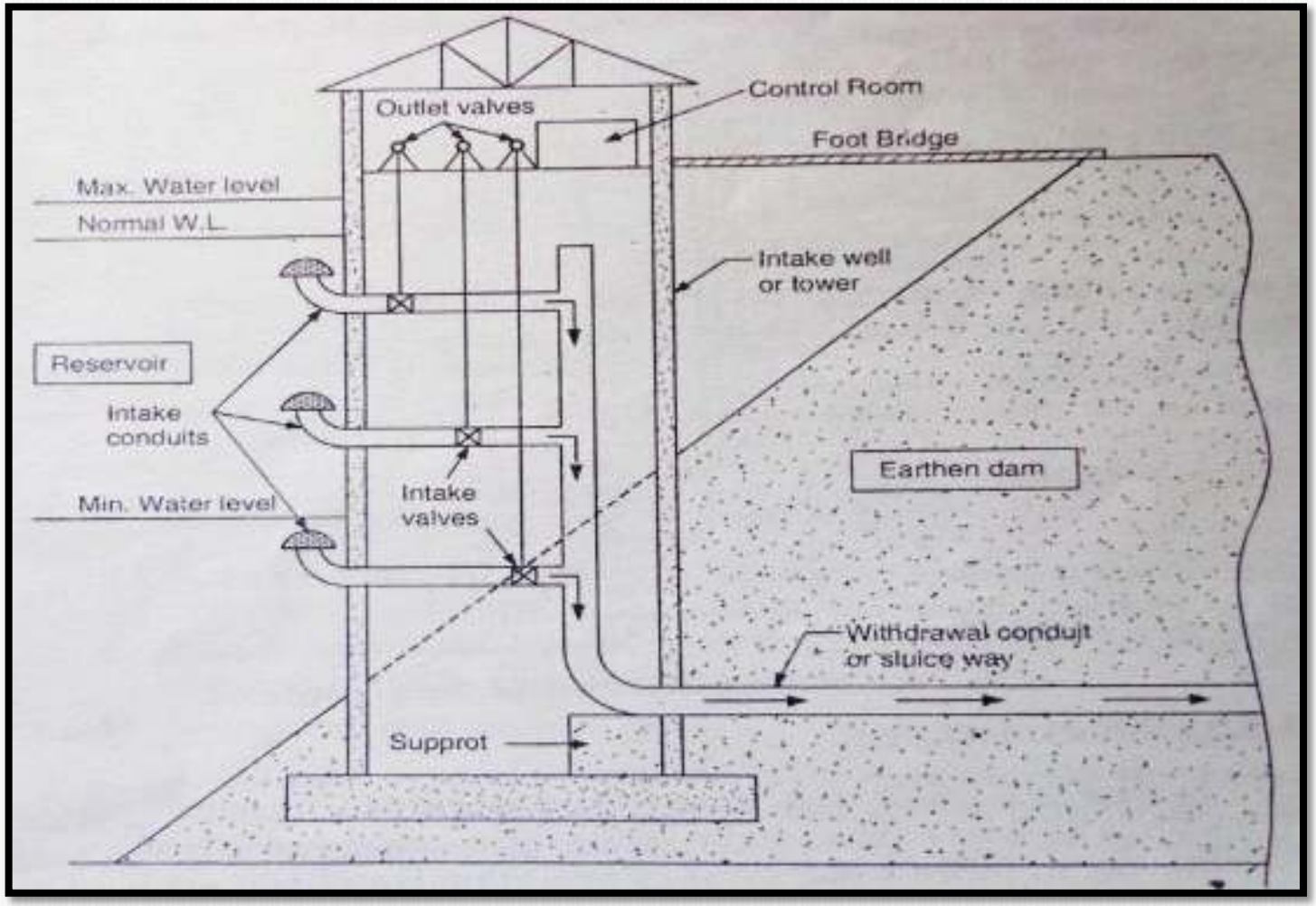


Fig: Valve tower situated at the upstream toe of an earthen dam

Intakes for Water Collection – Reservoir Intake

- In gravity dam, intake tower is constructed inside the dam itself.

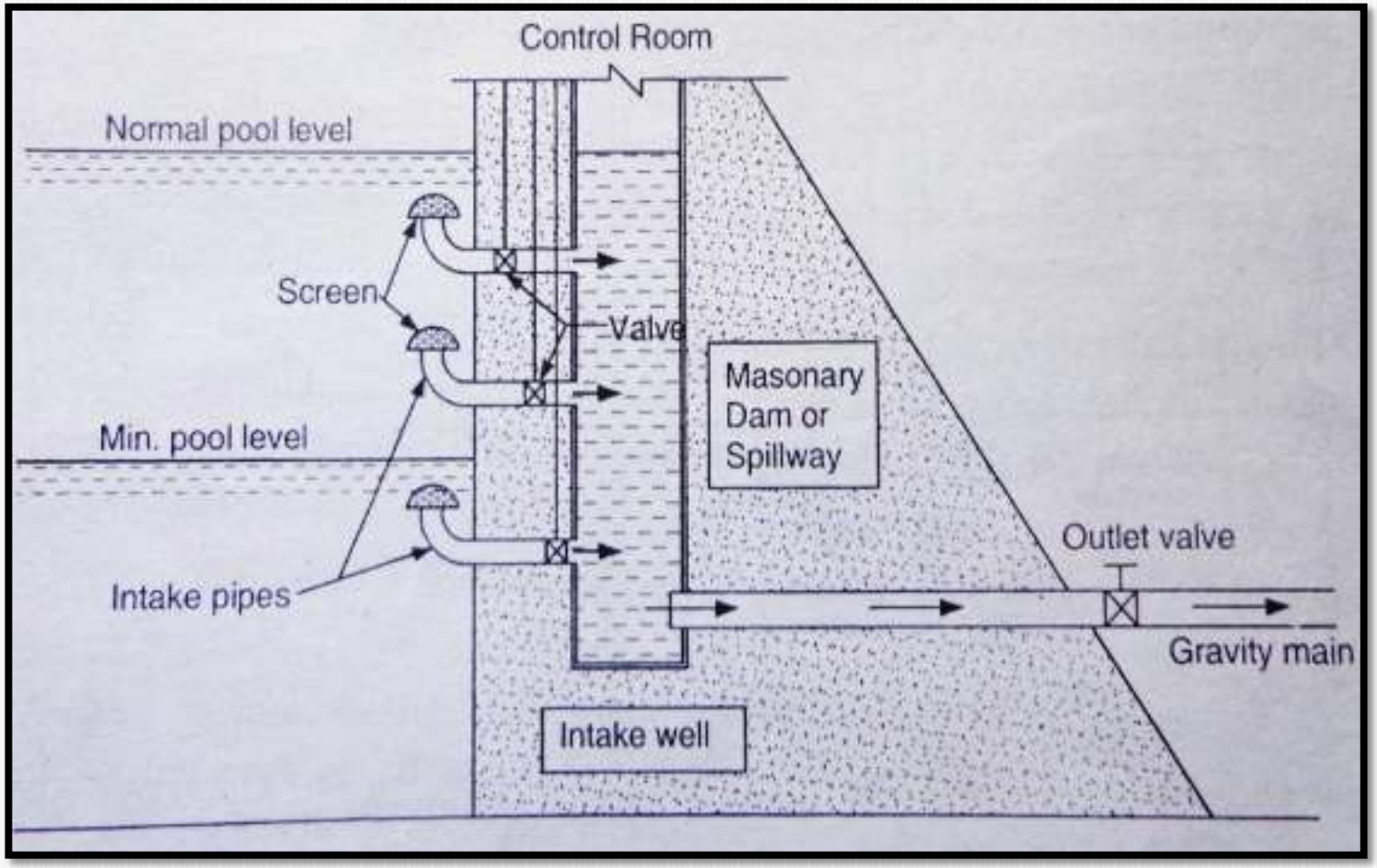
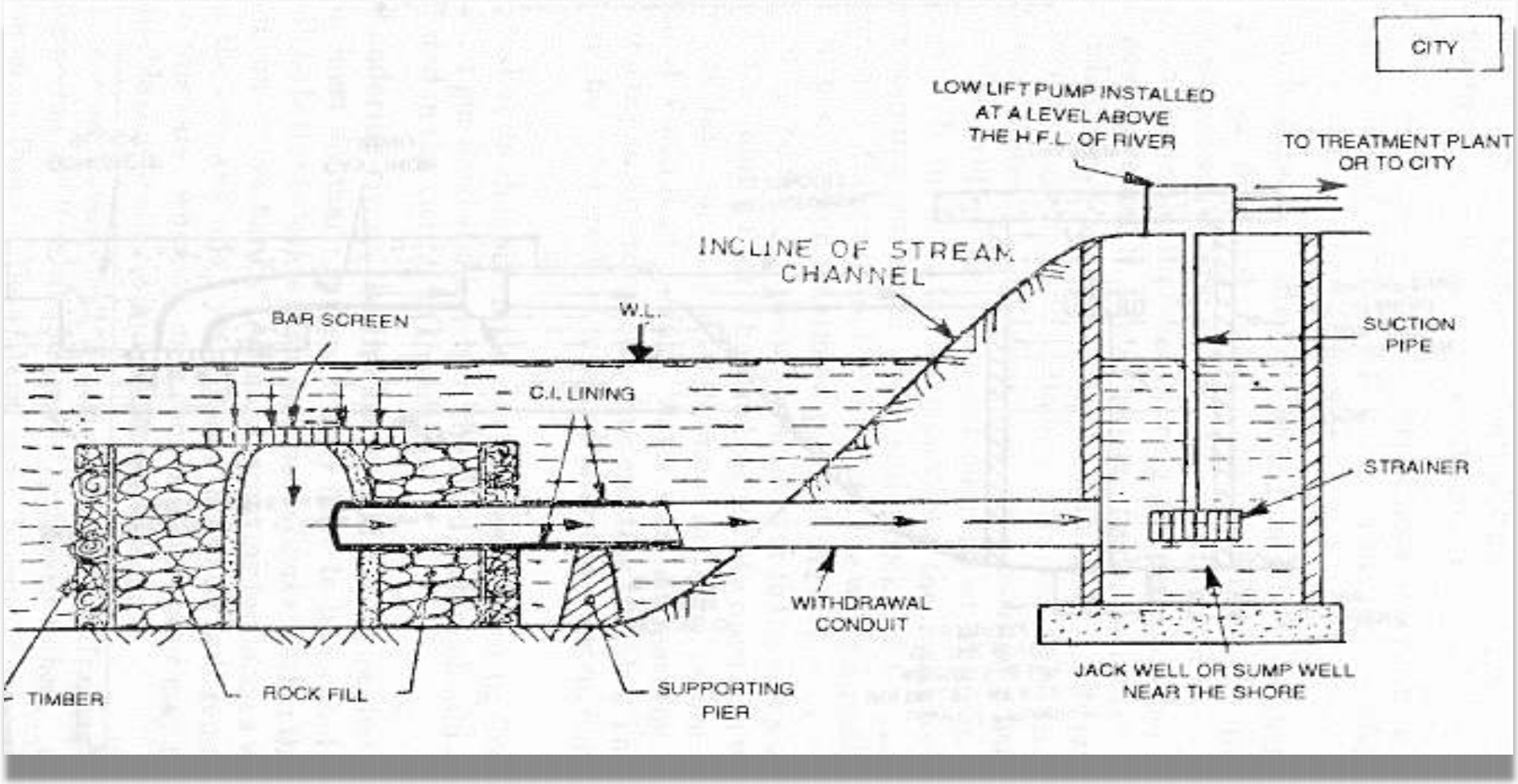


Fig: Intake well / Valve tower for concrete gravity or masonry dams

Intakes for Water Collection – Lake Intake

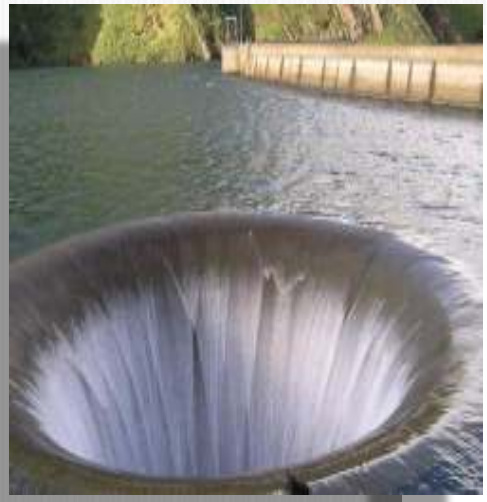
- Lake Intakes are mostly submerged intake.
- These Intakes are constructed in the bed of lake below the low water level so as to draw water even in dry season.
- It mainly consist of a pipe laid in the bed of the lake.
- One end of the pipe which is in middle of the lake is fitted with bell mouth opening covered with a mesh and protected timber or concrete crib.

Intakes for Water Collection – Lake Intake



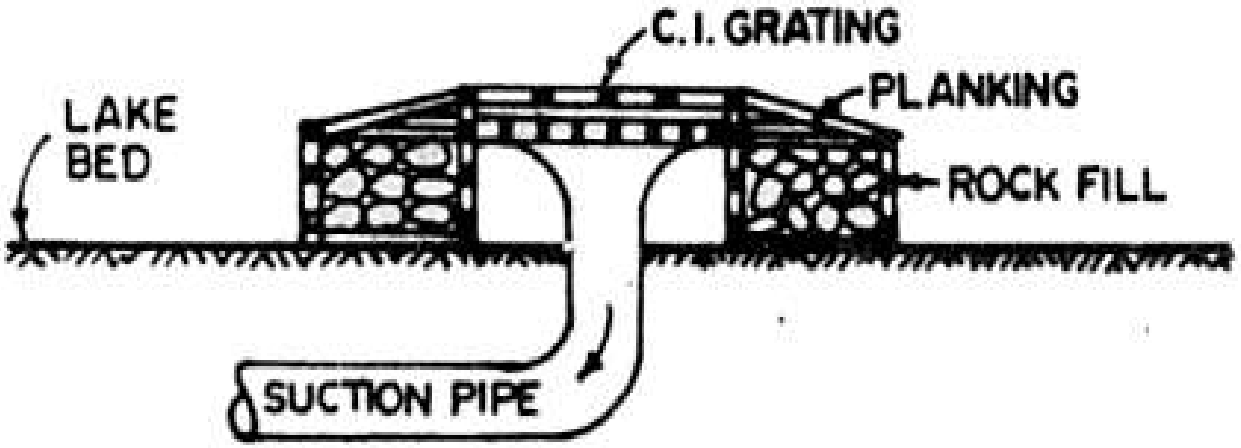
Intakes for Water Collection – Lake Intake

- The water enters in the pipe through the bell mouth opening and flows under gravity to the bank where it is collected in a sump well and then pumped to the treatment plant for necessary treatment.





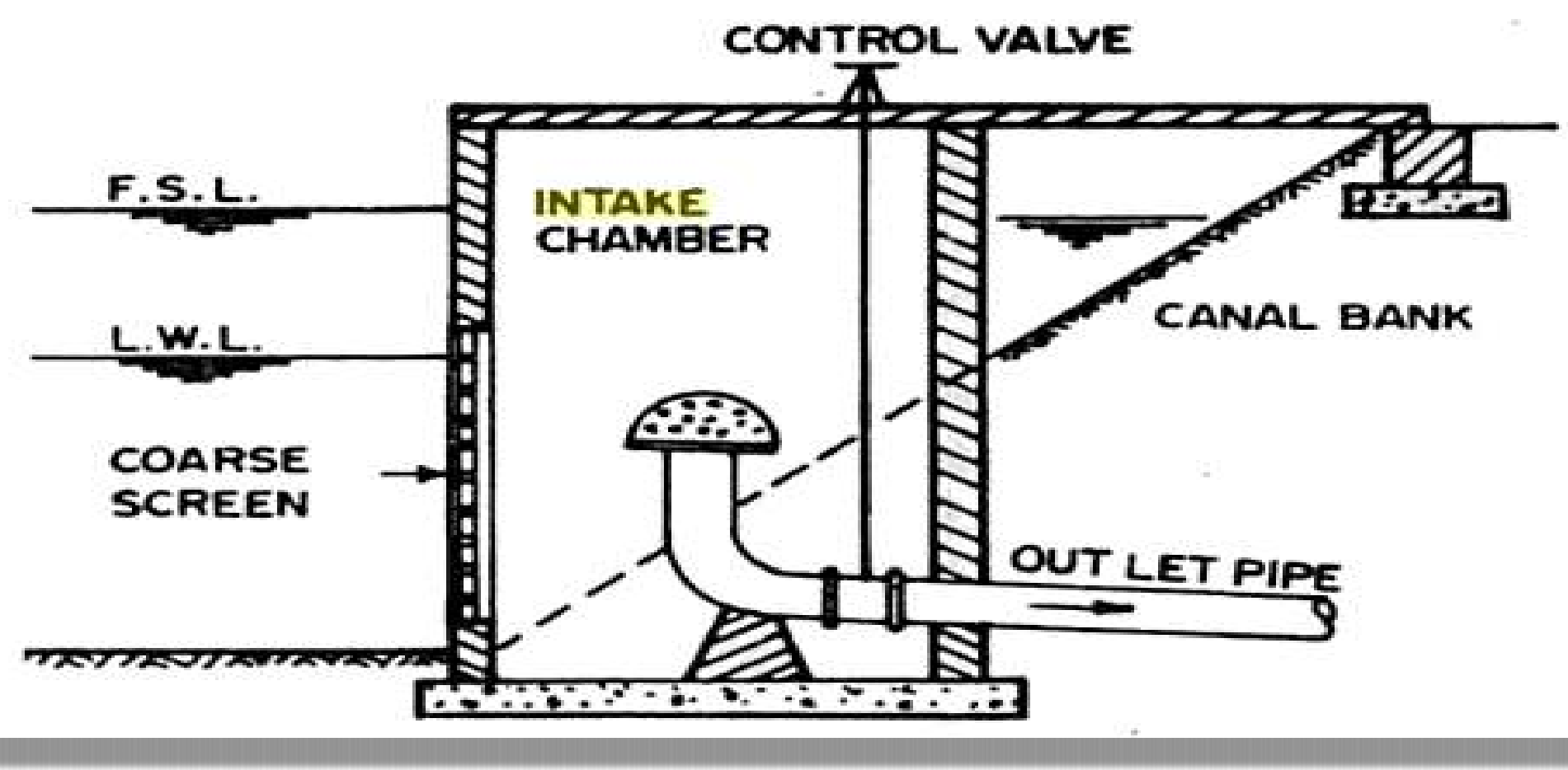
Bell Mouth Entrance



Intakes for Water Collection – Canal Intake

- For small town a nearby irrigation canal can be used as the source of water.
- The intake well is generally located in the bank of the canal.
- Canal should lie on upstream and downstream side of the intake to prevent erosion of sides and bed of canal.

Intakes for Water Collection – Canal Intake



Intake Design Consideration

Intake Velocity:

- velocity below 0.3 fps allows fish to escape, reduces ice problems and reduce entrainment of suspended matter

Intake Port Location:

- multiple intake ports at several elevations are preferable

- location of ports determined by testing water quality

- topmost port not less than 2m below water surface

- bottom port at least 1 m above bottom

Intake Design Consideration

Gates:

- Sluice gates typically used to control flow of water from source to the water conveyance system

Control of Ice: (for colder regions)

- keep intake ports sufficiently below water level

- steam piping, compressed air, space heaters

Intake Design Consideration - Screening

Coarse Screen:

- bar racks with 2- 3″ clear spacing
- should be installed in the outside
- provision for cleaning

Fine Screen:

- to remove smaller objects that might damage pumps
- heavy wire mesh having 0.25″ square openings
- design velocity 0.4 - 0.8 m/s
- requires frequent cleaning (travelling screens used often)

Intake Design Consideration - Screening

Microstrainer:

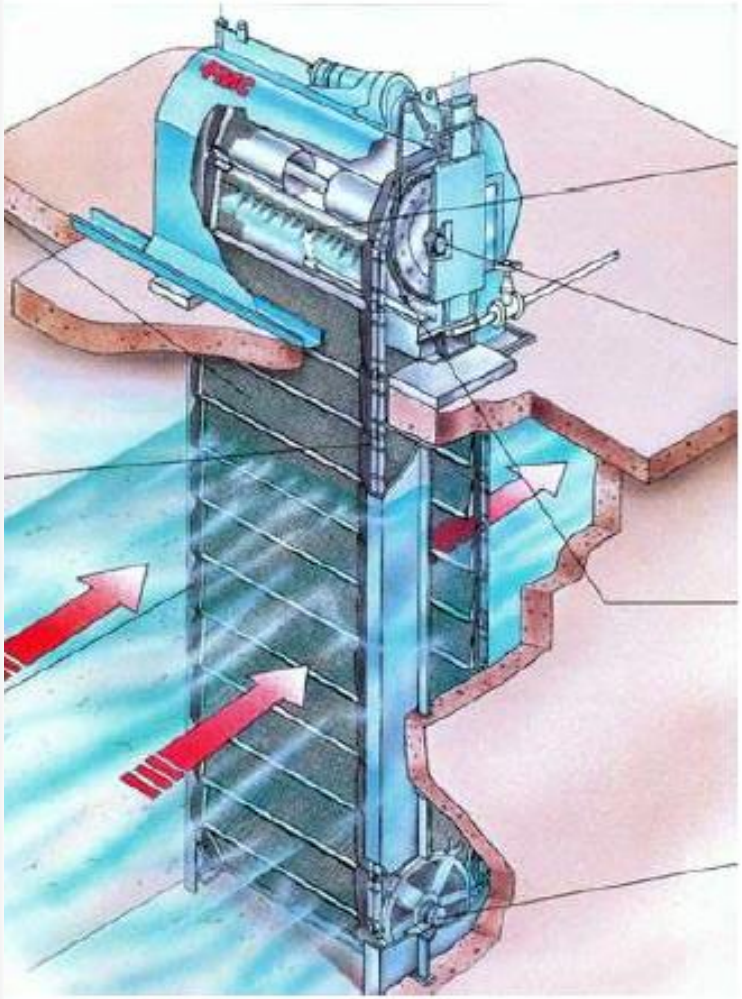
- to remove plankton and algae
(to improve sedimentation and chlorination performance)

- fine wire mesh

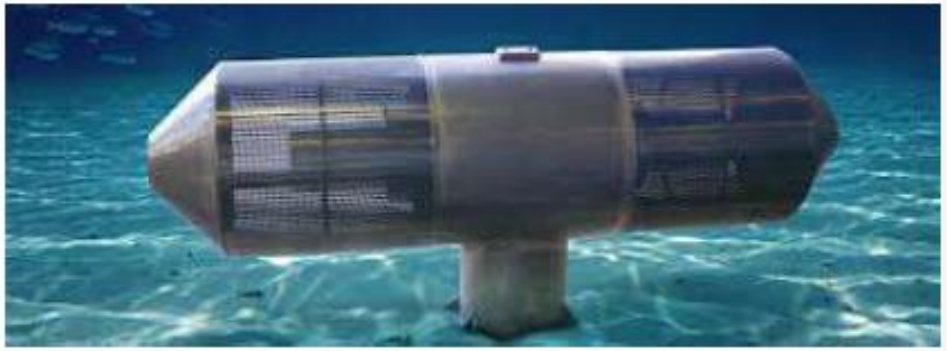
- slime build up

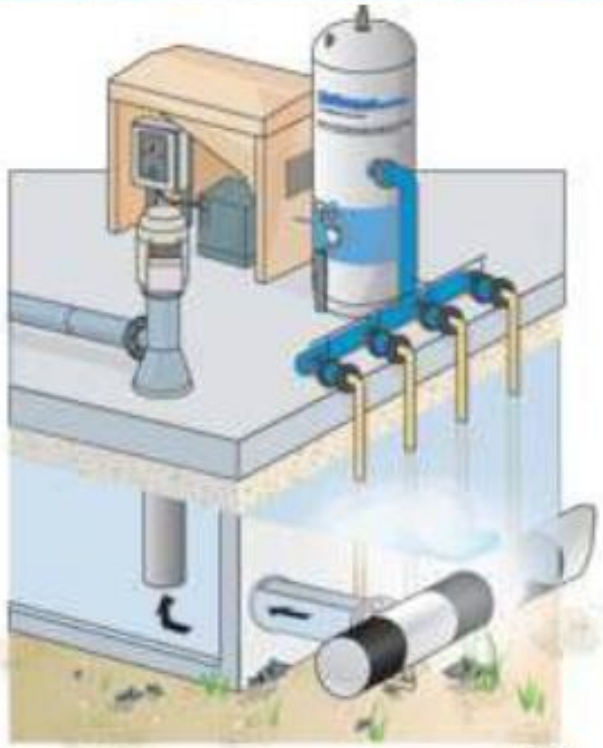
- will not handle sand, silt and abrasive material

Travelling and Passive Fine Screens



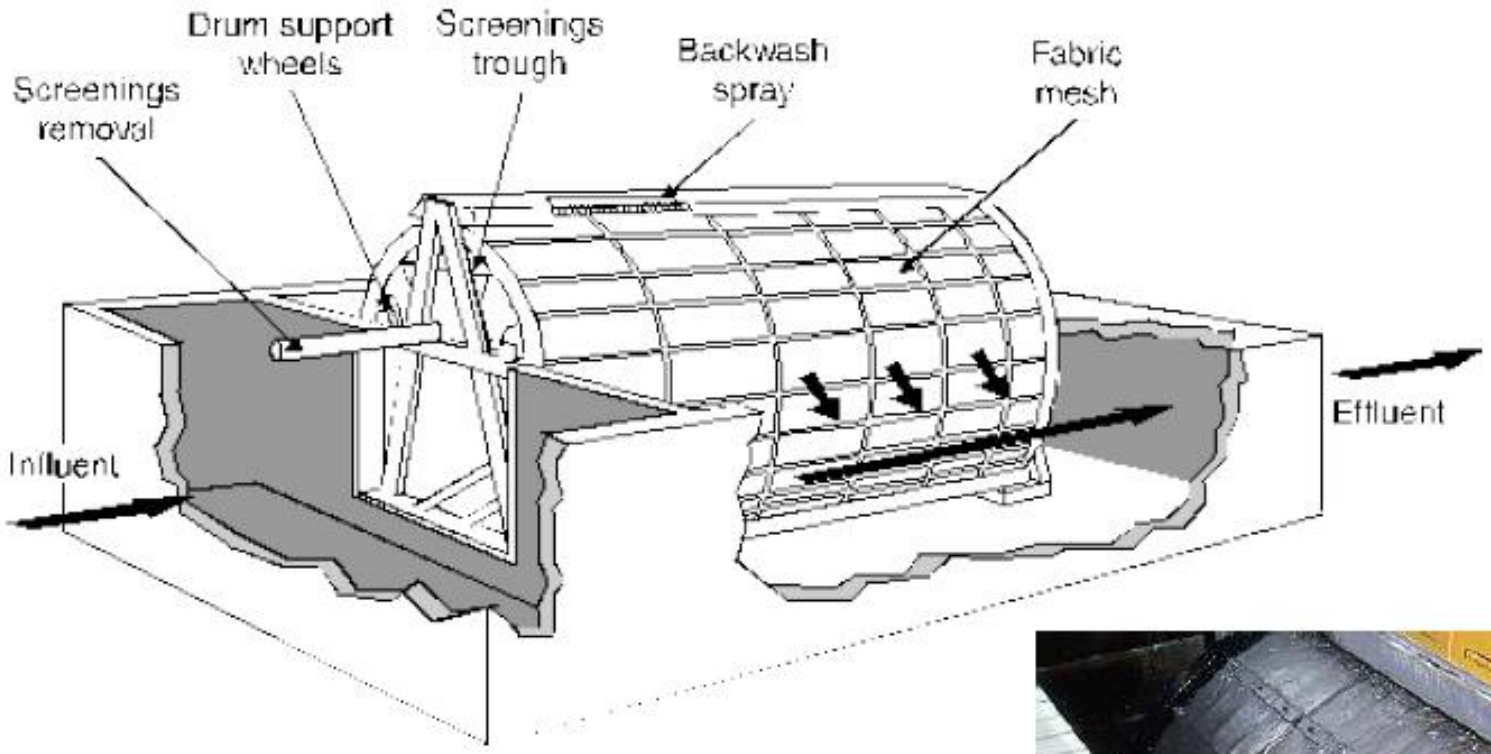
www.power-technology.com





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Microstrainer

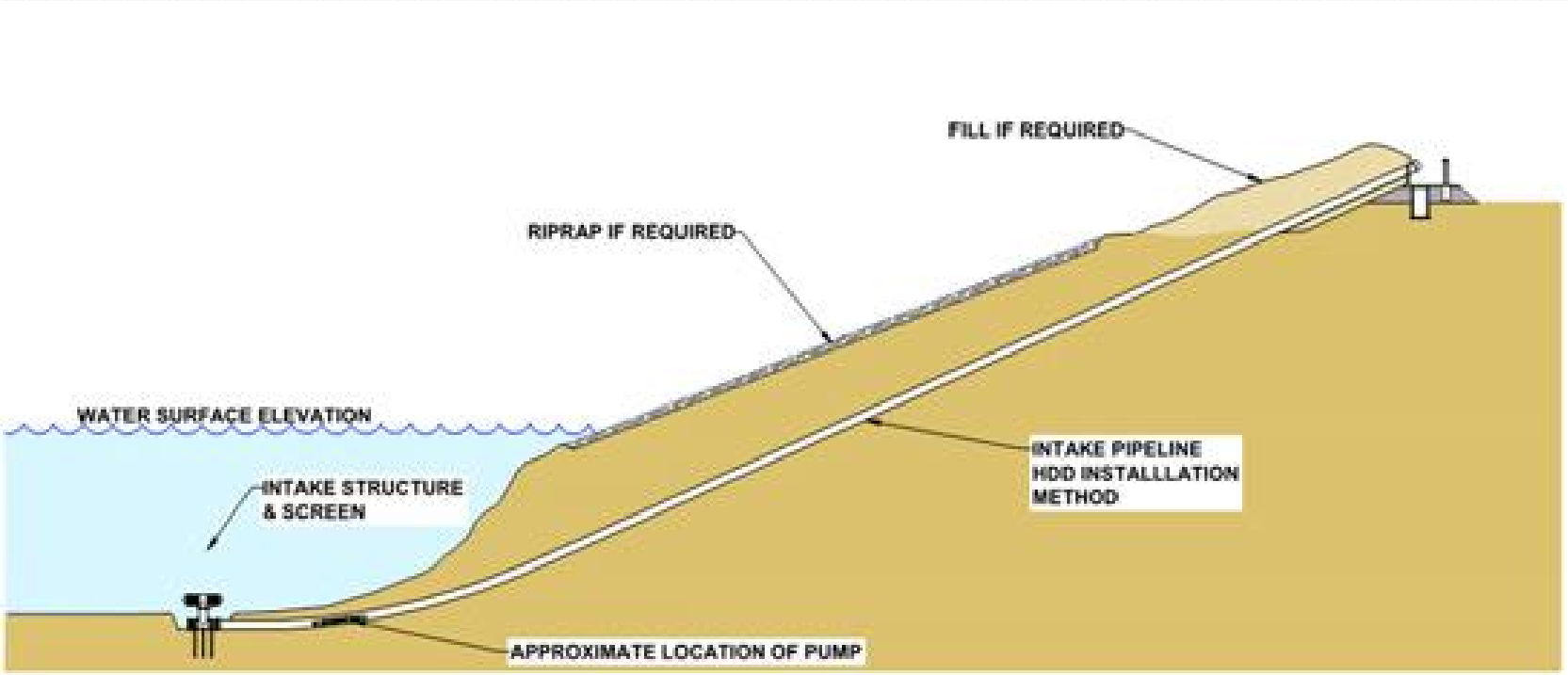


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Intake Main & Transmission Main

- A pipe line must be used to deliver water from the source to the treatment plant.
- Intakes located at long distances from the pumps usually deliver their water to the pump well at the shore end by gravity.



Intake Main & Transmission Main

- Conveyance of water from intake will require a large pipe or conduit so that the velocity would be low.

- But velocity should not be low enough to allow sedimentation.

- The conduit may be a submerged pipe or tunnel.

- A submerged pipe should be protected -

✓ By burying it in a trench

✓ By surrounding it with rock or holding it in place with piling

Intake Main & Transmission Main

- The kind of pipe to be used – cast iron, steel, concrete, asbestos cement or even wood, will depend to some extent on local conditions and local economy, determined on an engineering basis.

- The size of the pipe/ conduit is determined by the volume of water to be delivered and the pressure or head of water.

Surface Water Collection – **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.





[Source: ATC Williams Consultancy, Australia]

Surface Water Treatment – **Treatment Units**

- In case of **surface water**, the treatment procedure may involve the removal of –
  - ✓ turbidity
  - ✓ color
  - ✓ taste
  - ✓ odor
  - ✓ microorganisms (bacteria)

- **Ground water** from wells may be treated to reduce –
  - ✓ hardness
  - ✓ iron
  - ✓ corrosive qualities (alkalinity)

Surface Water Treatment – **Treatment Units**

- The type of treatment required depends on the physical, chemical and biological characteristics of water.

- The most common steps in water treatment are clarification and disinfection.

- Clarification involves –

  ✓ plain and chemical sedimentation to remove suspended and colloidal particles including color producing substances

  ✓ filtration to remove visible impurities and make the water acceptable to the consumers.

Surface Water Treatment – **Treatment Units**

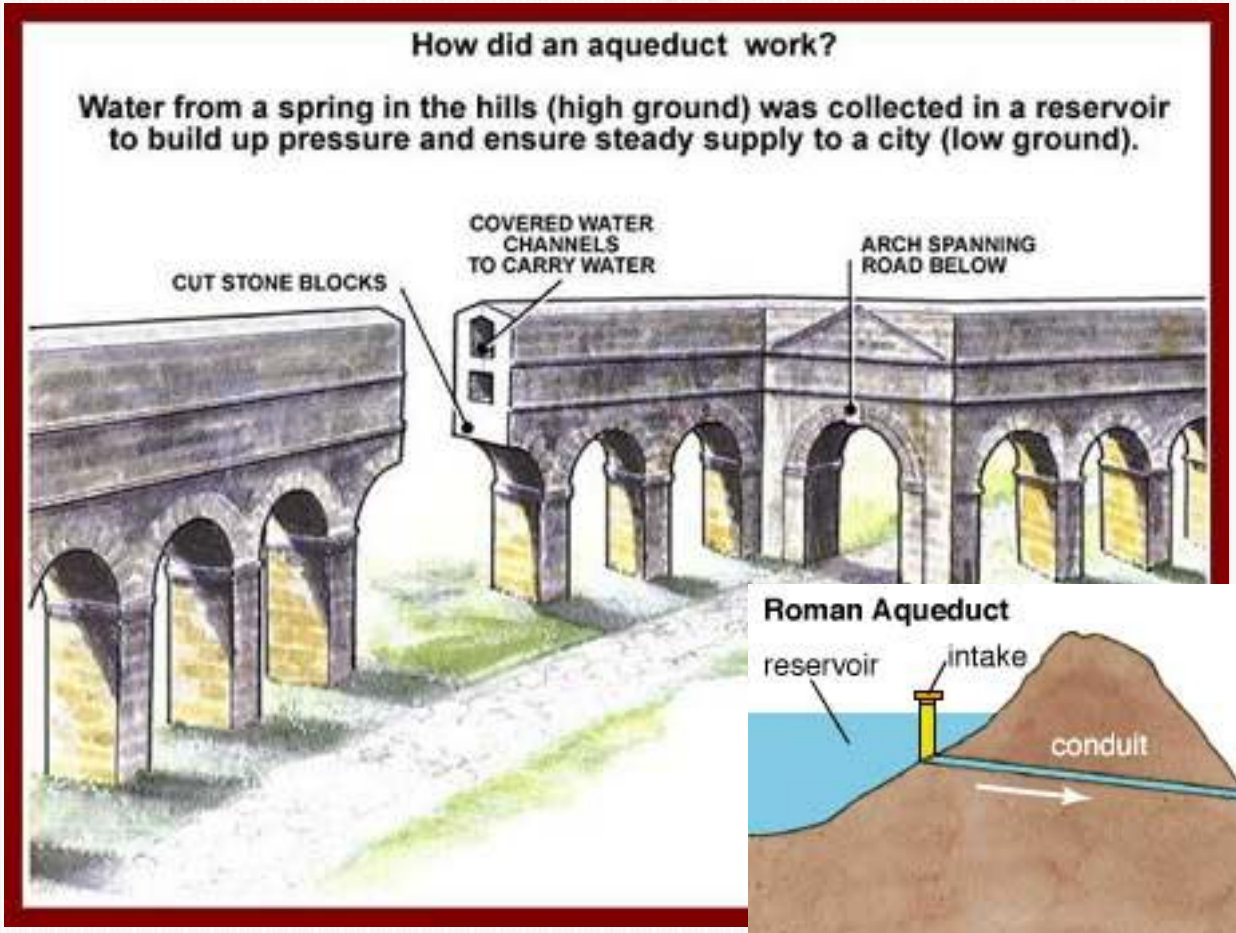
- Disinfection means destruction of pathogenic organisms to make the water safe.

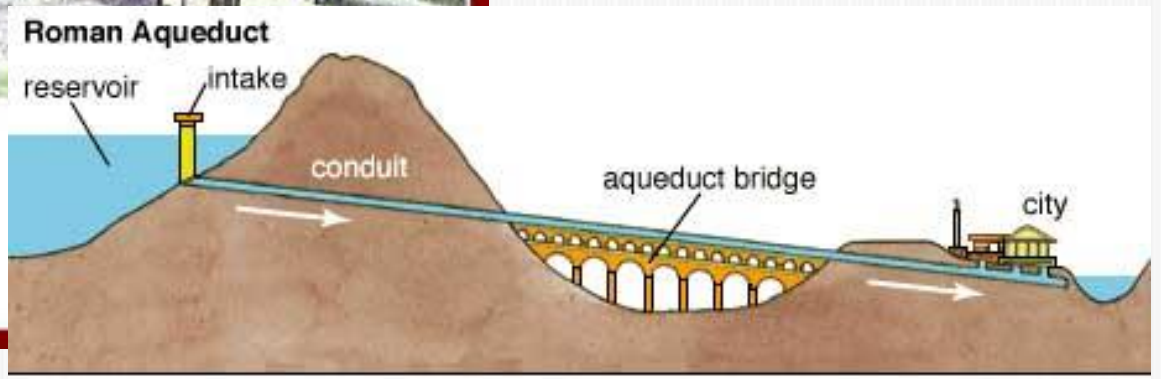
- Commonly used water treatment methods include –
  - ✓ screening
  - ✓ sedimentation
  - ✓ chemical treatment
  - ✓ sand filtration
  - ✓ disinfection

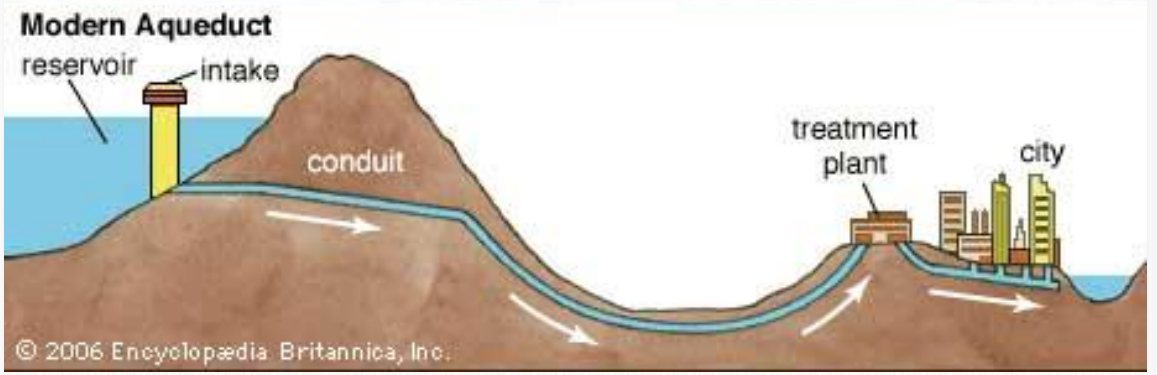
Surface Water Treatment – **Treatment Units**

- Some of the treatment processes/unit operations for removal of specific impurities are –
  - ✓ Aeration
  - ✓ Water softening
  - ✓ Arsenic removal
  - ✓ Iron removal
  - ✓ Activated carbon application
  - ✓ Fluoridation and de-fluoridation
  - ✓ Demineralization
  - ✓ Desalination

Appendix - Aqueduct







Appendix – Shore Intake

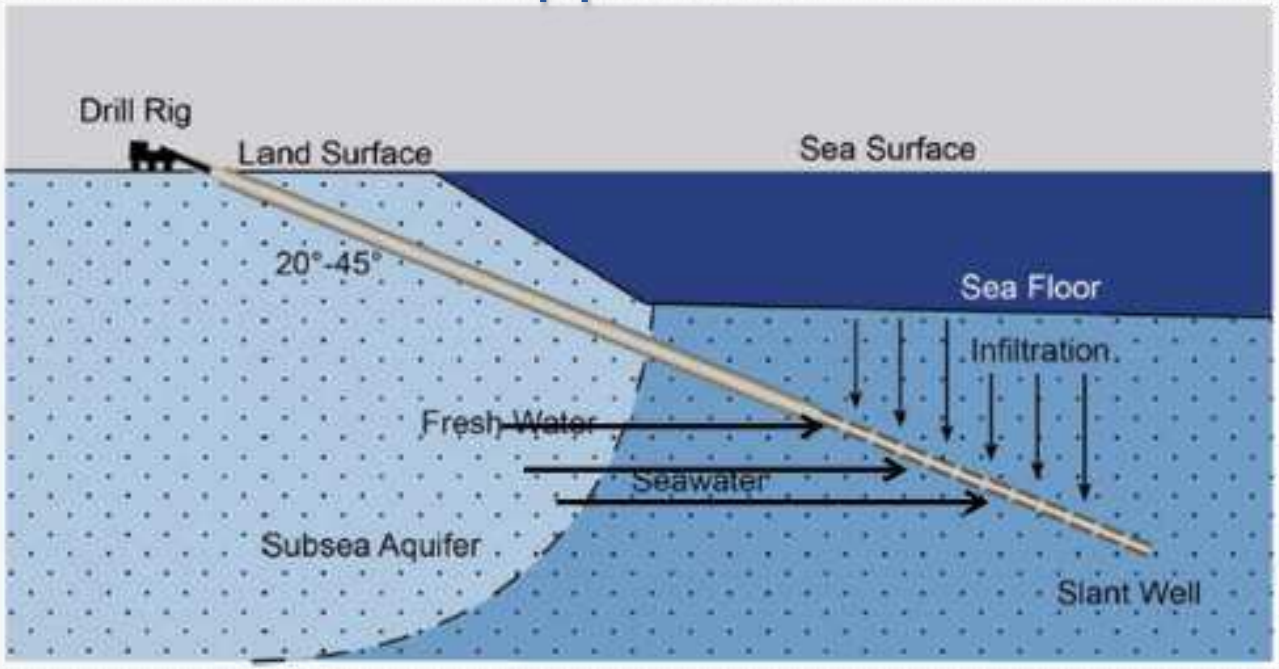


Figure 3.4. Conceptual diagram of the slant well (from Missimer et al., 2013).



EWCE 331
Water Supply Engineering

Lecture 2

Instructor

Lt Col Dr. Kazi Shamima Akter, Engrs

Department of EWCE, MIST

Lecture outline

Surface water collection and transmission

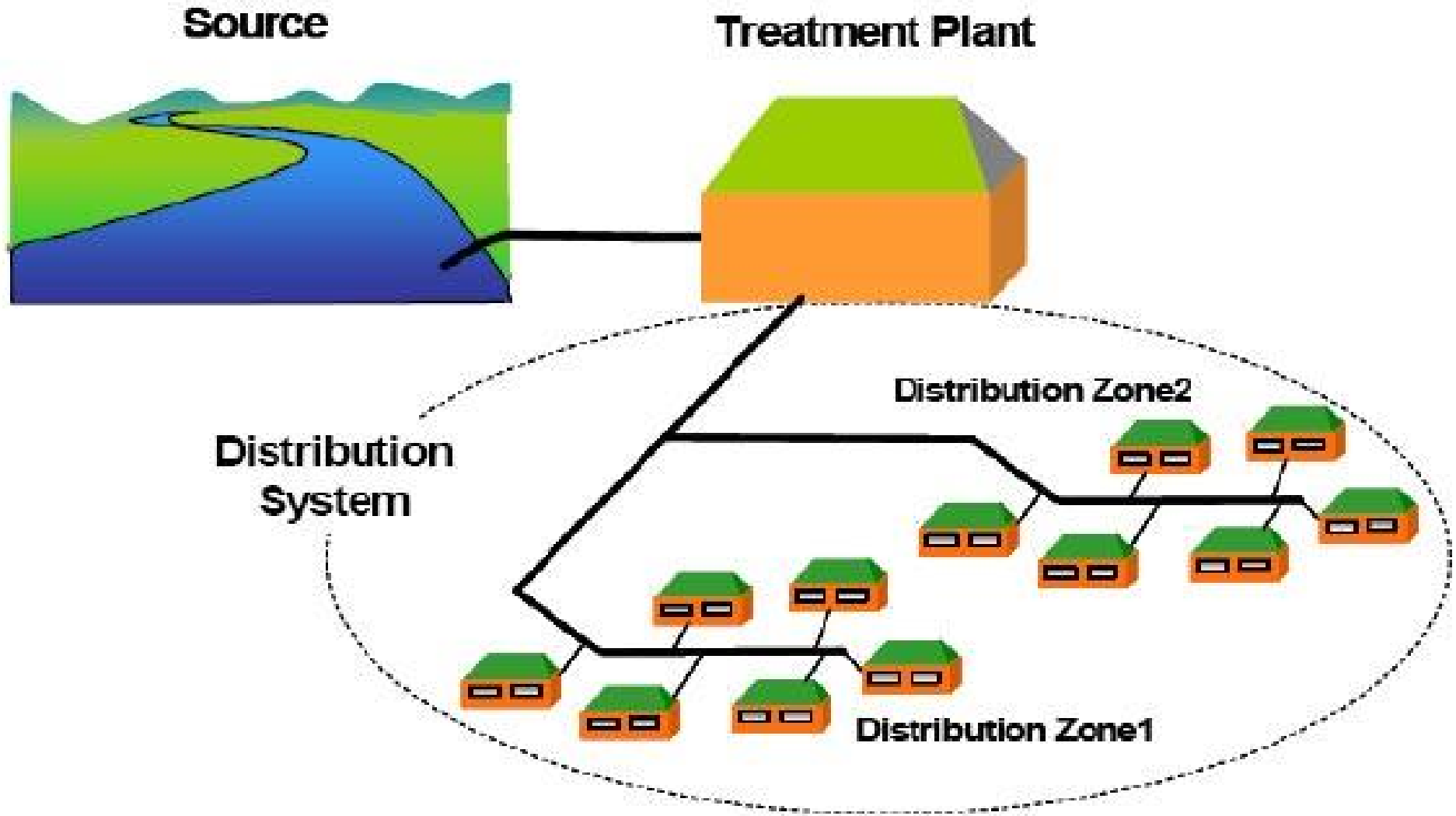
Topics	References
• **Water distribution system** • **Water Distribution methods**	**1. A Text Book of Water Supply Engineering** Authors: M. A. Aziz 1st ed., Hafiz Book Center **3. Water Supply and Sanitation** Authors: M. Feroz Ahmed, Md. Mujibur Rahman 1st ed., ITN-BUET **3. Water and Environmental Engineering** Authors: M. Habibur Rahman, Abdullah Al-Muyeed 1st ed., ITN-BUET

Water Distribution System

- The distribution system is that part of water works which –
  - receives the water from the pumping station of from conduits by the gravity flow and
  - delivers it throughout the district to be served.

- Distribution system comprises a network of pipelines that distribute water to the consumers.

Water Distribution System



Purpose of Water Distribution System

- Water distribution system is designed to adequately satisfy the water requirement for a combination of -
  - o Domestic
  - o Commercial
  - o Industrial
  - o Fire fighting purposes.

Requirement of Good Water Distribution System

A good distribution system should satisfy the followings:

o Adequate water pressure at the consumer's taps for a specific rate of flow (i.e., pressures should be great enough to adequately meet consumer needs).

o Pressures should be great enough to adequately meet fire fighting needs.

o At the same time, pressures should not be excessive because development of the pressure head brings important cost consideration and as pressure increases leakages increases too.

Requirement of Good Water Distribution System

- Note: In tower buildings, it is often necessary to provide booster pumps to elevate the water to upper floors.

- Purity of distributed water should be maintained. This requires distribution system to be completely water-tight.

- Maintenance of the distribution system should be easy and economical.

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

Requirement of Good Water Distribution System

- It should be capable of supplying the requisite amount of water during fire fighting.

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

- Maintenance of the distribution system should be easy and economical.

Means of Water Distribution/ Supply

- Depending on the topography relationship between the source of supply and the consumer, water can be transported by:

  - ✓ Canals
  - ✓ Tunnels
  - ✓ Pipelines

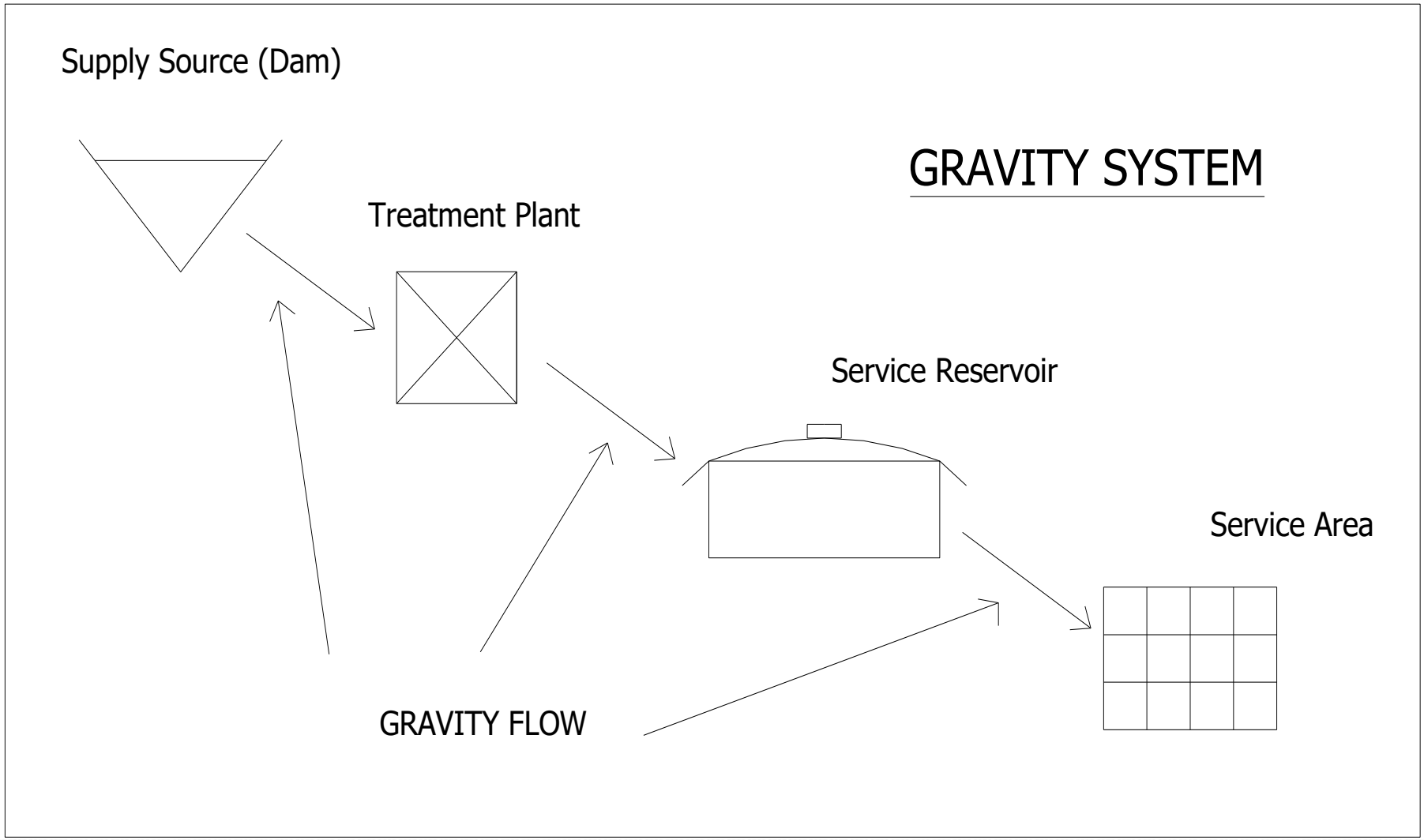
Water Distribution Methods

- For efficient distribution system adequate water pressure required at various points.

- Depending upon the level of source, topography of the area and other local conditions, the water may be forced into distribution system by following ways –

  - ❑ Gravity Flow System (Free-flow Conduit)
  - ❑ Direct Pumping System (Pressurized pipelines)
  - ❑ Combined gravity and pumping system

Water Distribution Methods – Gravity Flow

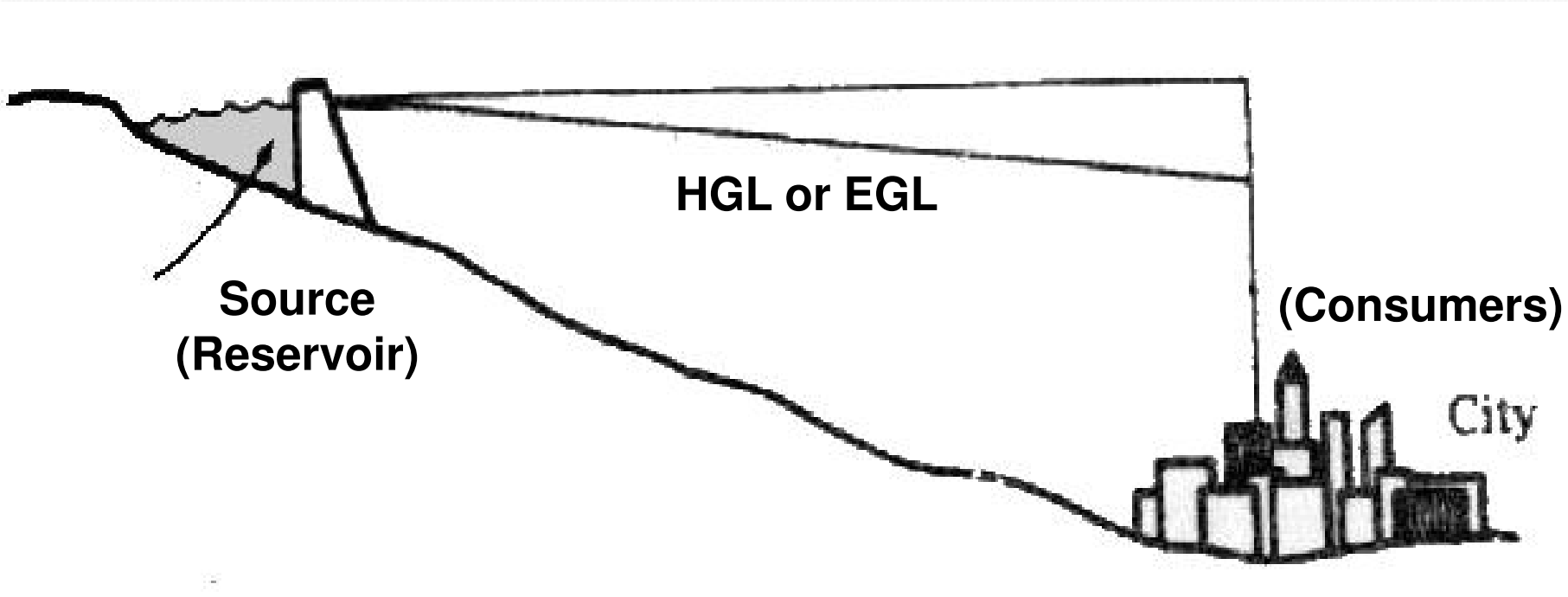


- Suitable when source of supply is at sufficient height.

Water Distribution Methods – Gravity Flow

- Free-flow conduits (canals, aqueducts and tunnels) are preferred in hilly areas or in areas where the required slope of the conduit more or less coincides with the slope of the terrain.
- Most reliable and economical distribution system.
- The water head available at the consumer is just minimum required.
- The remaining head is consumed in the frictional and other losses.
- Pump is not used.

Water Distribution Methods – Gravity Flow



Water Distribution Methods – Gravity Flow

Advantages

- Requires no energy to operate as water is conveyed by gravity.
- No pump is required and there are very few moving parts.
- Construction, operation and maintenance are simple.

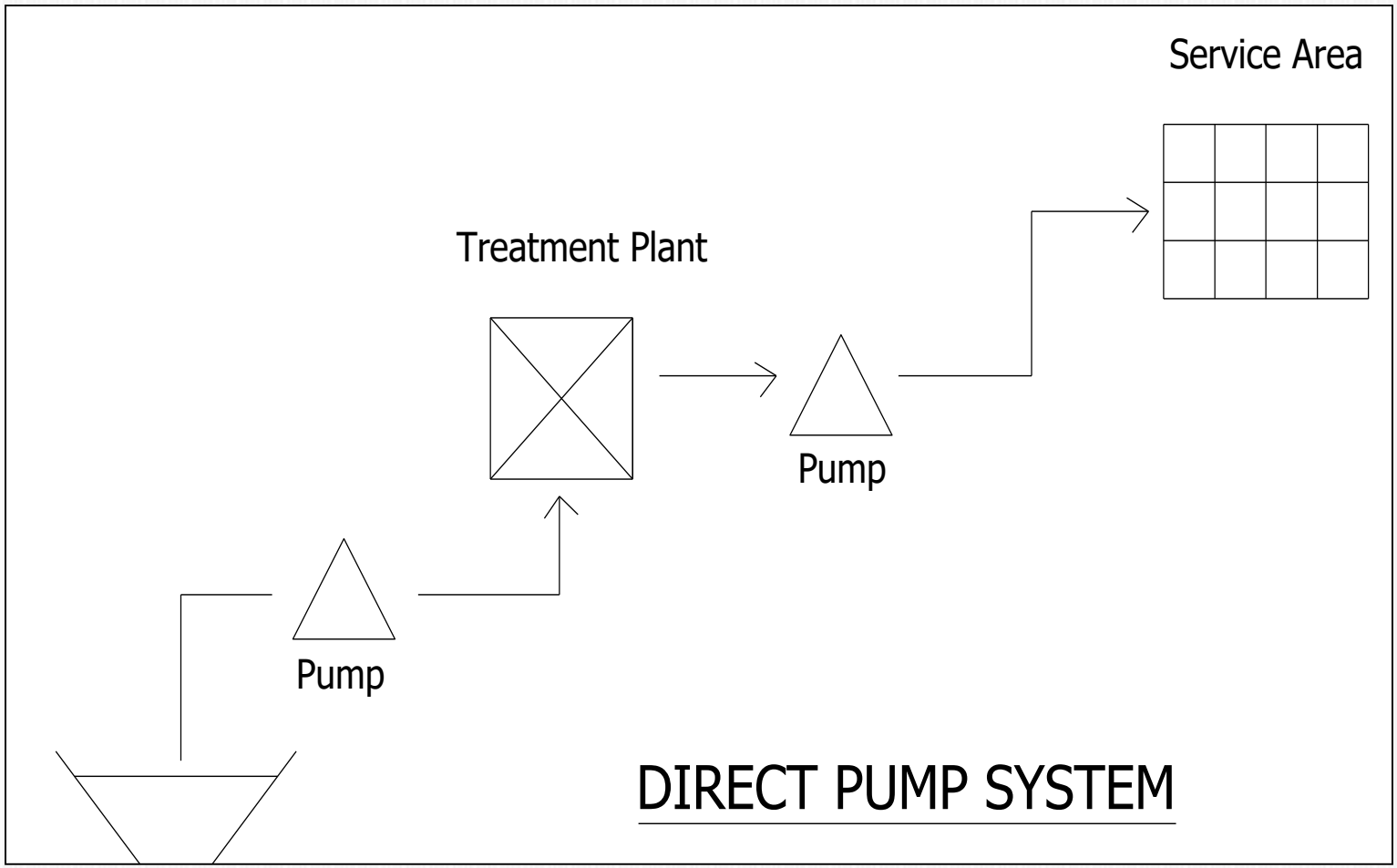
Water Distribution Methods – Gravity Flow

Disadvantages

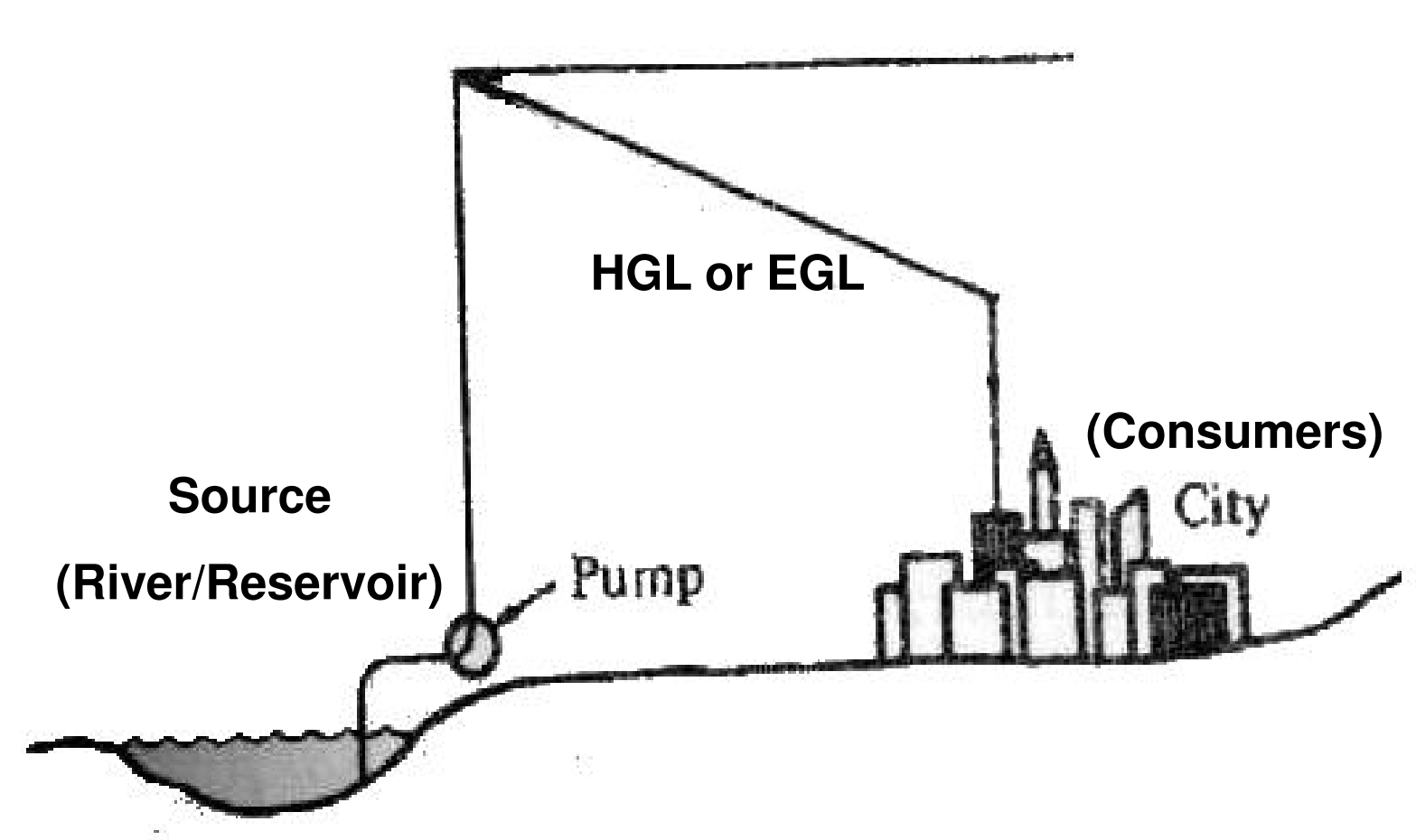
- Not applicable in those countries where an elevated source of water supply is not available.
- Water loss by leakage and wastage is comparatively higher as the system remains under constant pressure.

Water Distribution Methods – Direct Pumping System

- For small community water supplies through pressurized pipelined (direct pumping) are most common, since they are not very limited by the topography of the area to be traversed.



Water Distribution Methods – Direct Pumping System



Water Distribution Methods – Direct Pumping System

- Level of water sources is at the same height or lower from the service areas
- Treated water is directly pumped into the distribution main.
- Also called pumping without storage system.

Water Distribution Methods – Direct Pumping System

- High lifts pumps are required.
- If power supply fails, complete stoppage of water supply.
- The method is not generally used, since this system is expensive as well as less effective.

Water Distribution Methods – Direct Pumping System

Advantages

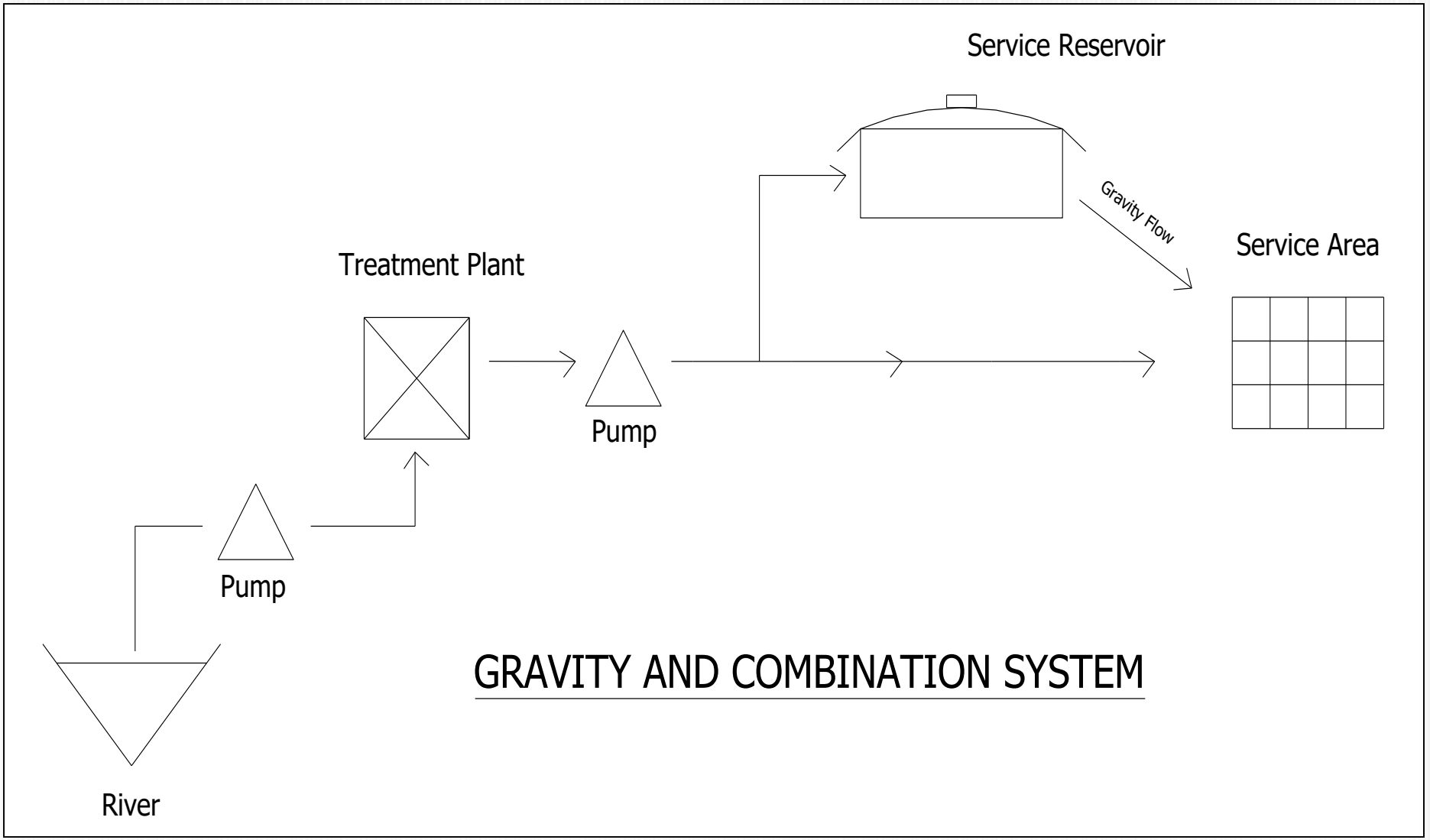
- Water can be pumped when required.
- Low water loss due to system leakage.

Water Distribution Methods – Direct Pumping System

Disadvantages

- Direct pumping at a uniform rate is not able to meet varying water demand and maintain required pressure under varying rates of consumption.
- A power failure means breakdown of the system.
- Maintenance and operation costs are high
- Inflow of water through leaks may cause water contamination during non-pumping hours.

Water Distribution Methods – Combined System

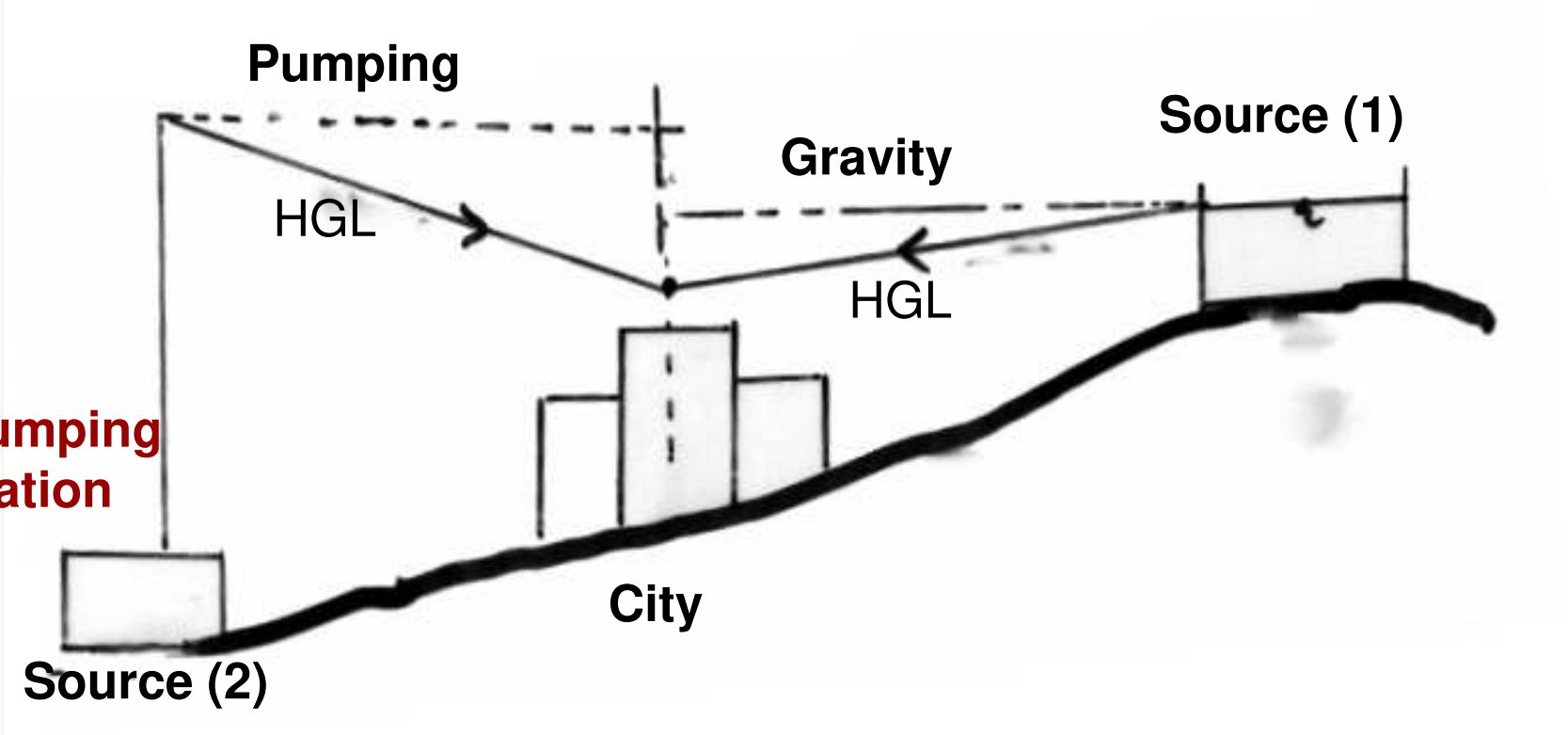


Water Distribution Methods – Combined System

- Most common system
- Treated water is pumped and stored in an elevated distribution reservoir.
- Then supplies to consumer by action of gravity.
- The excess water during low demand periods get stored in reservoir and get supplied during high demand period.
- Economical, efficient and reliable system.

Water Distribution Methods – Combined System

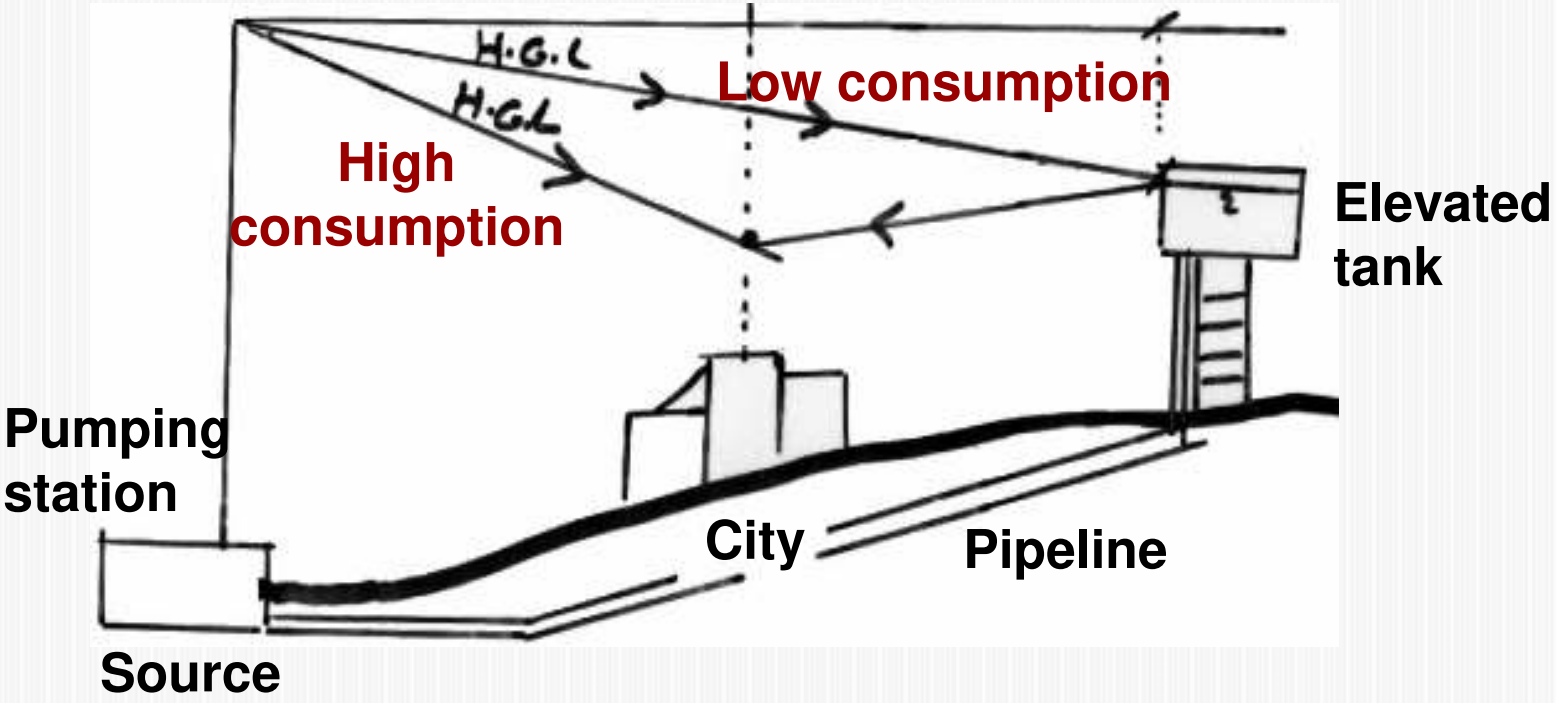
Case 1: When two sources of water are used to supply water



Water Distribution Methods – Combined System

Case 2: In the pumped system sometimes a storage (elevated) tank is connected to the system

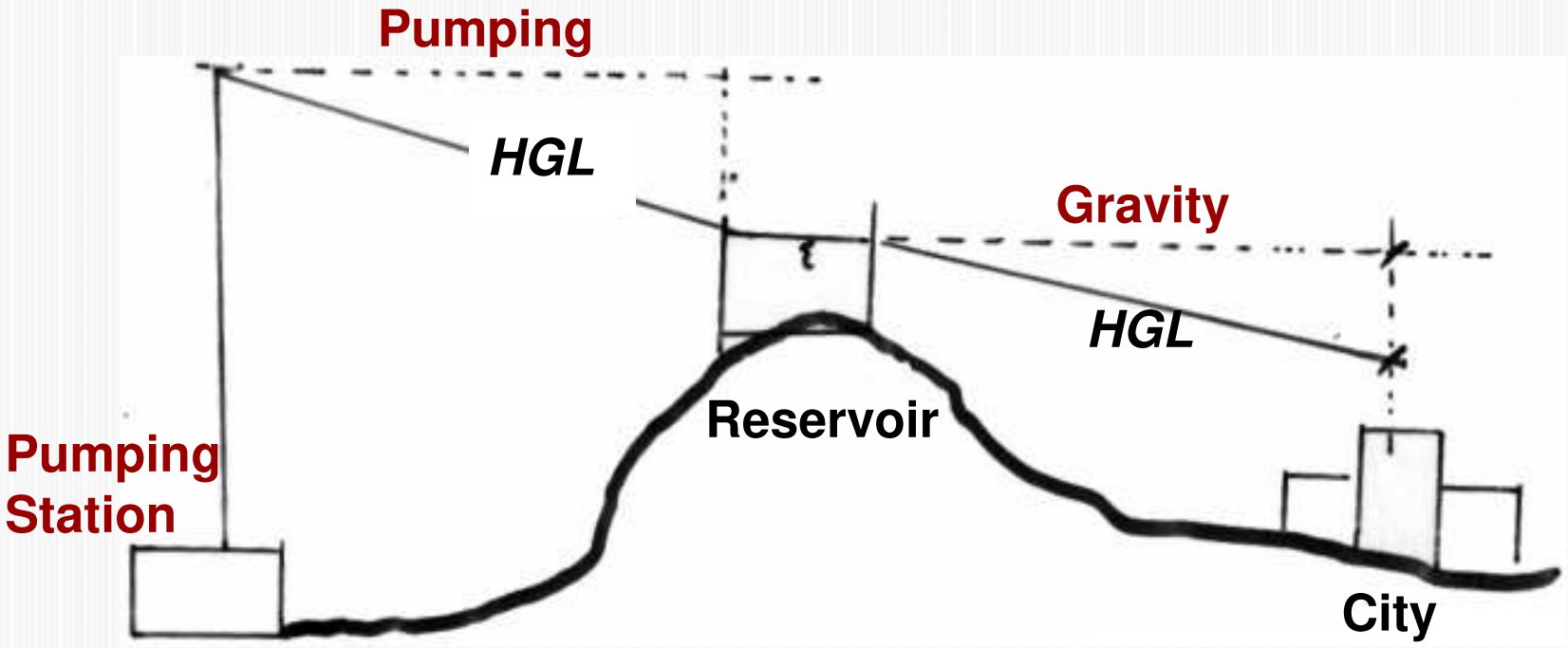
- When the water consumption is low, the residual water is pumped to the tank.
- When the consumption is high the water flows back to the consumer area by gravity.



Water Distribution Methods – Combined System

Case 3: When the source is lower than the consumer area

- A tank is constructed above the highest point in the area.
- Then the water is pumped from the source to the storage tank (reservoir).
- And hence the water is distributed from the reservoir by gravity.



Water Distribution Methods – Combined System

Advantages

- The system is more reliable and cope with fluctuation of water demand.
- The pumps can be operated at rated capacity, resulting in higher efficiency and economy of operation.
- Reasonable pressure can be maintained with varying water demand and there is no possibility of inflow of polluted water in the system.

Water Distribution Methods – Combined System

Disadvantages

- Relatively higher initial cost.
- Comparatively higher loss due to leakage and wastage.

Water Distribution Pipe System

Pipe system comprises of the following four units:

- Supply main
- Sub-main
- Minor distributors
- Valves

Water Distribution Pipe System

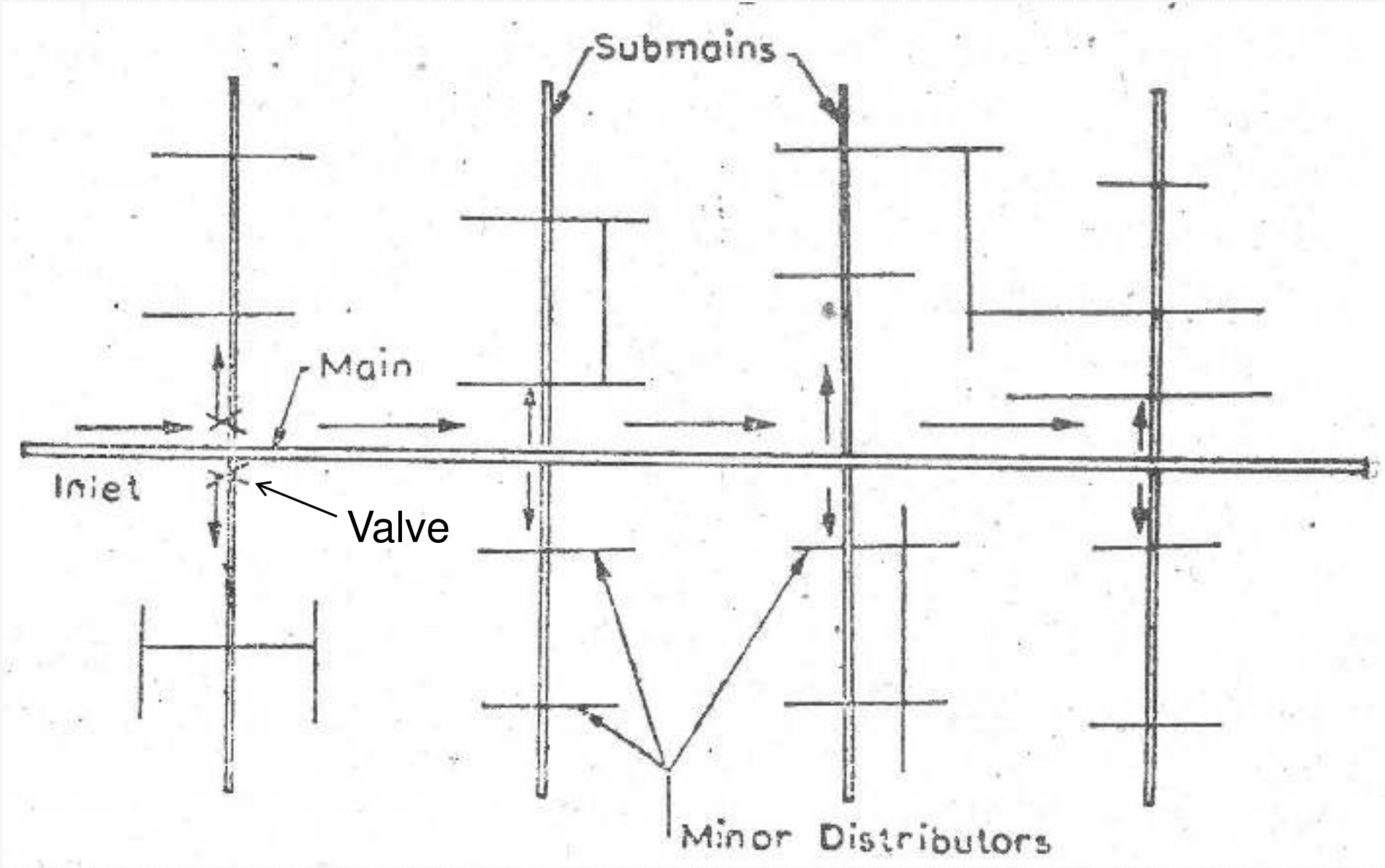
Supply main / Main

- Direct conveyor of water from the pumping plant or the gravity conduit.
- It should be of different size to carry the flow.

Sub-main

- Secondary feeders connected to either side
- May be placed at about 1000 ft apart
- Should be of sufficient size to discharge domestic supply and fire flow.

Water Distribution Pipe System



Water Distribution Pipe System

Minor Distributor/ Branches

- Make up the grid iron of pipes
- Supply water to the fire hydrants and service pipes of the residences and other buildings.
- For fire service, minimum diameter of pipe should be 6 inch and for domestic service alone, 4 inch or less.

Water Distribution Pipe System

Valves

- Needed to operate and control the pipe system.
- These should be sufficient in number and suitably located.

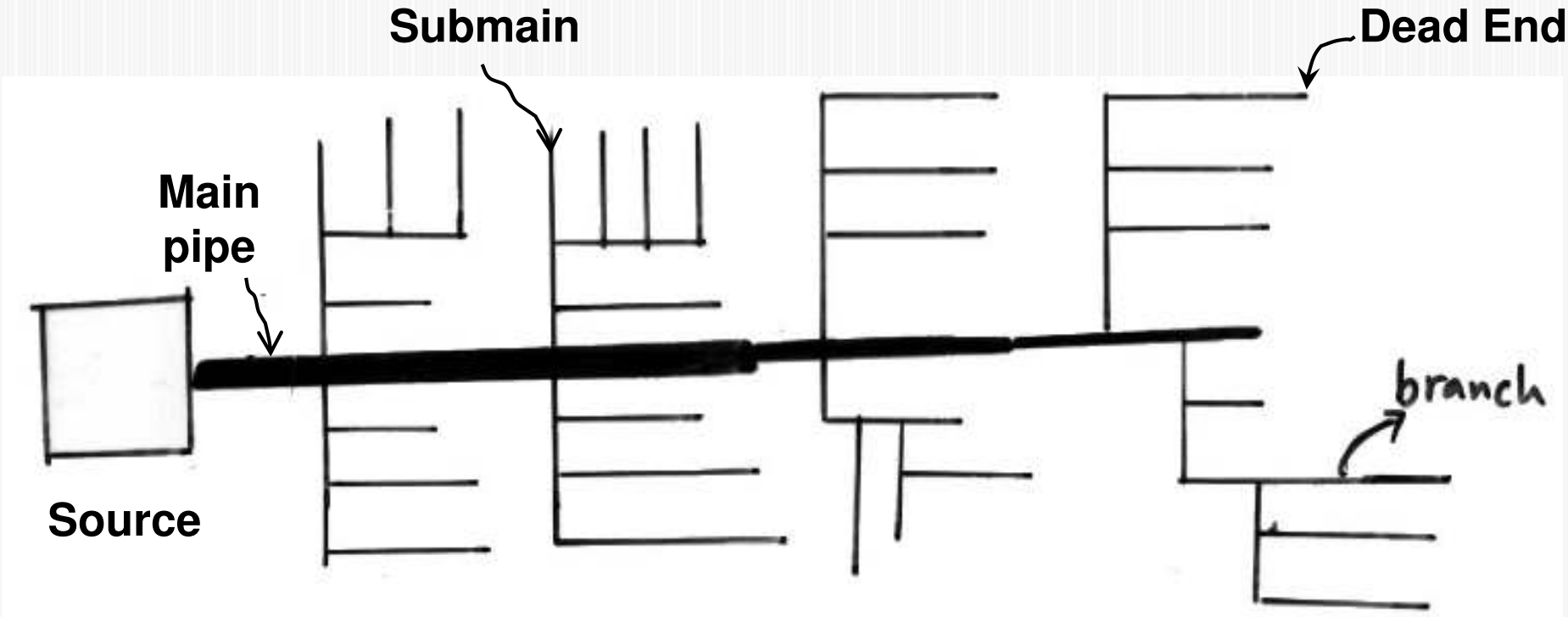
Layout of Water Distribution Network

- The distribution pipes are generally laid below the road pavements, and as such their layouts generally follow the layouts of roads.

- ***Types/ Configuration of distribution network:***
  (a) Branched distribution with dead end/ Tree system
  (b) Looped distribution network
    - ✓ Grid system
    - ✓ Ring system
    - ✓ Radial system
  (c) Combination of dead end and loop network

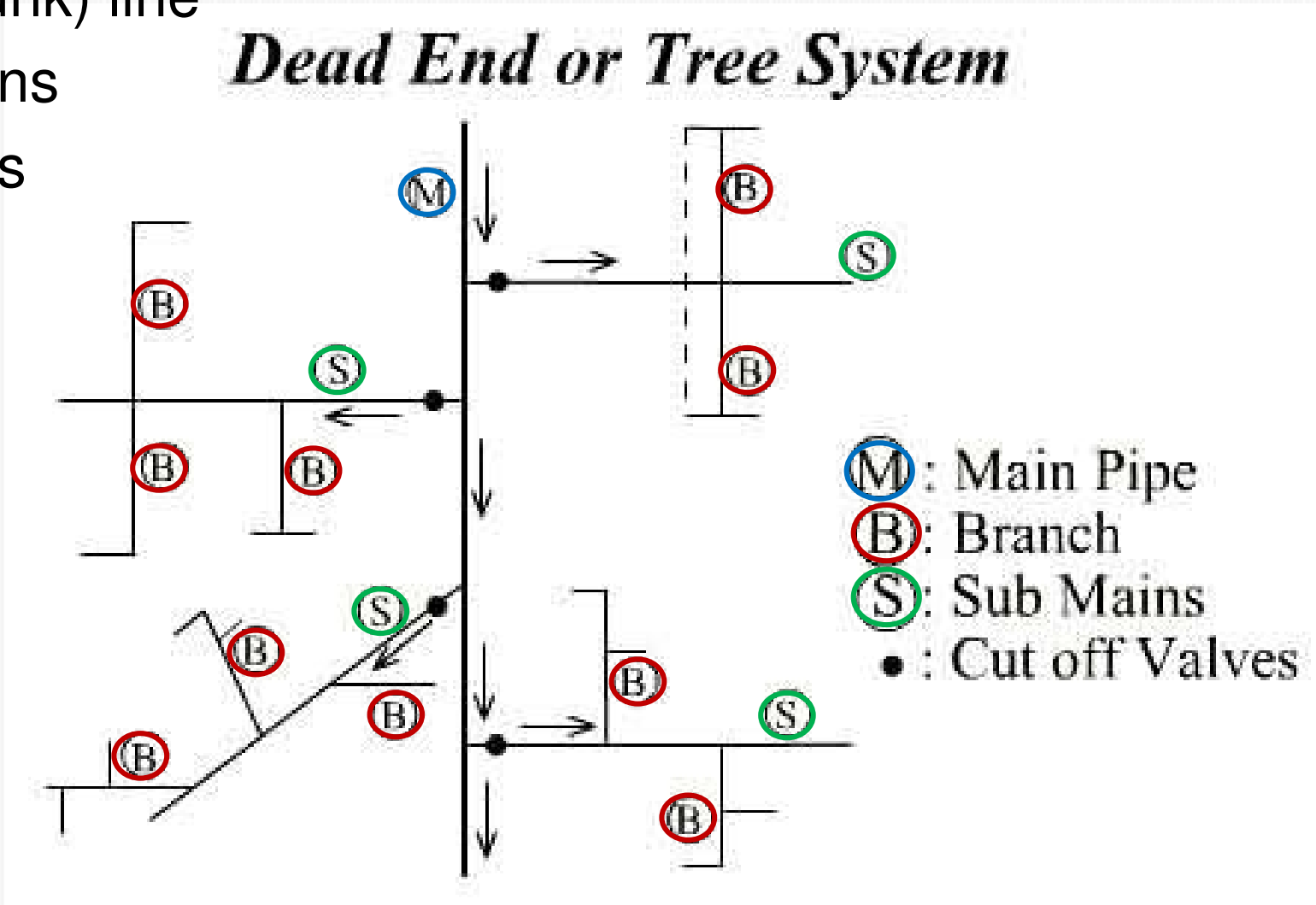
- Any one of the above mentioned systems either singly or in combinations, can be used for a particular place.

Branched Distribution Network / Dead End System



Branched Distribution Network / Dead End System

- It consists of
  - ✓ Main (trunk) line
  - ✓ Sub-mains
  - ✓ Branches



Branched Distribution Network / Dead End System

- Main line is the main source of water supply. There is no water distribution to consumers from trunk line.
- Sub-mains are connected to the main line and they are along the main roads.
- Branches are connected to the sub-mains and they are along the streets.
- Lastly service connections are given to the consumers from branches.

Dead End Distribution System

Advantages:

- It is a very simple method of water distribution and comparatively cheaper.
- Calculations for discharge and pressure are easy and simple to do.
- The required dimensions of the pipes are economical.
- This method requires comparatively less number of cut-off valves.
- It is suitable for old towns and cities having no definite pattern of roads.

Dead End Distribution System

Disadvantages:

- The area receiving water from a pipe under repair is without water until the work is completed.
- In this system, there are large number of dead ends where water does not circulate but remains static.
- Sediments accumulate due to stagnation of the dead end and bacterial growth may occur at these points.

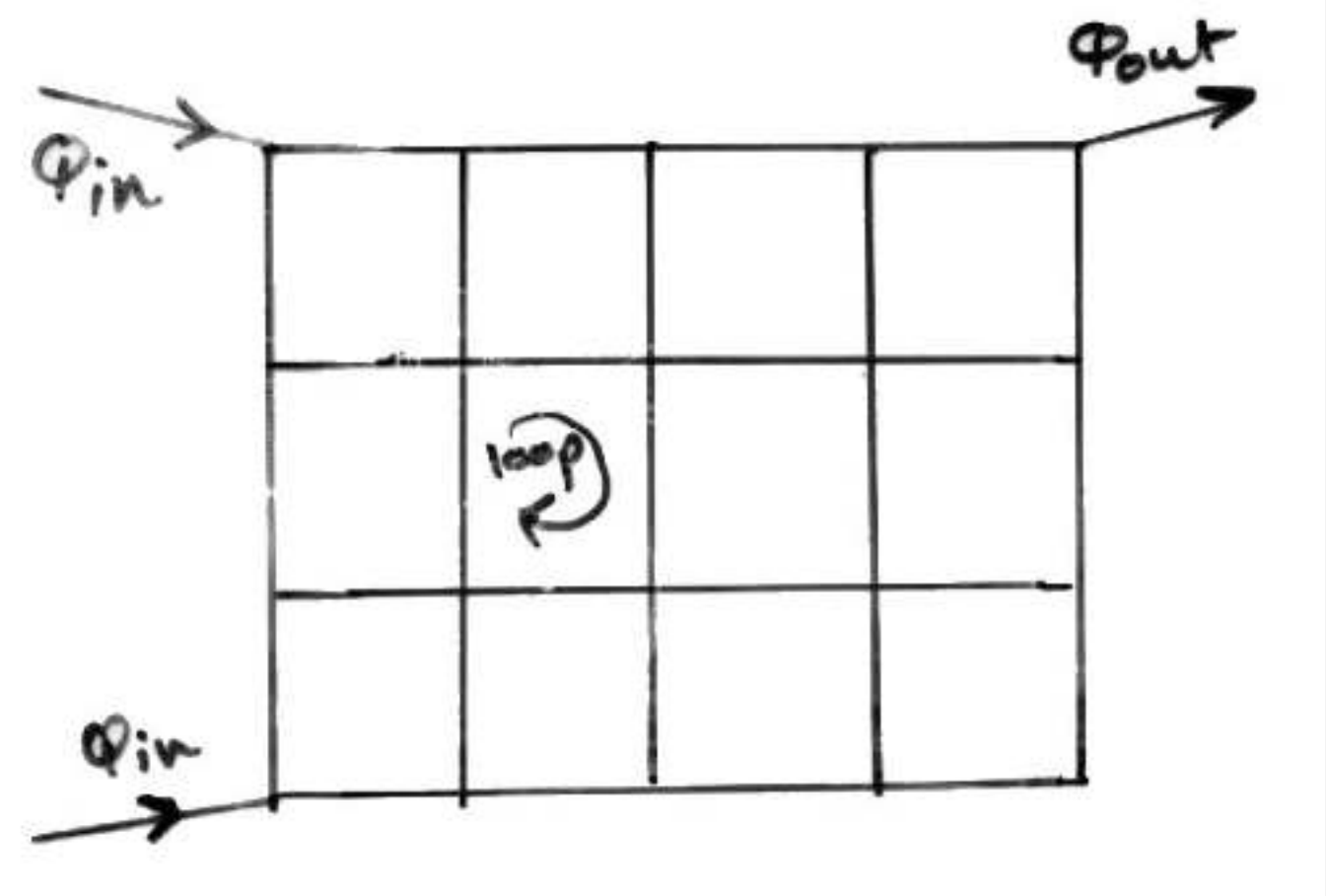
Dead End Distribution System

Disadvantages:

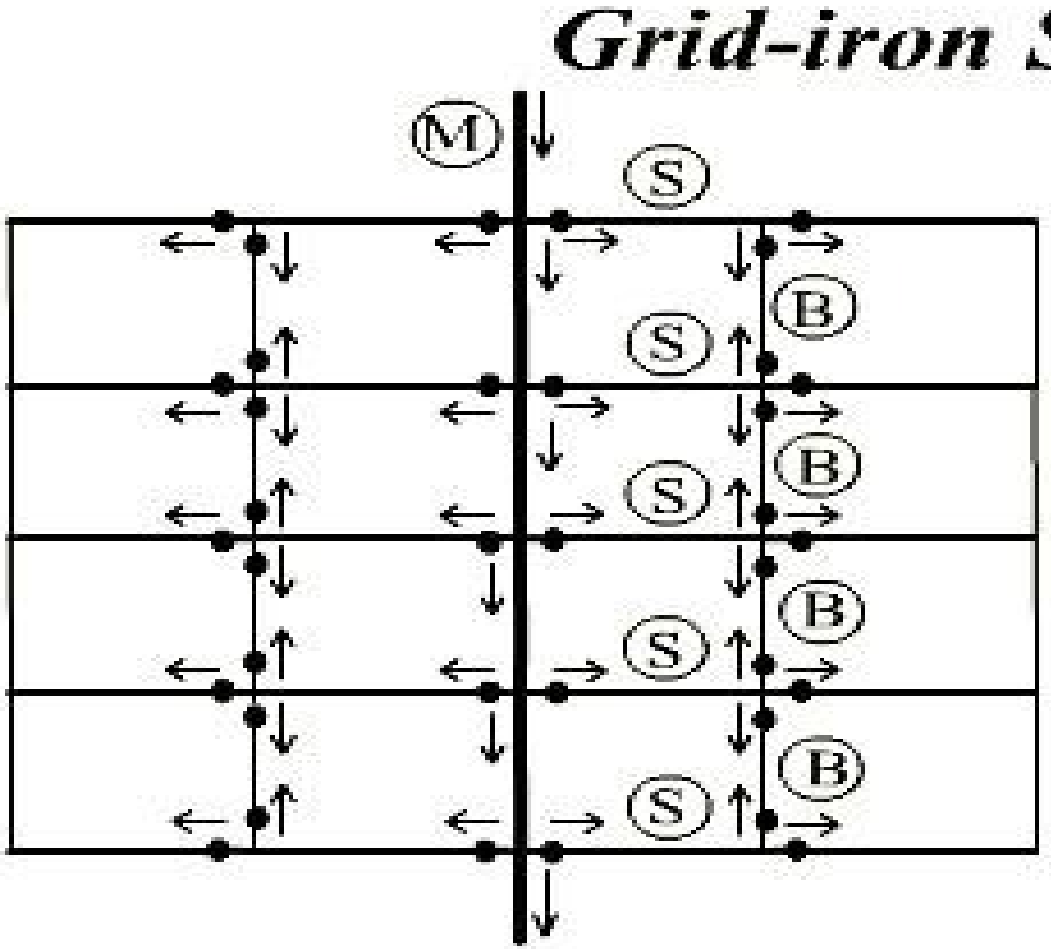
- To overcome the problem of standing water, drain valves are provided at dead ends and stagnant water is drained out by periodically opening these valves but a large amount of water is wasted.
- It is difficult to maintain chlorine residual at the dead ends of the pipe.
- Water available for fire-fighting will be limited since it is being supplied by only one water main.
- The pressure at the end of the line may become undesirably low as additional areas are connected to the water supply system.

Looped/ Grid System

The grid system overcomes all of the difficulties of the branching system discussed before.



Grid System



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

Grid System

- In grid pattern, all the pipes are interconnected with no dead-ends.
- In such a system, water can reach any point from more than one direction.
- It is suitable for cities with rectangular layout, where the water mains and branches are laid in rectangles.

Grid System

Advantages

- Since water in the supply system is free to flow in more than one direction, stagnation does not occur as readily as in the branching pattern.
- In case of repair or break down in a pipe, the area connected to that pipe will continue to receive water, as water will flow to that area from the other side.
- Water reaches all points with minimum head loss.
- At the time of fires, by manipulating the cut-off valves, plenty of water supply may be diverted and concentrated for fire-fight.

Grid System

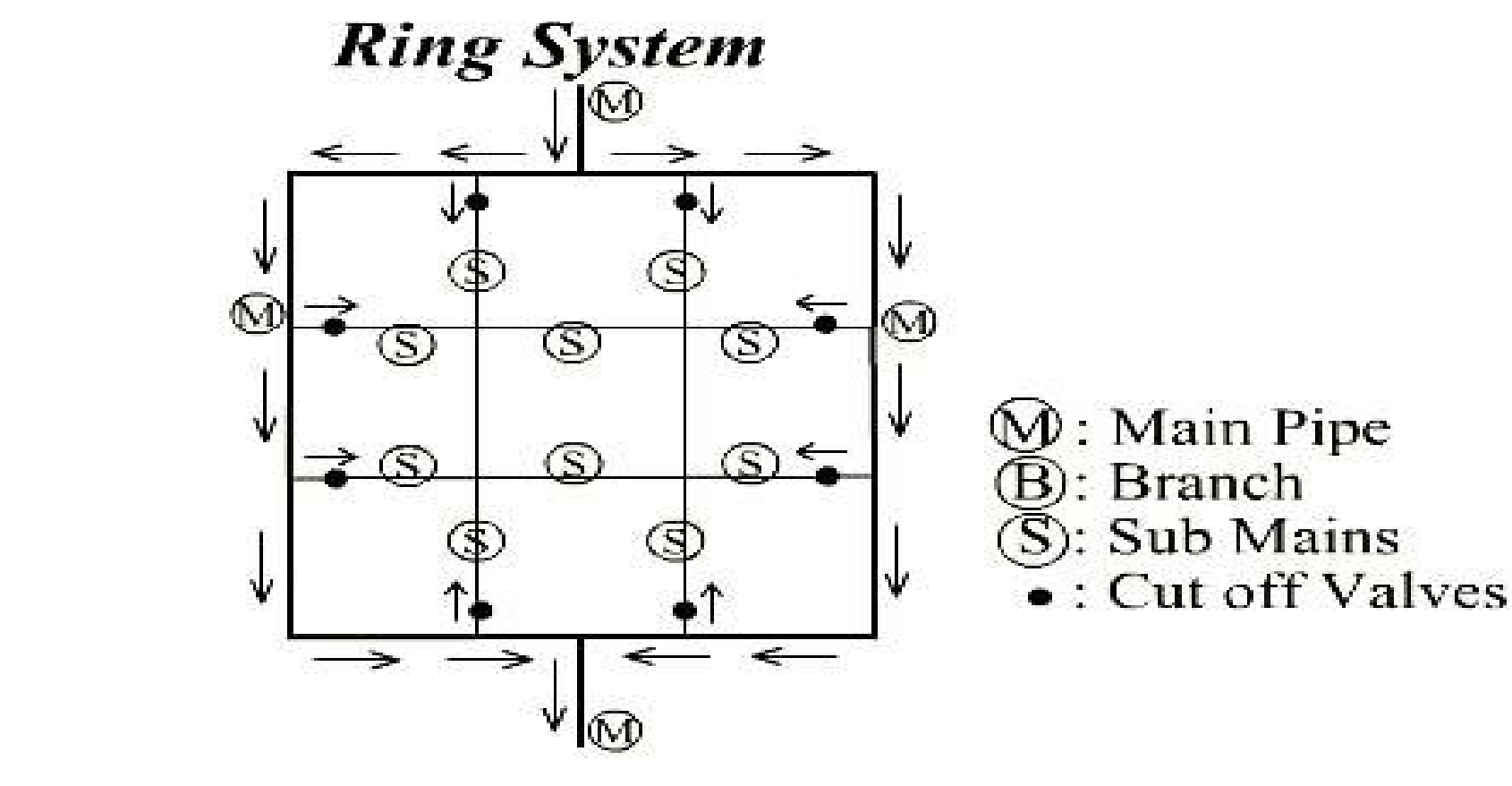
Disadvantages

- Cost of pipe laying is more because relatively more length of pipes is required.
- More number of valves are required.
- The calculation of pipe sizes are more complicated.

Ring System

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

Ring System

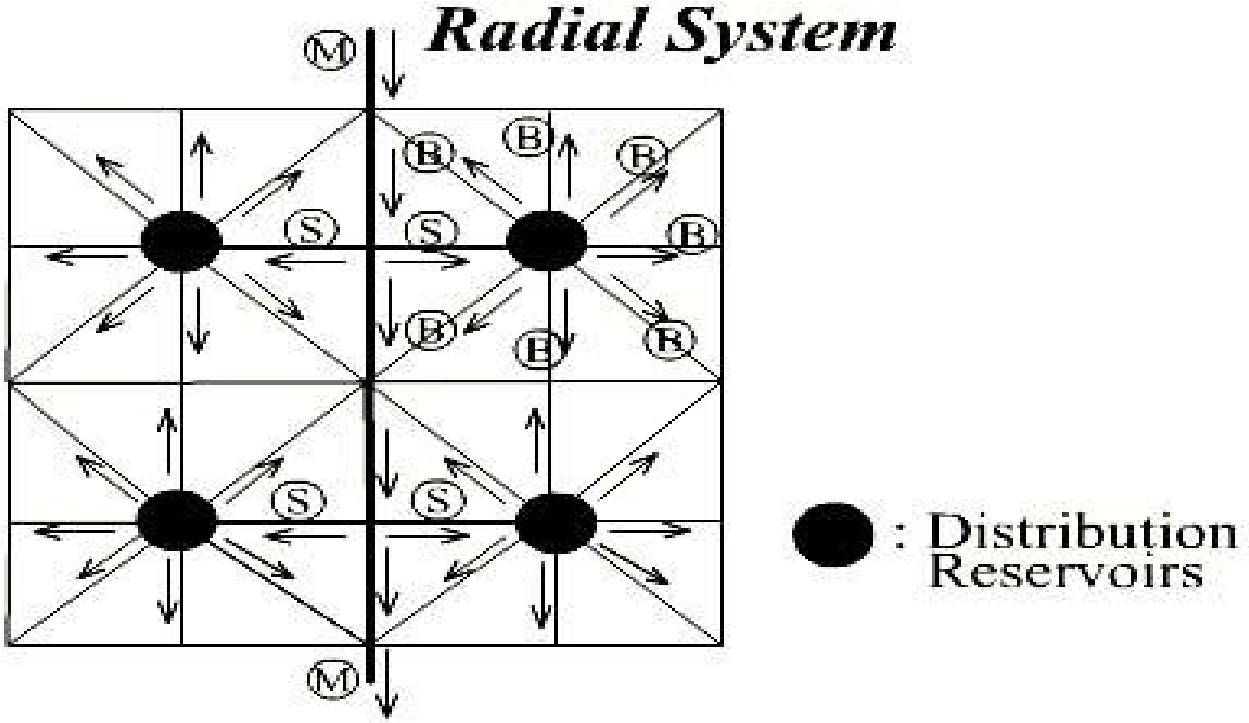


Advantages

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

Radial System

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



Radial System

Advantages:

- It gives quick service.
- Calculation of pipe sizes is easy.

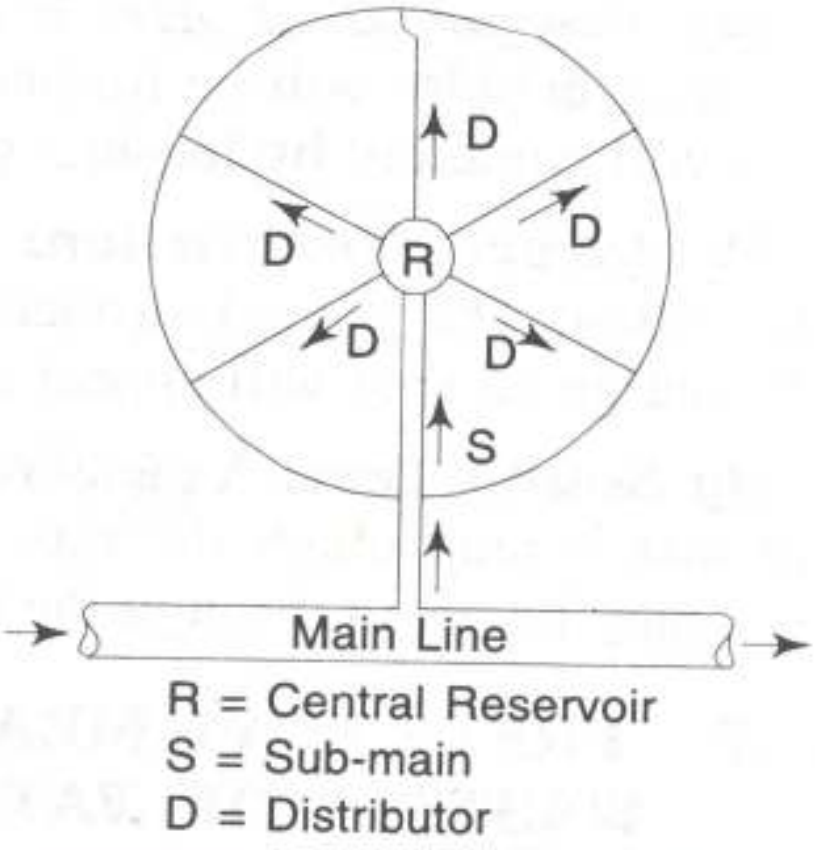
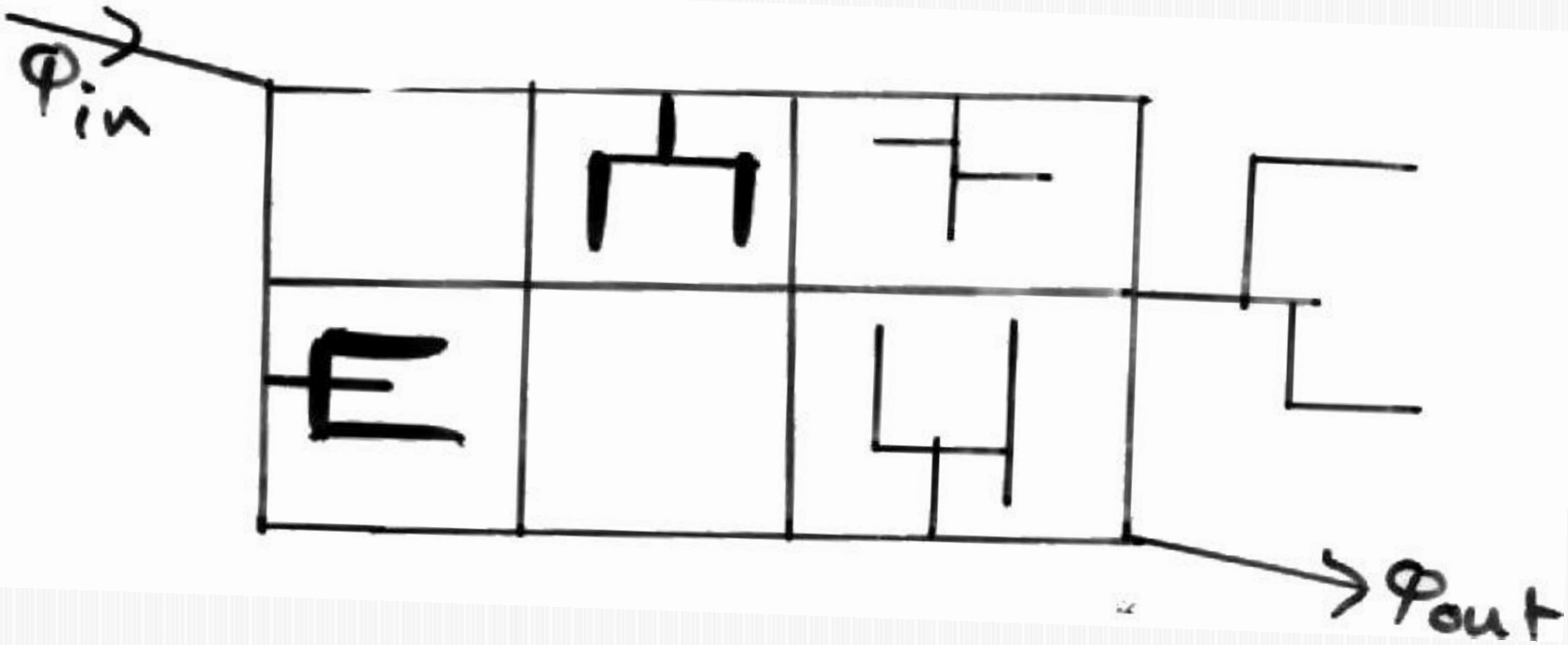


Fig. 13.7 *Radial method*

Combination of Dead End and Loop Network System



- It is a combination of both Grid and Branching systems
- This type is widely used all over the world.

Fire Hydrant



- **Main function :** provide water for firefighting
- **Spacing and location :** Depends on fire protection and insurance needs
- **Other function :**

i. Flush the distribution system lines to remove sediments and bio-growth accumulation

ii. Supply water to construction projects

iii. Provide water to water trucks and street sweepers

Distribution Reservoirs

- Distribution reservoirs, also called **service reservoirs**, are the **storage reservoirs**.
- Store the treated water for supplying water during emergencies (such as during fires, repairs, etc.)
- Also help in absorbing the hourly fluctuations in the normal water demand.

Distribution Reservoirs

- Such a reservoir can be filled by pumping water at a certain rate.
- Can be used to supply water even at rate higher than inflow rate during period of maximum demands called critical periods of demand.
- Such reservoirs are helpful in permitting the pumps or the water treatment plants to work at a uniform rate, and
- They store water during the hours of no demand or less demand, and supply water from their storage during the critical periods of maximum demand

Functions/ Purpose of Distribution Reservoirs

- To absorb the hourly variations in demand.
- To maintain constant pressure in the distribution main.
- Water stored can be supplied during emergencies.

Design Criteria of Distribution Reservoirs

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

Types of Reservoirs

Depending upon the elevation with respect to ground, it may be classified into the following types:

- **Surface reservoirs**
- **Elevated/ Overhead reservoirs**





Surface Reservoirs

- These also called ground reservoir.
- Mostly circular or rectangular tanks.
- Underground reservoir are preferred especially when the size is large.
- These reservoirs are constructed on high natural grounds and are usually made of stones, brick, plain or reinforced concrete cement.
- The side walls are designed to take up the pressure of the water, when the reservoir is full and the earth pressure, when it is empty.

Elevated/ Overhead Reservoirs

- It is also referred to as overhead tanks.
- Are required at distribution areas which are not governed and controlled by the gravity system of distribution.
- These are rectangular, circular or elliptical in shape.
- If the topography of the town not suitable for under gravity, the elevated tank or reservoir are used.
- They are constructed where combine gravity and pumping system of water distribution is adopted.
- These tanks may be steel or RCC.

EWCE 331
Water Supply Engineering

Lecture 4

Instructor

Lt Col Dr. Kazi Shamima Akter, Engrs

Department of EWCE, MIST

Lecture outline

Surface water collection and transmission

Topics	References
• **Water Supply Network Analysis** ✓ **Dead-end Method** ✓ **Equivalent Pipe Method**	**1. A Text Book of Water Supply Engineering** Authors: M. A. Aziz 1st ed., Hafiz Book Center **3. Water Supply and Sanitation** Authors: M. Feroz Ahmed, Md. Mujibur Rahman 1st ed., ITN-BUET **3. Water and Environmental Engineering** Authors: M. Habibur Rahman, Abdullah Al-Muyeed 1st ed., ITN-BUET

Significance/ Purpose of Pipe Network Analysis

- A pipe network is analyzed for the determination of the nodal pressure heads, head loss and the link discharges.

- As the discharges withdrawn from the network vary with time, it results in a continuous change in the nodal pressure heads and the link discharges.

- The network is analyzed for the worst combination of discharge withdrawals that may result in low-pressure heads in some areas.

Significance/ Purpose of Pipe Network Analysis

- It is also required to identify pipe links that would be closed in an emergency to meet firefighting demand in some localities due to limited capacity of the network.
- The effect of closure of pipelines on account of repair work is also studied by analyzing a network.
- Thus, network analysis is critical for proper operation and maintenance of a water supply system.

Hydraulic Analysis of Water Distribution System

Distribution Main:

- A pipeline in which there are multiple withdrawals is called a distribution main.

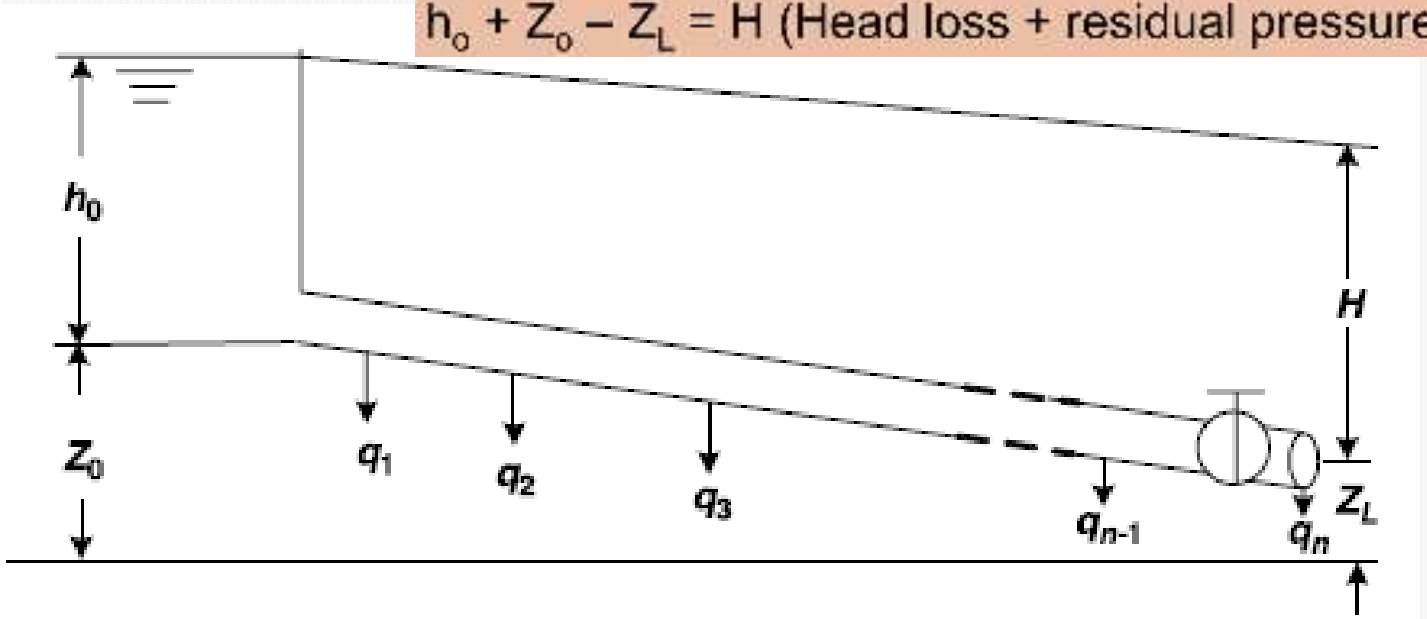
- In a distribution main, water may flow on account of gravity (Fig. 1) or by pumping (Fig. 2) with withdrawals q_1, q_2, q_3, . . . , q_n at the nodal points 1, 2, 3, . . . , n.

Hydraulic Analysis of Water Distribution System

Distribution Main:

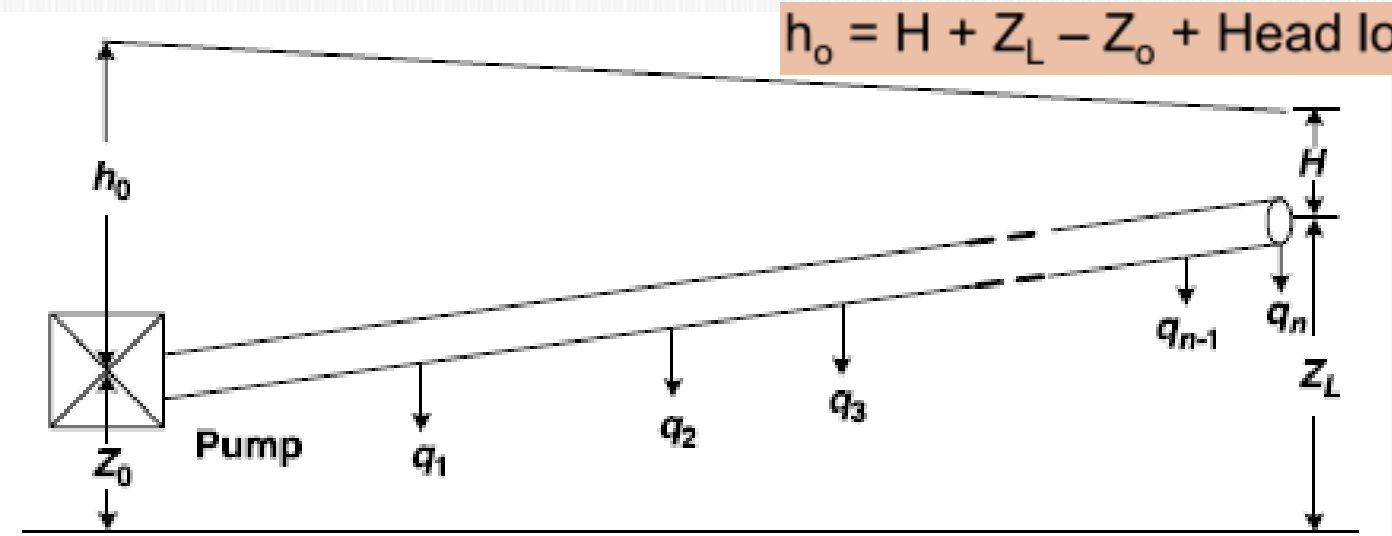
$h_o + Z_o - Z_L = H$ (Head loss + residual pressure)

Fig 1: A gravity sustained distribution mair



$h_o = H + Z_L - Z_o$ + Head loss

Fig 2: A pumpin distribution mair



Hydraulic Analysis of Water Distribution System

Distribution Main:

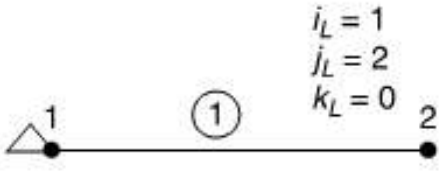
- In the analysis of a distribution main, one is required to find the nodal heads h_1, h_2, h_3, . . . , H.

- The discharge flowing in the j th pipe link Q_j is given by –

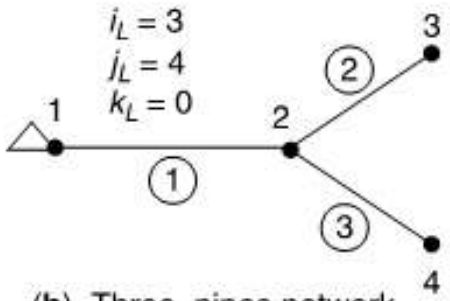
$$Q_j = \sum_{p=0}^{j} Q_{n-p}$$

Hydraulic Analysis of Water Distribution System

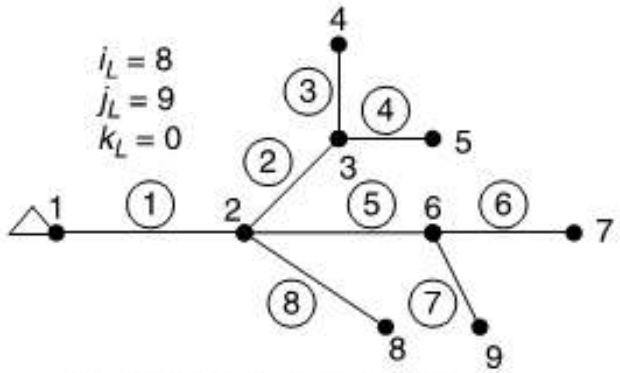
Pipe Node Connectivity



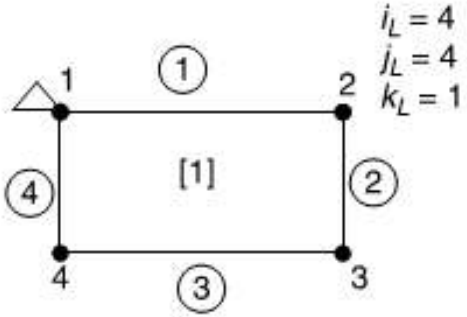
(a) Single pipe network



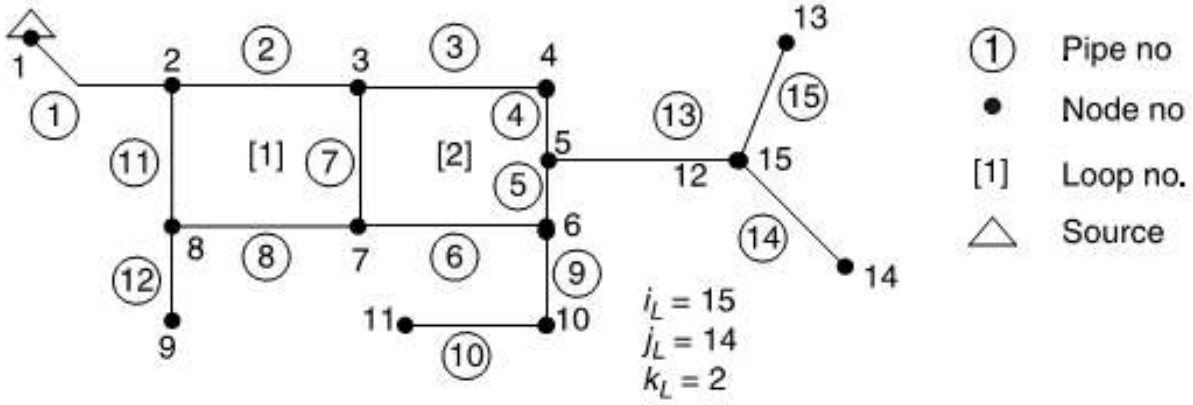
(b) Three pipes network



(c) Branched pipe network



(d) Single looped network



(e) Branched & looped network

$$i_L = j_L + k_L - 1$$

i_L = no. of pipes
j_L = no. of nodes
k_L = no. of loops

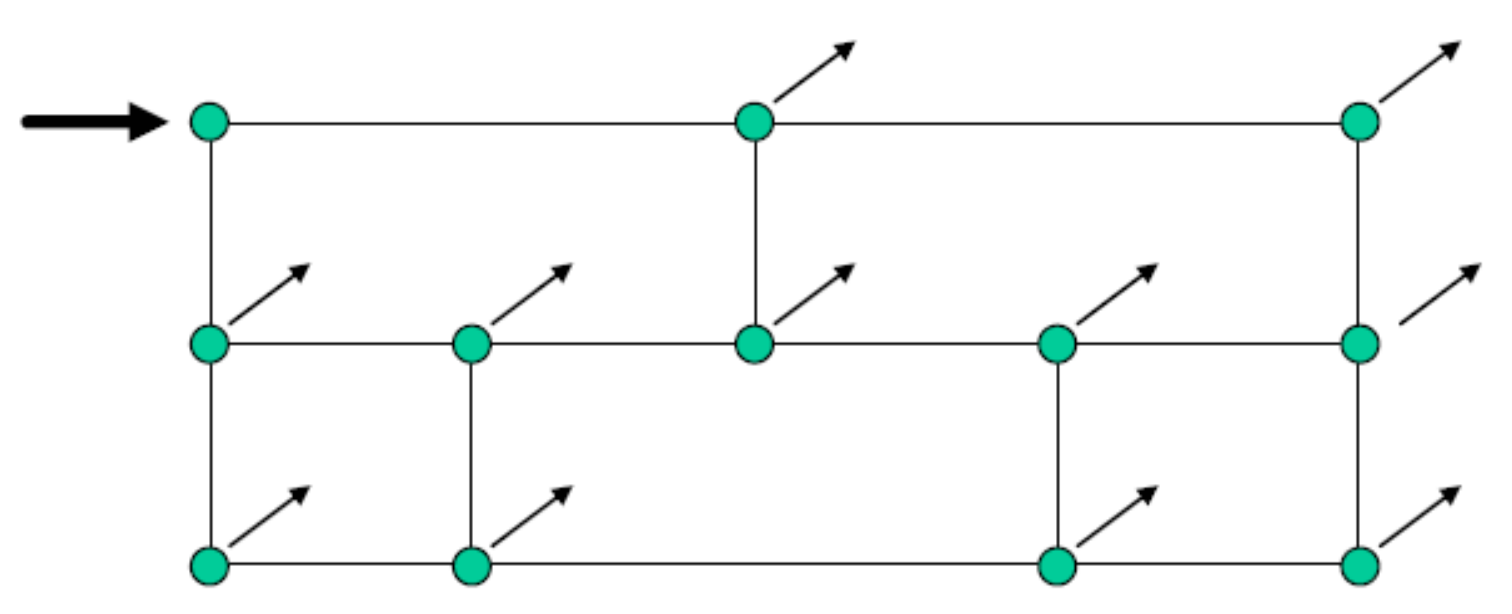
Hydraulic Analysis of Water Distribution System

Most commonly used methods are:

(a) Dead-end method

(b) Equivalent pipe method

(c) Hardy-Cross method

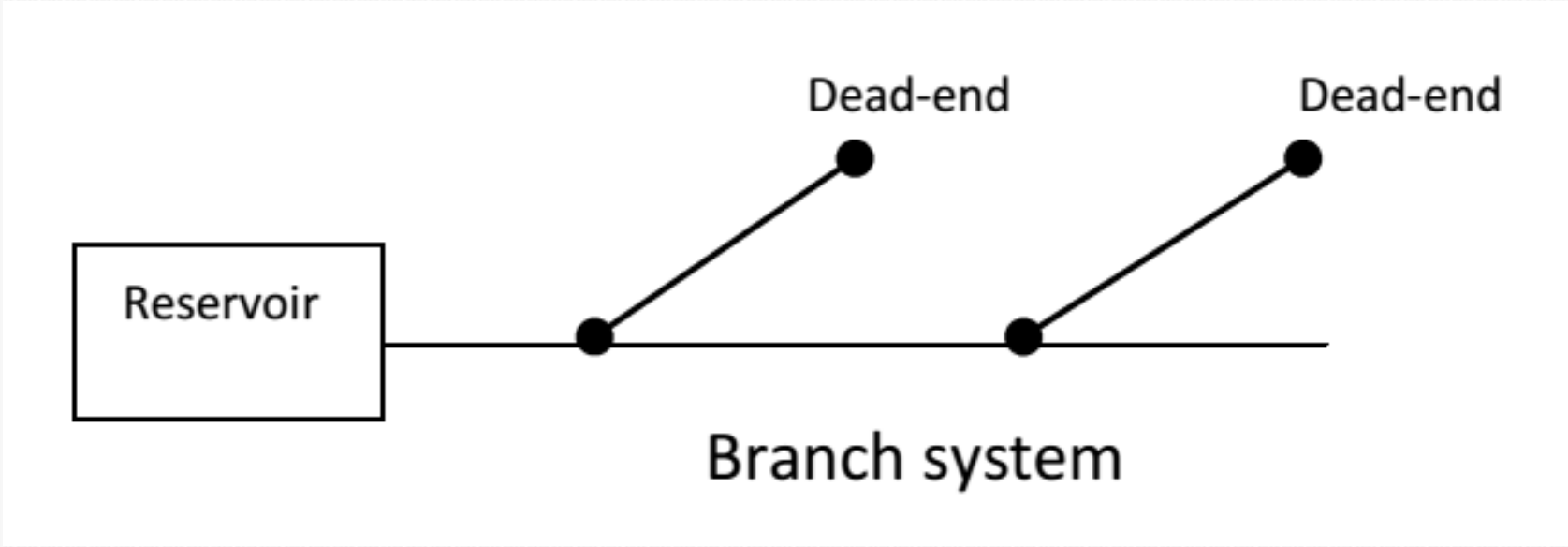


Hydraulic Analysis of Water Distribution System

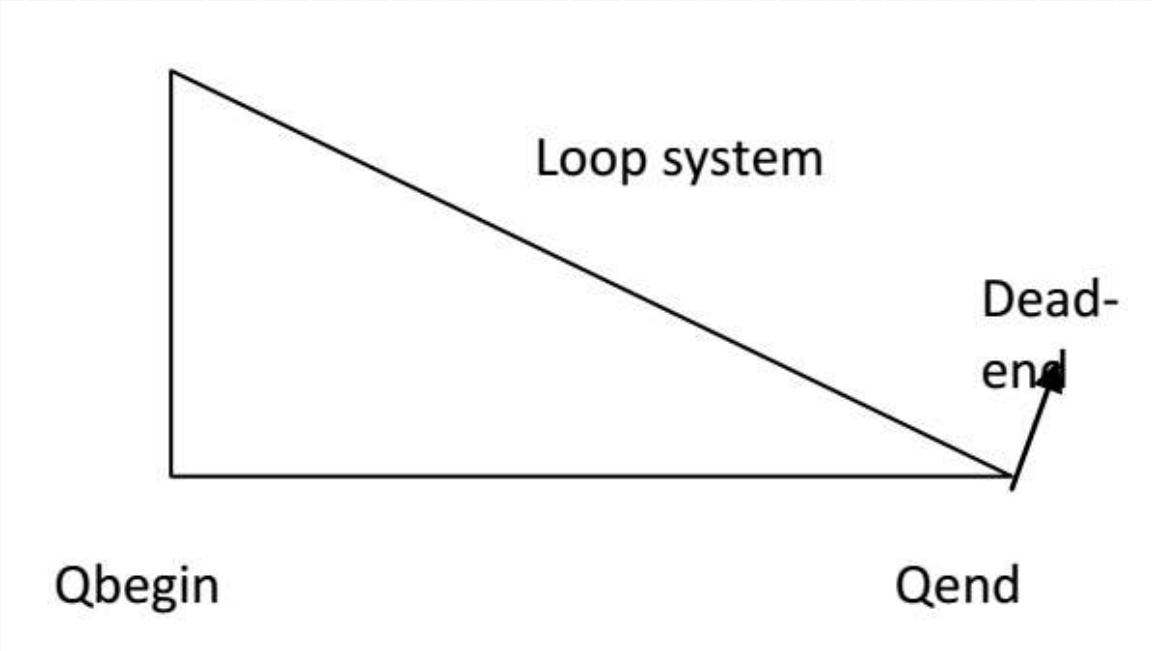
a) Dead-end method:

- Determine the locations of "dead-ends" providing that water will be distributed in the shortest way.

- At the dead-end points, there will be no flow distribution.

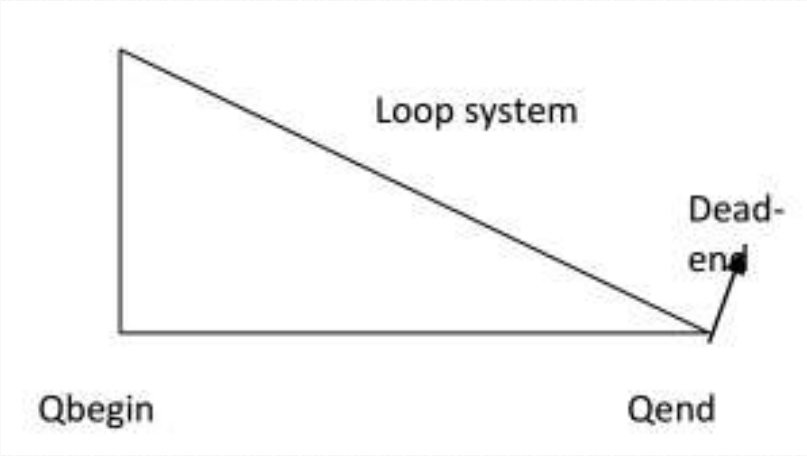


Hydraulic Analysis of Water Distribution – Dead-end Method



- To apply dead-end method for loop systems, convert it to branch system.
- To do this, a dead-end point is identified for each loop.

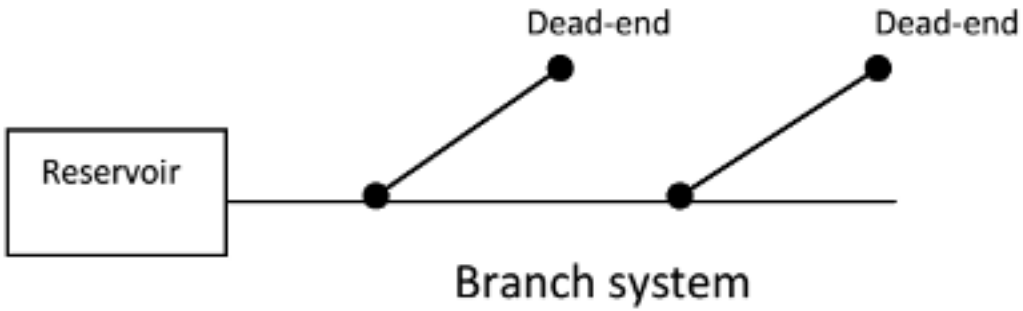
Hydraulic Analysis of Water Distribution – Dead-end Method

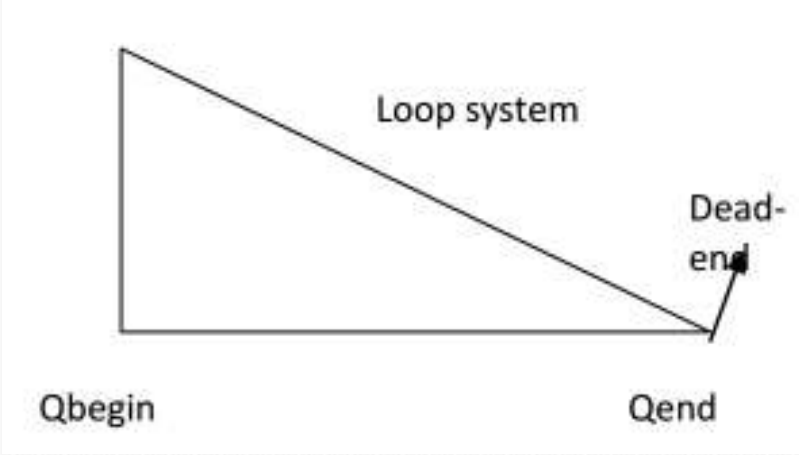


- The location of dead end point is chosen such that distance travelled to reach dead-end point from 2 different directions will almost equal to each other. Because, in a closed loop,

$$\sum HL_{from\ one\ direction} \cong \sum HL_{from\ other\ direction}$$

Hydraulic Analysis of Water Distribution – Dead-end Method





- Start calculations from dead-ends to service reservoir.
- Calculate the total flow rate to be distributed (Q_{max_h} + Q_{fire})
- To estimate design flow rate of each pipe, calculate -
  - ✓ Q distributed
  - ✓ Q begin
  - ✓ Q end

Hydraulic Analysis of Water Distribution – Dead-end Method

To calculate Q distributed:

- Population density coefficients (k) are calculated from the areas to where water to be distributed.

- Population density in each area is determined according to number of building stories:

Number of story	1	2	3	4	5
One-sided buildings	0.5	1	1.5	1.75	2
Two-sided buildings	1	2	3	3.5	4

- Unit of k = population/m length of pipe

Hydraulic Analysis of Water Distribution – Dead-end Method

To calculate Q distributed:

- Equivalent pipe lengths for each pipe:

$$(L_{eq})_i = k.\ L_i$$

- Distributed flow in unit pipe length:

$$q = \frac{Qtotal}{\sum L_{eq}}$$

- Distributed flow (Q_{dist}) in each pipe:

$$(Q_{dist})_i = q.\ (L_{eq})_i$$

Hydraulic Analysis of Water Distribution – Dead-end Method

To determine design flow:

A) For the pipes having dead-end:

$$Q_{design} = 0.577Q_{dist} + Q_{end} + Q_{fire}$$

B) For the pipes having no dead-end:

$$Q_{design} = 0.55Q_{dist} + Q_{end} + Q_{fire}$$

Hydraulic Analysis of Water Distribution – Dead-end Method

- Diameter of each pipe is selected providing that velocity should be within the allowable range.

- Head losses through each pipe is calculated by using Darcy-Weisbach or Hazen-Williams equation.

Hydraulic Analysis of Water Distribution – Dead-end Method

H_L calculation according to Darcy-Weisbach:

- The continuity equation for steady flow in a circular pipe of diameter D is –

$$Q = \frac{\pi}{4} D^2 V \qquad \text{…….. (1)}$$

where, V = average velocity of flow, and

Q = volumetric rate of flow, called discharge.

Hydraulic Analysis of Water Distribution – Dead-end Method

H_L calculation according to Darcy-Weisbach:

- The head loss on account of surface resistance is given by the Darcy–Weisbach equation

$$H_L = \frac{fLV^2}{2gD} \qquad \text{…….. (2)}$$

where, L = the pipe length, and

f = coefficient of surface resistance (friction factor)

Hydraulic Analysis of Water Distribution – Dead-end Method

H_L calculation according to Darcy-Weisbach:

- Eliminating V between equations (1) and (2), the following equation is obtained:

$$H_L = \frac{8 f L Q^2}{\pi^2 g D^5} \quad \text{..... (3)}$$

- The coefficient of surface resistance (f) for turbulent flow depends on the average height of roughness projection (ε) of the pipe wall.

Hydraulic Analysis of Water Distribution – Dead-end Method

H_L calculation according to Darcy-Weisbach:

- The average height of roughness projection (ε) of pipe wall for commercial pipes is listed in Table 1.

Pipe Material	Roughness Height (mm)
1. Wrought iron	0.04
2. Asbestos cement	0.05
3. Poly(vinyl chloride)	0.05
4. Steel	0.05
5. Asphalted cast iron	0.13
6. Galvanized iron	0.15
7. Cast /ductile iron	0.25
8. Concrete	0.3 to 3.0
9. Riveted steel	0.9 to 9.0

Roughness height varies with manufacturing processes for the same material.

Hydraulic Analysis of Water Distribution – Dead-end Method

H_L calculation according to Darcy-Weisbach:

- The coefficient of surface resistance also depends on the Reynolds number **R** of the flow, defined as –

$$\mathbf{R} = \frac{VD}{\nu} \quad \text{..... (4)}$$

where, ν = kinematic viscosity of fluid

$$\nu = 1.792 \times 10^{-6} \left[1 + \left(\frac{T}{25} \right)^{1.165} \right]^{-1} \quad \text{..... (5)}$$

where, T = temperature (°C)

Hydraulic Analysis of Water Distribution – Dead-end Method

H_L calculation according to Darcy-Weisbach:

- Eliminating V between Eqs. (1) and (4), the following equation is obtained:

$$\mathbf{R} = \frac{4Q}{\pi \nu D} \quad \text{..... (6)}$$

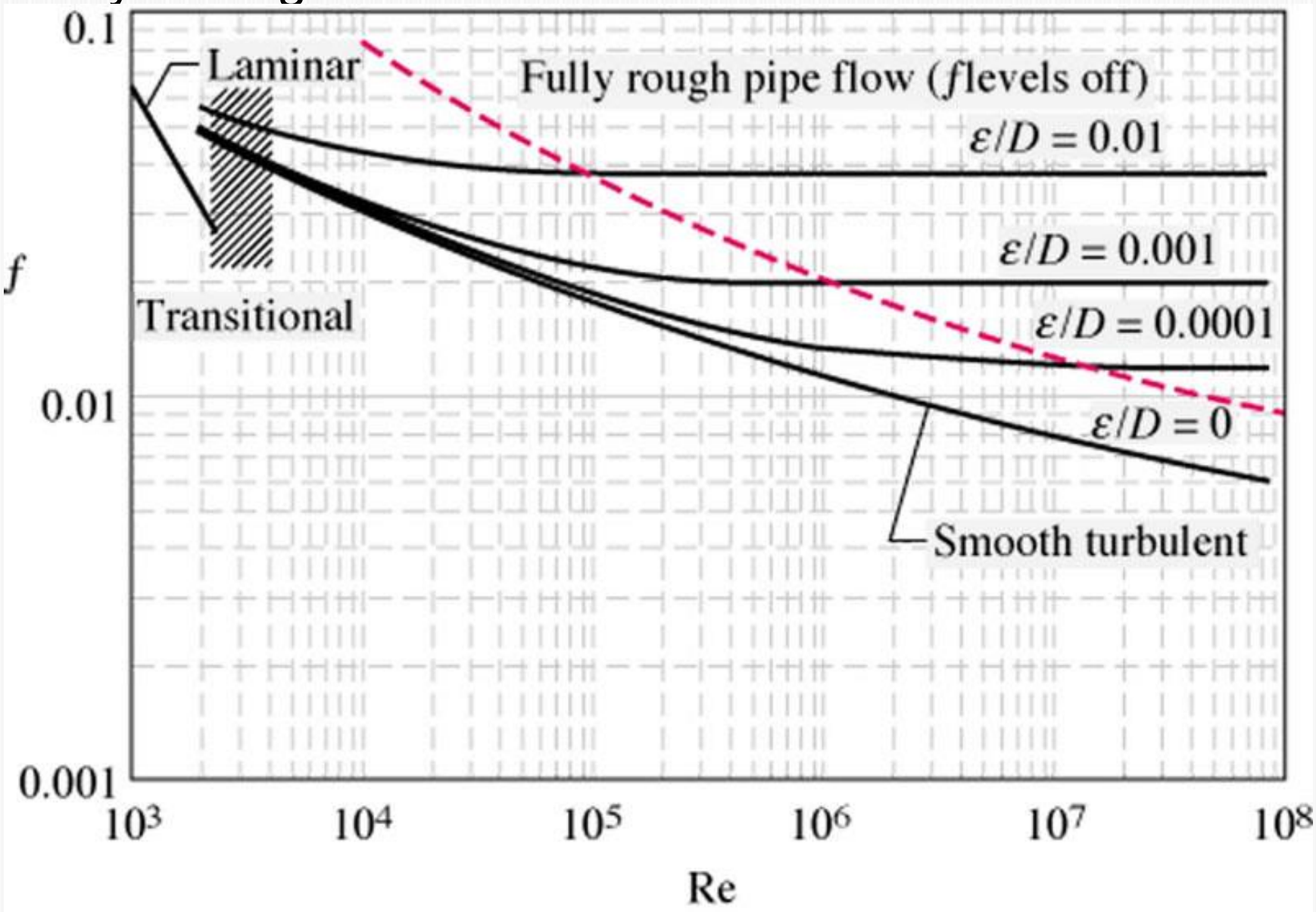
- For turbulent flow (R ≥4000), Colebrook (1938) found the following implicit equation for f:

$$f = 1.325\left[\ln\left(\frac{\varepsilon}{3.7D} + \frac{2.51}{\mathbf{R}\sqrt{f}}\right)\right]^{-2} \quad \text{..... (7)}$$

Using Eq. (7), Moody (1944) constructed a family of curves between f and R for various values of relative roughness ε /D.

Hydraulic Analysis of Water Distribution – Dead-end Method

Moody' s Diagram

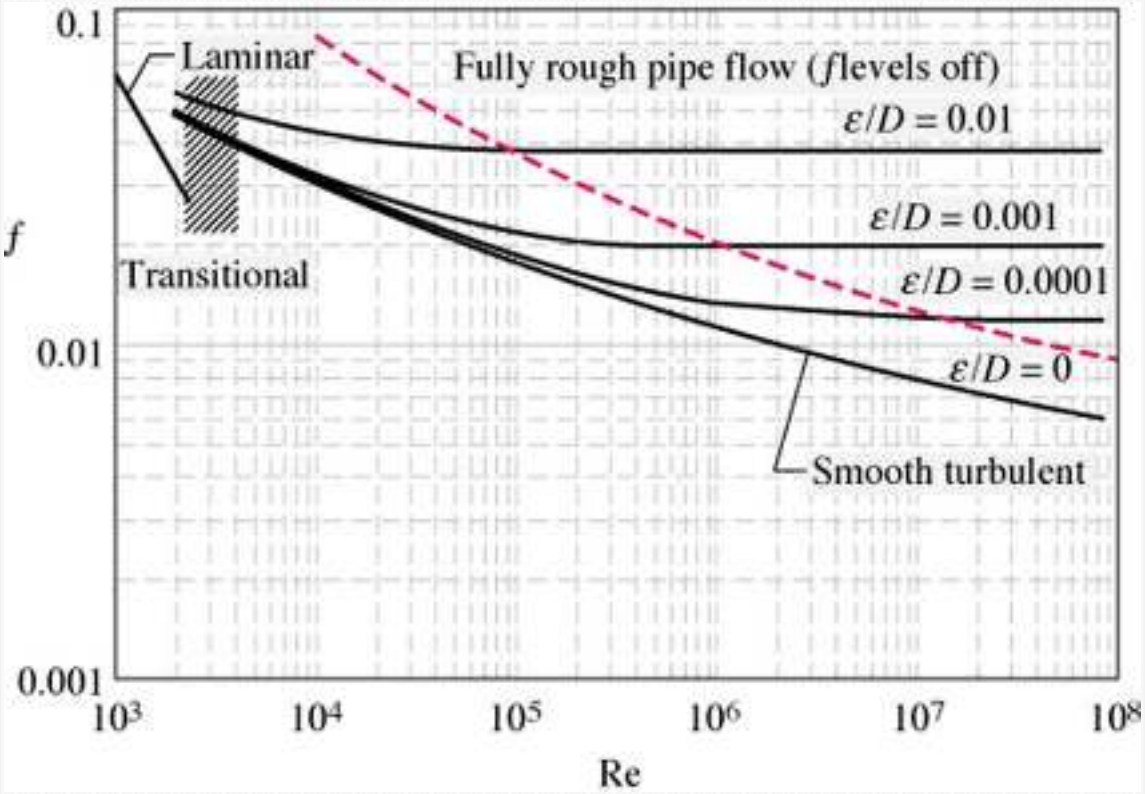


Hydraulic Analysis of Water Distribution – Dead-end Method

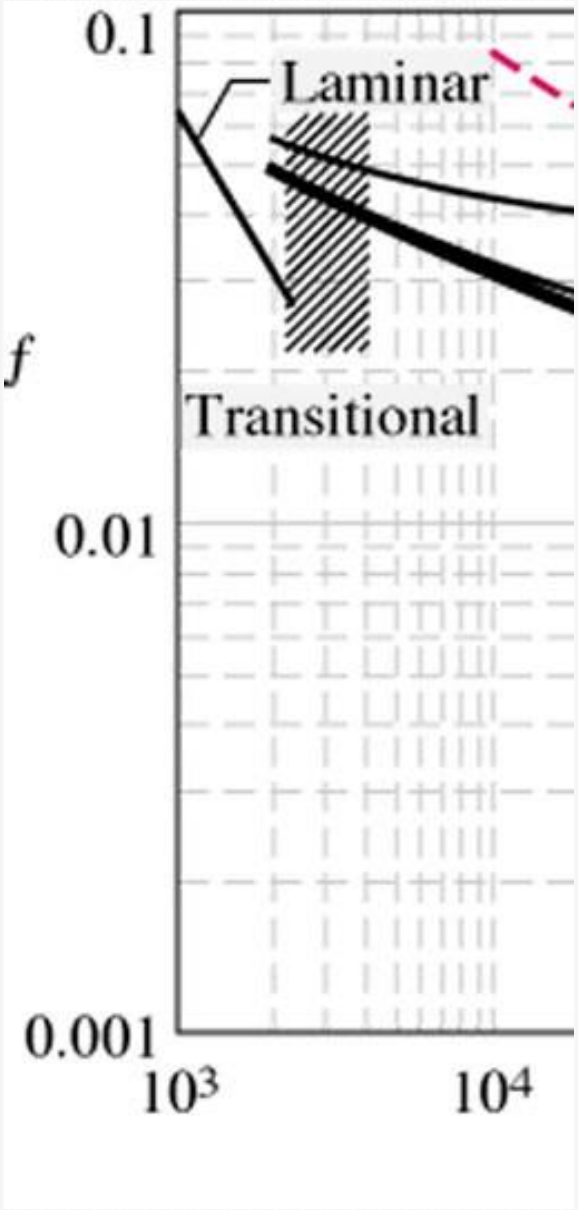
Moody's Diagram

For a given Reynolds number of flow, as the relative roughness is increased, the friction factor *f* decreases.

For a given relative roughness , the friction factor *f* decreases with increasing Reynolds number until the zone of complete turbulence is reached.



Hydraulic Analysis of Water Distribution – Dead-end Method



Moody' s Diagram

The **transition region** is shown in the shaded area **(2300<Re<4000)**

The friction factors alternate between laminar and turbulent flow.

Hydraulic Analysis of Water Distribution – Dead-end Method

Moody' s Diagram

Application:

The Moody diagram is used to help determine the value of **the friction factor, *f*** for turbulent flow.

- First determine the value of the Reynolds number (calculations)
- Then determine the relative roughness (dividing Diameter of the pipe to the pipe roughness).

Hydraulic Analysis of Water Distribution – Dead-end Method

Moody' s Diagram

Application:

Basic data required for applying Moody's Diagram are:

1. The pipe inside diameter (for D)

2. The pipe material (for ε)

3. The flow velocity, and the kind of fluid and its temperature (for R), from which the viscosity can be found.

Hydraulic Analysis of Water Distribution – Dead-end Method

H_L calculation according to Darcy-Weisbach:

- For laminar flow (R ≤ 2000),f depends on R only and is given by the Hagen – Poiseuille equation as follows –

$$f = \frac{64}{\mathbf{R}} \quad \text{..... (8)}$$

- For R lying in the range between 2000 and 4000 (called transition range),

$$f = \left\{ \left(\frac{64}{\mathbf{R}}\right)^{8} + 9.5 \left[\ln\left(\frac{\varepsilon}{3.7D} + \frac{5.74}{\mathbf{R}^{0.9}}\right) - \left(\frac{2500}{\mathbf{R}}\right)^{6} \right]^{-16} \right\}^{0.125} \quad \text{..... (9)}$$

Hydraulic Analysis of Water Distribution – Dead-end Method

H_L calculation according to Hazen-Williams:

$$H_L = k.Q^{1.85}.L \qquad \text{…….. (10)}$$

where $$k = \left(\frac{1}{0.278CD^{2.63}}\right)^{\frac{1}{0.54}}$$

- Piezometric elevations and pressures are calculated.
- To do this, water level in the reservoir and diameter and length of the main line have to be known.

Hydraulic Analysis of Water Distribution System

Simple Pipe Network Design Procedure:

(i) Assign the required demand at each node

(ii) Estimate the discharge flowing through the pipes

(iii) Assume possible pipe diameters

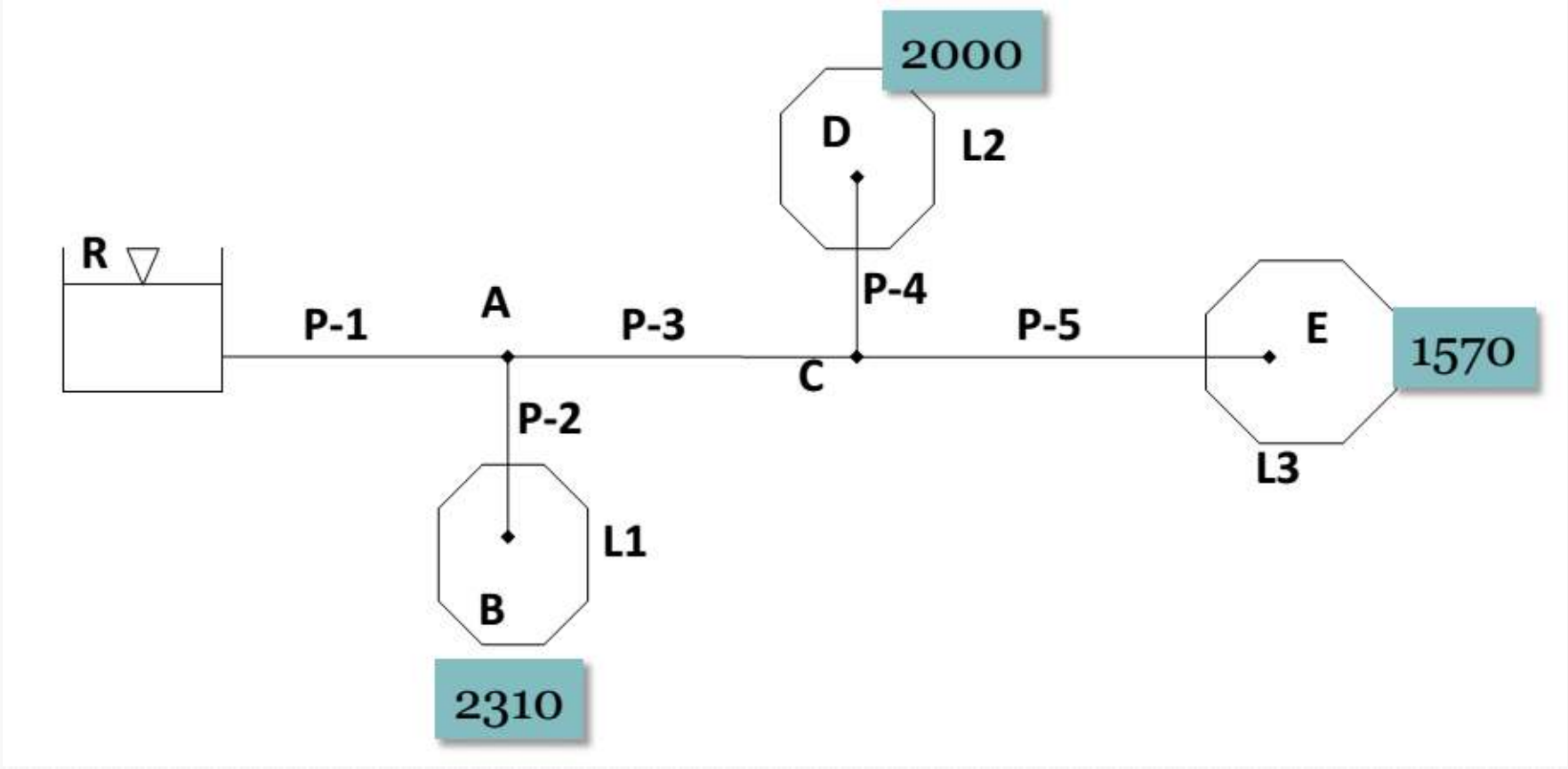
(iv) Calculate the head loss through the pipes

(vi) Compare this terminal pressure with the desired minimum and maximum pressures.

Hydraulic Analysis of Water Distribution System

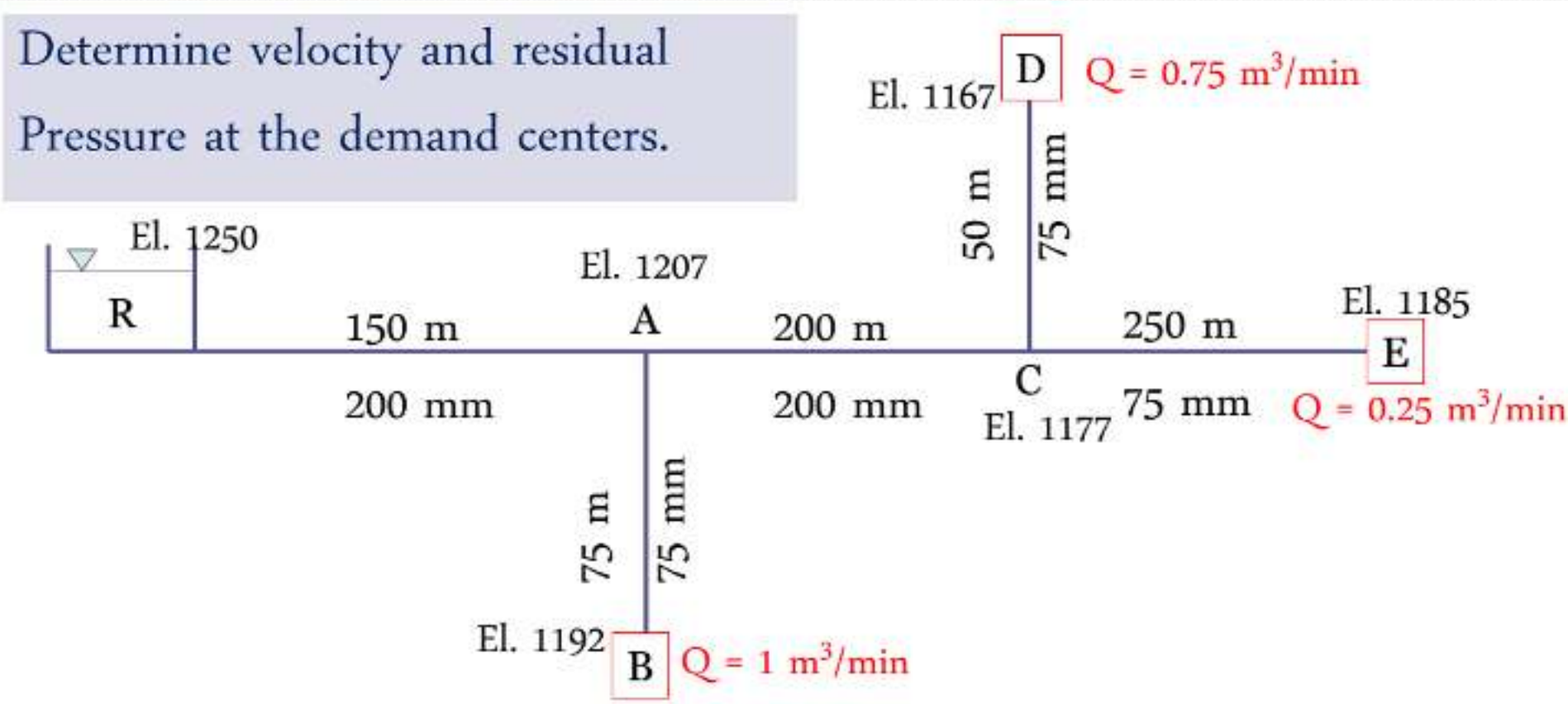
Simple Pipe Network Design Procedure:

(vii) If the required condition is not satisfied, then repeat steps (ii) through (vi) until the required conditions are met.



Hydraulic Analysis of Water Distribution

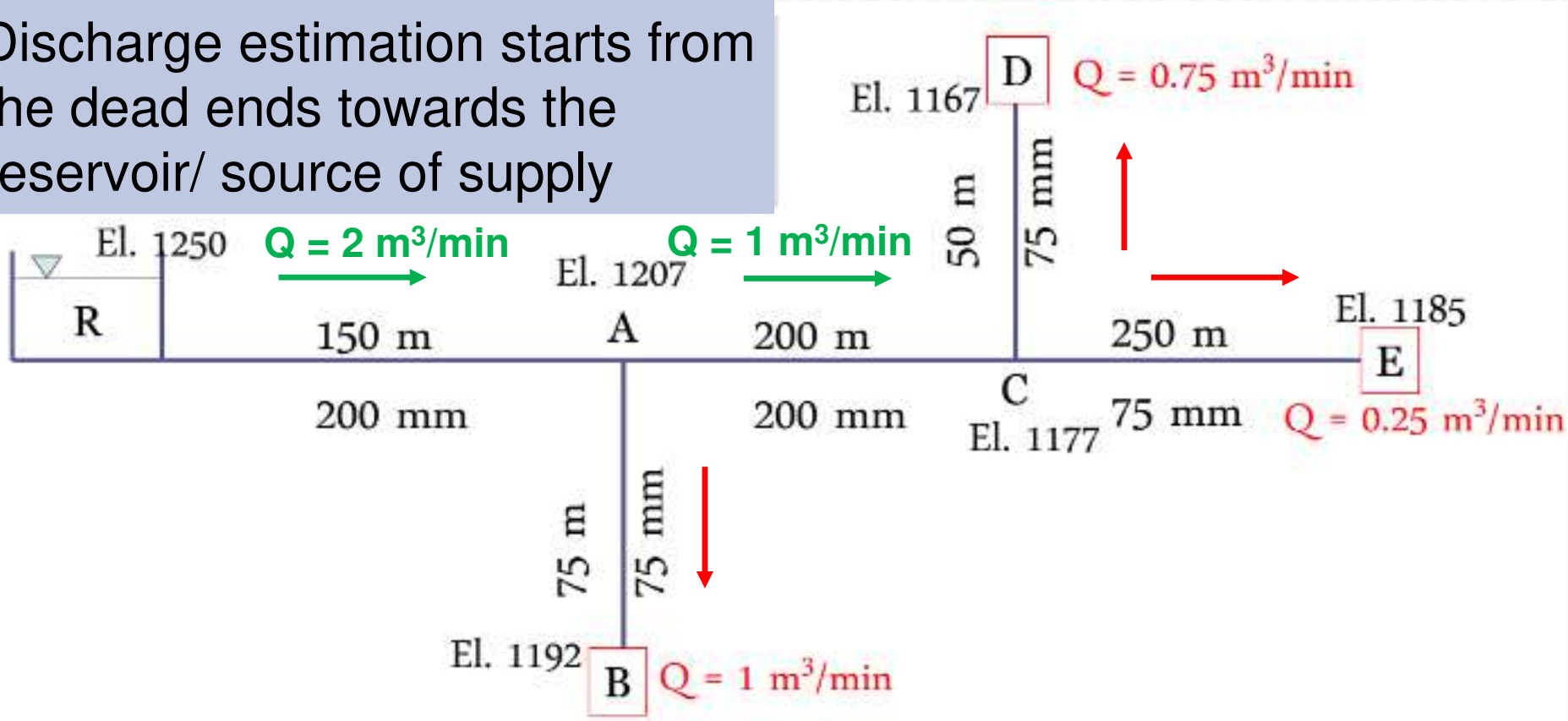
Example: Simple Pipe Network Design



Hydraulic Analysis of Water Distribution System

Solution: Estimation of Discharge

Discharge estimation starts from the dead ends towards the reservoir/ source of supply

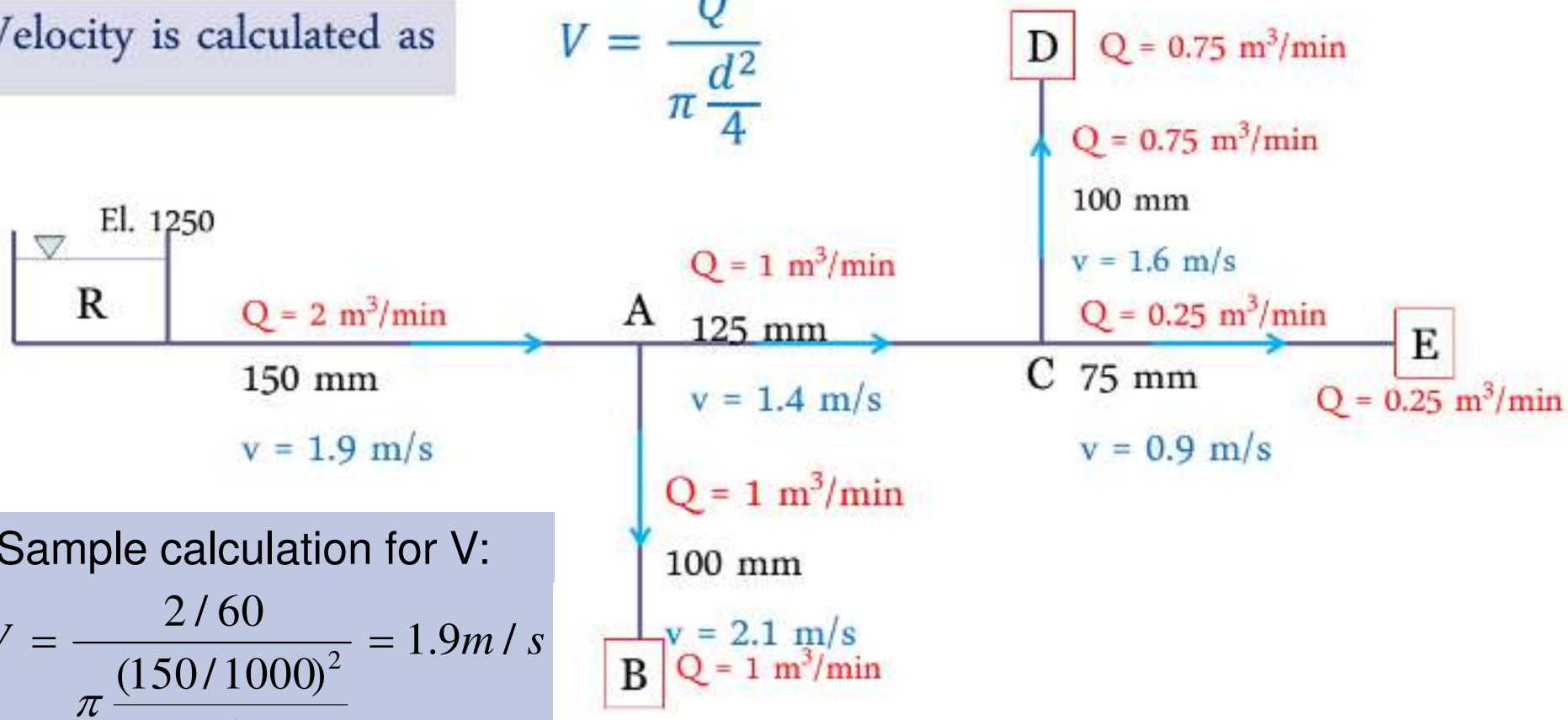


Hydraulic Analysis of Water Distribution System

Solution: Velocity Calculation

Velocity is calculated as

$$V = \frac{Q}{\pi \frac{d^2}{4}}$$



Sample calculation for V:

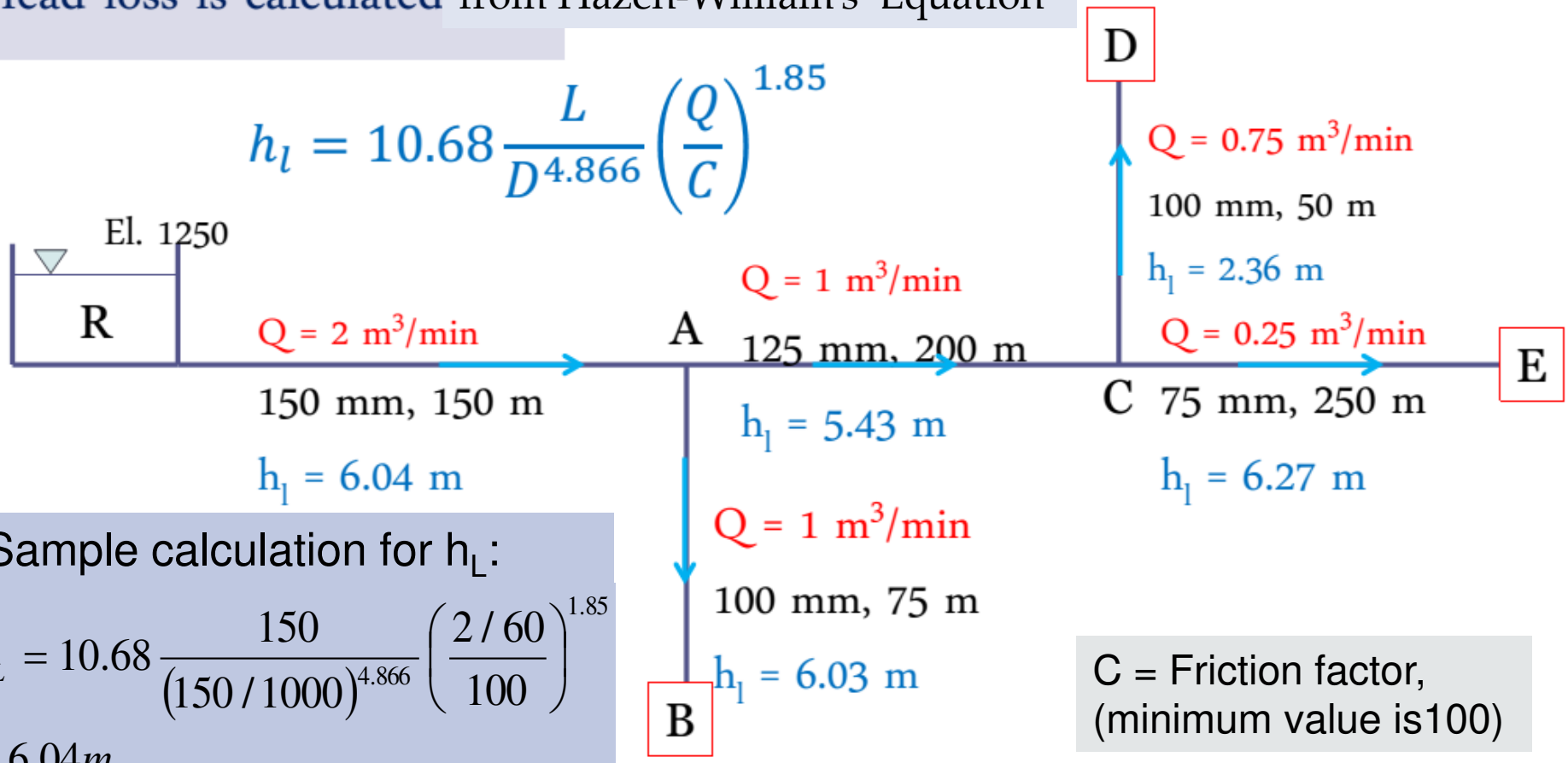
$$V = \frac{2/60}{\pi \frac{(150/1000)^2}{4}} = 1.9 m/s$$

Hydraulic Analysis of Water Distribution System

Solution: Head Loss Calculation

Head loss is calculated from Hazen-William's Equation

$$h_l = 10.68 \frac{L}{D^{4.866}} \left(\frac{Q}{C}\right)^{1.85}$$



Sample calculation for h_L:

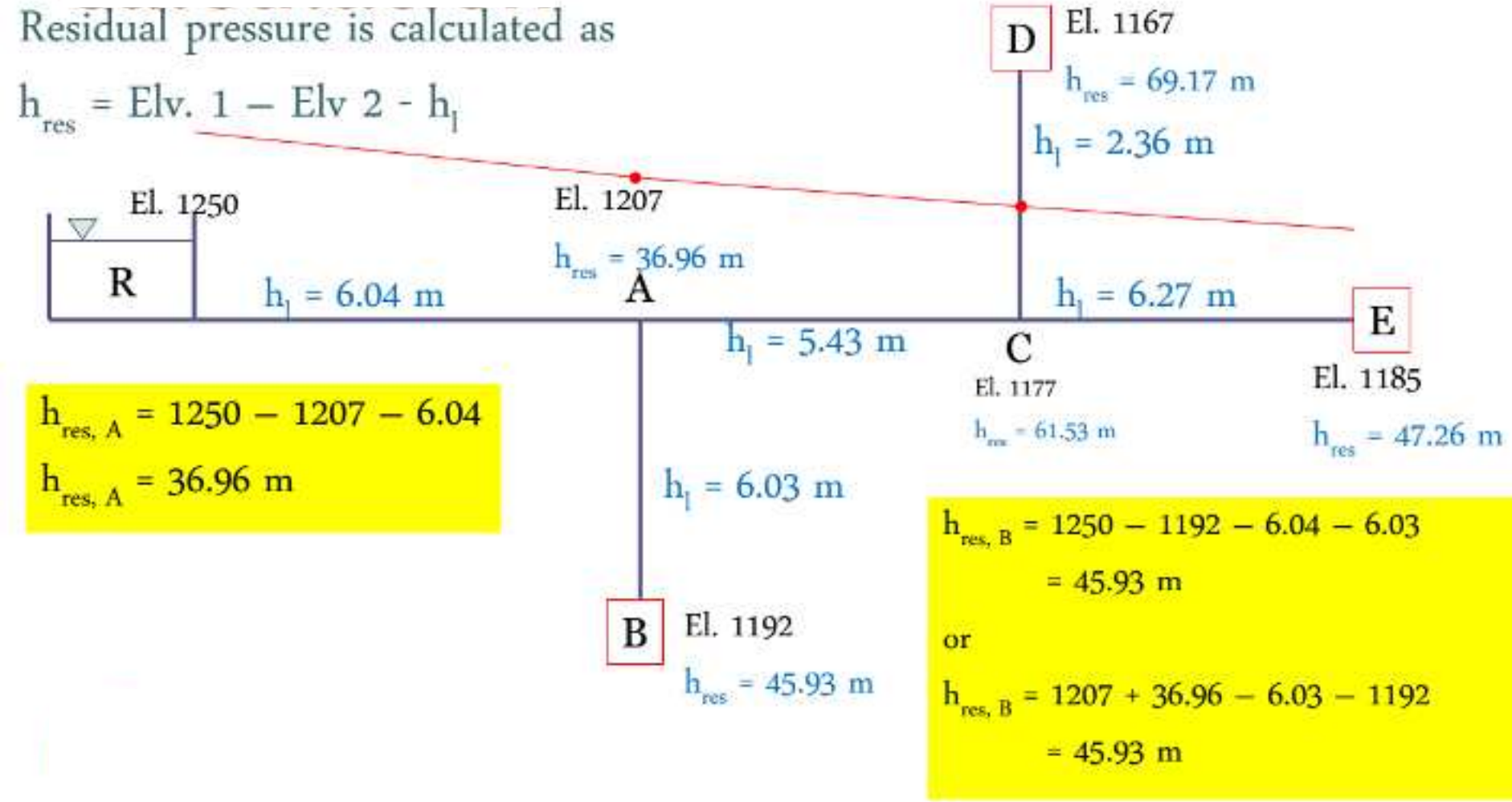
$$h_L = 10.68 \frac{150}{(150/1000)^{4.866}} \left(\frac{2/60}{100}\right)^{1.85}$$

$$= 6.04m$$

C = Friction factor, (minimum value is100)

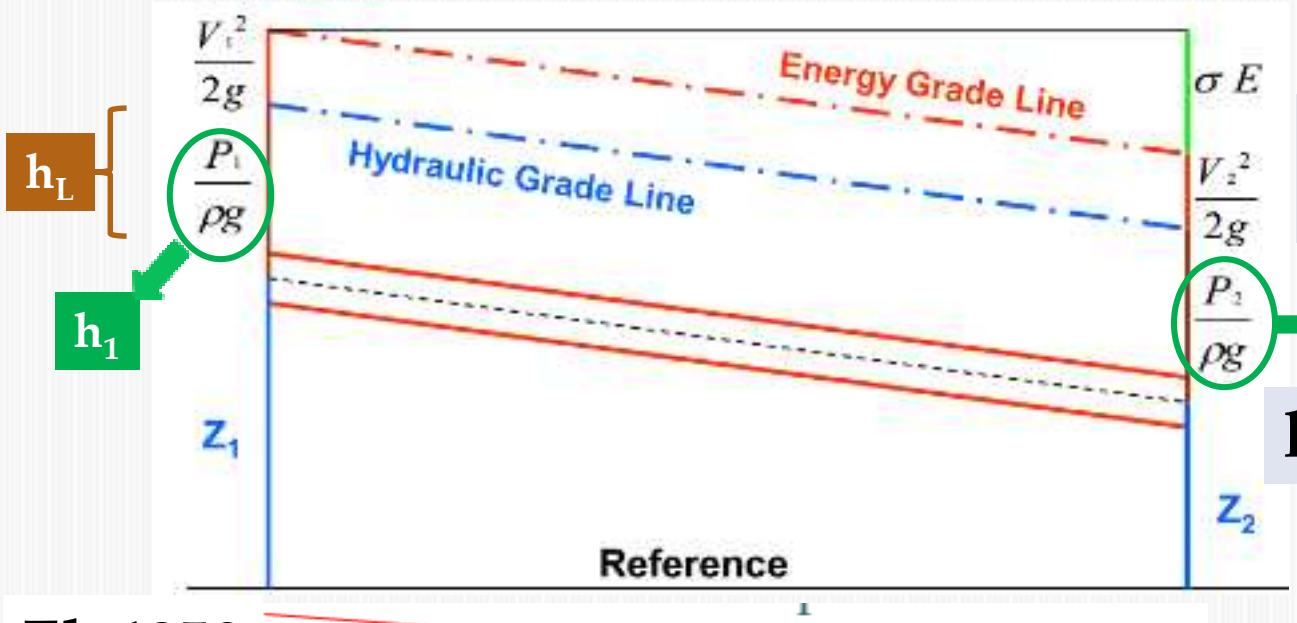
Hydraulic Analysis of Water Distribution System

Solution: Residual Pressure Calculation



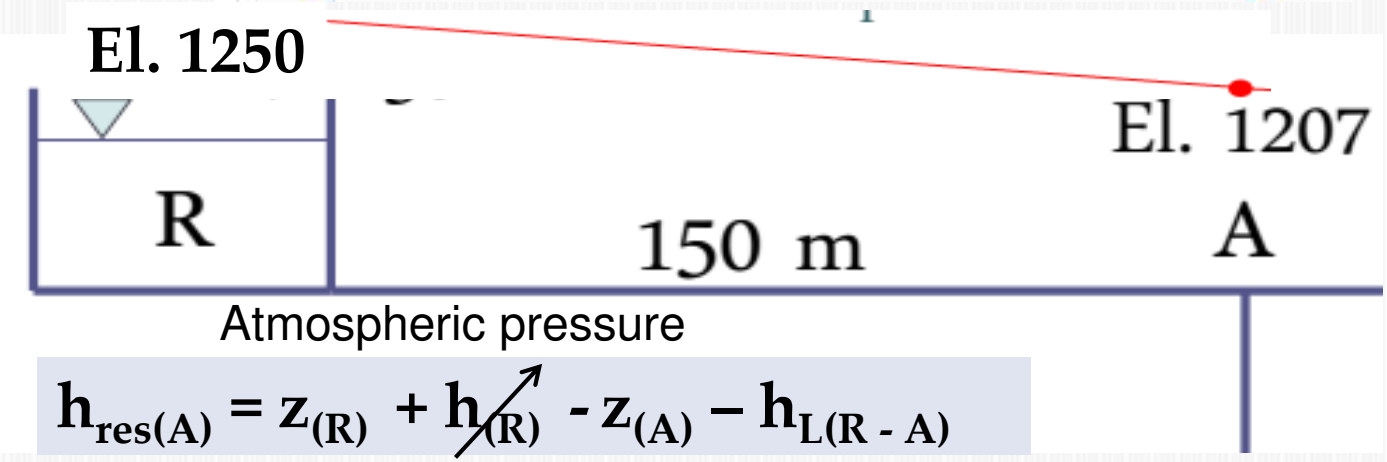
Hydraulic Analysis of Water Distribution System

Principle of Residual Pressure Calculation



h_1, h_2 = pressure head
h_L = head loss

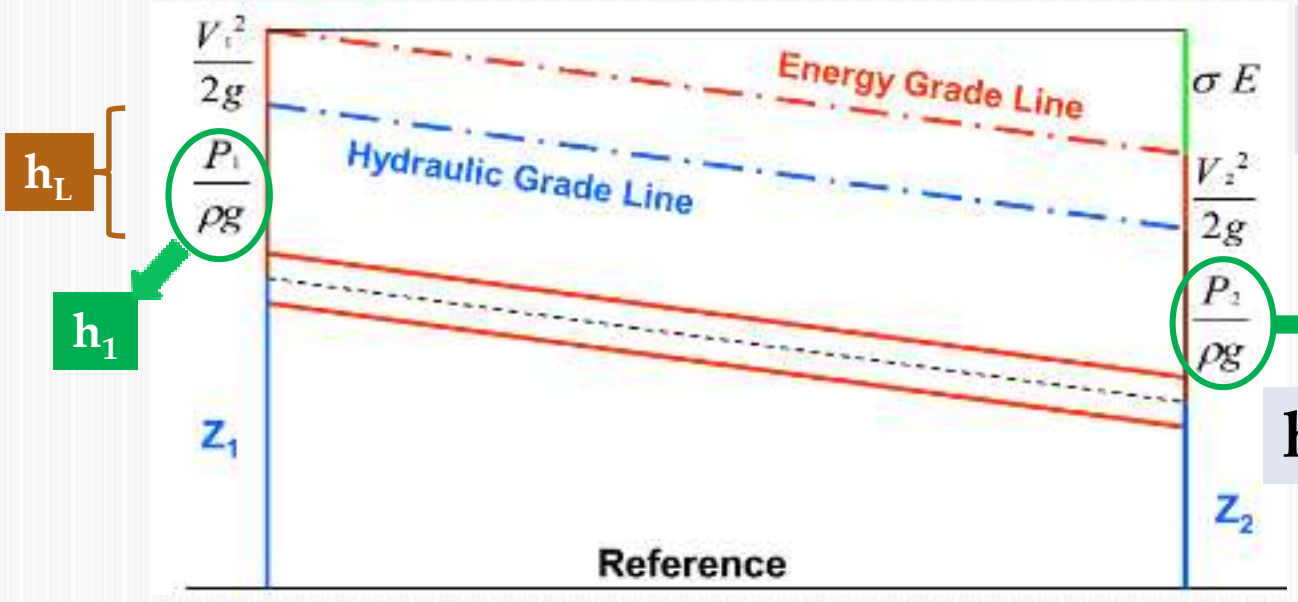
$$h_2 = z_1 + h_1 - z_2 - h_L$$



$$h_{res(A)} = z_{(R)} + \cancel{h_{(R)}} - z_{(A)} - h_{L(R-A)}$$

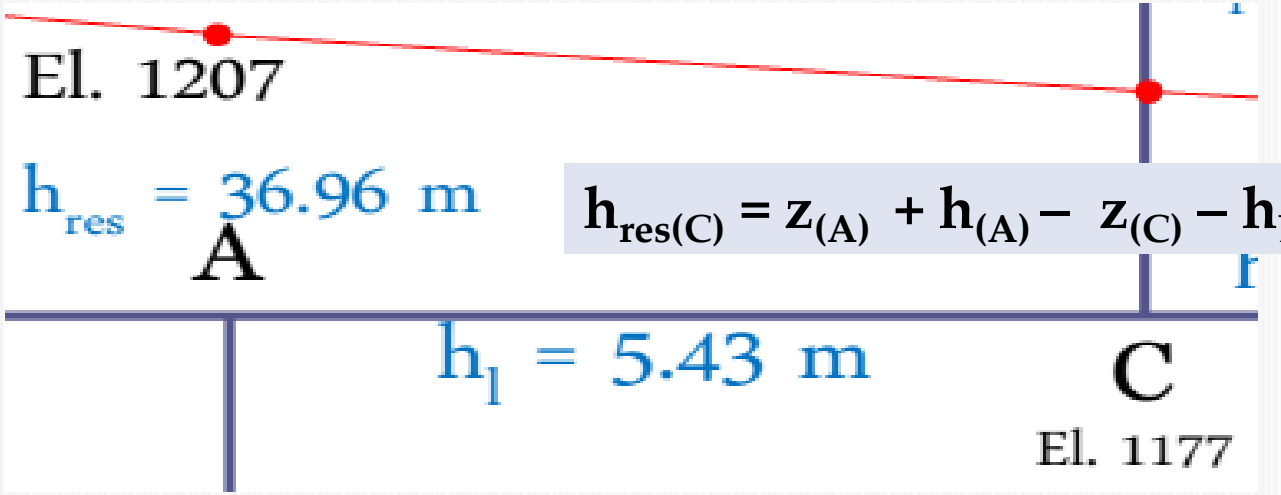
Hydraulic Analysis of Water Distribution System

Principle of Residual Pressure Calculation



h_1, h_2 = pressure head
h_L = head loss

$$h_2 = z_1 + h_1 - z_2 - h_L$$



$$h_{res(C)} = z_{(A)} + h_{(A)} - z_{(C)} - h_{L(A-C)}$$

Hydraulic Analysis of Water Distribution System

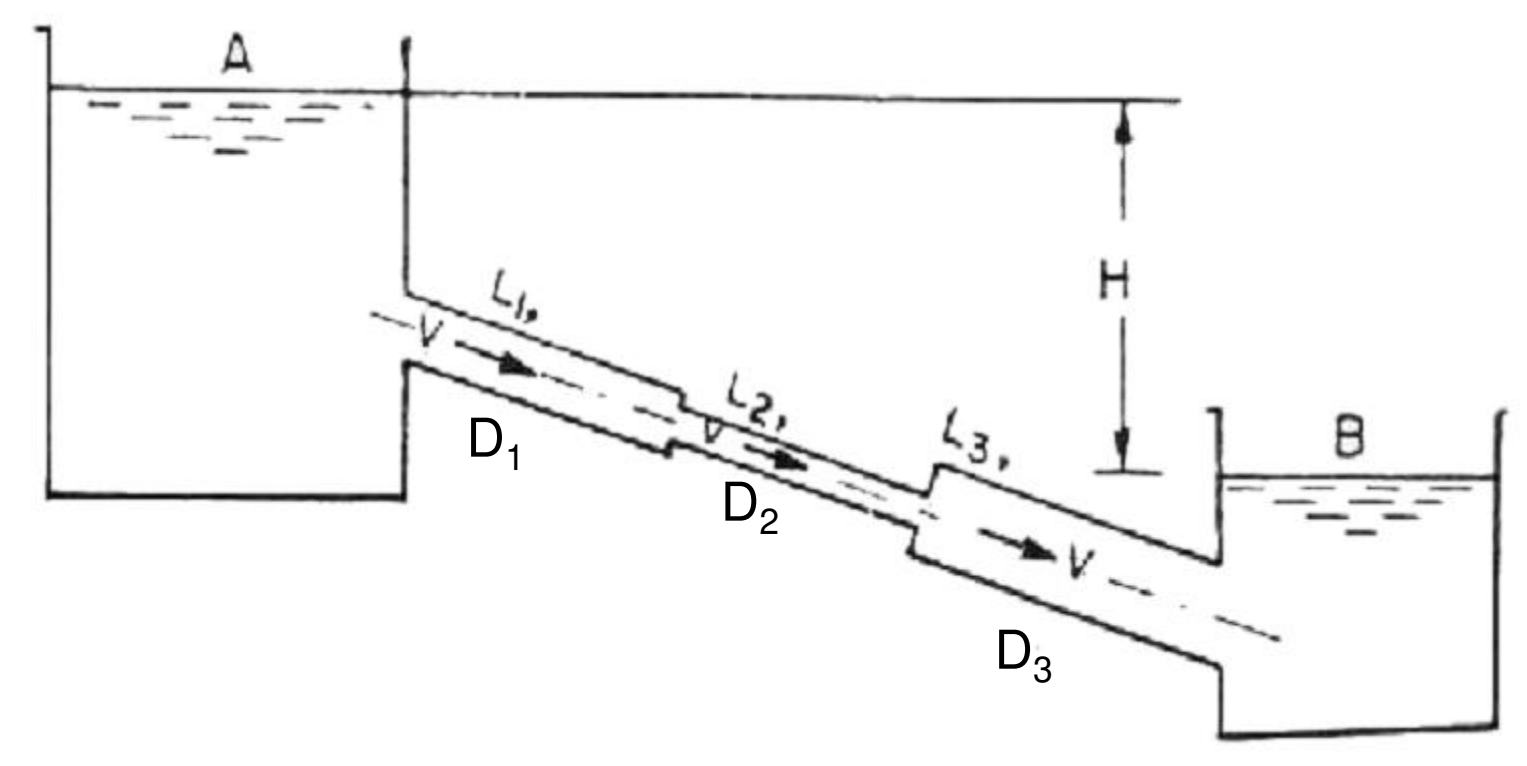
Compound Pipe Flow

- When two or more pipes with different diameters are –
  - ✓ connected together head to tail (in series) or
  - ✓ connected to two common nodes (in parallel).

Hydraulic Analysis of Water Distribution System

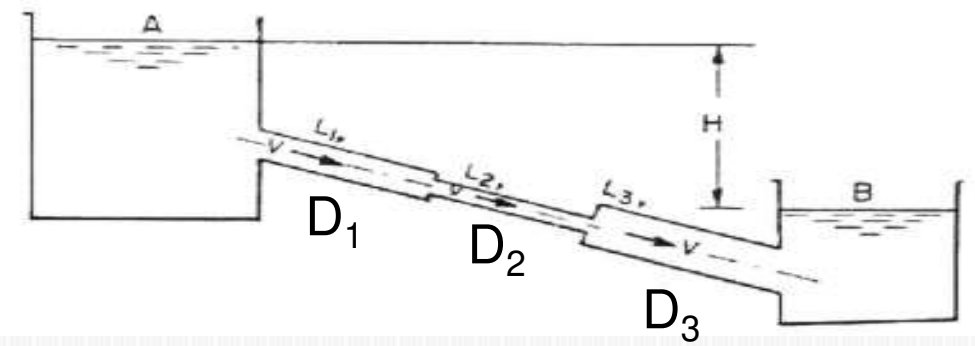
(A) Flow Through Pipes in Series

- Pipes of different lengths and different diameters connected end to end (in series) to form a pipeline



Hydraulic Analysis of Water Distribution System

(A) Flow Through Pipes in Series



- **Discharge**: The discharge through each pipe is the same

$$Q = A_1V_1 = A_2V_2 = A_3V_3$$

- **Head loss**: The difference in liquid surface levels is equal to the sum of the total head loss in the pipes

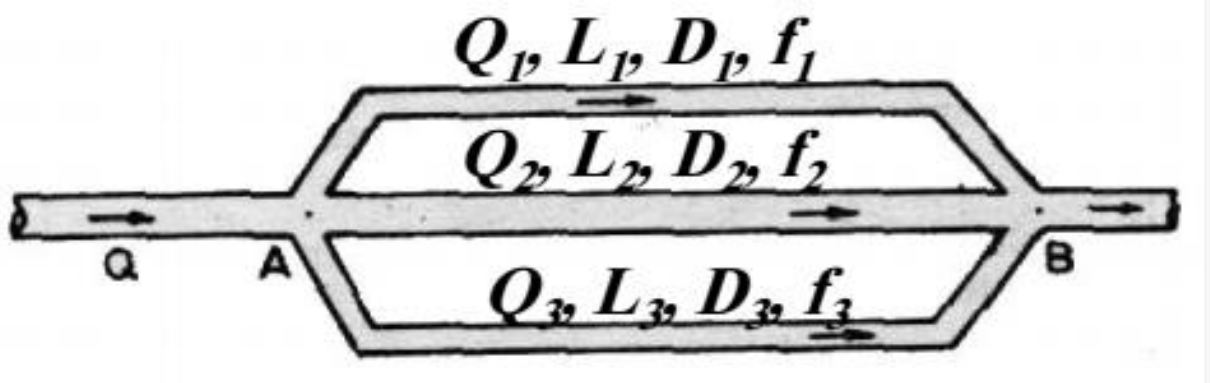
$$H_L \text{ total} = H_{L1} + H_{L2} + H_{L3}$$

Hydraulic Analysis of Water Distribution System

(B) Flow Through Parallel pipes

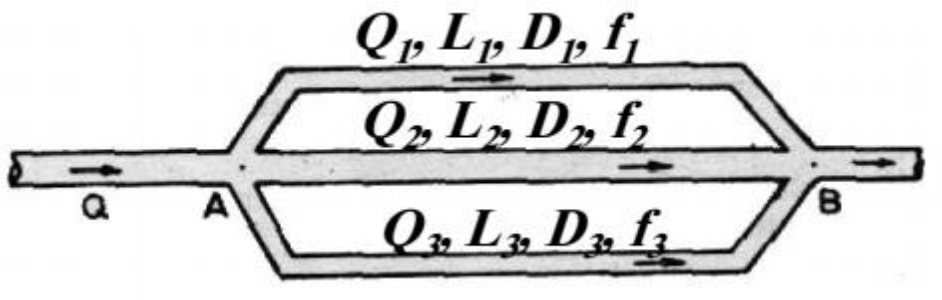
- If a main pipe divides into two or more branches and again join together downstream to form a single pipe, then the branched pipes are said to be connected in parallel (compound pipes).

- Points A and B are called nodes.



Hydraulic Analysis of Water Distribution System

(B) Flow Through Parallel Pipes



- **Discharge**:

$$Q = Q_1 + Q_2 + Q_3 = \sum_{i=1}^{3} Q_i$$

- **Head loss**: the head loss for each branch is the same

$$h_L = h_{f1} = h_{f2} = h_{f3}$$

Darcy-Weisbach Formula

$$f_1 \frac{L_1}{D_1} \frac{V_1^2}{2g} = f_2 \frac{L_2}{D_2} \frac{V_2^2}{2g} = f_3 \frac{L_3}{D_3} \frac{V_3^2}{2g}$$

Hydraulic Analysis of Water Distribution System

Example of Parallel Pipes

Four pipes connected in parallel as shown. The following details are given



Pipe	L (m)	D (mm)	f
1	200	200	0.020
2	300	250	0.018
3	150	300	0.015
4	100	200	0.020

If $Z_A = 150$ m , $Z_B = 144$m, determine the discharge in each pipe (assume $P_A = P_B = P_{atm}$)

Hydraulic Analysis of Water Distribution System

Solution for Parallel Pipes



Pipe	L (m)	D (mm)	f
1	200	200	0.020
2	300	250	0.018
3	150	300	0.015
4	100	200	0.020

$Z_A = 150$ m , $Z_B = 144$m,

$Z_A - Z_B = h_f = h_{f1} = h_{f2} = h_{f3} = h_{f4}$ (neglect minor losses)

$150 - 144 = 6 = h_{fi} = f_i \frac{L_i}{D_i} \frac{V_i^2}{2g}$

Darcy-Weisbach Formula

$$H_L = \frac{fLV^2}{2gD}$$

But Vi = $\frac{Q_i}{A_i} = \frac{Q_i}{\frac{\pi}{4} \times D_i^2}$

$$6 = \frac{8 f_i L_i Q^2}{\pi^2 g D_i^2}$$ Substitute for Pipe 1, 2, 3 and 4

Q = 0.0762 + 0.1146+ 0.28 + 0.1078 = 0.579 m^3/s

Hydraulic Analysis of Water Distribution System

(b) Equivalent Pipe method:

- Equivalent pipe is a method of reducing a combination of pipes into a simple pipe system for easier analysis of a pipe network, such as a water distribution system.

- An equivalent pipe is an imaginary pipe in which the head loss and discharge are equivalent to those for the real pipe system.

- There are three main properties of a pipe: diameter, length, and roughness.

Hydraulic Analysis – Equivalent Pipe Method

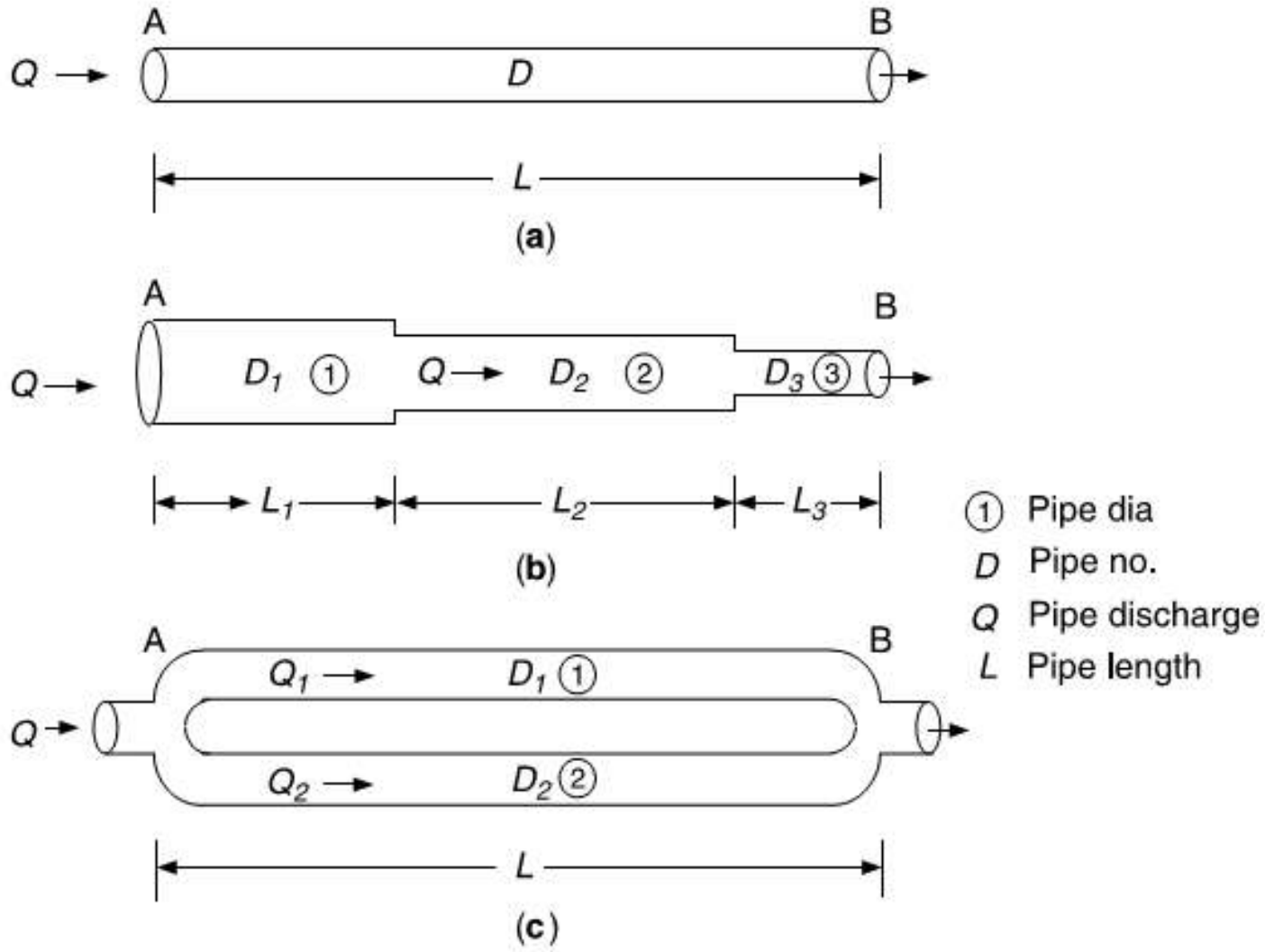


Figure 2.17. Pipe arrangements.

Hydraulic Analysis – Equivalent Pipe Method

- Therefore, for a system of pipes with different diameters, lengths, and roughness factors, one could assume a specific roughness factor (most commonly C = 100) and diameter (most commonly D = 8").

- The most common formula for computing equivalent pipe is the Hazen-Williams formula.

$$h_L = 10.5 \frac{Q^{1.85} L}{C^{1.85} D^{4.87}} \quad \text{..... (11)}$$

Hydraulic Analysis – Equivalent Pipe Method

Example:

For the pipe system shown in Figure 1, determine the length of a single equivalent pipe that has a diameter of 8 inches.

Use the Hazen - Williams equation and assume that C_{HW}= 120 for all pipes.

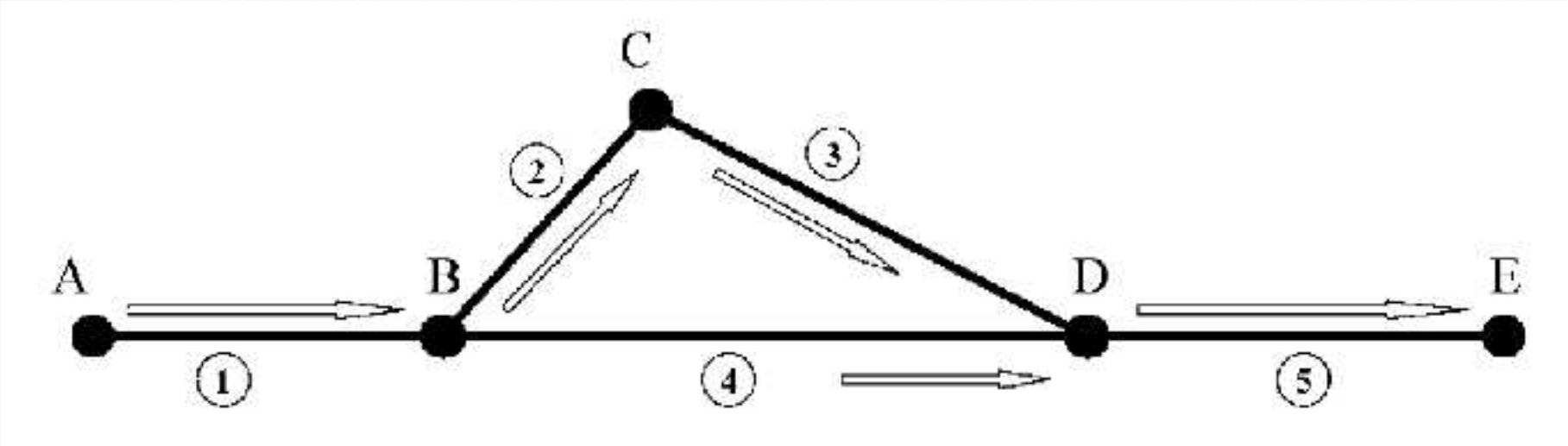


Figure 1. Pipe System for equivalent pipe problem

Hydraulic Analysis – Equivalent Pipe Method

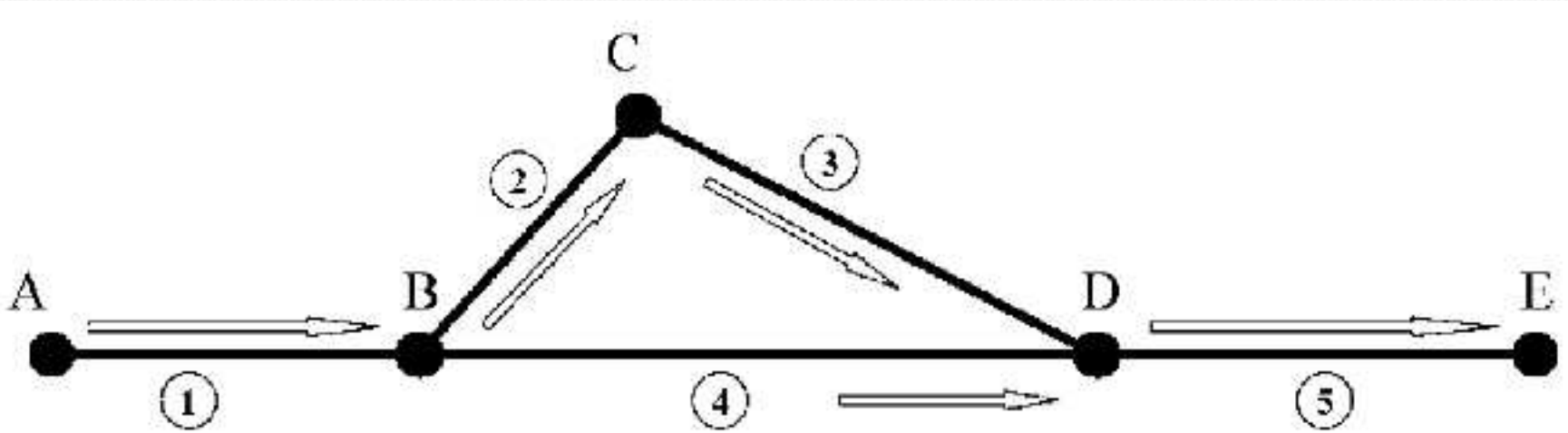


Figure 1. Pipe System for equivalent pipe problem

Table 1. Pipe Data for Figure 1 Pipe System

	Pipe 1	Pipe 2	Pipe 3	Pipe 4	Pipe 5	
Length	500	500	800	1000	700	ft
Diameter	12	6	8	10	12	in

Hydraulic Analysis – Equivalent Pipe Method

Solution:

a) **Firstly**, determine an equivalent pipe (with D=8 in) for pipes #2 and #3 in series.

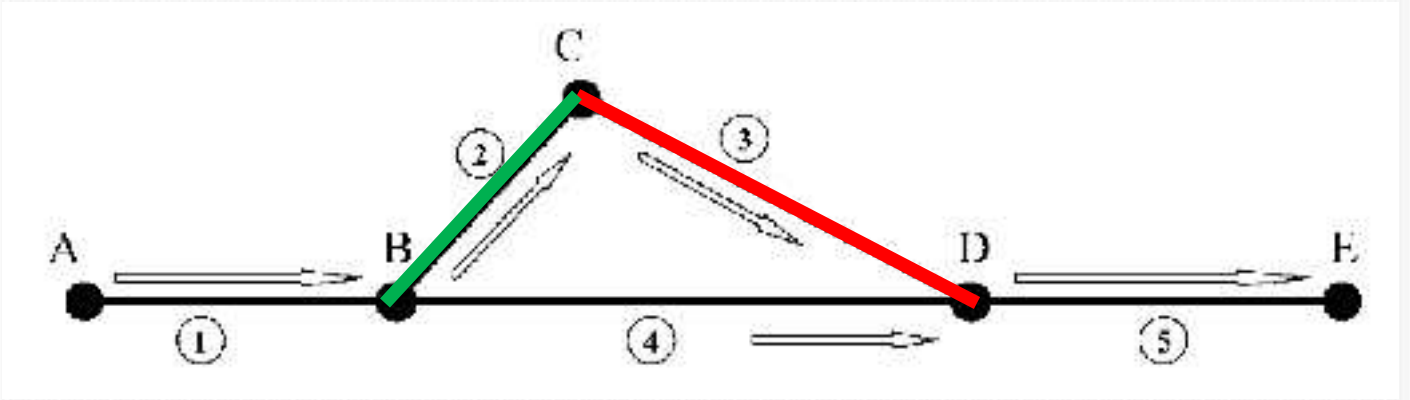
- Use a flow of 800 gpm through pipes #2 and #3.
- Use the Hazen Williams equation, with **Q in gpm and diameter (D) in inches**.

$$h_L = 10.5 \frac{Q^{1.85} L}{C^{1.85} D^{4.87}}$$

- Calculate the head loss in pipe 2 and pipe 3 (recognizing that the flow in pipe 3 must also be 800 gpm)

Hydraulic Analysis – Equivalent Pipe Method

Solution:



	Pipe 2	Pipe 3	
C	120	120	
L	500	800	ft
D	6	8	in
Q	800	800	gpm
h_L	28.49666	11.23213	ft

$$h_L = 10.5 \frac{Q^{1.85} L}{C^{1.85} D^{4.87}}$$

- The total head loss is the sum of these two

  H_L total = 39.73 ft

Hydraulic Analysis – Equivalent Pipe Method

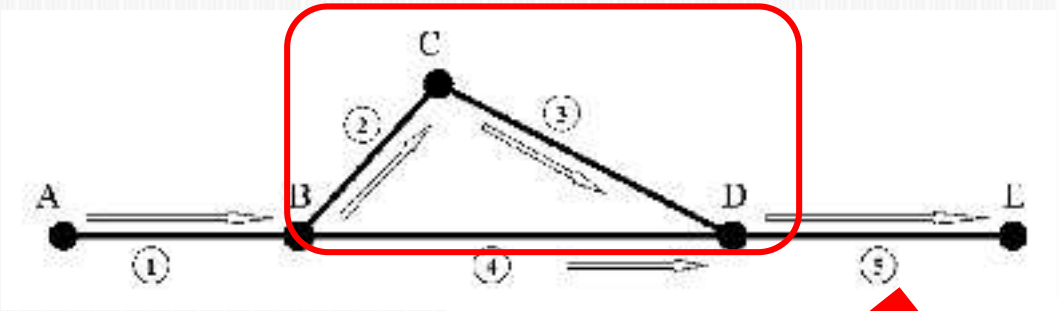
Solution:

- Now, the equivalent length for a 8 in pipe is calculated by rearranging the H-W formula and solving for L as follows:

D = 8 inch
Q = 800 gpm
C = 120

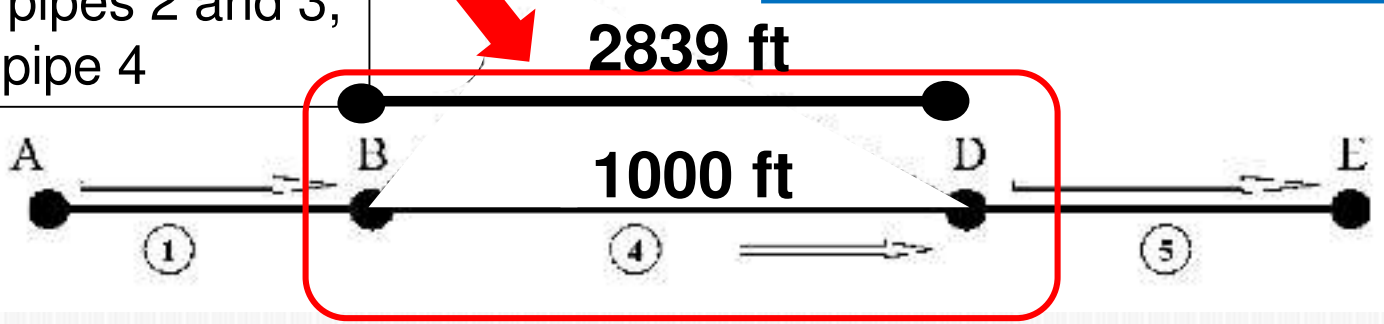
$$L = \frac{h_L C^{1.85} D^{4.87}}{10.5 Q^{1.85}}$$

$$= 2839\ ft$$



h_L from B to D = 39.73 ft

Equivalent pipe for pipes 2 and 3, which is parallel to pipe 4



Hydraulic Analysis – Equivalent Pipe Method

Solution:

b) **Secondly**, determine an equivalent pipe for pipe #4 and the parallel equivalent pipe from part (a).

- Use the head loss resulting from the flow for part (a) as the basis for determining the equivalent pipe length (use D=8 in).

- Determine the flow split between these two parallel pipes (i.e., for 800 gpm through the part (a) pipe, calculate the flow in the parallel pipe 4, and the total flow)

Hydraulic Analysis – Equivalent Pipe Method

Solution:

Now that we know the head loss from node B to node D is 39.73 feet, we can determine the flow in pipe #4 by the H-W formula, rearranged as follows:

Q for pipe 4

$$Q = \frac{h_L^{0.54} C D^{2.63}}{3.56 L^{0.54}}$$

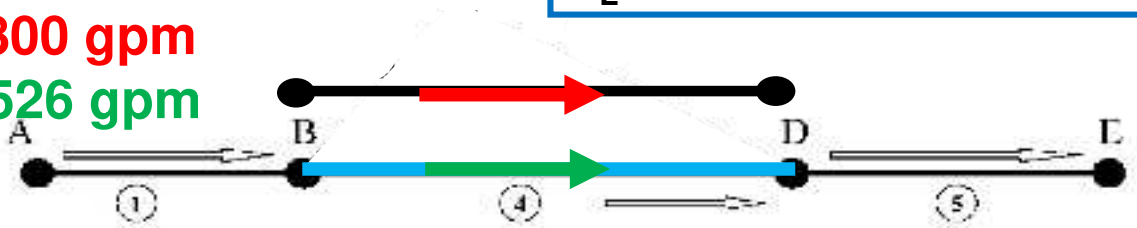
= 2526 gpm

For pipe 4
L = 1000 ft
D = 10 inch
C = 120

Now the total flow between nodes B and D is then the sum: **$Q_{B\text{-}D}$ = 2526 + 800 = 3326 gpm**

h_L from B to D = 39.73 ft

$Q_{2,3}$ = 800 gpm
Q_4 = 2526 gpm



Hydraulic Analysis – Equivalent Pipe Method

Solution:

Finally using the H-W equation, we can calculate an equivalent length of an 8 inch pipe that gives the existing head loss with this flow:

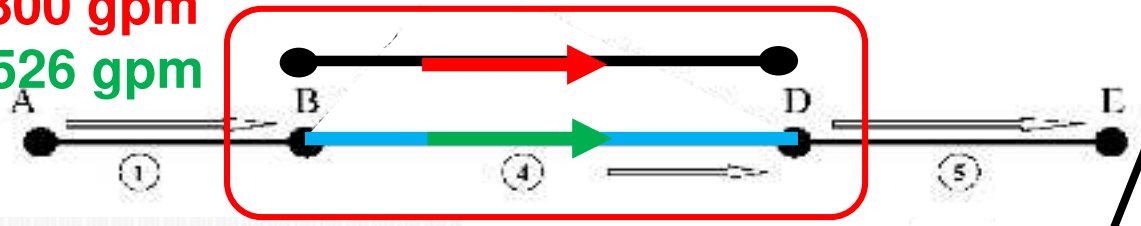
D = 8 inch
$Q_{B\text{-}D}$= 3326 gpm
C = 120
h_L = 39.73 ft

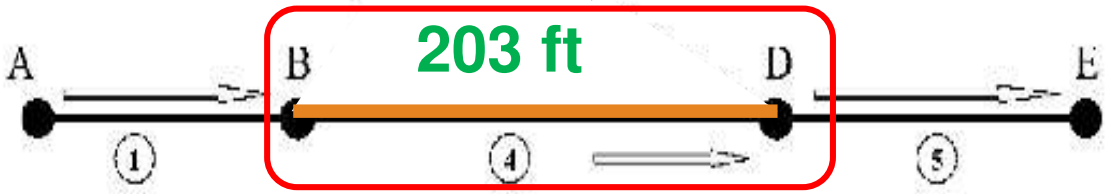
$$L = \frac{h_L C^{1.85} D^{4.87}}{10.5 Q^{1.85}}$$

= 203 ft

h_L from B to D = 39.73 ft

$Q_{2,3}$ = 800 gpm
Q_4 = 2526 gpm





Hydraulic Analysis – Equivalent Pipe Method

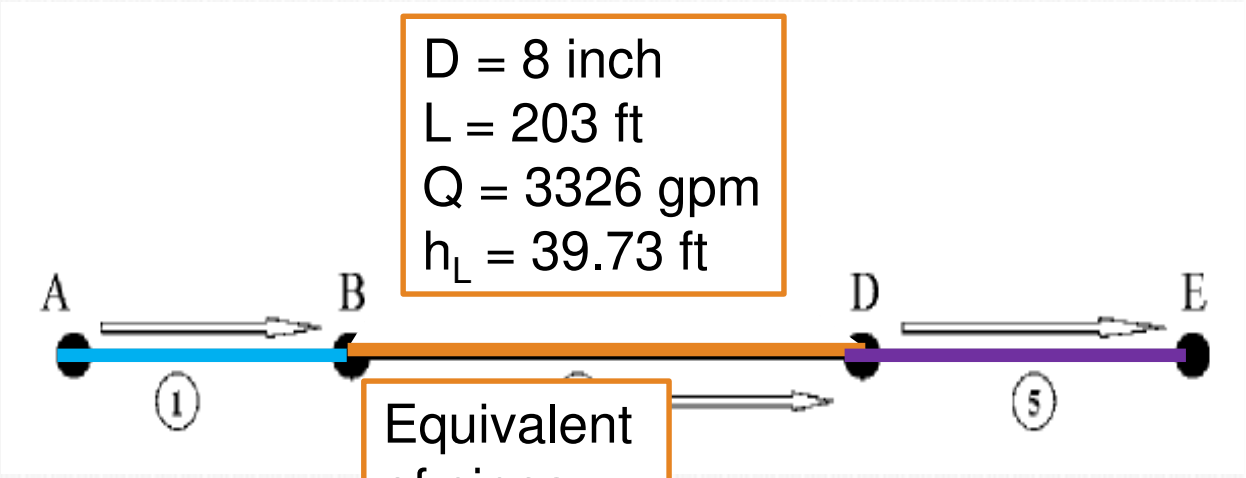
Solution:

c) Finally, determine a single equivalent pipe (D = 8 in) for the three pipes in series, pipe #1, the pipe from part (b), and pipe #5.

- Next we can use the H-W formula to calculate the head loss in pipes #1 and #5, recognizing that the flow in each must be the same as the flow determined for node B to node D (e.g., 3326 gpm)

Hydraulic Analysis – Equivalent Pipe Method

Solution:



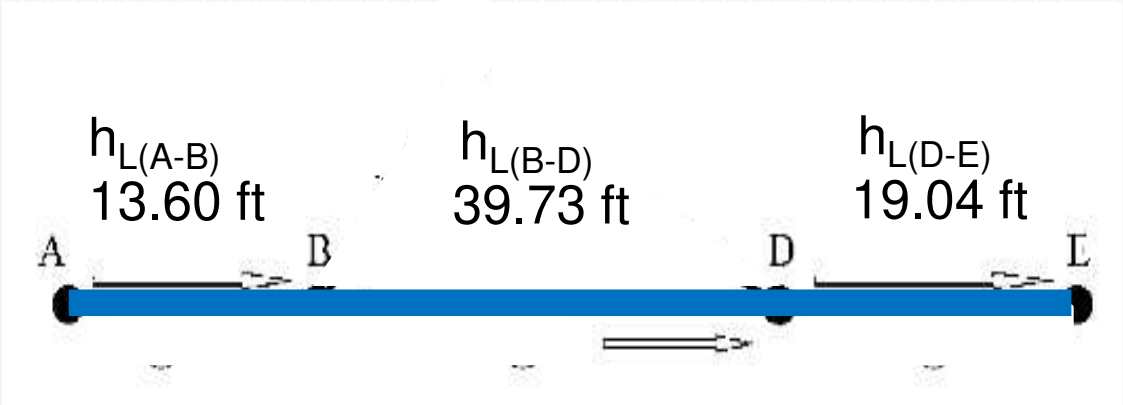
	Pipe 1	Pipe 5	
C	120	120	
L	500	700	ft
D	12	12	in
Q	3326	3326	gpm
h_L	13.60007	19.0401	ft

$$h_L = 10.5 \frac{Q^{1.85} L}{C^{1.85} D^{4.87}}$$

Hydraulic Analysis – Equivalent Pipe Method

Solution: The total head loss is then the sum:

$h_L = 39.73 + 13.60 + 19.04 = \mathbf{72.37\ ft}$



Now, we can calculate an equivalent length based on this head loss and to flow.

$$L = \frac{h_L C^{1.85} D^{4.87}}{10.5 Q^{1.85}}$$

= 369 ft

Q= 3326 gpm
h_L = 72.37 ft
D = 8 inch
C = 120

Hydraulic Analysis – Equivalent Pipe Method

Solution:

d) Show that your pipe is hydraulically equivalent by calculating the head loss for this single pipe and comparing it to the sum of the head losses for pipes in the original system.

- Recalculate the head loss in each of the original pipes.

- Sum the head loss from each node to the next one, recognizing that there are two ways of getting from node B to node D (use either one, but not both).

Hydraulic Analysis – Equivalent Pipe Method

Solution:

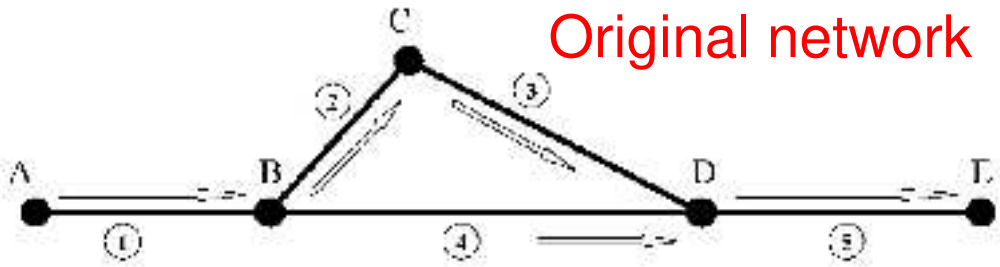
$$h_L = 10.5 \frac{Q^{1.85} L}{C^{1.85} D^{4.87}}$$

	Pipe 1	Pipe 2	Pipe 3	Pipe 4	Pipe 5	
C	120	120	120	120	120	
L	500	500	800	1000	700	ft
D	12	6	8	10	12	in
Q	3325.68	800	800	2525.684	3325.68	gpm
h_L	13.60007	28.49666	11.23213	39.72879	19.0401	ft

Total h_L = **72.36896 ft**

For h_L from B to D,
either h_L for pipe 4
or sum of h_L for pipes 2 and 3

Original network



Equivalent network



Total h_L = **72.37 ft**

EWCE 331
Water Supply Engineering

Lecture 5

Instructor

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Department of EWCE, MIST

Lecture outline

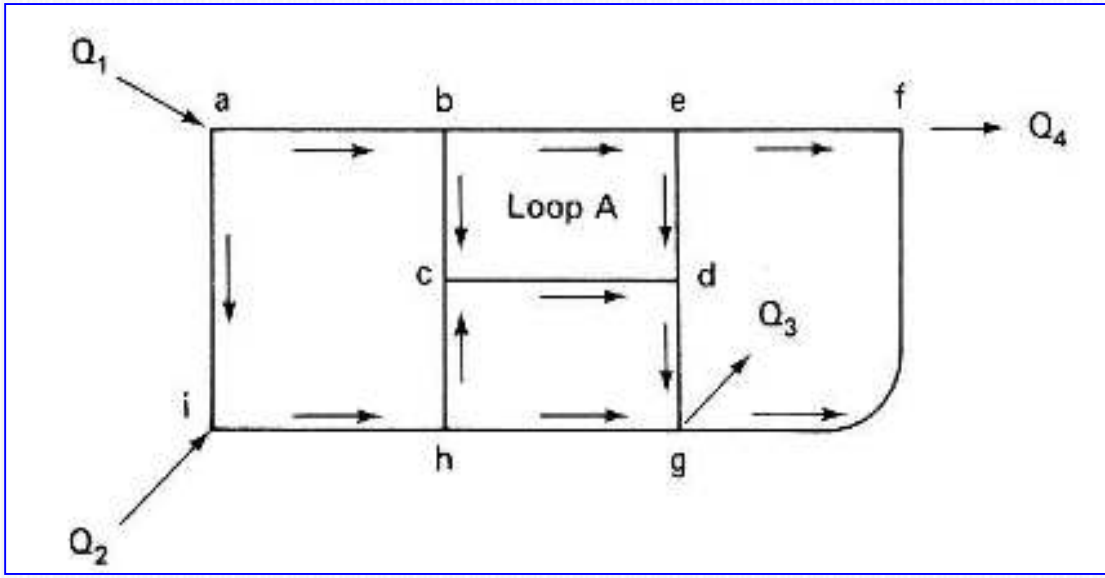
Surface water collection and transmission

Topics	References
• **Water Supply Network Analysis** ✓ **Hardy Cross Method**	**1. Design of Water Supply Pipe Networks** Authors: Prabhata K. Swamee and Ashok K. Sharma Wiley Interscience, A John Wiley & Sons Inc. Publications, New Jersey **2. Water Supply and Sanitation** Authors: M. Feroz Ahmed, Md. Mujibur Rahman 1st ed., ITN-BUET

Hydraulic Analysis of Water Distribution System

Hardy Cross Method

- The earliest systematic method of network analysis (Hardy-Cross Method) is known as the head balance or closed loop method.



- This method is applicable to system in which pipes form closed loops.

Hydraulic Analysis of Water Distribution System

Hardy Cross Method

- The outflows from the system are generally assumed to occur at the nodes junction.

- For a given pipe system with known outflows, the Hardy-Cross method is an iterative procedure based on initially iterated flows in the pipes.

- At each junction, these flows must satisfy the continuity criterion, i.e. the algebraic sum of the flow rates in the pipe meeting at a junction, together with any external flows is zero.

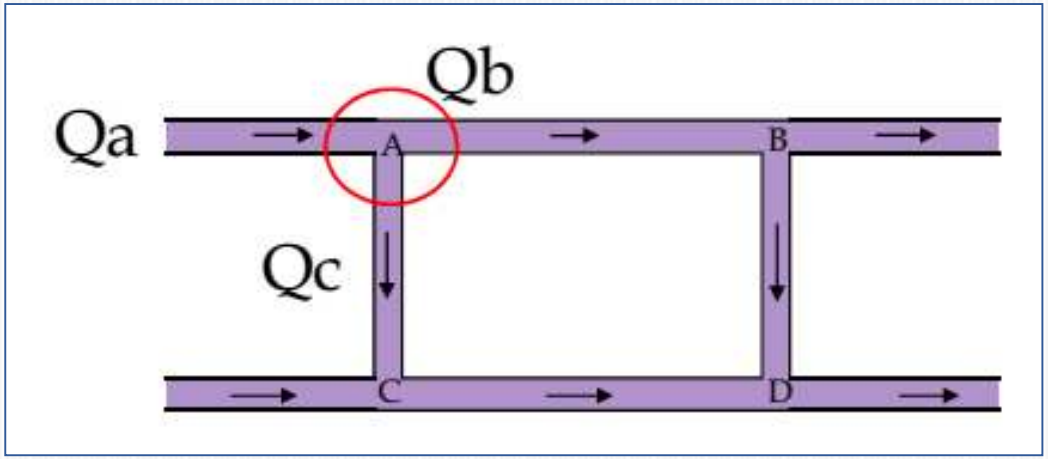
Hydraulic Analysis of Water Distribution System

Hardy Cross Method - is based on

✓ ***Continuity Equation:***

Inflow = outflow at nodes

$$Q_a = Q_b + Q_c$$



Hydraulic Analysis of Water Distribution System

Hardy Cross Method - is based on

✓ ***Energy Equation:***

Summation of head loss in closed loop is zero

$$\sum h_l(loop) = 0 \Rightarrow \sum K(Q + \Delta Q)^n = 0$$

Darcy-Weisbach

$$H_L = \frac{8 f L Q^2}{\pi^2 g D^5} = K.Q^2$$

Hazen-Williams

$$H_L = k.Q^{1.85}.L$$

where $$k = \left(\frac{1}{0.278 C D^{2.63}}\right)^{\frac{1}{0.54}}$$

Hydraulic Analysis of Water Distribution System

Assumptions/ Steps in Hardy Cross Method

- Assume that the water is withdrawn from nodes only; not directly from pipes.

- The discharge, Q , entering the system will have (+) value, and the discharge, Q , leaving the system will have (-) value.

- Usually neglect minor losses since these will be small with respect to those in long pipes, i.e.; or could be included as equivalent lengths in each pipe.

Hydraulic Analysis of Water Distribution System

Assumptions/ Steps in Hardy Cross Method

- Assume flows for each individual pipe in the network.

- At any junction (node), as done for pipes in parallel,

$$\sum Q_{in} = \sum Q_{out} \quad \Longrightarrow \quad \sum Q = 0$$

- Around any loop in the grid, the sum of head losses must equal to zero:

$$\sum_{loop} h_f = 0$$

Hydraulic Analysis of Water Distribution System

Assumptions/ Steps in Hardy Cross Method

- Conventionally, clockwise flows in a loop are considered (+ve) and produce positive head losses; counterclockwise flows are then (-ve) and produce negative head losses.

- This fact is called the head balance of each loop, and this can be valid only if the assumed Q for each pipe, within the loop, is correct.

Hydraulic Analysis of Water Distribution System

Assumptions/ Steps in Hardy Cross Method

- The probability of initially guessing all flow rates correctly is virtually null.

- Therefore, to balance the head around each loop, a flow rate correction (Δ) for each loop in the network should be computed, and hence some iteration scheme is needed.

Hydraulic Analysis of Water Distribution System

Assumptions/ Steps in Hardy Cross Method

- After finding the discharge correction, Δ (one for each loop), the assumed discharges Q_0 are adjusted and another iteration is carried out until all corrections (values of Δ) become zero or negligible.

- At this point the condition of :

$$\sum_{loop} h_f \cong 0.0$$ is satisfied.

Hydraulic Analysis of Water Distribution System

Assumptions/ Steps in Hardy Cross Method

Notes:

- The flows in pipes common to two loops are positive in one loop and negative in the other.

- When calculated corrections are applied, with careful attention to sign, pipes common to two loops receive both corrections.

Hydraulic Analysis of Water Distribution System

Steps in Hardy Cross Method

- The relationship between head loss and discharge must be maintained for each pipe.

✓ Darcy-Weisbach Equation

$$h_l(pipe) = KQ^n \quad n = 2 \quad K = \frac{8fL}{g\pi^2 D^5}$$

✓ Exponential friction formula of Hazen-Williams

$$h_l(pipe) = KQ^n \quad n = 1.85 \quad K = \frac{10.67}{C^{1.85} d^{4.87}}$$

Hydraulic Analysis of Water Distribution System

How to find the correction value (Δ)

$$h_f = k\,Q^x$$

$$Q = Q_0 + \Delta$$

$$h_f = k\,Q^x = k\,(Q_0 + \Delta)^x = k\left[Q_0^x + x\,Q_0^{(x-1)}\Delta + \frac{x\,(x-1)}{2}\,Q_0^{(x-2)}\,\Delta^2 + \cdots\right]$$

$$h_f = k\,Q^x = k\left[Q_0^x + x\,Q_0^{(x-1)}\Delta\right]$$ [Neglecting higher degree of Δ]

Hydraulic Analysis of Water Distribution System

How to find the correction value (Δ)

Since for each loop in the grid:

$$\sum_{loop} h_f = \sum_{loop} kQ^x = 0$$

$$\sum k\,Q^x = \sum k\,Q_0^x + \sum x\,k\,Q_0^{(x-1)}\,\Delta = 0$$

Therefore, we have (for each loop in the network)

$$\Delta = \frac{-\sum k\,Q_0^x}{\sum x\,k\,Q_0^{(x-1)}} = \frac{-\sum h_f}{x\sum \frac{h_f}{Q}}$$

$$h_f = KQ^x$$

$$\Rightarrow \frac{h_f}{Q} = \frac{KQ^x}{Q}$$

$$\Rightarrow \frac{h_f}{Q} = KQ^{x-1}$$

Hydraulic Analysis of Water Distribution System

How to find the correction value (Δ)

- If Hazen Williams (which is generally used in this method) is used to find the head losses, then

$$h_f = 10.7 \frac{L}{D^{4.87}} \left(\frac{Q}{C_{HW}} \right)^{1.85} \qquad h_f = k\,Q^{1.85} \qquad \Delta = \frac{-\sum h_f}{1.85 \sum \frac{h_f}{Q}}$$

- If Darcy -Wiesbach is used to find the head losses, then

$$h_f = f\left(\frac{L}{D}\right)\frac{V^2}{2g} \qquad h_f = k\,Q^2 \qquad \Delta = \frac{-\sum h_f}{2 \sum \frac{h_f}{Q}}$$

Pipe Network Analysis – Hardy Cross Method

Problem 1: Simple Looped Network

A single looped network as shown in the Fig. 1 has to be analyzed by Hardy Cross method for given pipe diameter, length, inflow and outflow discharges.

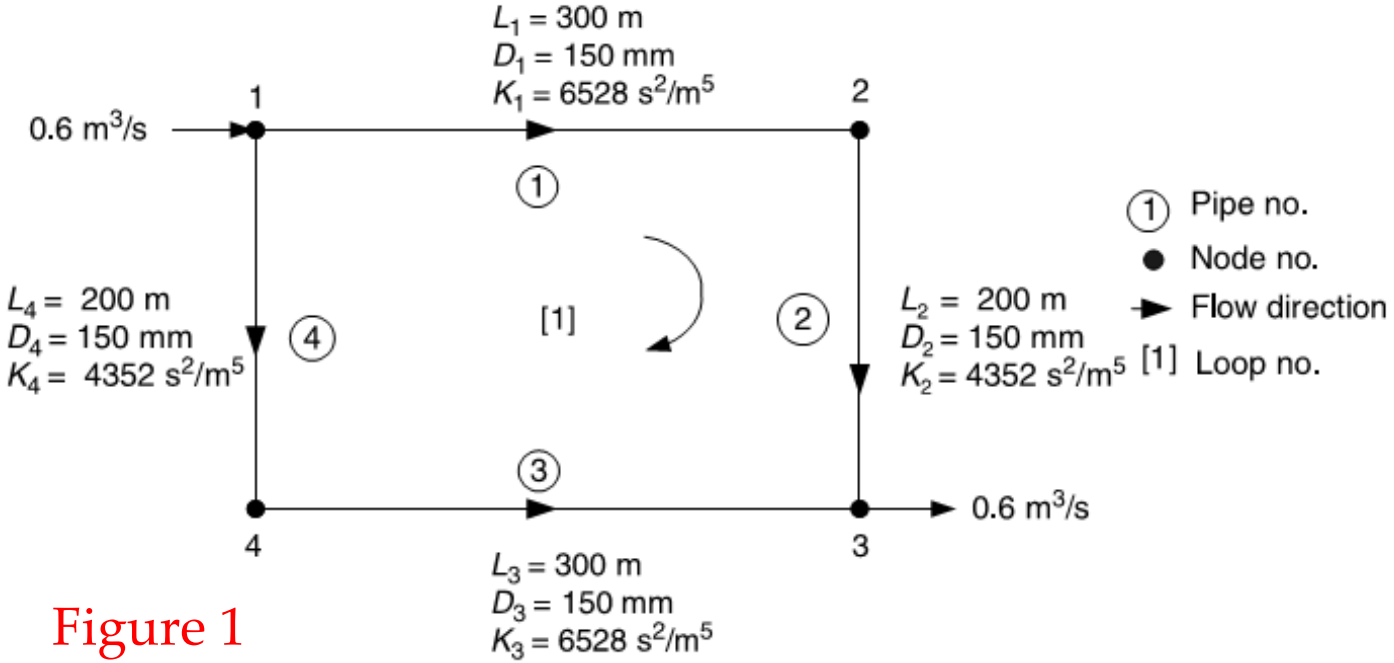


Figure 1

Use Darcy – Weisbach head loss – discharge relationship assuming a constant friction factor, f=0.02.

Pipe Network Analysis – Hardy Cross Method

Solution:

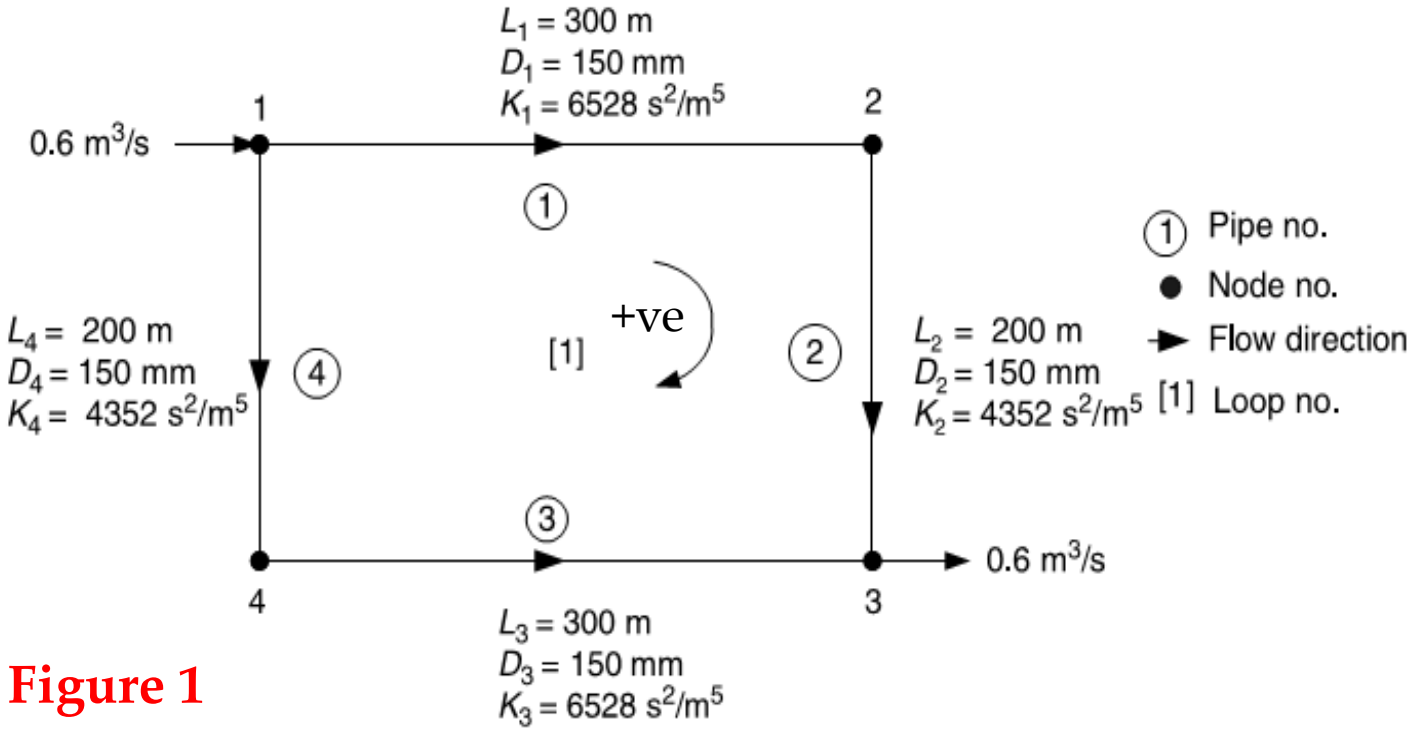


Figure 1

- **Step 1:** The pipes, nodes, and loop are numbered as shown in given Fig (1).

- **Step 2:** Adopt the following sign conventions:

Pipe Network Analysis – Hardy Cross Method

Solution

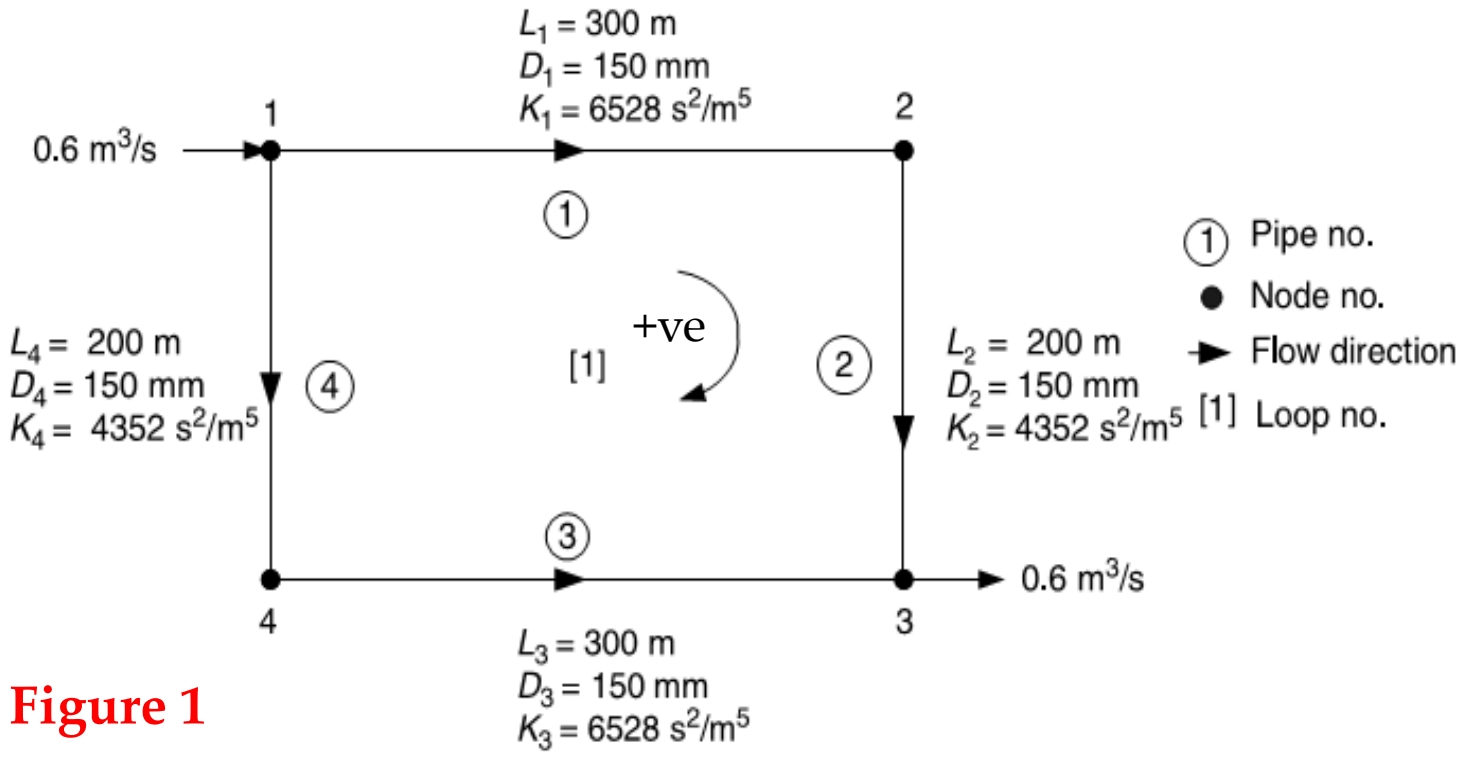


Figure 1

- ✓ A positive pipe discharge flows from a lower node to a higher node.
- ✓ Inflow into a node is positive, whereas withdrawal is negative.

Pipe Network Analysis – Hardy Cross Method

Solution:

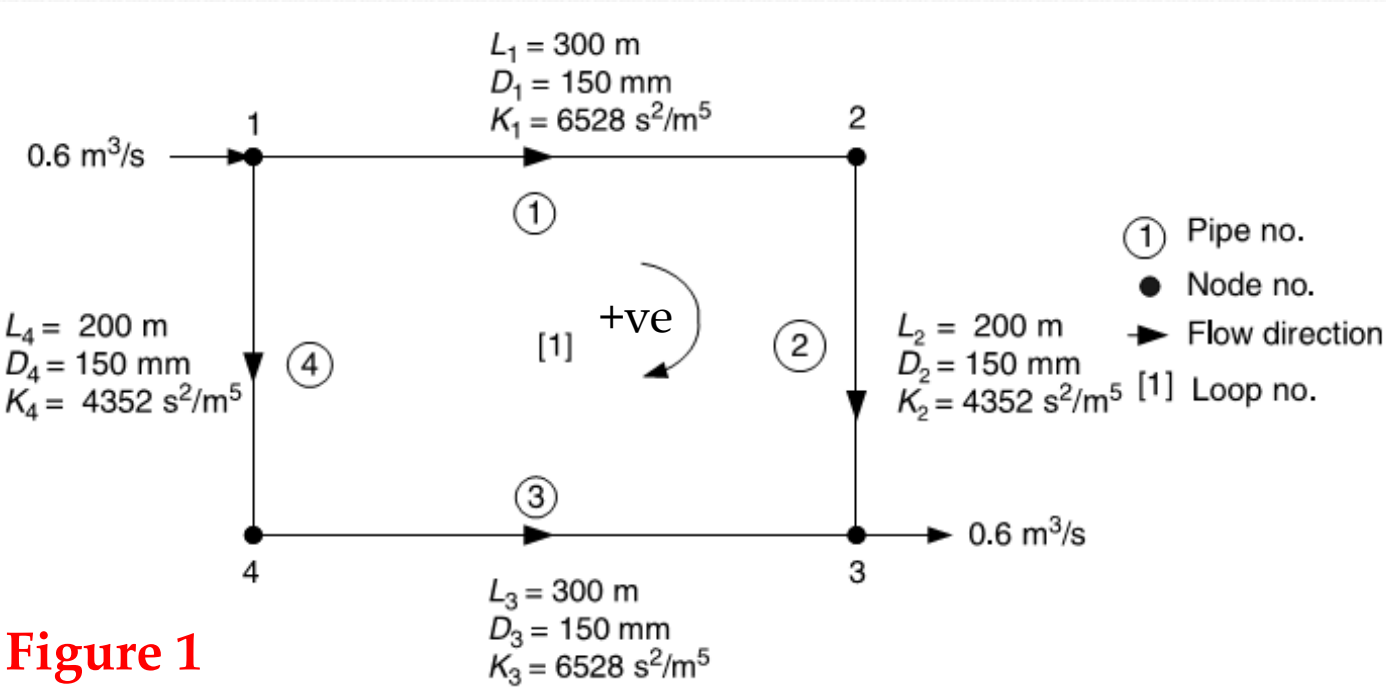


Figure 1

✓ In the summation process of the equation,

$$\sum Q_i = q_j \qquad \text{for all nodes } j = 1, 2, 3, \ldots, j_L, \quad \ldots\ldots (1)$$

a positive sign is used if the discharge in the pipe is out of the node under consideration. Otherwise, a negative sign will be used.

Pipe Network Analysis – Hardy Cross Method

Solution:

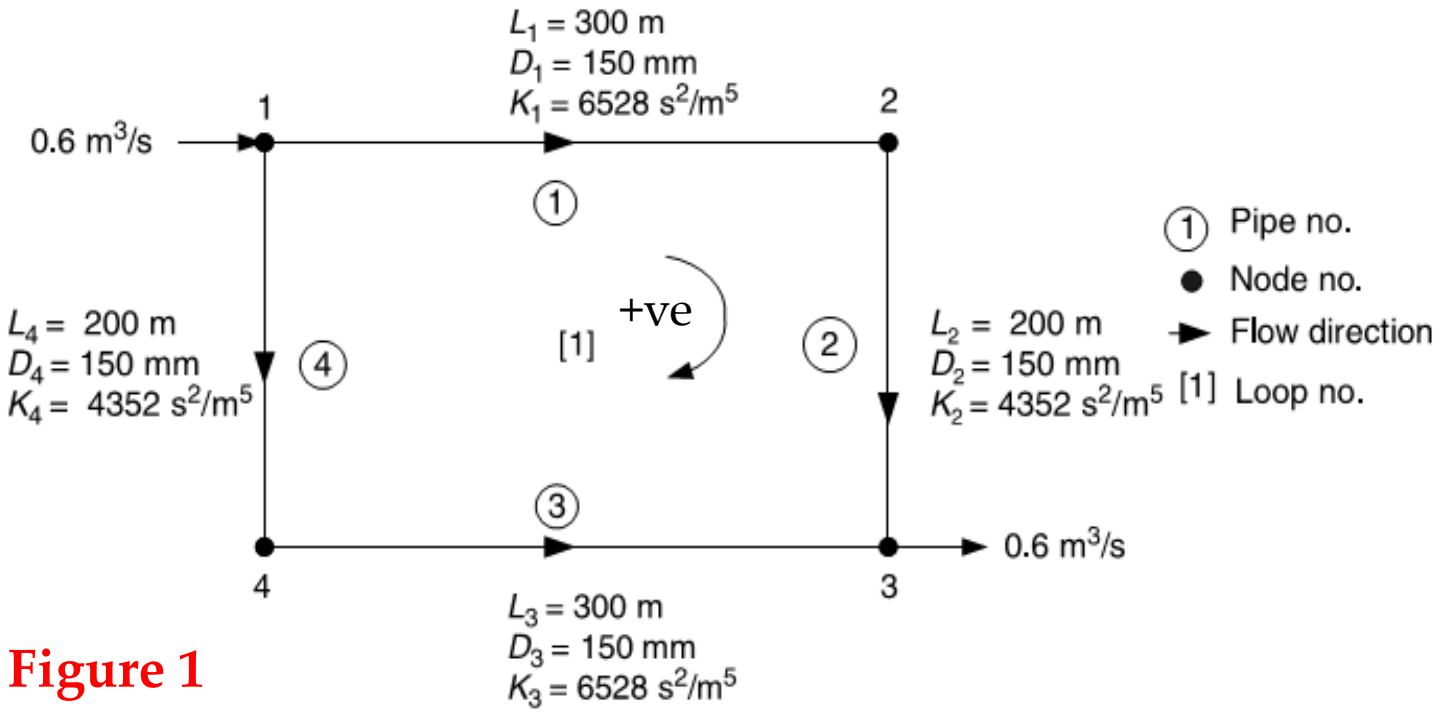


Figure 1

- For example in the given network (Fig 1), at node 2, the flow in pipe 1 is towards node 2, thus the Q_1 at node 2 will be negative while applying Eq. 1.

$$\sum Q_i = q_j \qquad \text{for all nodes } j = 1, 2, 3, \ldots, j_L, \qquad \ldots\ldots (1)$$

Simple Looped Network Analysis – Hardy Cross Method

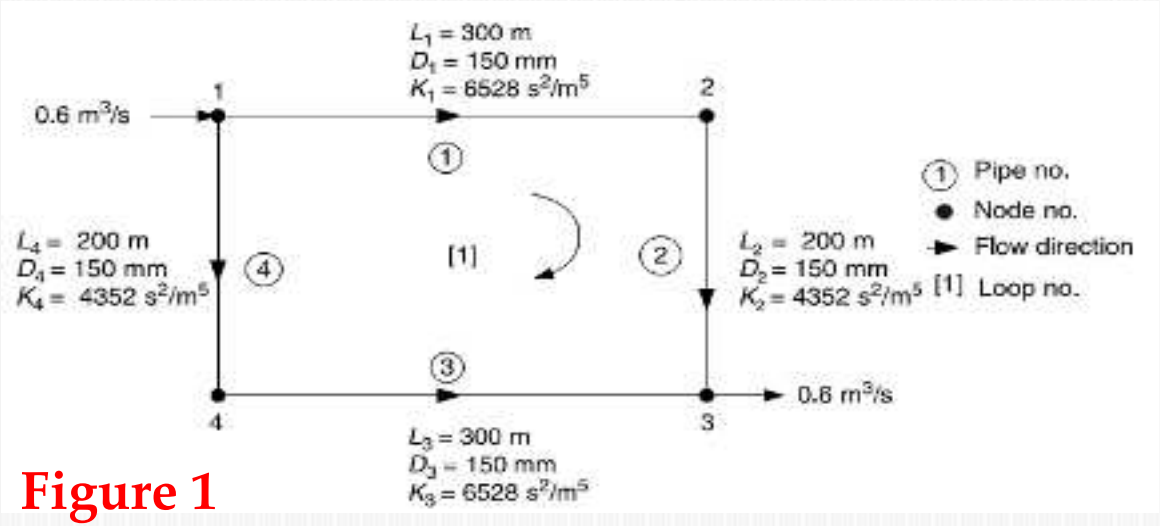


Figure 1

Step 3: Apply continuity equation to obtain pipe discharges.

- The nodal inflow q_1 is 0.6 m^3/s and nodal outflow q_3 is 0.6 m^3/s. The q_2 and q_3 are zero.

- Assume an arbitrary flow of 0.1 m^3/s in pipe 1 (Q_1=0.1 m^3/s), meaning thereby that the flow in pipe 1 is from node 1 to node 2.

Simple Looped Network Analysis – Hardy Cross Method

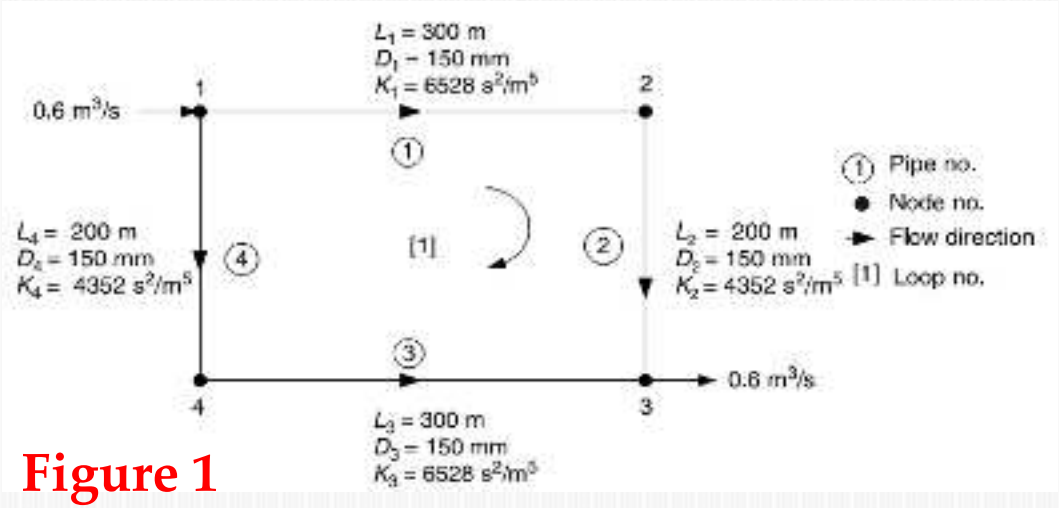


Figure 1

- The discharge in pipe Q_4 can be calculated by applying continuity equation at node 1 as –

$$Q_1 + Q_4 = q_1 \text{ or } Q_4 = q_1 - Q_1$$

$$\text{hence } Q_4 = 0.6 - 0.1 = 0.5\,\text{m}^3/\text{s}$$

- The discharge in pipe 4 is positive, hence the flow will be from node 1 to node 4 (toward higher numbering node).

Simple Looped Network Analysis – Hardy Cross Method

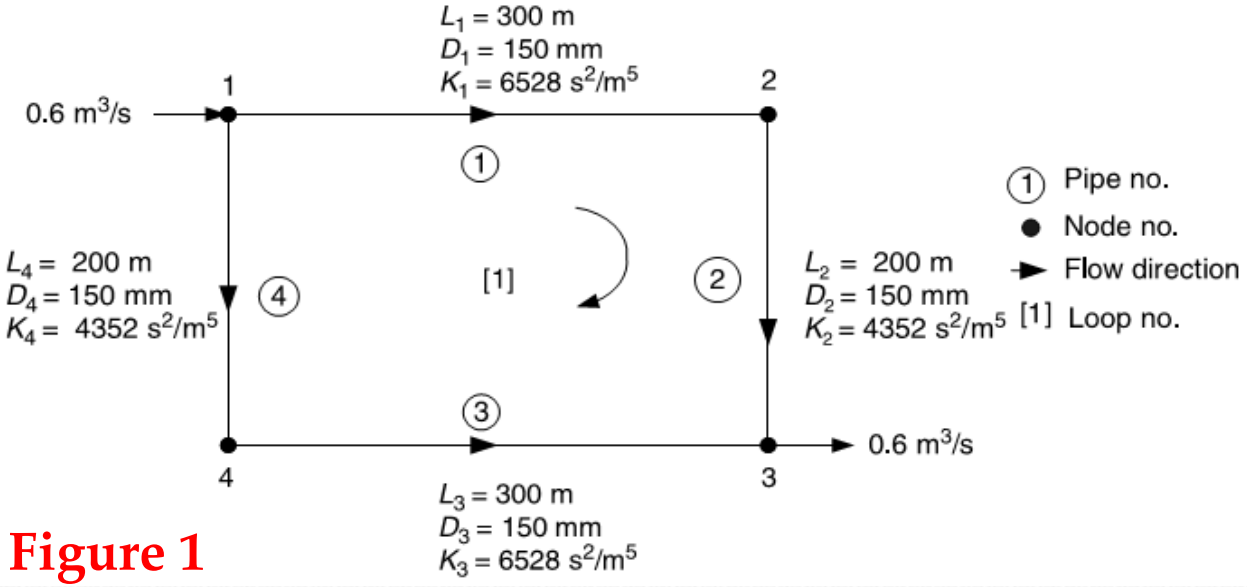


Figure 1

- Also applying continuity equation at node 2:

$$-Q_1 + Q_2 = q_2 \text{ or } Q_2 = q_2 + Q_1$$

$$\text{hence } Q_2 = 0 + 0.1 = 0.1\ \text{m}^3/\text{s}.$$

- Similarly, at node 3, flow in pipe Q_3 = 0.5 m3/s
- The pipe flow directions for the initial flows are shown in the figure.

Simple Looped Network Analysis – Hardy Cross Method

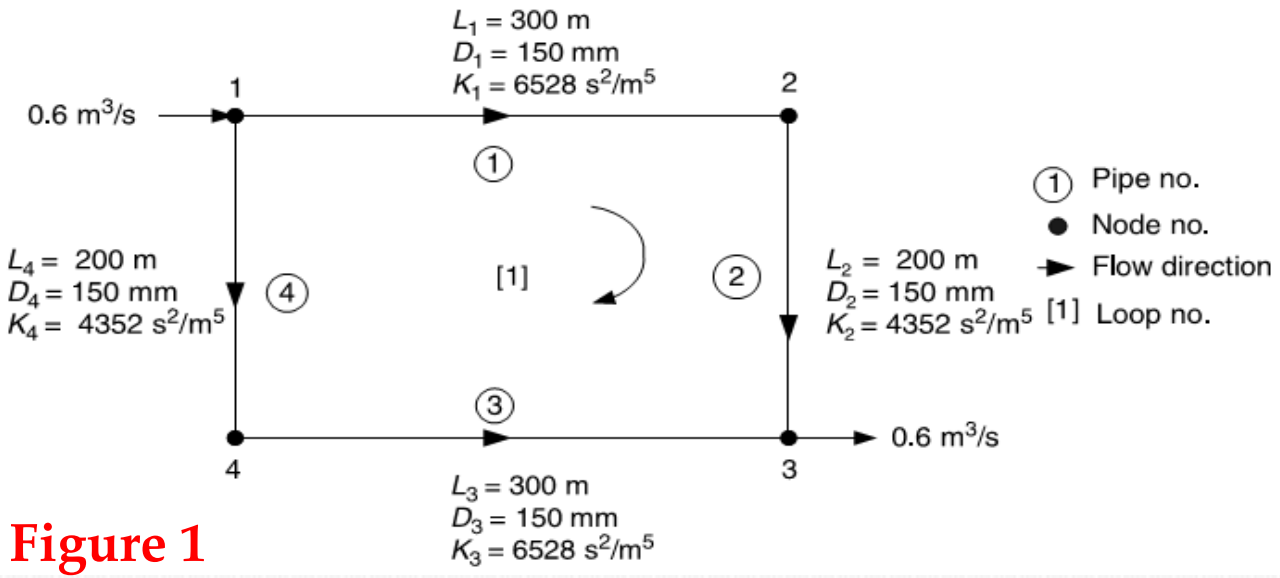


Figure 1

Step 4: For assumed pipe friction factors f_i =0.02, the calculated K values as for all the pipes are given in Fig.1. here, from Darcy – Weisbach head loss equation,

$$K = 8fL/\pi^2 gD^5$$

Step 5: Adopted clockwise flows in pipes positive and counterclockwise flows negative.

Simple Looped Network Analysis – Hardy Cross Method

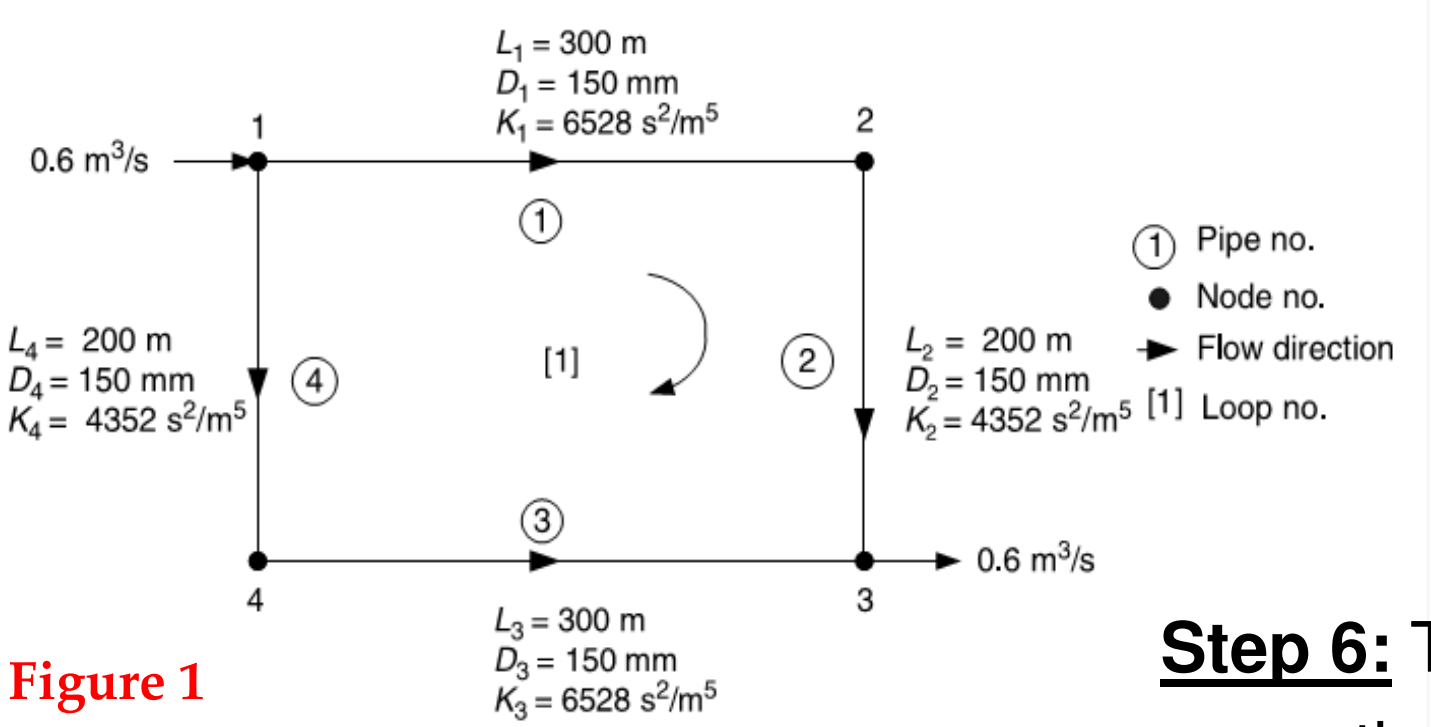


Figure 1

$$K = 8fL/\pi^2 gD^5$$

$$h_f = f\left(\frac{L}{D}\right)\frac{V^2}{2g} \qquad h_f = kQ^2 \qquad \Delta = \frac{-\sum h_f}{2\sum \frac{h_f}{Q}}$$

Step 6: The discharge correction for the initially assumed pipe discharges are calculated.

Simple Looped Network Analysis – Hardy Cross Method

$$h_f = f\left(\frac{L}{D}\right)\frac{V^2}{2g} \qquad h_f = kQ^2 \qquad \Delta = \frac{-\sum h_f}{2\sum \frac{h_f}{Q}}$$

$$K = 8fL/\pi^2 gD^5$$

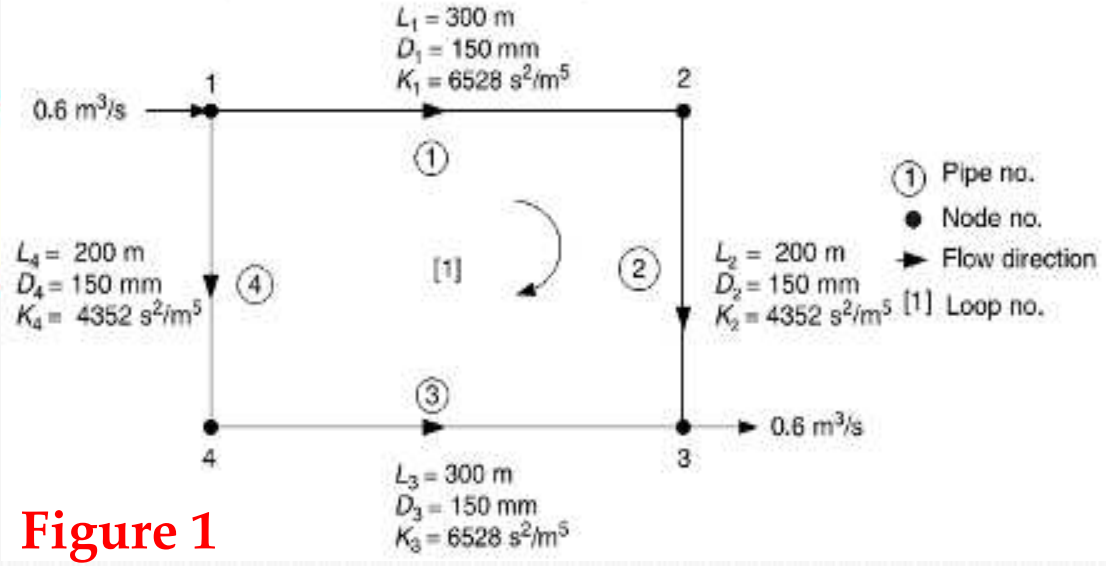


Figure 1

Iteration 1

Pipe	Flow in Pipe Q (m^3/s)	K (s^2/m^5)	h_f (m)	$2h_f/Q$ (s/m^2)	Corrected Flow $Q = Q + \Delta Q$ (m^3/s)
1	0.10	6528.93	65.29	1305.79	0.30
2	0.10	4352.62	43.53	870.52	0.30
3	−0.50	6528.93	−1632.23	6528.93	−0.30
4	−0.50	4352.62	−1088.15	4352.62	−0.30
Total			−2611.57	13,057.85	
ΔQ				$-(-2611.57/13{,}057) = 0.20\ m^3/s$	

Discharge correction, ΔQ is quite large, hence more iteration is required.

Simple Looped Network Analysis – Hardy Cross Method

Step 7: Repeat the process again for the revised pipe discharges.

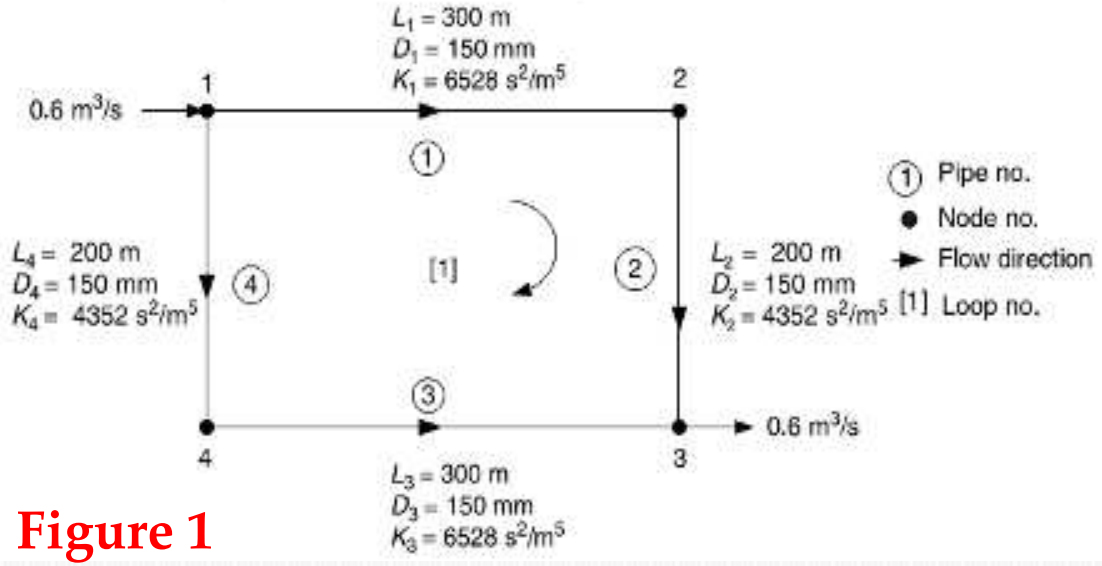


Figure 1

Iteration 2

Pipe	Flow in Pipe Q (m^3/s)	K (s^2/m^5)	h_f (m)	$2h_f/Q$ (s/m^2)	Corrected Flow $Q = Q + \Delta Q$ (m^3/s)
1	0.30	6528.93	587.60	3917.36	0.30
2	0.30	4352.62	391.74	2611.57	0.30
3	−0.30	6528.93	−587.60	3917.36	−0.30
4	−0.30	4352.62	−391.74	2611.57	−0.30
Total			0.00	13,057.85	
ΔQ				$= -(0/13{,}057) = 0.00\ m^3/s$	

Here, discharge correction, ΔQ Is zero.

Simple Looped Network Analysis – Hardy Cross Method

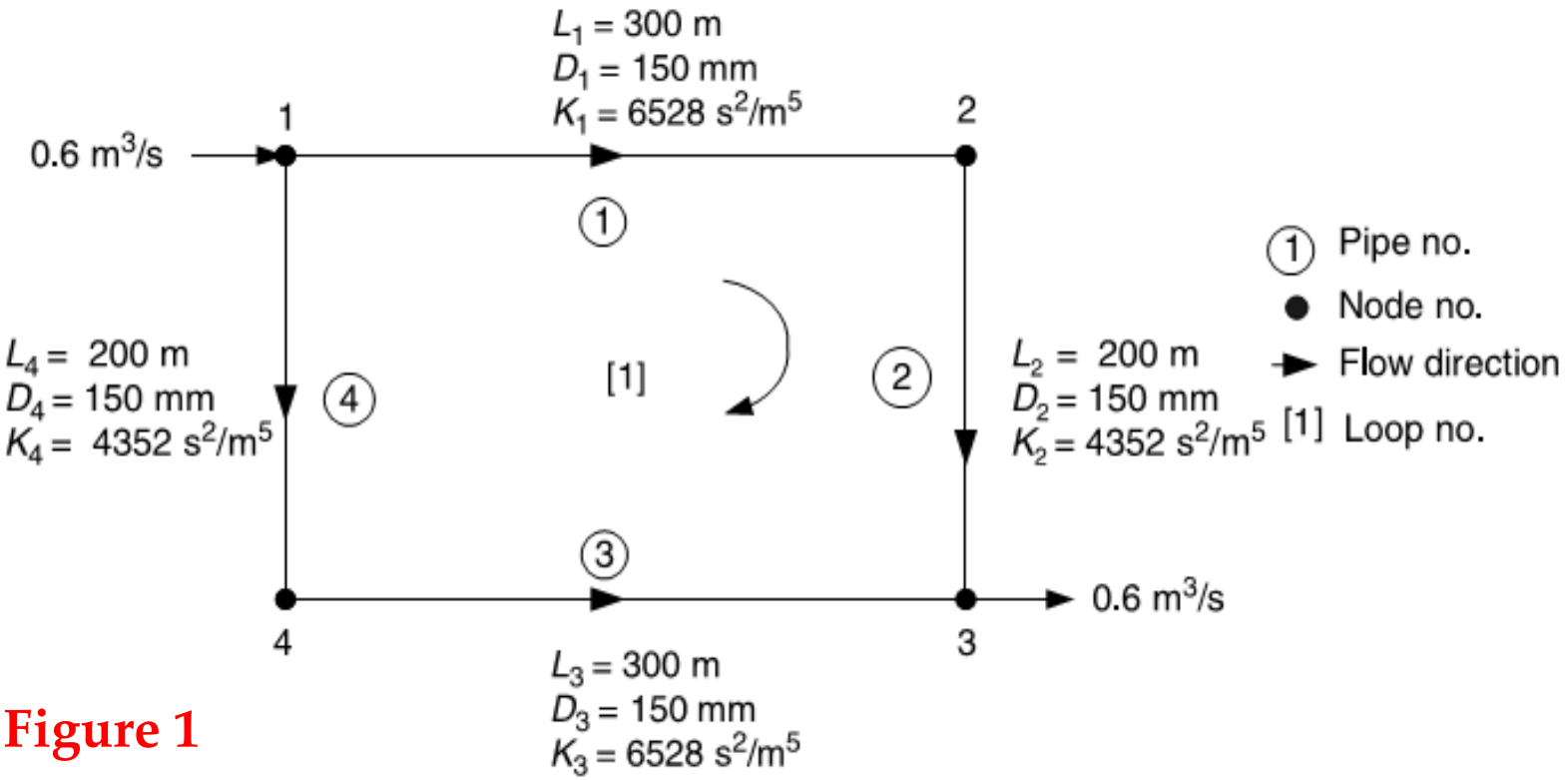


Figure 1

The final discharges are:

$$Q_1 = 0.3 \text{ m}^3/\text{s}$$
$$Q_2 = 0.3 \text{ m}^3/\text{s}$$
$$Q_3 = 0.3 \text{ m}^3/\text{s}$$
$$Q_4 = 0.3 \text{ m}^3/\text{s}.$$

Pipe Network Analysis – Hardy Cross Method

Problem 2: Simple Looped Network

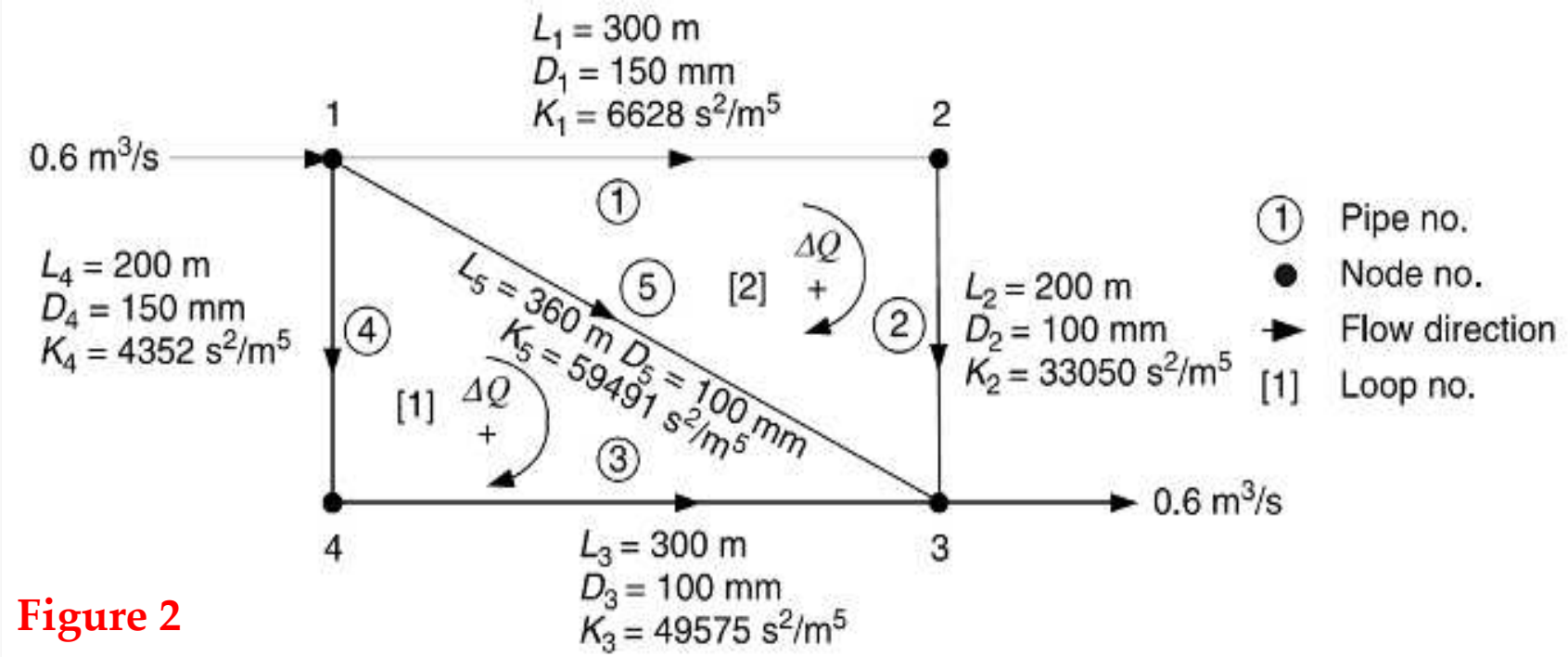


Figure 2

The pipe network of two loops as shown in Fig. 2 has to be analyzed by the Hardy Cross method for pipe flows for given pipe lengths L and pipe diameters D. The nodal inflow at node 1 and nodal outflow at node 3 are shown in the figure. Assume a constant friction factor, f=0.02.

Pipe Network Analysis – Hardy Cross Method

Solution:

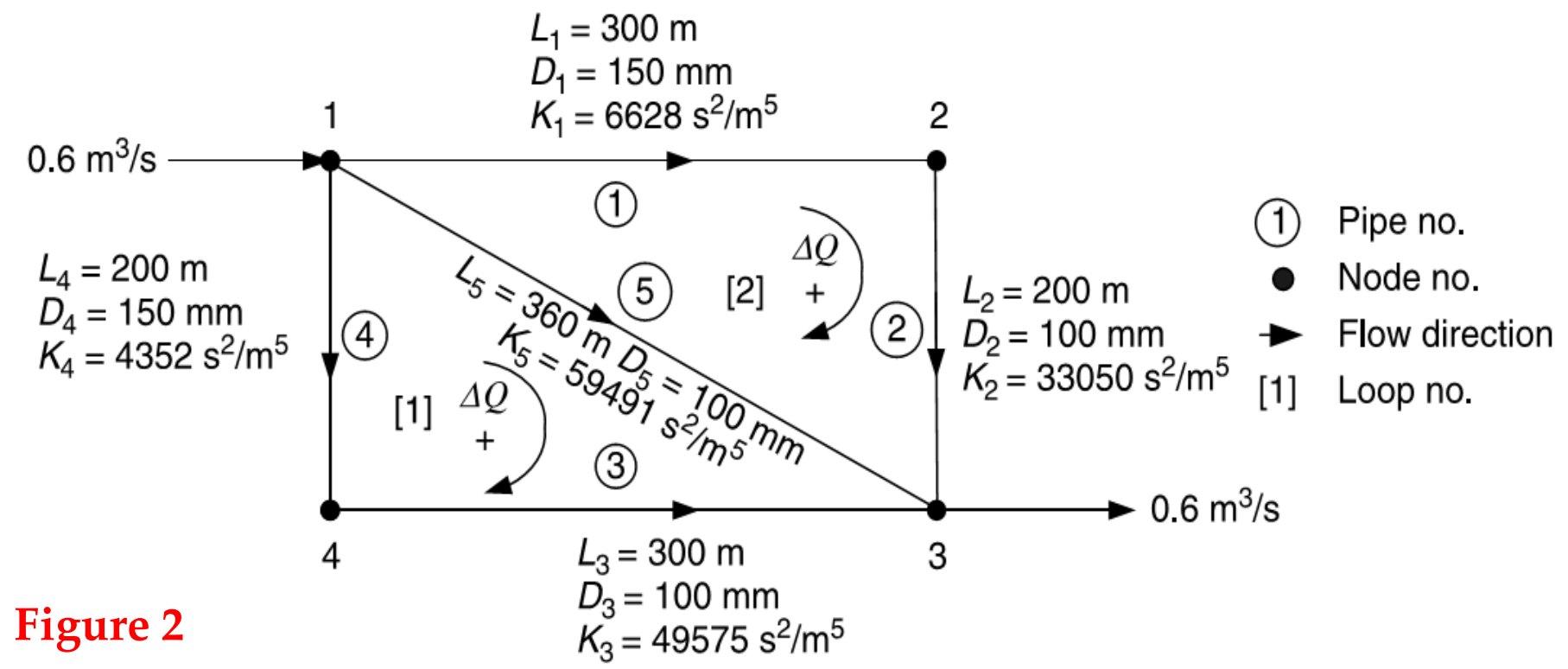


Figure 2

Applying steps 1 – 7 (as mentioned in Problem 1), the looped network analysis can be conducted as illustrated in this example. The K values for Darcy – Weisbach head loss – discharge relationship are also given in Fig. 2 above.

Pipe Network Analysis – Hardy Cross Method

Solution:

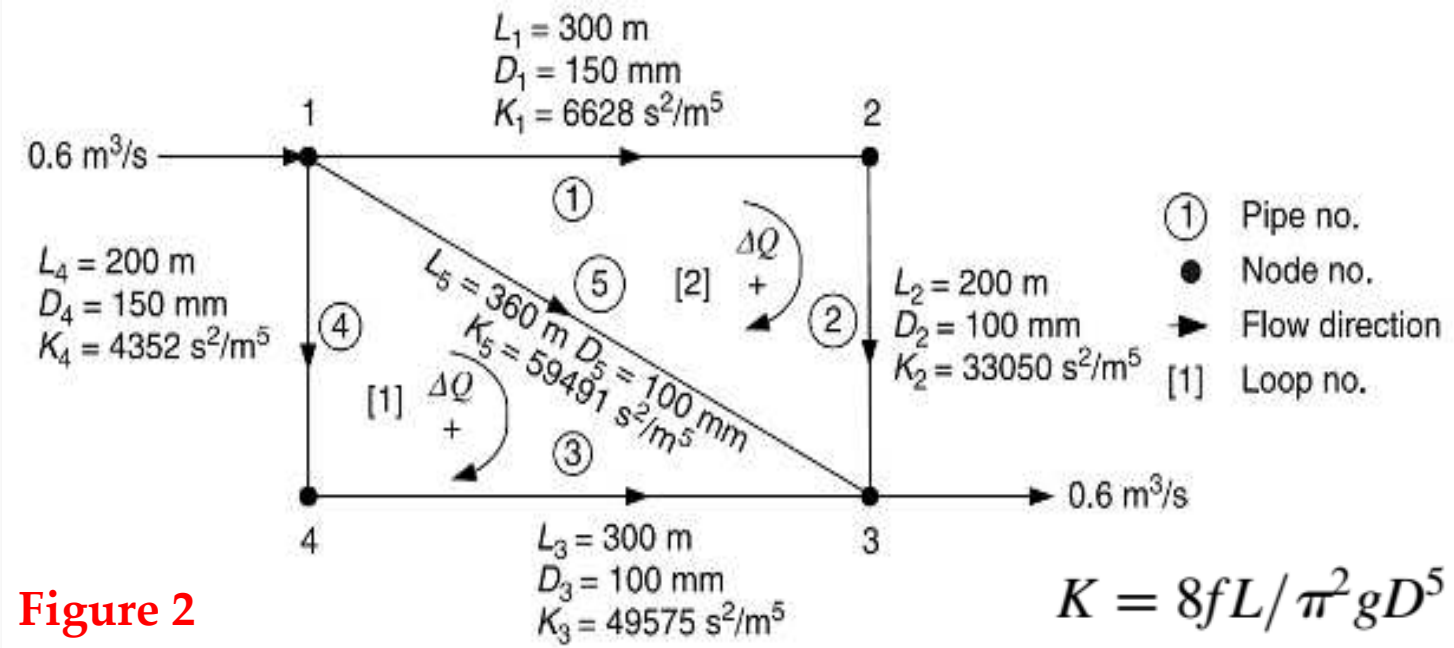


Figure 2

To apply continuity equation for initial pipe discharges, the discharges in pipes 1and 5 equal to 0.1 m^3/s are assumed.

Now, the obtained discharges are -

$Q_1 = 0.1\ m^3/s$ (flow from node 1 to node 2)

$Q_2 = 0.1\ m^3/s$ (flow from node 2 to node 3)

$Q_3 = 0.4\ m^3/s$ (flow from node 4 to node 3)

$Q_4 = 0.4\ m^3/s$ (flow from node 1 to node 4)

$Q_5 = 0.1\ m^3/s$ (flow from node 1 to node 3)

Pipe Network Analysis – Hardy Cross Method

Solution:

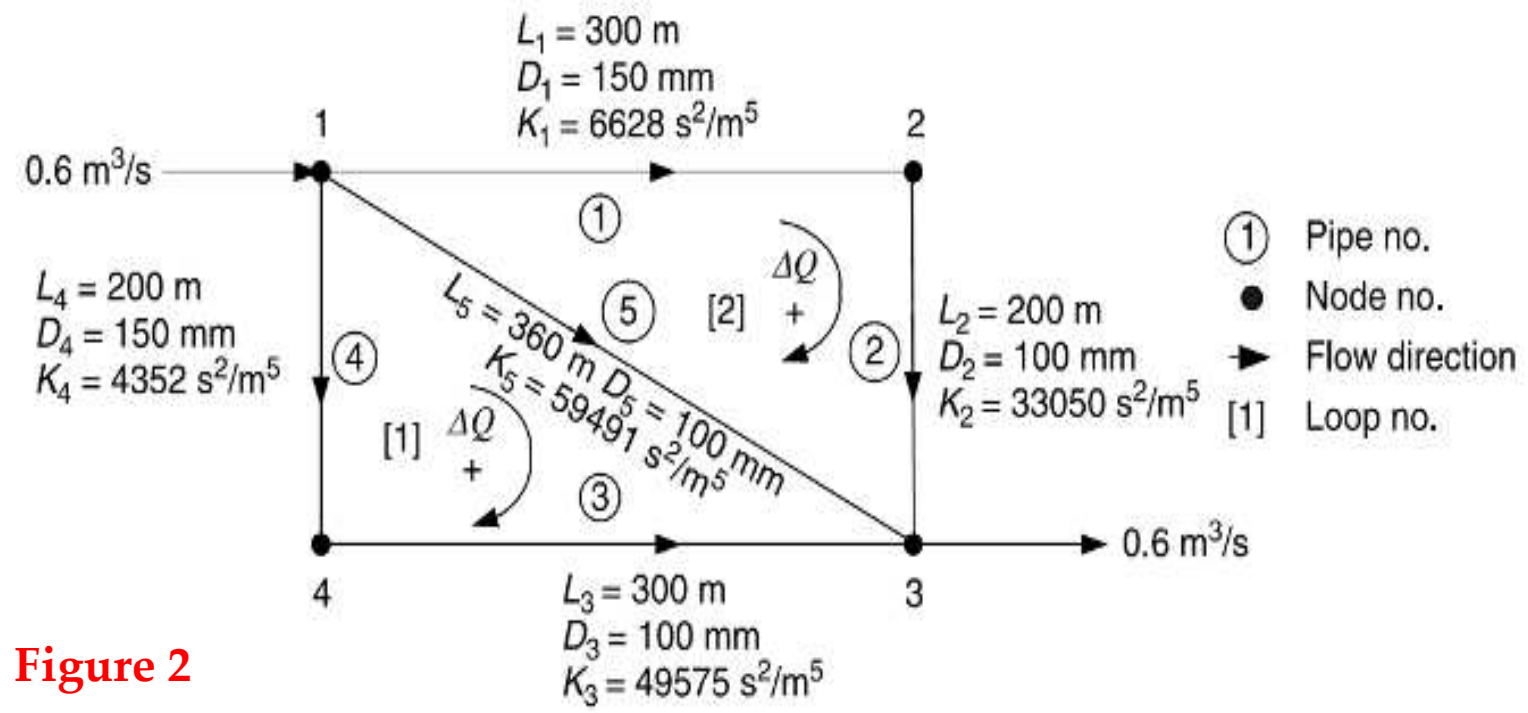


Figure 2

The discharge correction ΔQ is applied in one loop at a time until the ΔQ is very small in all the loops. ΔQ in Loop 1 (loop pipes 3, 4, and 5) and corrected pipe discharges are given in the following table:

Pipe Network Analysis – Hardy Cross Method

Solution:

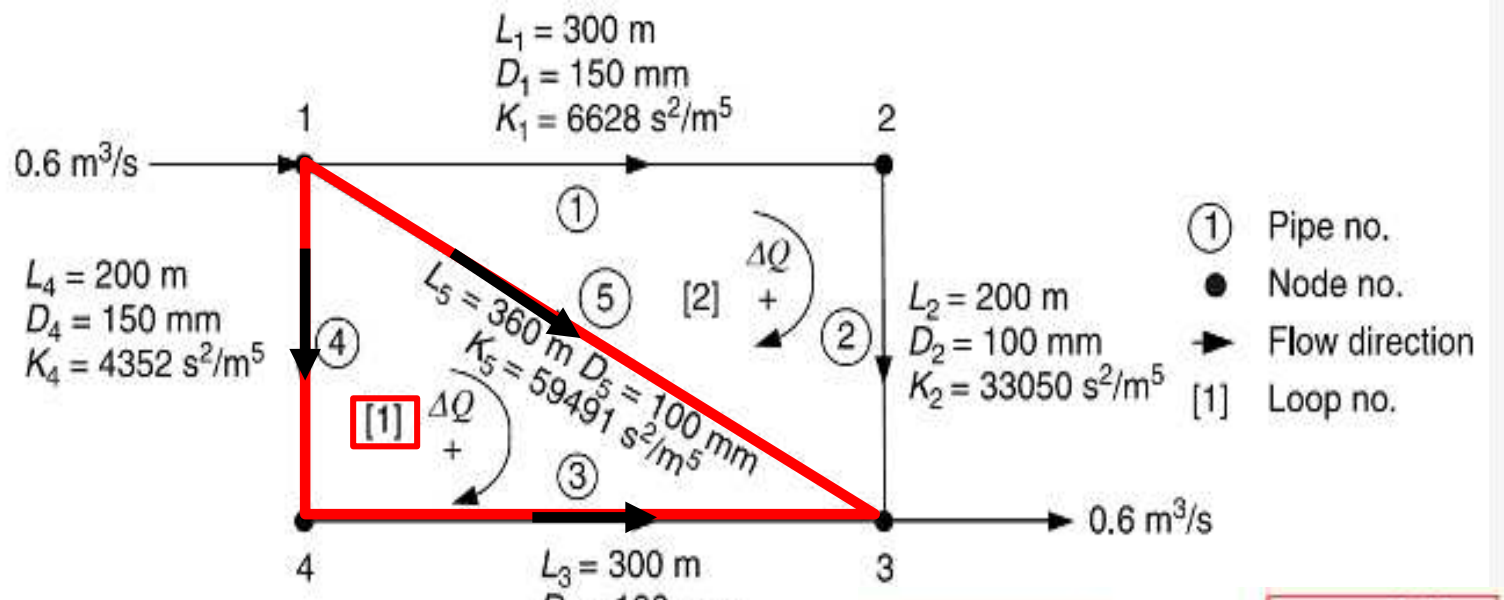


Figure 2

$$h_f = f\left(\frac{L}{D}\right)\frac{V^2}{2g} \qquad h_f = kQ^2 \qquad \Delta = \frac{-\sum h_f}{2\sum \frac{h_f}{Q}}$$

Loop 1: Iteration 1

Pipe	Flow in Pipe Q (m^3/s)	K (s^2/m^5)	h_f (m)	$2h_f/Q$ (s/m^2)	Corrected Flow $Q = Q + \Delta Q$ (m^3/s)
3	−0.40	49,576.12	−7932.18	39,660.89	−0.25
4	−0.40	4352.36	−696.38	3481.89	−0.25
5	0.10	59,491.34	594.91	11,898.27	0.25
Total			−8033.64	55,041.05	
ΔQ			0.15 m^3/s		

Pipe Network Analysis – Hardy Cross Method

Solution:

Pipe 5 is common to **Loop 1 and loop 2,** hence it will **take correction from both loops.**

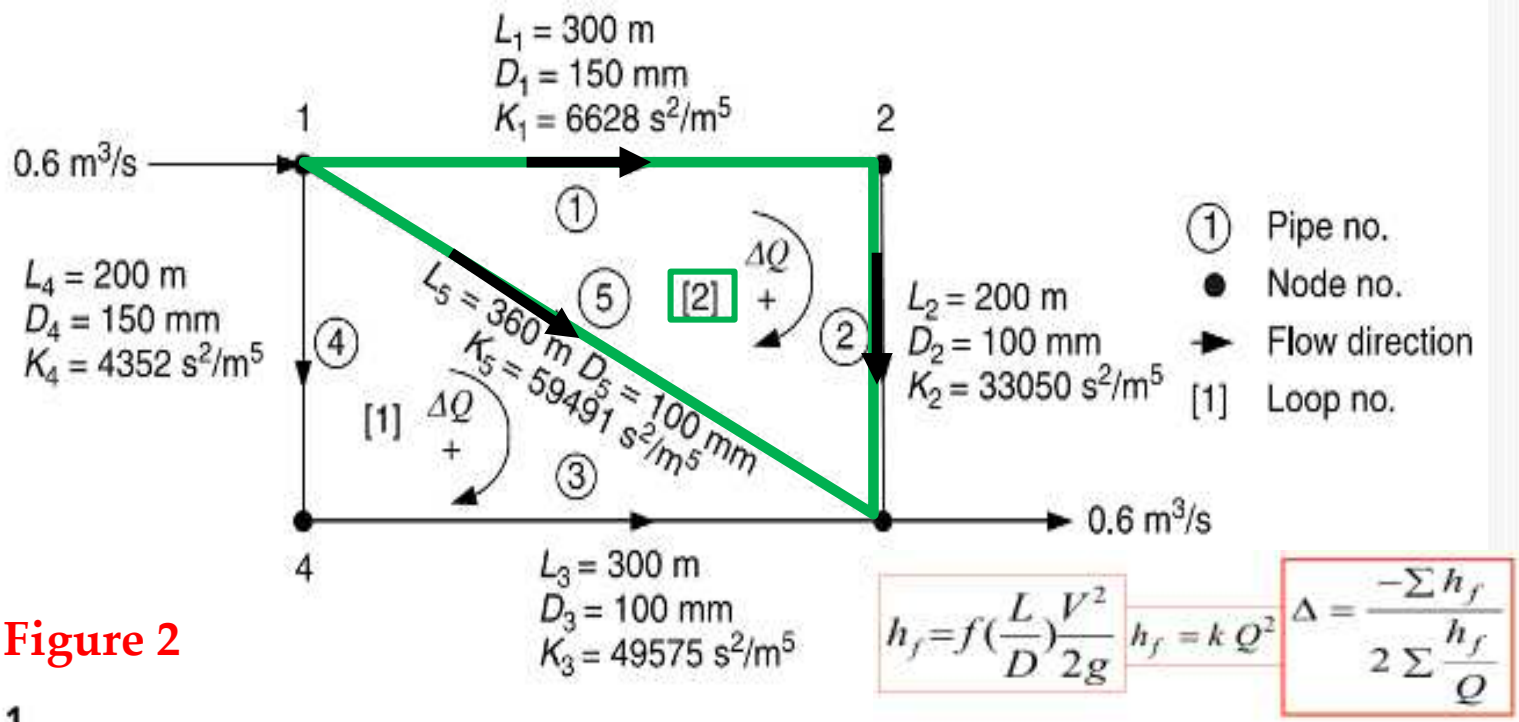


Figure 2

$$h_f = f\left(\frac{L}{D}\right)\frac{V^2}{2g} \qquad h_f = kQ^2 \qquad \Delta = \frac{-\sum h_f}{2\sum \frac{h_f}{Q}}$$

Loop 2: Iteration 1

Pipe	Flow in Pipe Q (m^3/s)	K (s^2/m^5)	h_f (m)	$2h_f/Q$ (s/m^2)	Corrected Flow $Q = Q + \Delta Q$ (m^3/s)
1	0.10	6528.54	65.29	1305.71	0.19
2	0.10	33,050.74	330.51	6610.15	0.19
5	−0.25	59,491.34	−3598.93	29,264.66	−0.16
Total			−3203.14	37,180.52	
ΔQ			0.09 m^3/s		

Pipe Network Analysis – Hardy Cross Method

Solution:

Pipe 5 is common to **Loop 1 and loop 2,** hence it will **take correction from both loops.**

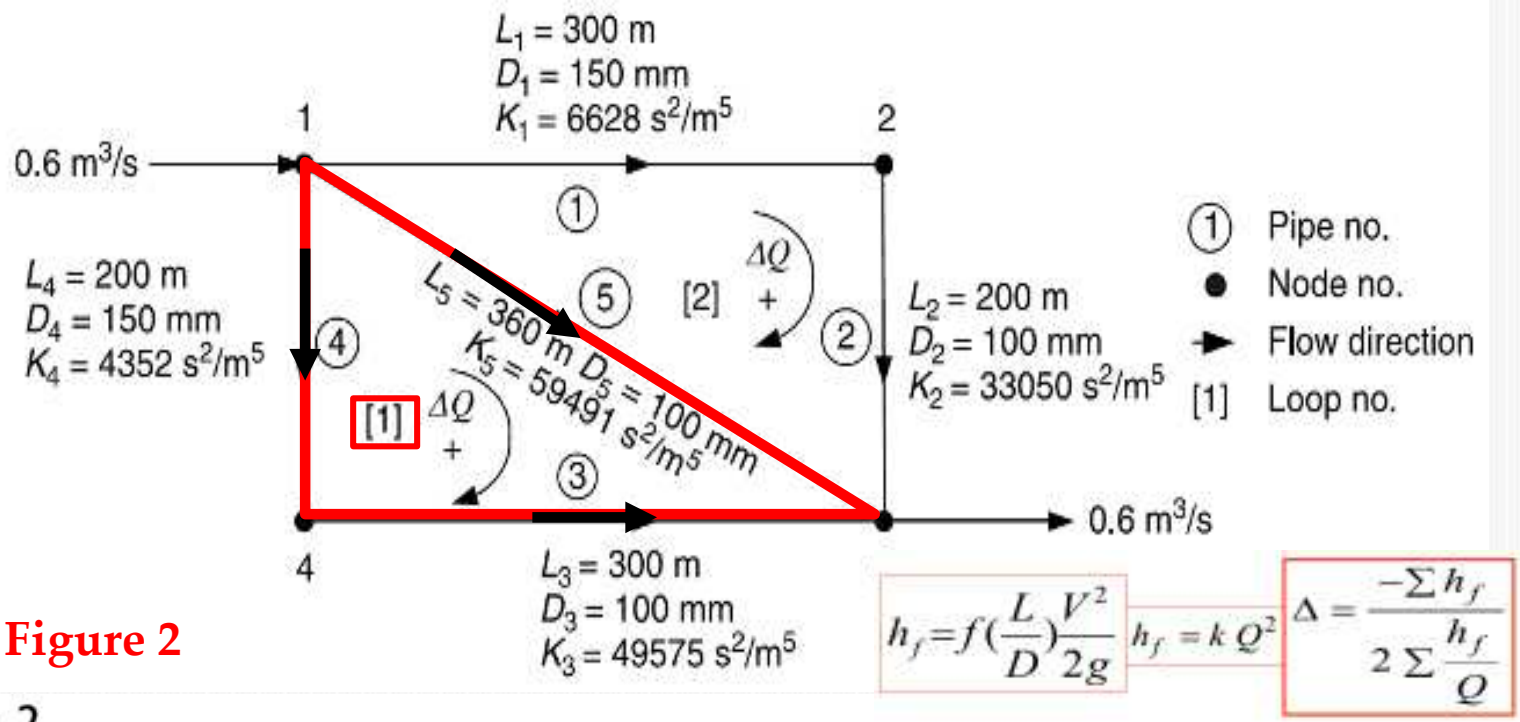


Figure 2

$$h_f = f\left(\frac{L}{D}\right)\frac{V^2}{2g} \qquad h_f = kQ^2 \qquad \Delta = \frac{-\sum h_f}{2\sum \frac{h_f}{Q}}$$

Loop 1: Iteration 2

Pipe	Flow in Pipe Q (m^3/s)	K (s^2/m^5)	h_f (m)	$2h_f/Q$ (s/m^2)	Corrected Flow $Q = Q + \Delta Q$ (m^3/s)
3	−0.25	49,576.12	−3098.51	24,788.06	−0.21
4	−0.25	4352.36	−272.02	2176.18	−0.21
5	0.16	59,491.34	1522.98	19,037.23	0.20
Total			−1847.55	46,001.47	
ΔQ			0.04 m^3/s		

Pipe Network Analysis – Hardy Cross Method

Solution:

Pipe 5 is common to **Loop 1 and loop 2,** hence it will **take correction from both loops.**

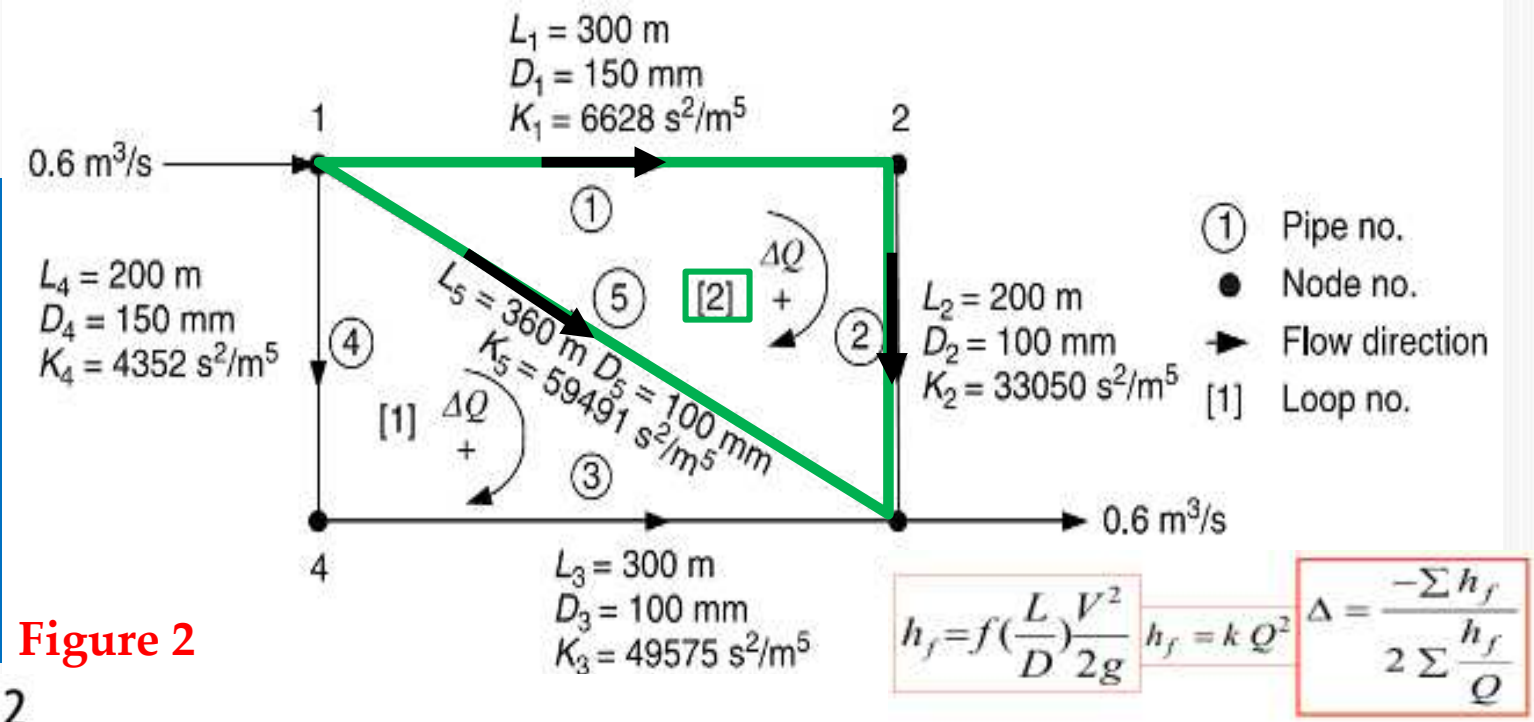


Figure 2

Loop 2: Iteration 2

Pipe	Flow in Pipe Q (m^3/s)	K (s^2/m^5)	h_f (m)	$2h_f/Q$ (s/m^2)	Corrected Flow $Q = Q + \Delta Q$ (m^3/s)
1	0.19	6528.54	226.23	2430.59	0.21
2	0.19	33,050.74	1145.28	12,304.85	0.21
5	−0.20	59,491.34	−2383.53	23,815.92	−0.17
Total			−1012.02	38,551.36	
ΔQ			0.03 m^3/s		

Pipe Network Analysis – Hardy Cross Method

Solution:

Pipe 5 is common to **Loop 1 and loop 2,** hence it will **take correction from both loops.**

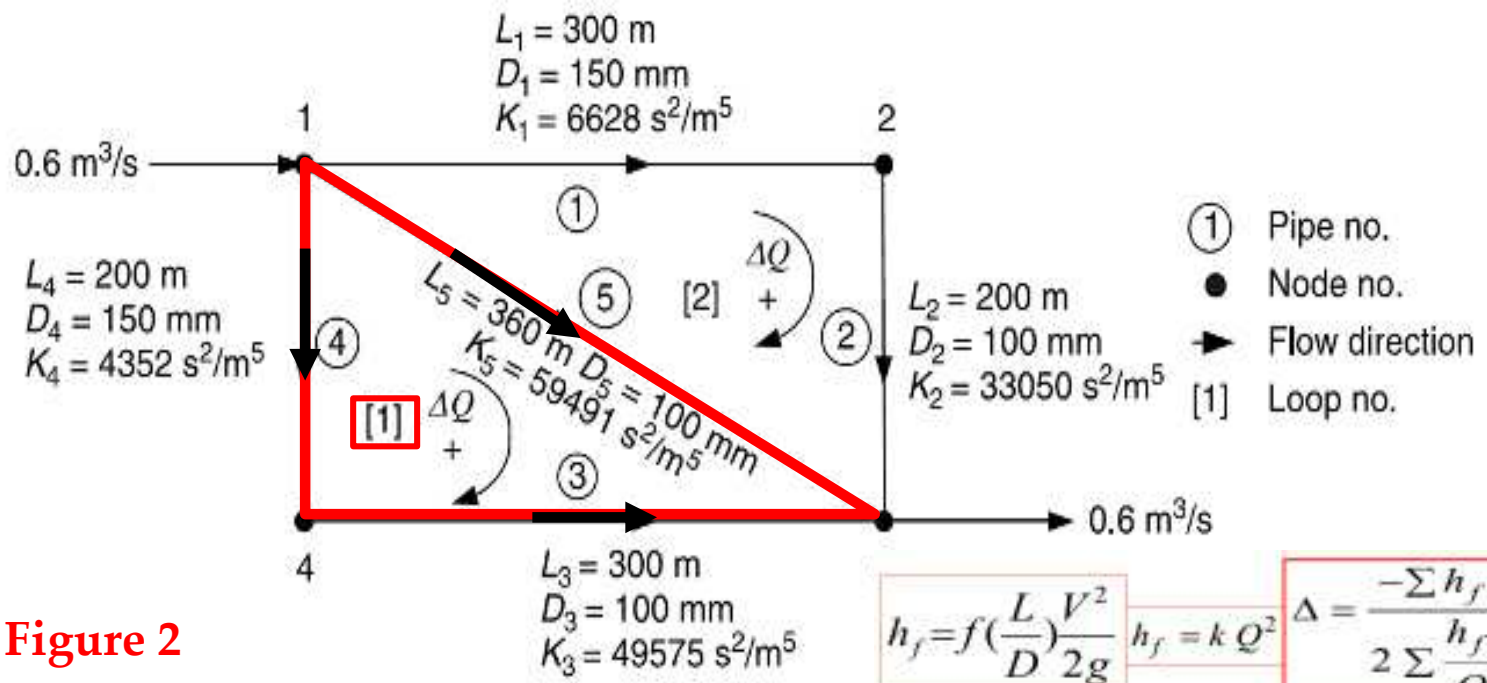


Figure 2

Loop 1: Iteration 3

Pipe	Flow in Pipe Q (m^3/s)	K (s^2/m^5)	h_f (m)	$2h_f/Q$ (s/m^2)	Corrected Flow $Q = Q + \Delta Q$ (m^3/s)
3	−0.210	49,576.12	−2182.92	20,805.82	−0.197
4	−0.210	4352.36	−191.64	1826.57	−0.197
5	0.174	59,491.34	1799.33	20,692.47	0.187
Total			−575.23	43,324.86	
ΔQ			0.01 m^3/s		

Pipe Network Analysis – Hardy Cross Method

Solution:

Pipe 5 is common to **Loop 1 and loop 2,** hence it will **take correction from both loops.**

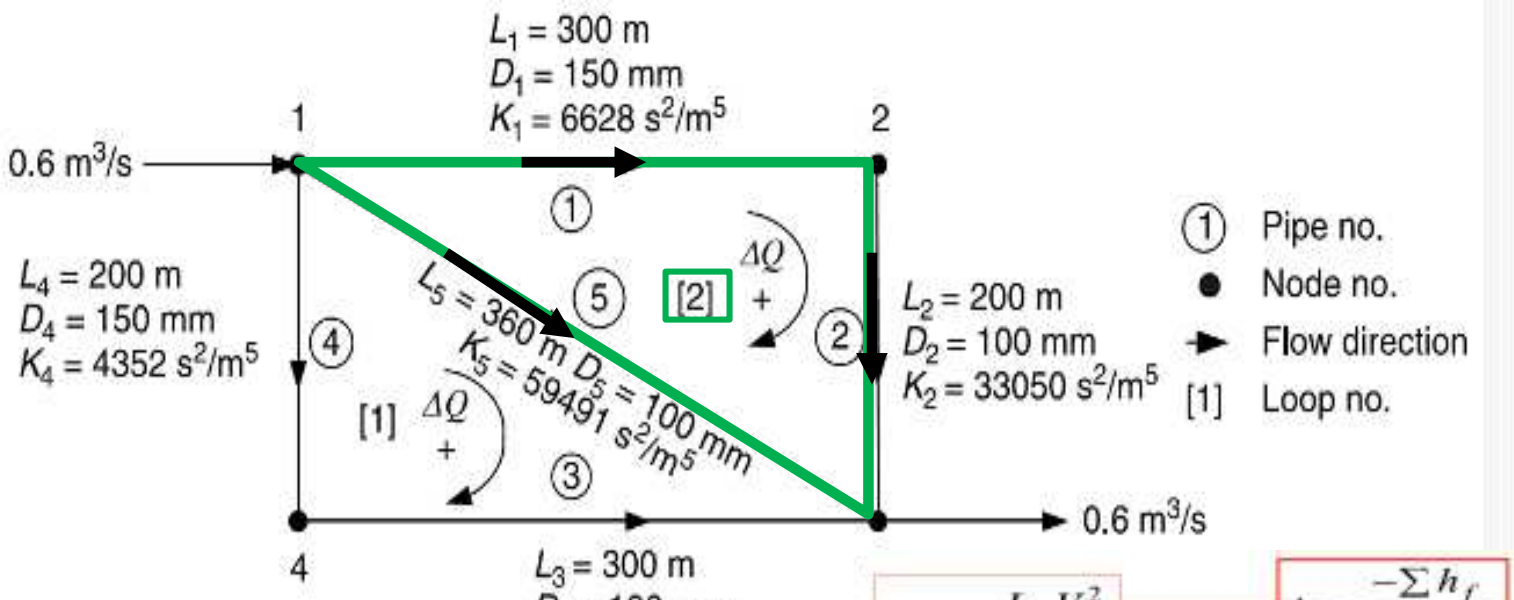


Figure 2

$$h_f = f\left(\frac{L}{D}\right)\frac{V^2}{2g} \qquad h_f = kQ^2 \qquad \Delta = \frac{-\sum h_f}{2\sum \frac{h_f}{Q}}$$

Loop 2: Iteration 3

Pipe	Flow in Pipe Q (m^3/s)	K (s^2/m^5)	h_f (m)	$2h_f/Q$ (s/m^2)	Corrected Flow $Q = Q + \Delta Q$ (m^3/s)
1	0.212	6528.54	294.53	2773.35	0.220
2	0.212	33,050.74	1491.07	14,040.10	0.220
5	−0.187	59,491.34	−2084.55	22,272.21	−0.180
Total			−298.95	39,085.67	
ΔQ			0.008 m^3/s		

Pipe Network Analysis – Hardy Cross Method

Solution:

Pipe 5 is common to **Loop 1 and loop 2,** hence it will **take correction from both loops.**

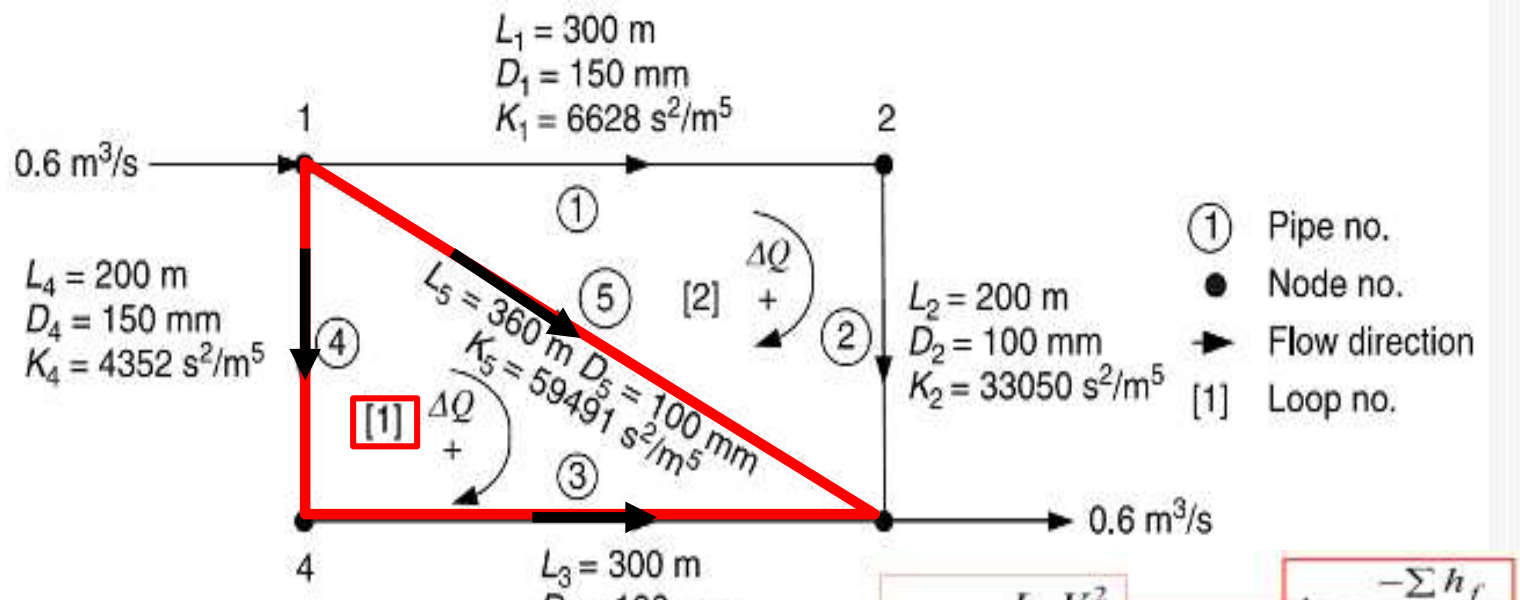


Figure 2

$$h_f = f\left(\frac{L}{D}\right)\frac{V^2}{2g} \qquad h_f = kQ^2 \qquad \Delta = \frac{-\sum h_f}{2\sum \frac{h_f}{Q}}$$

Loop 1: Iteration 4

Pipe	Flow in Pipe Q (m^3/s)	K (s^2/m^5)	h_f (m)	$2h_f/Q$ (s/m^2)	Corrected Flow $Q = Q + \Delta Q$ (m^3/s)
3	−0.197	49,576.12	−1915.41	19,489.36	−0.193
4	−0.197	4352.36	−168.16	1711.00	−0.193
5	0.180	59,491.34	1917.68	21,362.18	0.183
Total			−165.89	42,562.54	
ΔQ			0.004 m^3/s		

Pipe Network Analysis – Hardy Cross Method

Solution:

Pipe 5 is common to **Loop 1 and loop 2,** hence it will **take correction from both loops.**

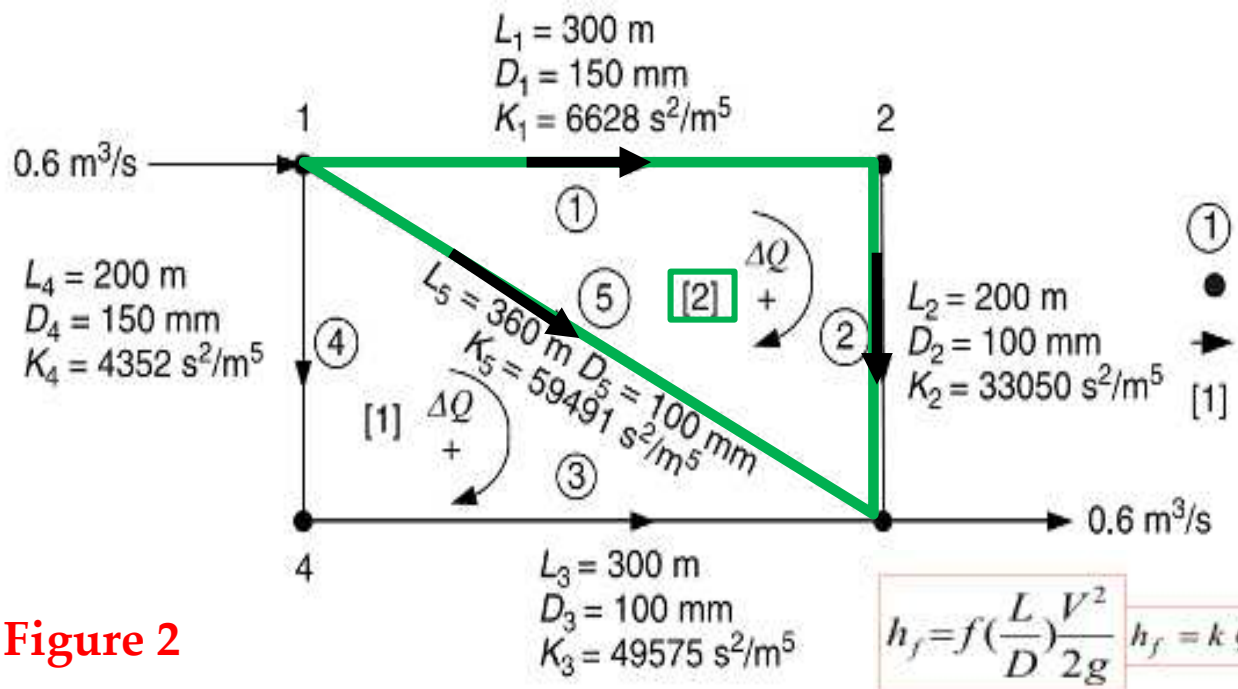


Figure 2

$$h_f = f\left(\frac{L}{D}\right)\frac{V^2}{2g} \qquad h_f = kQ^2 \qquad \Delta = \frac{-\sum h_f}{2\sum \frac{h_f}{Q}}$$

Loop 2: Iteration 4

Pipe	Flow in Pipe Q (m^3/s)	K (s^2/m^5)	h_f (m)	$2h_f/Q$ (s/m^2)	Corrected Flow $Q = Q + \Delta Q$ (m^3/s)
1	0.220	6528.54	316.13	2873.22	0.222
2	0.220	33,050.74	1600.39	14,545.68	0.222
5	−0.183	59,491.34	−2001.85	21,825.91	−0.181
Total			−85.33	39,244.81	
ΔQ			0.002 m^3/s		

Pipe Network Analysis – Hardy Cross Method

Solution:

Pipe 5 is common to **Loop 1 and loop 2,** hence it will **take correction from both loops.**

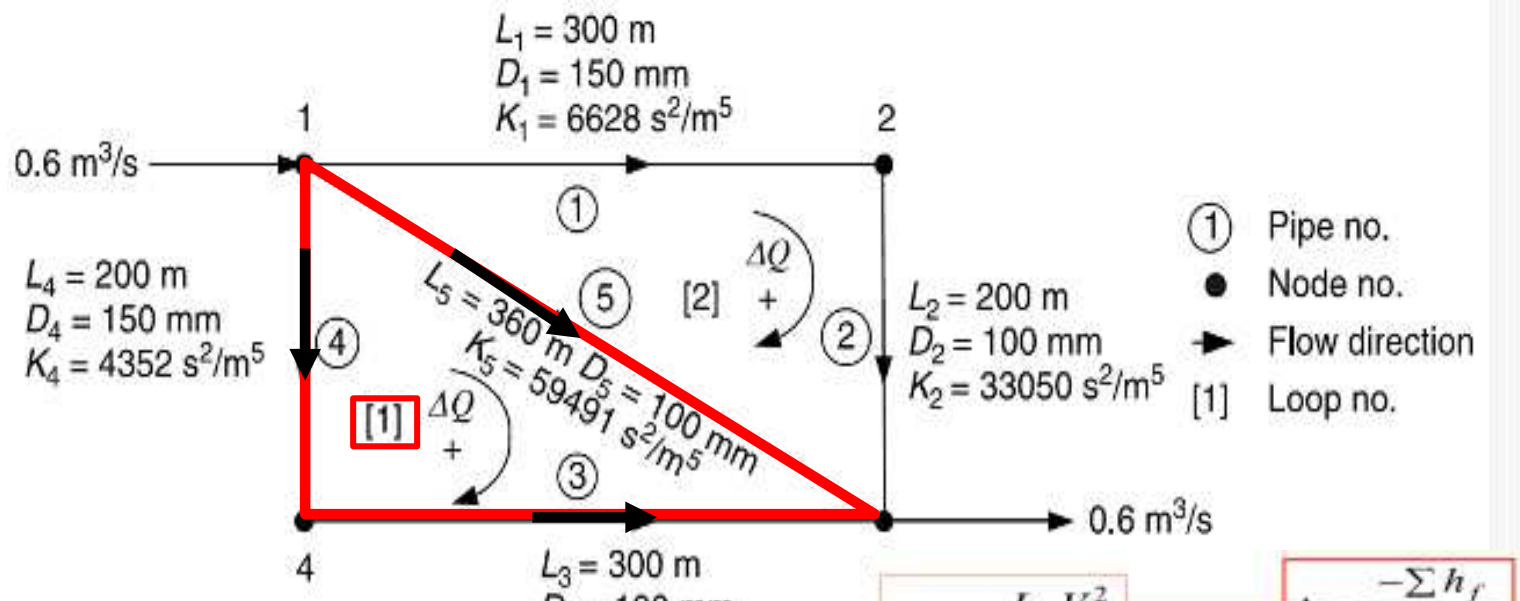


Figure 2

$$h_f = f\left(\frac{L}{D}\right)\frac{V^2}{2g} \qquad h_f = kQ^2 \qquad \Delta = \frac{-\sum h_f}{2\sum \frac{h_f}{Q}}$$

Loop 1: Iteration 5

Pipe	Flow in Pipe Q (m^3/s)	K (s^2/m^5)	h_f (m)	$2h_f/Q$ (s/m^2)	Corrected Flow $Q = Q + \Delta Q$ (m^3/s)
3	−0.193	49,576.12	−1840.21	19,102.92	−0.192
4	−0.193	4352.36	−161.55	1677.07	−0.192
5	0.181	59,491.34	1954.67	21,567.21	0.182
Total			−47.09	42,347.21	
ΔQ			0.001 m^3/s		

Pipe Network Analysis – Hardy Cross Method

Solution:

Pipe 5 is common to **Loop 1 and loop 2,** hence it will **take correction from both loops.**

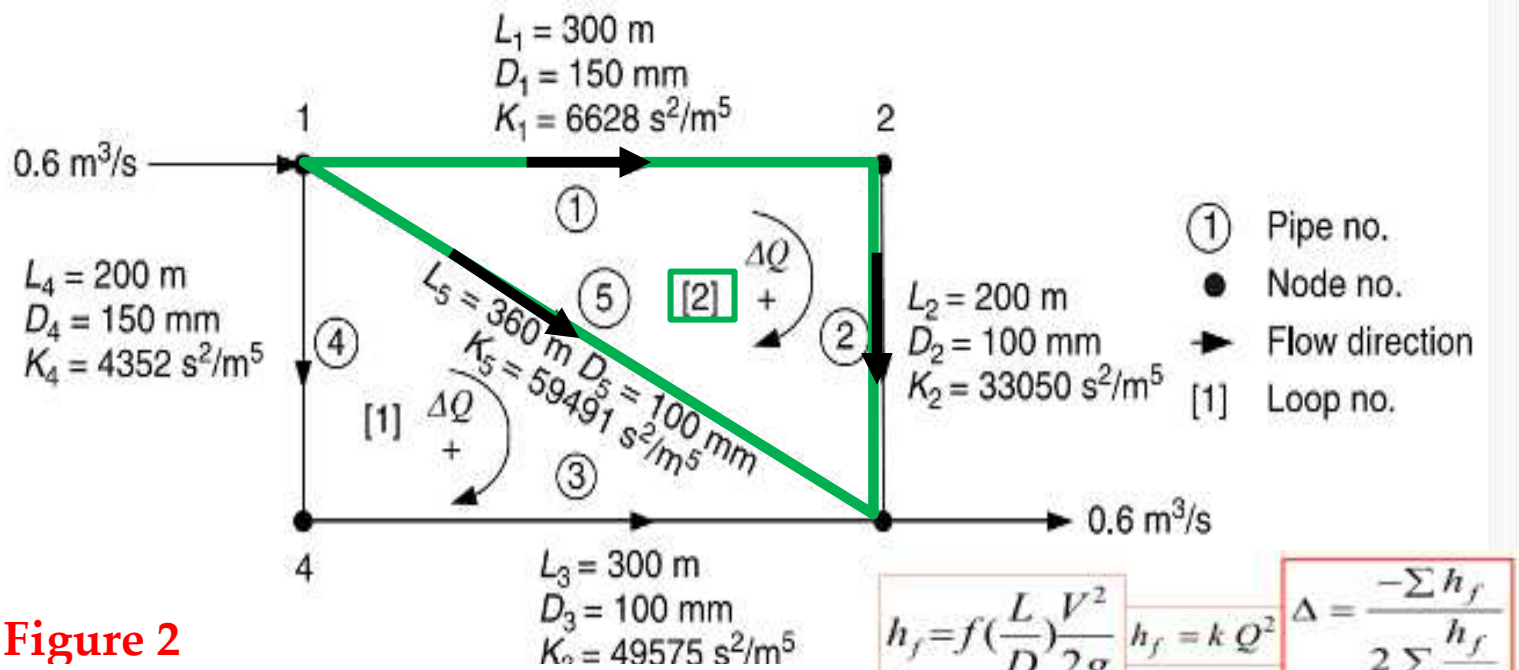


Figure 2

$$h_f = f\left(\frac{L}{D}\right)\frac{V^2}{2g} \qquad h_f = kQ^2 \qquad \Delta = \frac{-\sum h_f}{2\sum \frac{h_f}{Q}}$$

Loop 2: Iteration 5

Pipe	Flow in Pipe Q (m^3/s)	K (s^2/m^5)	h_f (m)	$2h_f/Q$ (s/m^2)	Corrected Flow $Q = Q + \Delta Q$ (m^3/s)
1	0.222	6528.54	322.40	2901.61	0.223
2	0.222	33,050.74	1632.17	14,689.40	0.223
5	-0.182	59,491.34	−1978.73	21,699.52	−0.182
Total			−24.15	39,290.53	
ΔQ			0.001 m^3/s		

Pipe Network Analysis – Hardy Cross Method

Solution:

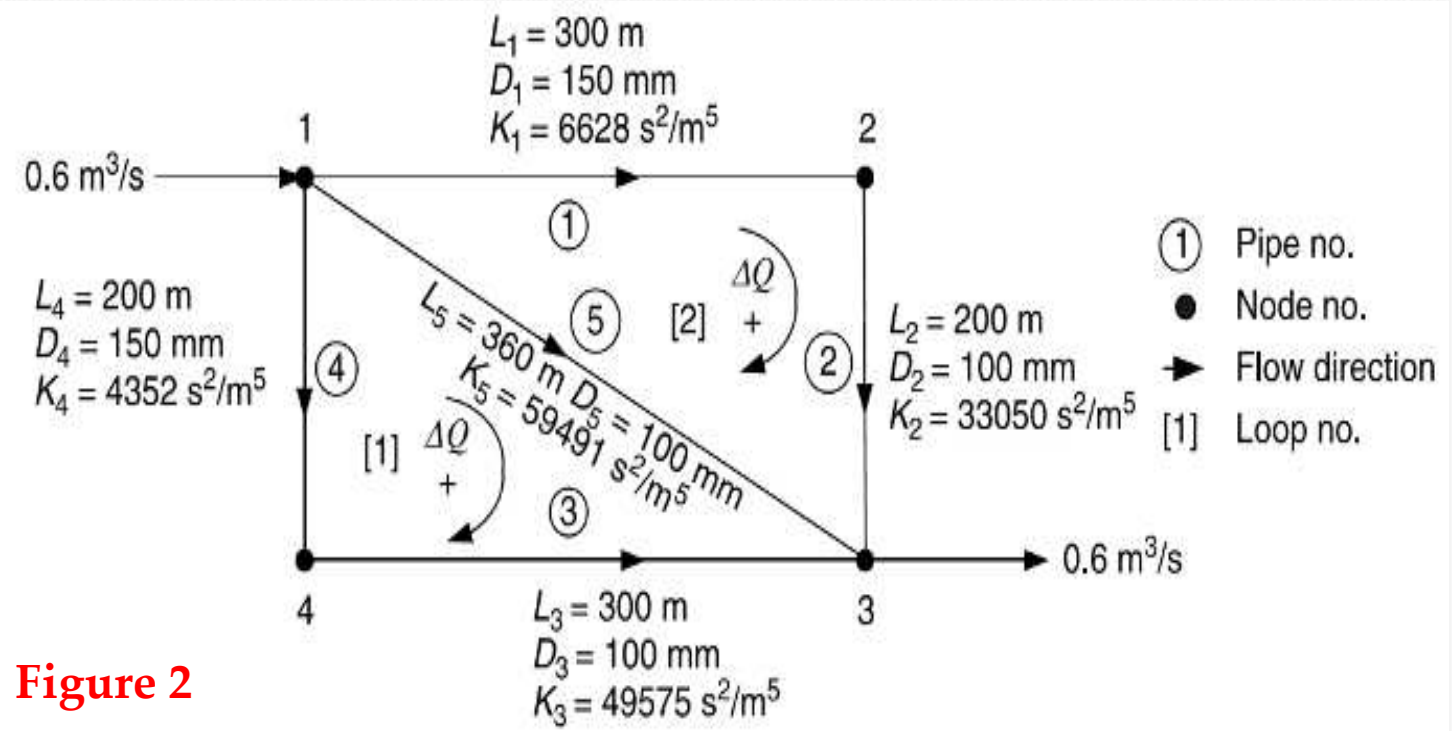


Figure 2

The discharge corrections in the loops are very small after five iterations, thus the final pipe discharges in the looped pipe network in Fig. 2 are -

$$Q_1 = 0.223\ \text{m}^3/\text{s}$$
$$Q_2 = 0.223\ \text{m}^3/\text{s}$$
$$Q_3 = 0.192\ \text{m}^3/\text{s}$$
$$Q_4 = 0.192\ \text{m}^3/\text{s}$$
$$Q_5 = 0.182\ \text{m}^3/\text{s}$$

EWCE 331
Water Supply Engineering

Lecture 6

Instructor

Lt Col Dr. Kazi Shamima Akter, Engrs

Department of EWCE, MIST

Lecture outline

Water Quality Requirements

Topics	References
• **Water impurities** • **Water quality requirements/ standards**	**1. Water and Environmental Engineering** Authors: M. Habibur Rahman, Abdullah Al-Muyeed 1st ed., ITN-BUET **2. Environmental Engineering** Authors: Howard S. Peavy, Donald R. Rowe and George Tchobanoglous International Edition, McGraw Hill Companies **2. Water Supply and Sanitation** Authors: M. Feroz Ahmed, Md. Mujibur Rahman 1st ed., ITN-BUET

Water Impurities

- Pure water is not available in nature nor it is desirable for water supply.

- The impurities present in natural water may be grouped into following categories:
  - ✓ Impurities of mineral origin
  - ✓ Impurities of organic origin
  - ✓ Living impurities
  - ✓ Radioactive impurities

- These impurities may be present in suspensions, solution or pseudo-solution.

Water Impurities

Table 17.4: Effect of impurities present in water

Impurities	Effect on water	Effect on health
Living impurities		
Bacteria	Turbidity at high concentrations	Diseases,
Viruses	--	Diseases
Algae, protozoa, fungi	Turbidity, odour, colour,	Diseases, toxicity
Impurities of mineral & organic origin		
Silt and clay	Turbidity	--
Salt or calcium and magnesium	Hardness, alkalinity, taste, corrosiveness and scale formation	--
Salt of Sodium	Alkalinity, salinity, foaming, taste, scaling,	--
Salt of Sodium	--	Tooth decay
Fluorides	Algal growth	Child disease
Nitrate	Taste, hardness, scaling	--
Iron and manganese	--	Toxicity, diseases
Arsenic, lead, heavy metals	Colour, acidity	Diseases
Vegetable dyes		
Gases		
• Oxygen	Corrosiveness, taste	--
• Carbon dioxide	Acidity, corrosiveness	--
• Hydrogen sulphide	Odour, corrosiveness, acidity	Toxicity
Radioactive impurities	--	Diseases

Water Impurities

- Some of the water quality parameters respond to human senses of sight (turbidity, color), taste (salty, offensive) and smell (odor).

- The presence of pathogens and poisons in drinking water cannot be identified by human senses. These are of greater importance in water supply.

Basic Requirement of Drinking Water

- Be completely free of pathogenic microorganisms that can cause diseases
- Contain no element or compound in concentrations that can cause acute or long term adverse effect on human health
- Be fairly clear and aesthetically acceptable i.e. low turbidity and color

Basic Requirement of Drinking Water

- Not be saline to cause salty taste
- Contain no compounds that can cause an offensive taste and odor
- Not cause corrosion, scale formation discoloration or staining
- Not have a temperature unacceptable to the consumers

Water Impurities – Bacteriological Quality of Water

- The most important parameter of drinking water quality is the bacteriological quality, i.e. presence of pathogens.

- The water-borne diseases are caused by the ingestion of pathogens with drinking water.

- In water supply, the water is examined for specific type of bacteria (*indicator organism*), originating in large numbers from human and animal excreta and whose presence in water is indicative of fecal contamination.

Terminology

- **Potable Water** –
  - ✓ the water which is physically, chemically and bacteriologically acceptable to use.



- **Palatable Water** –
  - ✓ the water is free from turbidity, color, taste, odor and with moderate temperature.
  - ✓ Palatable water is physically acceptable, but not necessary to be accepted as chemically or bacteriologically.



Water Quality Parameters - **pH**

- pH expresses the intensity of the acid or alkaline condition of a solution.

- pH is a measure of the concentration of free hydrogen ions (H^+) in water and expressed as pH = - log (H^+).

- pH of an aqueous system is a measure of acid-base equilibrium achieved by various dissolved compounds and in most natural waters, is controlled by CO_2-HCO_3-CO_3 equilibrium system.

Water Quality Parameters - **pH**

Significance of pH

- pH is important for coagulation, disinfection, water softening and corrosion control.

- In biological treatment of water, pH is very important as the organisms involve din treatment processes operate within a certain pH range.

- Dissolution and mobility of metal in natural waters are also greatly influenced by the pH of the water.

- Drinking water standard for pH is 6.5-8.5.

Water Quality Parameters - **Color**

Source of color

- Color in water is primarily due to the presence of colored organic substances 9humic acids), metals such as Fe, Mn or highly colored industrial wastes (e.g. from pulp and paper and textile industries).

- Limiting the color in potable water means limiting the concentration of undesirable substances that are complexed with or absorbed onto humic substances.

Water Quality Parameters - **Color**

Apparent color

- Caused by suspended matter
- Can be removed by centrifugation or filtration.

True color

- Caused by dissolved matter
- One True Color Unit (TCU) corresponds to the amount of color exhibited under the specific test conditions by a solution containing 1.0 mg of Pt per liter of water in the from of chloroplatinate ion.

Water Quality Parameters - **Turbidity**

Significance of color

- Colored water is not acceptable by the consumers for aesthetic reasons.

- Bangladesh standard and WHO standard for color in drinking water is 15 TCU.

Water Quality Parameters - **Turbidity**

Sources of turbidity

- Turbidity occurs in most surface water due to the presence of suspended clay, silt, finely divided organic and inorganic matters, plankton (algae) and microorganisms.

- Turbidity is an expression of certain light scattering and light absorbing properties of a water sample and depend in a complex manner, on such factors as the number, size, shape and refractive index of the particulate matter present in the water.

Water Quality Parameters - **Turbidity**

Measurement of turbidity

- Current standard method for measurement of turbidity employs the principle of nephelometry and measures the scattering of light from the particles causing turbidity.

- Results are expressed in nephelometric units (NTU).

Water Quality Parameters - **Turbidity**

Significance of turbidity

- A turbidity in excess of 5 NTU is generally objectionable to consumers.

- A turbid water protects microorganisms from disinfectants and hence reduces the effectiveness of disinfection process.

- Turbidity stimulates bacterial growth and exert a significant chlorine demand.

Water Quality Parameters – **Total Dissolved Solids**

- TDS comprises inorganic salts and small amounts of organic matter.

Significance of TDS

- The common dissolved mineral salts are claimed to affect the taste, hardness, corrosion and encrustation.

- Dissolved inorganic substances may exert adverse effects on aquatic animals and plants and may cause irrigation problem.

Water Quality Parameters – **Total Dissolved Solids**

Significance of TDS

- In general, water with total solid content of less than 500 mg/L are most desirable for domestic purpose.

- Water with a higher solid content often have a laxative and sometimes the reverse effects on people.
- Depending on TDS, water can be classified as:
  - ✓ Excellent — TDS < 300 mg/L
  - ✓ Good — 300 - 600 mg/L
  - ✓ Fair — 600 - 900 mg/L
  - ✓ Poor — 900 - 1200 mg/L
  - ✓ Unacceptable — TDS > 1200 mg/L

Water Quality Parameters – **Alkalinity**

- Alkalinity of water is a measure of its capacity to neutralize acids.

Sources of Alkalinity

- Alkalinity is due primarily to salts of weak acids and strong bases.

- Such substances act a s buffers to resist a drop in pH resulting from acidic condition.

- Alkalinity is a measure of the buffer capacity.

Water Quality Parameters – **Alkalinity**

- Most of the alkalinity in natural water is caused by three major classes of materials:
  - ✓ HCO_3^-
  - ✓ CO_3^{2-}
  - ✓ OH^-

- HCO3- represents the most common form of alkalinity since they are formed, in large quantities, from the action of CO_2 upon basic materials in the soil.

- Excessive or insufficient alkalinity interferes with water treatment (coagulation).

Water Quality Parameters – **Hardness**

- Hard waters are generally considered to be those waters –
  - ✓ that require considerable amounts of soap to produce a foam or lather and
  - ✓that also produce scale in hot-water pipes, heaters, boilers, and other units in which the temperature of water is increased substantially.

Water Quality Parameters – **Hardness**

Sources of Hardness

- Hardness is caused by multivalent metallic cations.
- Such cations are capable of reacting with soap to form precipitates and with certain anions present in water to form scale.
- The principal hardness causing cations are the divalent calcium, magnesium, strontium, ferrous iron, and manganous ions.

Water Quality Parameters – **Hardness**

- Hard water generally originates in –
  - ✓ areas with thick topsoil and limestone formations
  - ✓ groundwater rich in H_2CO_3 and DO.

- Groundwater is generally harder than surface water.

Water Quality Parameters – **Hardness**

Significance of Hardness

- Hard water consume too much soap
- It clogs skin, discolors porcelain, make stains, shorten fabrics
- Toughens and discolors vegetables and cooked foods
- Cardiovascular death rates are inversely correlated to hardness of water

Water Quality Parameters – **Hardness**

Significance of Hardness

- Soft water cause corrosion of pipes

- A hardness level of about 100 mg/L of $CaCO_3$ provides a n acceptable balance between corrosion and encrustation.

- Bangladesh drinking water quality standard recommends hardness between 200-5000 mg/L, based on taste and household use consideration.

Water Quality Parameters – **Chloride**

- Chloride is widely distributed in nature in the form of NaCl, KCl and $CaCl_2$.
- Taste thresholds for chlorides are in the range of 200-300 mg/L.
- High chloride concentration is corrosive to metals in the water distribution system, particularly in water of low alkalinity.
- A higher chloride content in inland water usually indicates sewage pollution.

Water Quality Parameters – Iron

Sources of Iron

- Dissolution of rocks and minerals, acid mine drainage, landfill lechates, sewage or discharge from iron-related industries.

Significance of Iron

- Iron in surface water is generally present in Fe(III) state.
- Causes hardness, undesirable taste in beverages, staining of clothes and plumbing fixtures, encrustation in water mains and may impart a reddish brown color to water.

Water Quality Parameters – **Arsenic**

Sources of Arsenic (As)

- Most of the As found in water derives from geological formations, industrial discharge, mining operations, use of arsenical insecticides and combustion of fossil fuel.

Significance of Arsenic (As)

- Many As compound are water soluble and thus cause contamination of water.

- The toxicity of As depends on chemical and physical form of As compounds, the route through which it enters the body, the dose and duration of exposure etc.

Water Quality Parameters – **Arsenic**

Significance of Arsenic (As)

- Inorganic As is more toxic than the organic ones.
- As (III) is more hazardous than As (V).
- Severe poisoning may arise from ingestion of arsenic as little as 100 mg arsenic trioxide.
- Chronic effects may result fro accumulation of As in body in low intake level.

Water Quality Parameters – **Arsenic**

Significance of Arsenic (As)

- The recommended allowable limit of As is 0.05 mg/L in Bangladesh.

- As concentration in excess of allowable limit has been found in shallow tubewells of many locations in Bangladesh.

Microbiological Quality Parameters – **TC and FC**

Total Coliform (TC)

- Total coliform bacteria are a collection of relatively harmless microorganisms that live in large numbers in soils, plants and in intestines of warm-blooded animals.

- Coliform aid in the digestion of food.

- There are 16 species of total coliform found in soils, plants and in animal and human waste.

- Characterized broadly by their ability to ferment lactose in culture at 35°C ~ 37°C with the production of acid, gas and aldehyde within 24 or 48 hours

Microbiological Quality Parameters – **TC and FC**

Total Coliform (TC)

- Total coliforms are to be monitored because their presence above the standard indicates problems in treatment or in the distribution system.

- If total coliforms are found, then the public water system must further be analyzed for the total coliform-positive samples to determine whether specific types of coliforms (i.e., fecal coliforms or E. coli) are present or not.

Microbiological Quality Parameters – **TC and FC**

Fecal Coliform (FC)

- A subgroup of total coliform, called fecal coliform bacteria, can grow at higher temperatures and are found only in the fecal waste of warm-blooded animals.

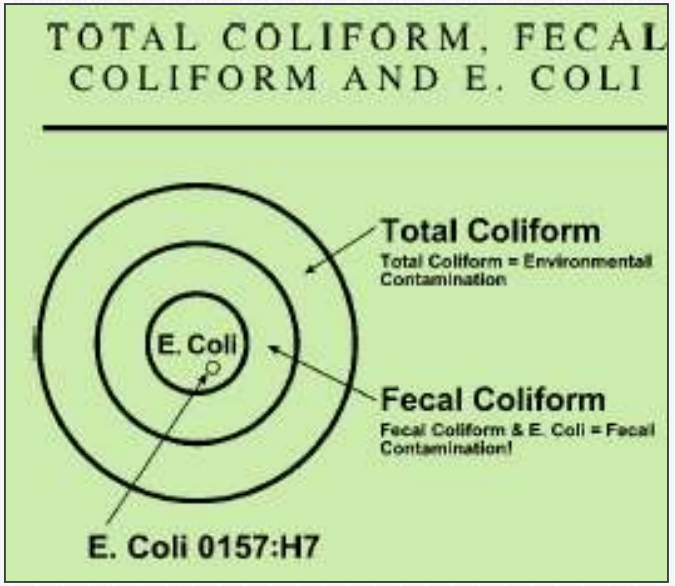
- E. coli is one of the six species of fecal coliform bacteria found in animal and human waste.

- Characterized broadly by their ability to ferment lactose in culture at 44°C ~ 44.5°C.

Microbiological Quality Parameters – TC and FC

Fecal Coliform (FC) – E. Coli

- E. coli is a sub-group of the fecal coliform group.



- Most E. coli bacteria are harmless and are found in great quantities in the intestines of people and warm-blooded animals. Some strains, however, can cause illness.

- The presence of E. coli in a drinking water sample almost always indicates recent fecal contamination, meaning there is a greater risk that pathogens are present.

Water Quality Standards

- Water for public water supplies should be drawn from the best available source for cost effective treatment of water.
- The degree and method of treatment to make water potable and acceptable to the consumers depend on the characteristics of the raw water.
- Waters containing hazardous and toxic substances require special and more expensive treatment.

Water Quality Standards

Table 17.7: Drinking water standards

Water quality parameters	Unit	Bangladesh standards	WHO guideline values, 2004
1. Aluminum	mg/l	0.2	0.2**
2. Ammonia (NH_3)	mg/l	0.5	1.5**
3. Arsenic	mg/l	0.05	0.01
4. Barium	mg/l	0.01	0.7
5. Benzene	mg/l	0.01	0.01
6. BOD_5 20°C	mg/l	0.2	
7. Boron	mg/l	1.0	0.5
8. Cadmium	mg/l	0.005	0.003
9. Calcium	mg/l	75	
10. Chloride	mg/l	150-600*	250**
11. Chlorinated alkenes			
Carbon tetrachloride	mg/l	0.01	0.004
1,1 Dichloroethylene	mg/l	0.001	
1,2 Dichloroethane	mg/l	0.03	0.03
Tetrachloroehylene	mg/l	0.03	
Trichloroethylene	mg/l	0.09	
12. Chlorinated phenols			
Pentachlorophenol	mg/l	0.03	
2, 4, 6 Trichlorophenol	mg/l	0.03	0.2
13. Chlorine (residual)	mg/l	0.2	0.6-1.0
14. Chloroform	mg/l	0.09	0.2
15. Chromium (hexavalent)	mg/l	0.05	
16. Chromium (total)	mg/l	0.05	0.05
17. Chemical oxygen demand)	mg/l	4	
18. Coliform (faecal)	N/100ml	0	0
19. Coliform (total)	N/100ml	0	0
20. Colour	Hazen Unit	15	15
21. Copper	mg/l	1	2
22. Cyanide	mg/l	0.1	0.07
23. Detergents	mg/l	0.2	
24. Dissolved oxygen	mg/l	6	
25. Flouride	mg/l	1	1.5
26. Hardness (as $CaCO_3$)	mg/l	200-500	

Water Quality Standards

Table 17.7: Drinking water standards

Water quality parameters	Unit	Bangladesh standards	WHO guideline values, 2004
27. Iron	mg/l	0.3-1.0	0.3**
28. Kjehldal nitrogen (total)	mg/l	1	
29. Lead	mg/l	0.05	0.01
30. Magnesium	mg/l	30-35	
31. Manganese	mg/l	0.1	0.4; 0.1***
32. Mercury	mg/l	0.001	0.001
33. Nickel	mg/l	0.1	0.02
34. Nitrate	mg/l	10	50
35. Nitrite	mg/l	<1	3
36. Odour	mg/l	Odourless	
37. Oil and grease	mg/l	0.01	
38. pH	—	6.5-8.5	
39. Phenolic compounds	mg/l	0.002	
40. Phosphate	mg/l	6	
41. Phosphorus	mg/l	0	
42. Potassium	mg/l	12	
43. Radioactive substances			
Total alfa radiation	Bq/l	0.01	
Total beta radiation	Bq/l	0.1	
44. Selenium	mg/l	0.01	0.01
45. Silver	mg/l	0.02	
46. Sodium	mg/l	200	200**
47. Suspended solids	mg/l	10	
48. Sulphide	mg/l	0	
49. Sulphate	mg/l	400	250**
50. Total dissolved solids	mg/l	1000	1000**
51. Temperature	°C	20-30	
52. Tin	mg/l	2	
53. Turbidity	JTU	10	5
54. Zinc	mg/l	5	3**

* For Coastal Areas of Bangladesh, in case of non-availability of alternative sources value is 1000.
** Value designated only for aesthetic purposes; No health-based guideline value is proposed.
*** Value designated for aesthetic purposes.

Water Quality Standards

Table 17.6: Bangladesh water quality standards for surface water for water supply

Water quality parameters	Unit	Values for water supply by	
		Disinfection only	Conventional treatment
PH	—	6.5 - 8.5	6.5 - 8.5
Biochemical oxygen demand	mg/l	2 or less	3 or less
Dissolved oxygen	mg/l	6 or more	6 or more
Total coliform	number/100ml	50 or less	5,000 or less

EWCE 331
Water Supply Engineering

Lecture 7

Instructor

Lt Col Dr. Kazi Shamima Akter, Engrs

Department of EWCE, MIST

Lecture outline

Water Treatment Methods

Topics	References
• **Preliminary Treatment methods** ✓ **Plain Sedimentation** ✓ **Coagulation** ✓ **Flocculation** ✓ **Filtration** ✓ **Disinfection**	**1. Water and Environmental Engineering** Authors: M. Habibur Rahman, Abdullah Al-Muyeed 1st ed., ITN-BUET **2. Environmental Engineering** Authors: Howard S. Peavy, Donald R. Rowe and George Tchobanoglous International Edition, McGraw Hill Companies **2. Water Supply and Sanitation** Authors: M. Feroz Ahmed, Md. Mujibur Rahman 1st ed., ITN-BUET

Objectives of Water Treatment

- To produce an adequate and continuous supply of water that is chemically, bacteriologically and aesthetically pleasing.

- More specifically, water treatment must produce water that is:
  - ✓ Palatable – having no unpleasant taste
  - ✓ Safe – not containing any pathogenic organisms or chemical that could be harmful to the users.
  - ✓ Clear – be free from suspended matter and turbidity
  - ✓ Colorless and odorless

Objectives of Water Treatment

✓ Reasonably soft – to allow consumers to wash clothes, dishes and themselves without excessive use of detergent or soap.

✓ Non-corrosive



✓ Low in organic content – a high organic content will encourage unwanted biological growth in pipe or storage tanks, which can affect the quality of the water supplied.

Objectives of Conventional Drinking Water Treatment

Primary objectives are removal of –

- Microbial pathogens (coliforms) – health concerns
- Particles (color and turbidity) – health and aesthetic concerns
- Total dissolved solids removal (hard waters) – health and aesthetic concerns

Objectives of Conventional Drinking Water Treatment

Secondary objectives are removal of dissolved pollutants – health concerns

- **General**: Odor, taste, pH

- **Inorganic** - Hardness, Alkalinity, Fe, Cl, F, Ca, Mg, Cu, Mn, SO_4^{2-},NO_3^-, Hg, Cd, Se, As, CN, Pb, Zn, Cr(VI), Al, B, radioactive materials, residual free chlorine, TDS

- **Organic** - Natural Organic Matter (NOM), Pesticides, Oils, PAHs, Anionic detergents, Phenols

Consideration for Water Treatment – **Surface Water Source**

General characteristics of surface water



- High turbidity and microbial concentrations

- Dissolved oxygen concentrations vary depending on organic matter concentrations





Consideration for Water Treatment – **Ground Water Source**

Characteristics of GW water compared to SW

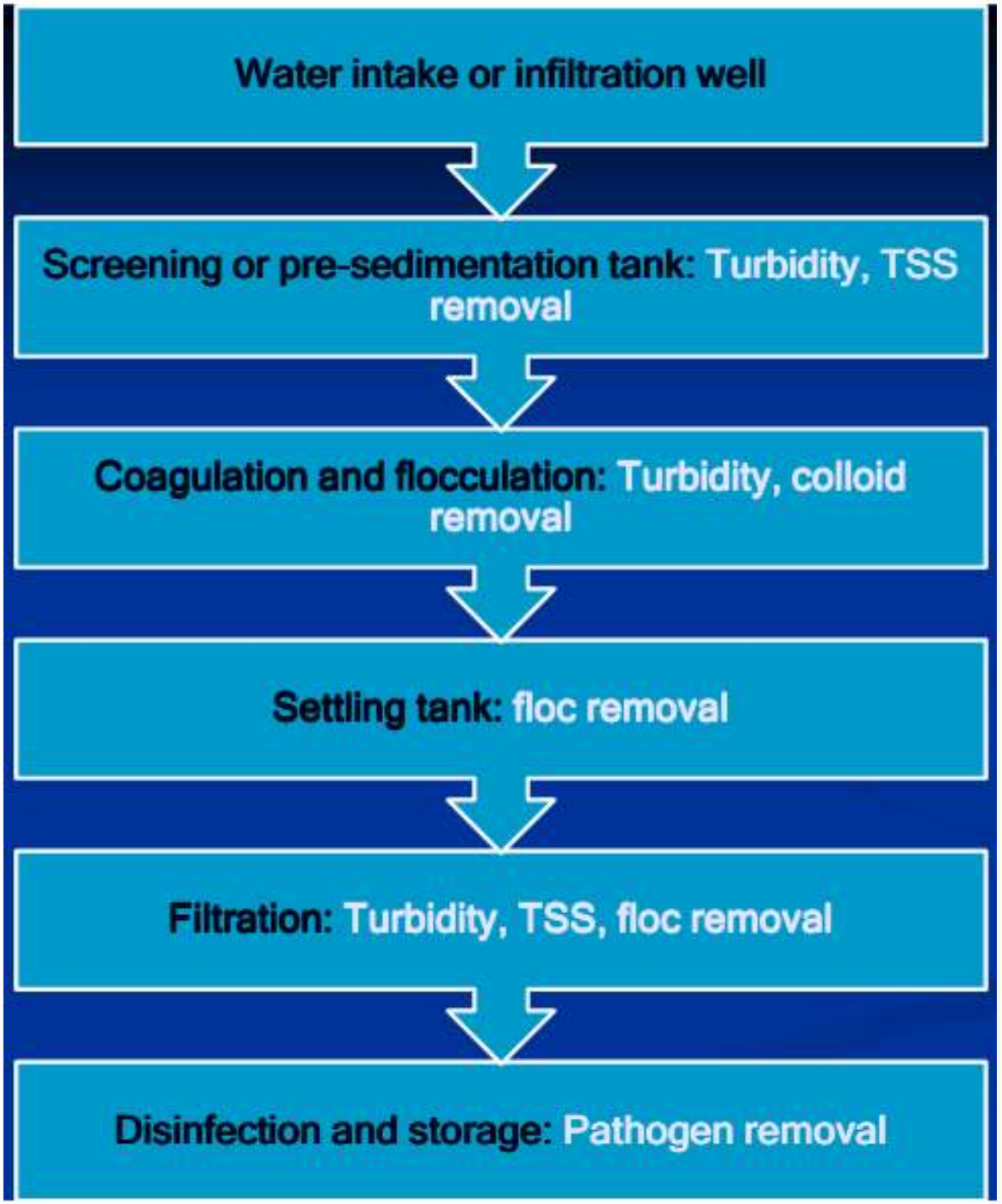
- Lower dissolved oxygen compared to waters.
- Can have very little microbial contamination especially if GW is from a deep aquifer.
- Much higher concentrations of inorganic compounds (or ions).
- **Anions**: chloride, carbonates, sulfates (or sulfides), bromide, nitrates, fluorides, arsenite [As(III)] and arsenate [As(V)]
- **Cations**: Ca, Mg, Fe, Mn, Al, As, (Hardness is the concentration of Ca and Mg in GW)

Consideration for **Water Source Characteristics**

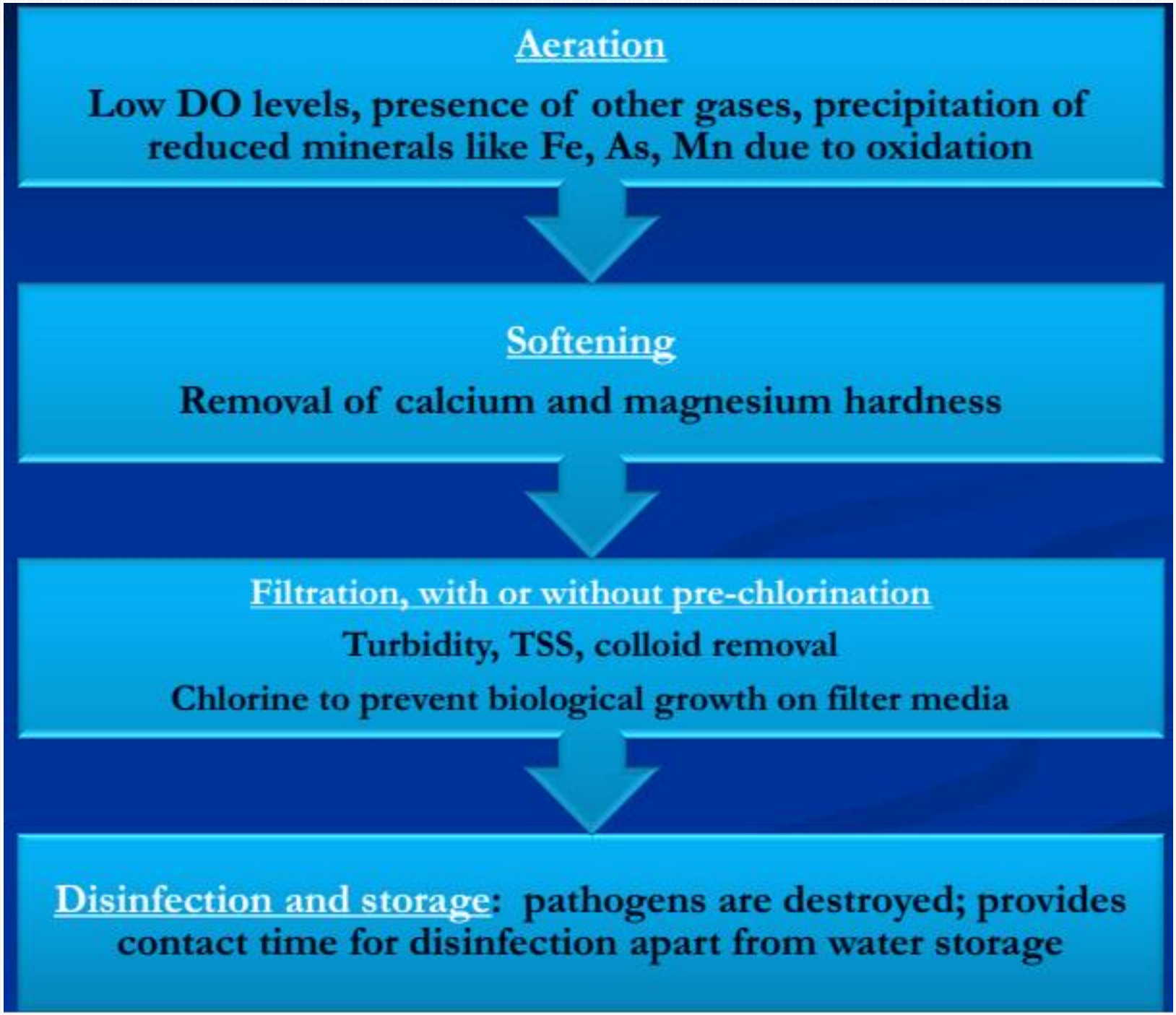
Groundwater	Surface water
• constant composition	• variable composition
• high mineral content	• low mineral content
• low turbidity	• high turbidity
• low color	• colored
• low or no D.O.	• D.O. present
• high hardness	• low hardness
• high Fe, Mn	• taste and odor

Source: Davis and Cornwell, 2008

Surface Water Treatment Scheme

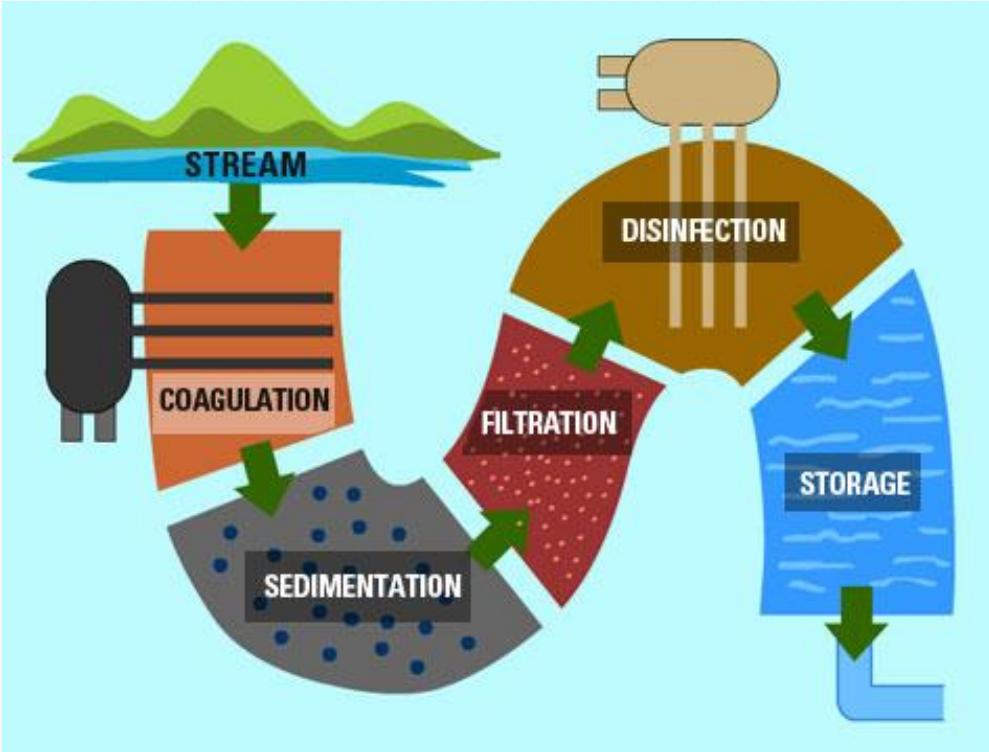


Ground Water Treatment Scheme



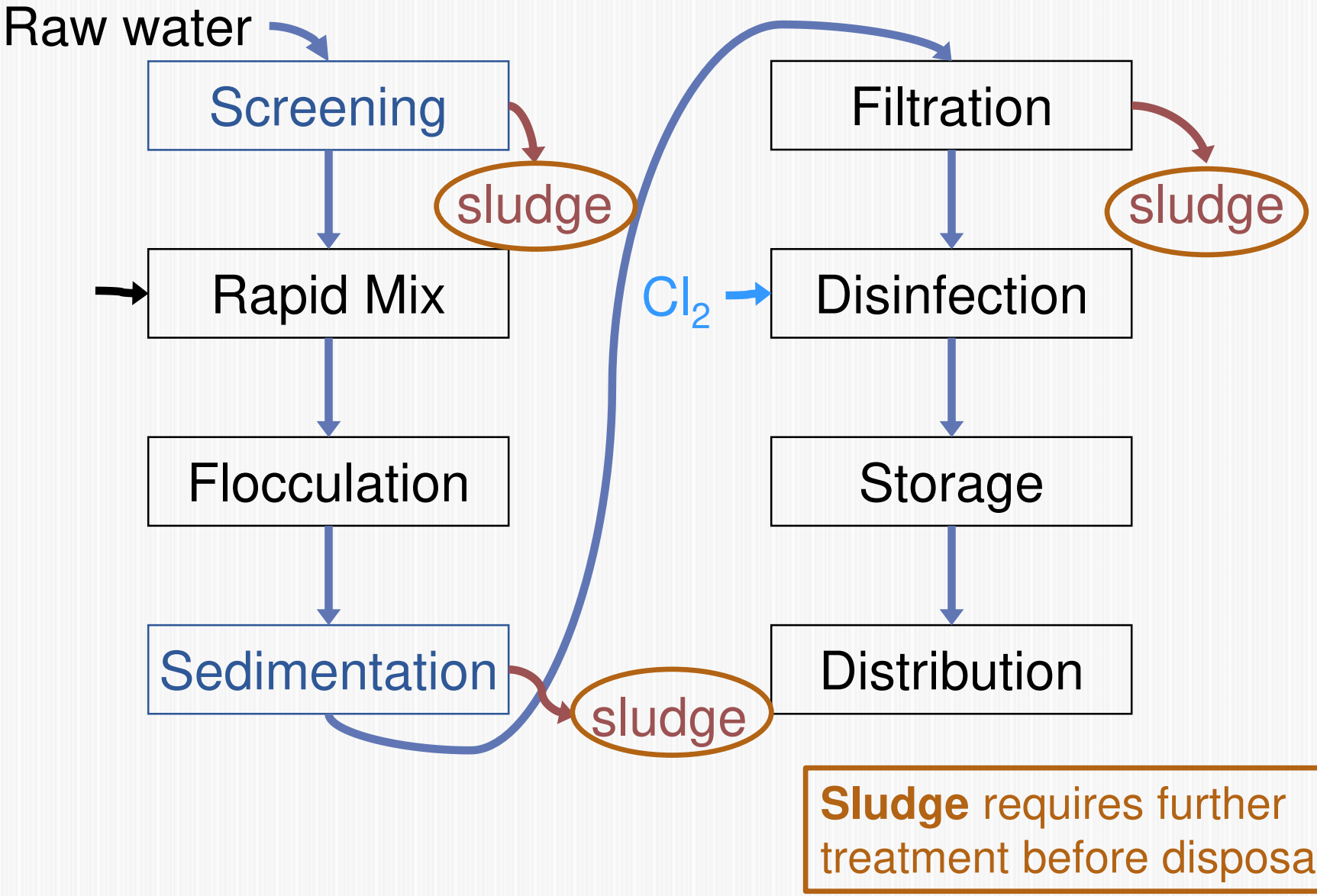
Conventional Water Treatment Unit Processes

Unit process: a process that is used in similar ways in many different applications



- **Preliminary Treatment**
  - ✓ Screening
  - ✓ Pre-sedimentation
  - ✓ Aeration
  - ✓ Monitoring (pH, temperature correction)
- **Primary Treatment**
  - ✓Coagulation and flocculation
  - ✓ Primary Sedimentation
  - ✓ Pre-chlorination and de-chlorination
  - ✓ Filtration
  - ✓ Disinfection
  - ✓ pH adjustment

Conventional Surface Water Treatment & Supply



Preliminary Water Treatment

- Preliminary treatment is **any physical, chemical or mechanical process** used on water before it undergoes the main treatment process.

- The purpose of preliminary treatment processes is **to remove any materials which will interfere with further treatment**.

- **Pretreatment** may include **screening, presedimentation, chemical addition, flow measurement, and aeration**.

Preliminary Water Treatment - **Screening**

- The screens are used **to remove rocks, sticks, leaves, and other debris.**

- Very small screens can be used to **screen out algae in the water**.

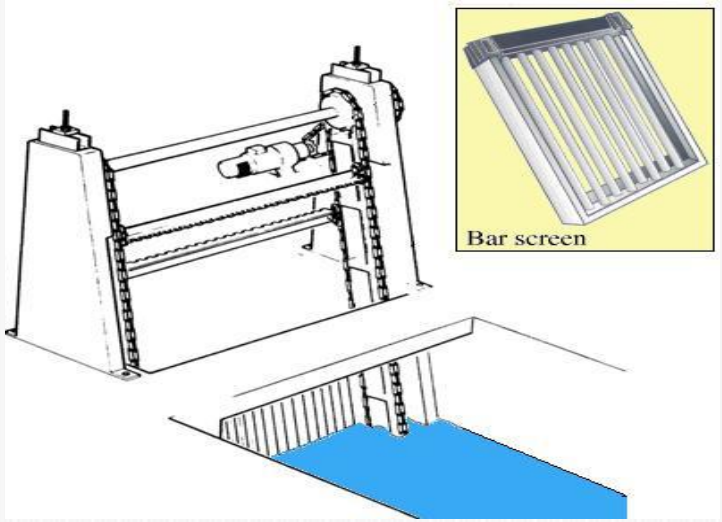
- All objects are removed by physical size separation.

- Screens on the outside of intakes are often cleaned by flushing water from the treatment plant backwards.

- There are two primary types of screens - bar screens and wire-mesh screens.

Preliminary Water Treatment - **Screening**

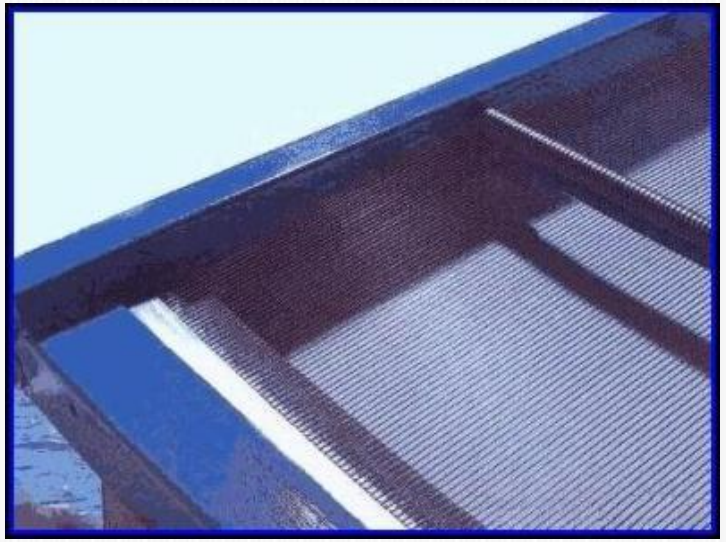
• A bar screen is used to remove large debris. The spaces between the bars are 2"- 4" inches wide.



A bar screen

• A wire-mesh screen is used to remove smaller debris. The gaps are about 1/2" wide.

• Water must be flowing slowly in order to pass through a wire-mesh screen - velocities should be no greater than 3.5 inches per second.



A wire-mesh screen

Preliminary Water Treatment - **Screening**



Bar screen



Fine screens

Preliminary Water Treatment – **Pre-sedimentation**

• **Pre-sedimentation** is to settle out sand, grit, and gravel which will settle rapidly out of the water without the addition of chemicals at the beginning of the treatment process.

• It depends on gravity and includes no coagulation and flocculation.

• It will reduce the load on the coagulation/flocculation basin and on the sedimentation chamber, as well as reducing the volume of coagulant chemicals required to treat the water.

Preliminary Water Treatment – **Pre-sedimentation**

- Pre-sedimentation basins are useful because raw water entering the plant from such a basin is usually more uniform in quality than water entering the plant without such a holding basin.

- The purpose of this process is to make the chemical treatment phase of the water treatment process more efficient by removing sediment from the raw water.

- In pre-sedimentation basin, activated carbon may be added to the basin for taste, odor, and color problems, and some chemicals to control the growth of algae.

Preliminary Water Treatment – **Aeration**

- **Aeration** removes carbon dioxide and hydrogen sulfide from the water.

- It also oxidizes the iron and manganese.

- Aeration is necessary for GWs that are anoxic.

- Aeration causes oxidation of reduced forms of Fe(II) to Fe(III) and Mn(II) to Mn(IV)

- For As-contaminated water, it can result in substantial removal of As, too

- Types of aerators: cascade, fountain, tray, diffuser

Preliminary Water Treatment – **Aeration**

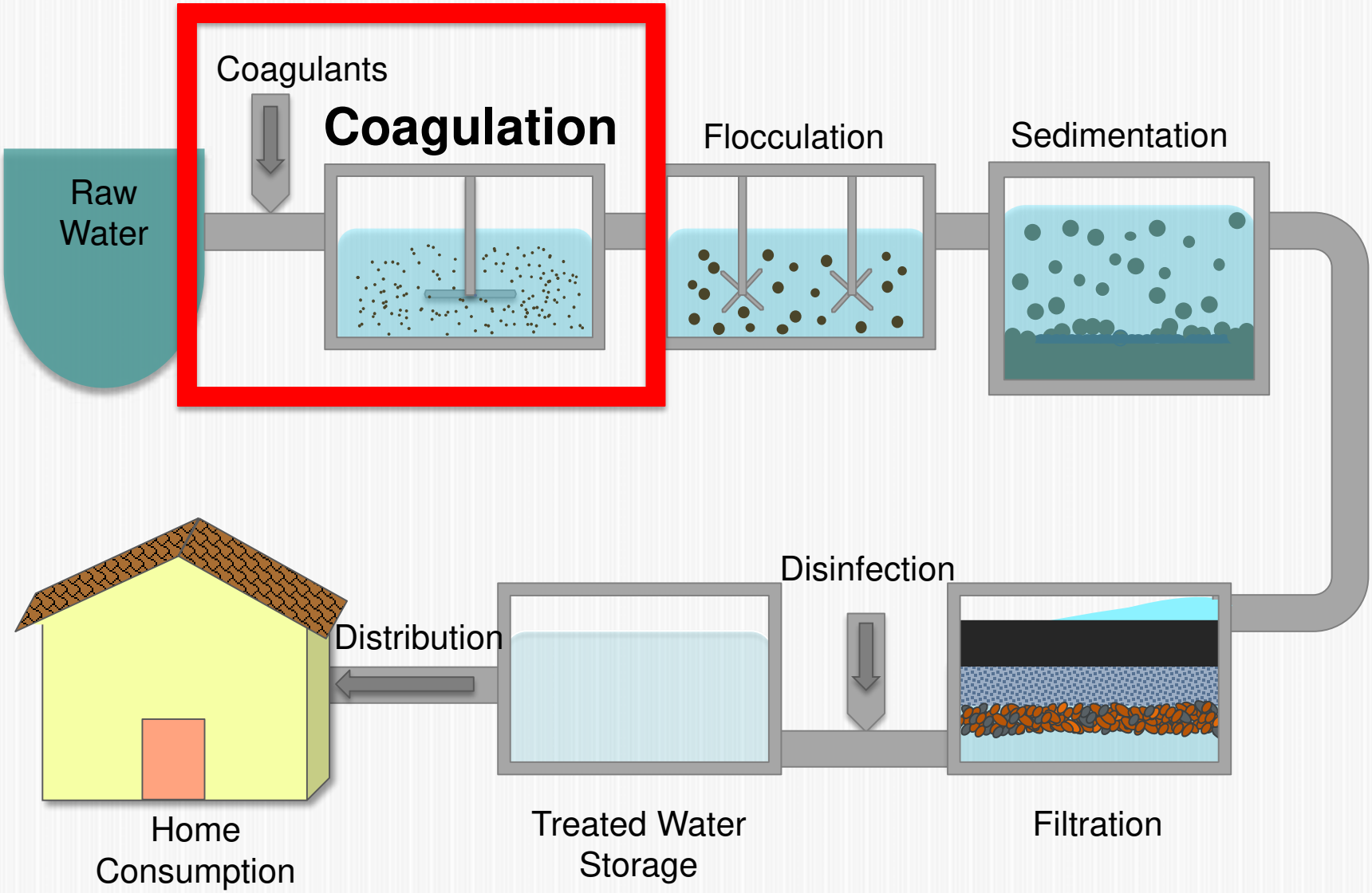
Aeration causes better dissolution of oxygen into the water which remove –

- ✓ smell and taste,
- ✓ promote helpful bacteria to grow,
- ✓ precipitate nuisance metals like iron and manganese.





Water Treatment Process - **Coagulation**



Water Treatment – **Coagulation**

Objectives of Coagulation process –

- The finest particles, such as colloidal minerals, bacteria, and pollen do not settle in the raw water.

- Removal of this colloidal particles is necessary:

✓ to give the finished water a clear appearance

✓ because they contain viruses and bacteria that are resistant to later disinfection process.

Water Treatment – **Coagulation**

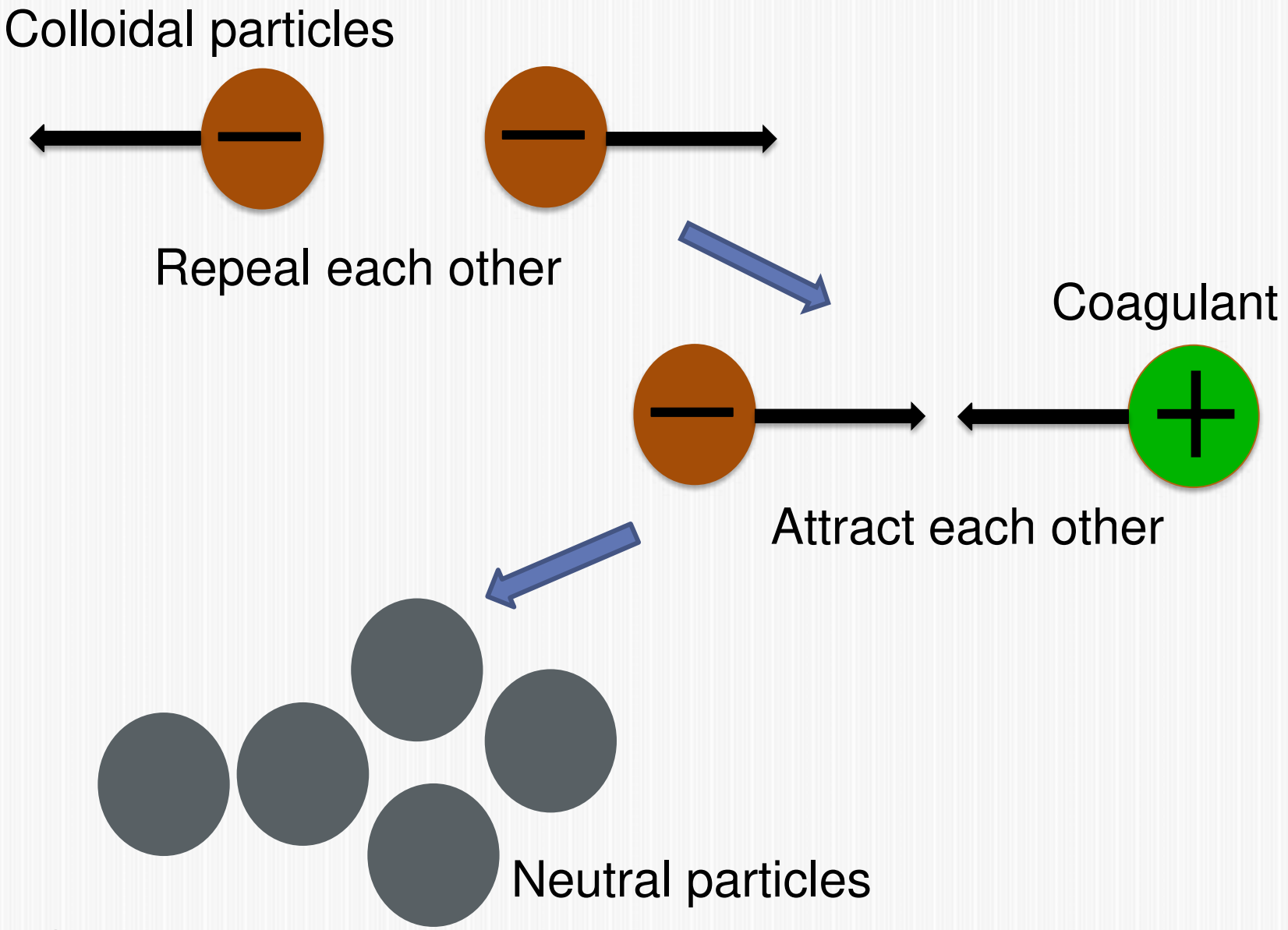
- Coagulation is the process of –

  ✓ addition of a salt that produces positive ions in water

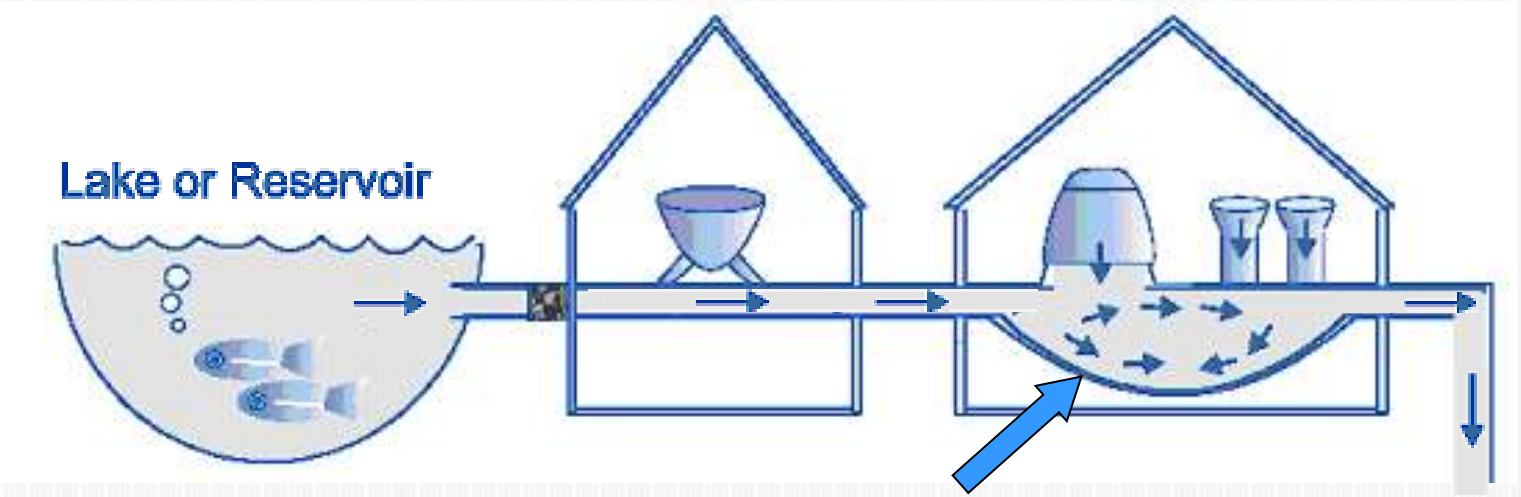
  ✓ rapid mixing leading to destabilization of colloids

  ✓ promotion of frequent contact among the particles.

Water Treatment – **Coagulation Principle**



Water Treatment – **Coagulation & Flocculation**



- **Coagulation** removes dirt and other particles suspended in water.

- Alum and other chemicals are added to water to form tiny sticky particles called "**floc**" which attract the dirt particles.

- The combined weight of the dirt and the alums (**floc**) becomes heavy enough to sink to the bottom during sedimentation.

Water Treatment – **Coagulation**

- Coagulants generally used are –
  - ✓ iron(III) sulfate, $Fe_2(SO_4)_3$
  - ✓ aluminum sulfate, $Al_2(SO_4)_3$

- In the case of aluminum sulfate, $Al(OH)_3$ is formed (in the pH range of 6-8):

$$Al^{3+}(aq) + 3\,HCO_3^-(aq) \rightarrow Al(OH)_3(s) + 3\,CO_2(aq)$$

- At this pH values, $Al(OH)_3$ is close to its minimum solubility and at equilibrium very little aluminum is left dissolved in the water.

Water Treatment – **Coagulation**

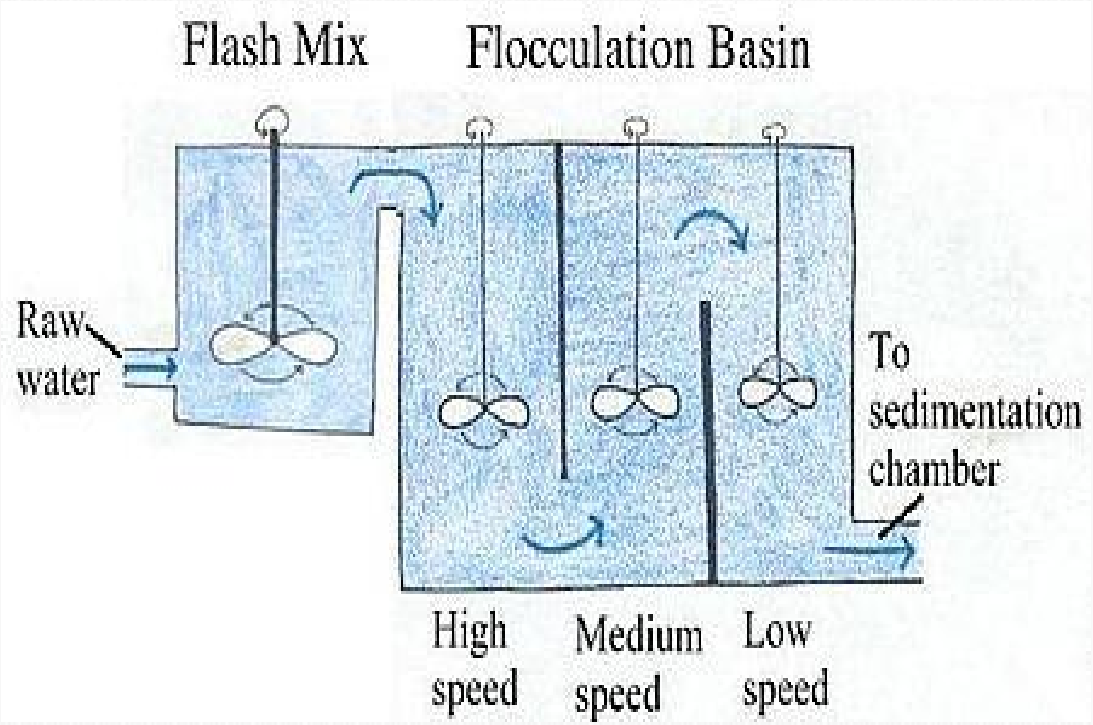
- Aluminum hydroxide forms a very gelatinous precipitate, which settles very slowly and which incorporate the colloidal particles.

- With iron(III) sulfate the chemistry is analogous to aluminum (III) sulfate:
  - Fe^{3+} forms gelatinous iron hydroxide $Fe(OH)_3$.

$$\mathbf{Fe^{3+}(aq) + 3\,HCO_3^-(aq) \rightarrow Fe(OH)_3(s) + 3\,CO_2(aq)}$$

- These reactions consume hydroxide, hence pH decreases (neutralize alkaline water)

Water Treatment – **Coagulation**







Water Treatment – **Coagulation**

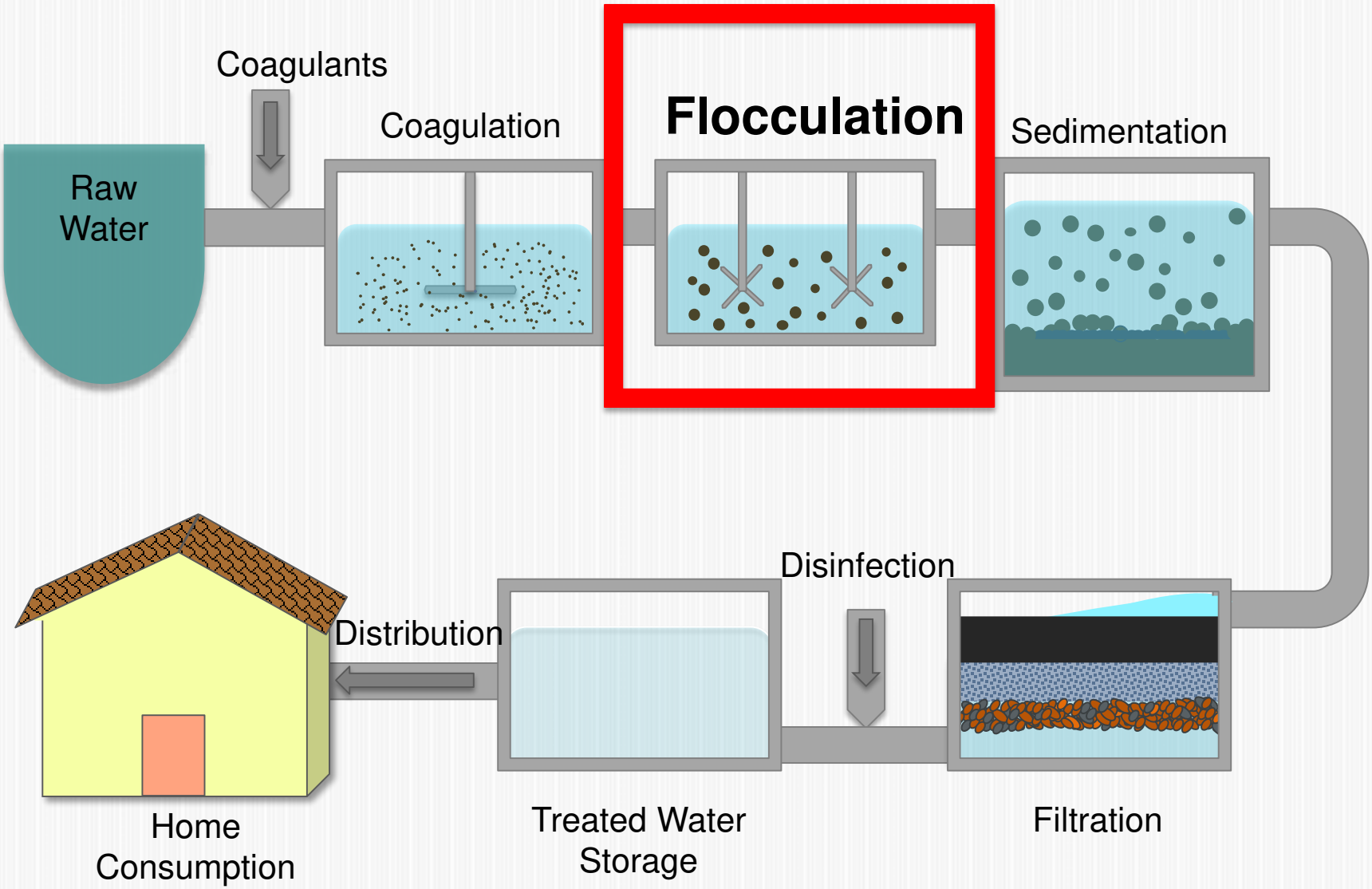






Addition of coagulant

Water Treatment Process - **Flocculation**



Water Treatment – **Flocculation**

- Flocculation is a process of gentle and continuous stirring for agglomeration of micro-flocs formed during the coagulation process.

- The stirring should be gentle, so that the microflocs formed do not disintegrate and can collide with each other to form even bigger particles, called flocs.

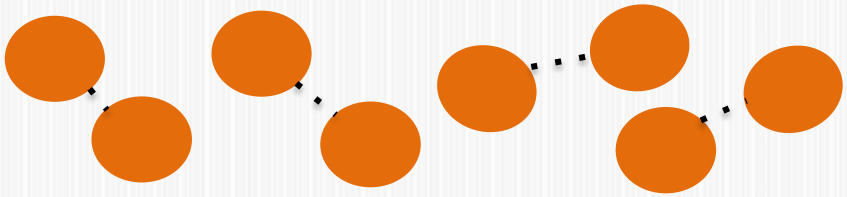
- Larger flocs are with good settling characteristics.

- It requires very slow and continuous mixing of water for frequent contact between fine particles and the hydrolyzed product of the coagulants.

Water Treatment – **Flocculation**

- The floc is generally a collection of most of the suspended load and bacteria in the water that caused its turbidity, and once it is formed the water will be clearer.

- The efficiency of the flocculation process largely depends on the number of random collisions among the coagulated particles per unit of time.



Particles collide and link together through weak bonds

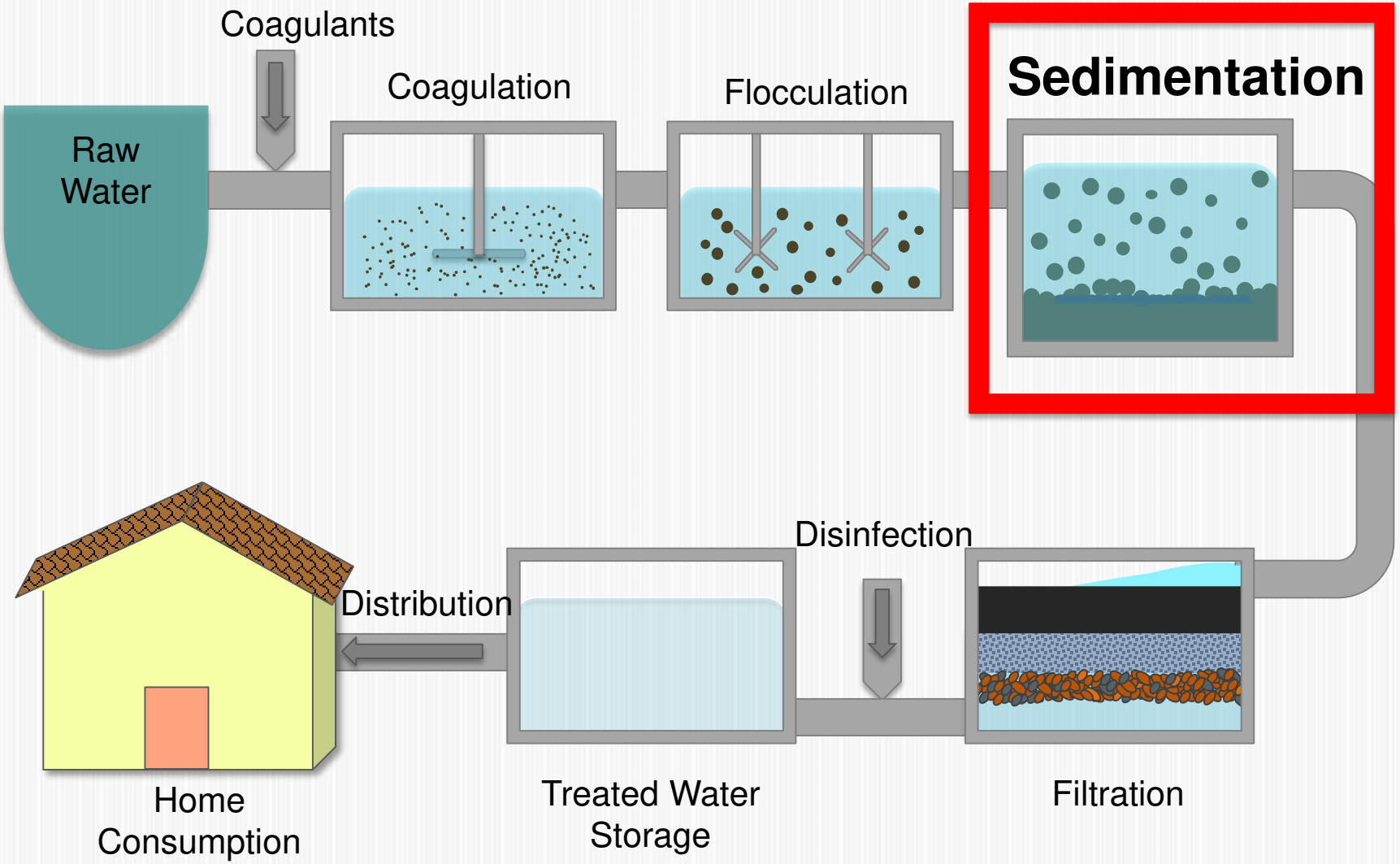


And form big clumps called **flocs**



Flocculation chamber

Water Treatment Process - **Sedimentation**



Water Treatment Process – **Sedimentation**

- Particles in water that will settle by gravity within a reasonable period of time can be removed by "sedimentation" in sedimentation basins (also known as "clarifiers").

- In sedimentation process, water velocity is lowered below the suspension velocity and the suspended particle settle out of the water due to gravity.

- The process is also known as settling or clarification

Water Treatment Process – **Sedimentation**

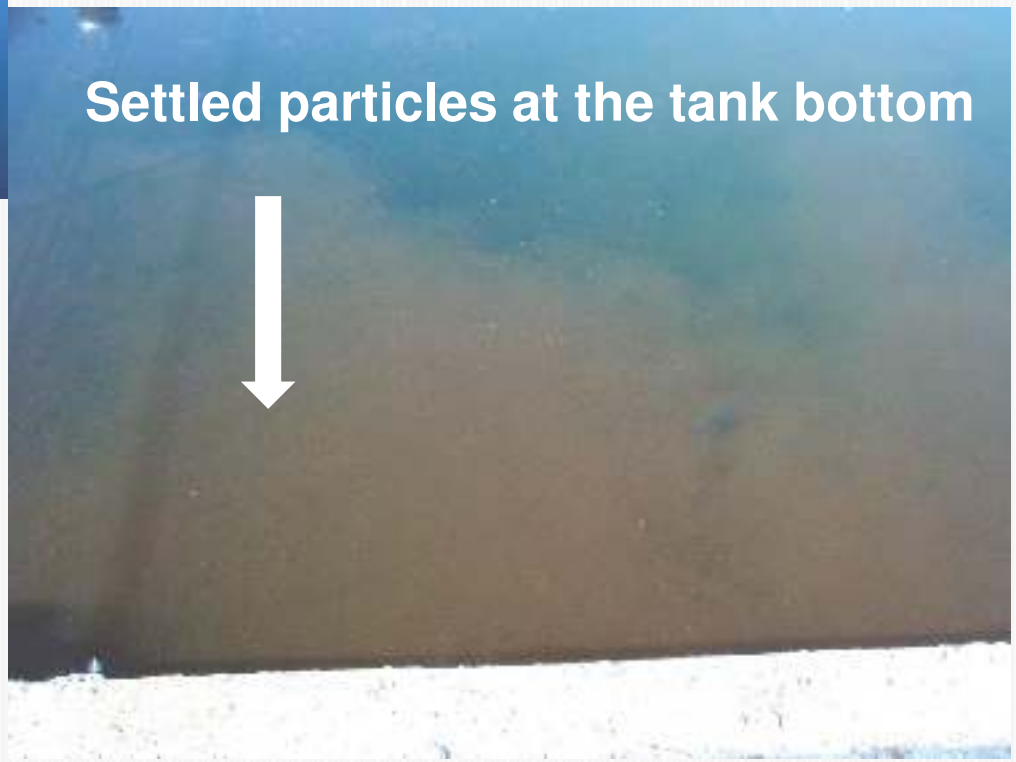
- Settled solids in the sedimentation basin are removed as sludge, and floating solids are removed as scum.

- Sedimentation basins are usually included as integrated units of treatment plants and are heavily dependent on sedimentation mechanism.

Water Treatment Process – **Sedimentation**



Rectangular Sedimentation Tank



Water Treatment Process – Sedimentation

Objectives of Sedimentation

1) Producing a clarified (free of suspended solids) effluent.

2) Producing a highly concentrated solid sludge stream.

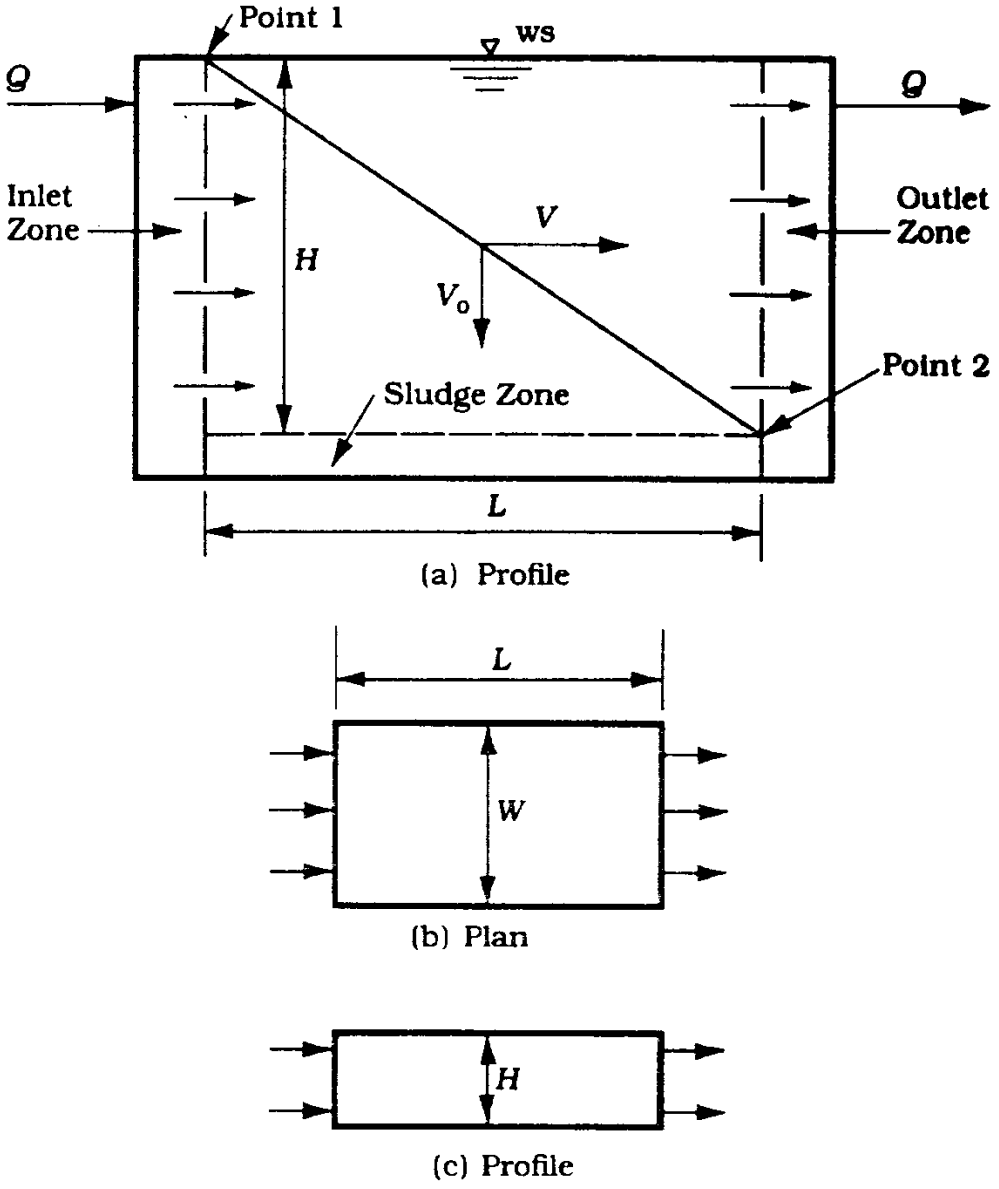


FIGURE 9.6 *Ideal Rectangular Settling Basin*

Water Treatment Process – **Sedimentation**

Mechanism of Sedimentation

- In this process, the organic and inorganic particles heavier than water settle by gravity in a tank or basin.

- These particles are held in suspension in natural water mainly by turbulence or current and when the current is slowed down, the suspended particles settle at the bottom of the basin.

Water Treatment Process – **Sedimentation**

Mechanism of Sedimentation

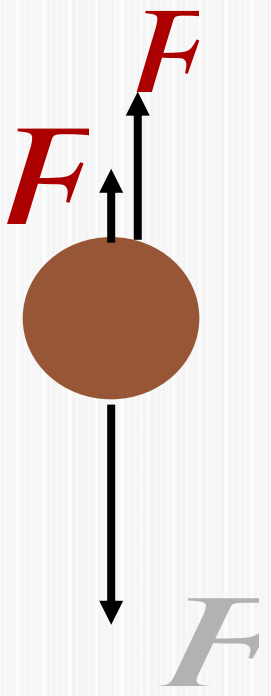
- Particle having specific gravity > 1, moves downward in relatively inactive water by the force of gravity, accelerating until the frictional resistance ('drag') of water equals the gravitational force acting upon the particle.

- Thereafter the particle travels with a constant velocity called the '*terminal velocity*' or '*settling velocity*' of the particle.

Water Treatment Process – Sedimentation

Mechanism of Sedimentation

• For a rigid particle of mass *m* moving in a fluid, there are three forces acting on the body:



(1) **Gravity force, F_g,** acting downward

$$F_g = mg$$

(2) **Buoyant force, F_b,** acting upward

$$F_b = \rho g V_s = \frac{m\rho g}{\rho_s}$$

where,

ρ= density of the fluid

ρ_s = density of the solid particle

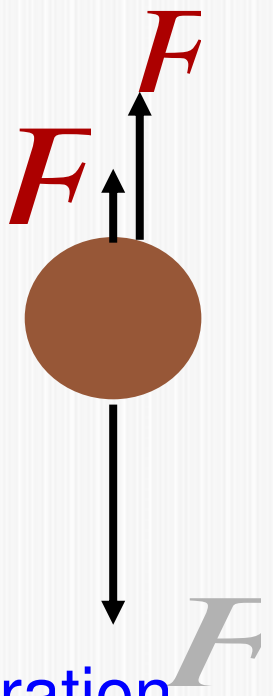
V_s = volume of the particle

Water Treatment Process – Sedimentation

Mechanism of Sedimentation

(3) **Drag force, F_D,** acting in opposite direction to the particle motion

$$F_D = C_D A \frac{\rho v^2}{2}$$



where, C_D = the drag coefficient

A = the projected area of the particle

The resultant force equals the force due to acceleration.

$$m\frac{dv}{dt} = mg - \frac{m\rho g}{\rho_s} - C_D A \frac{\rho v^2}{2}$$

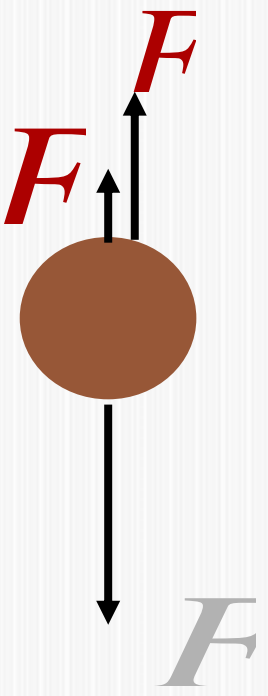
Water Treatment Process – Sedimentation

Mechanism of Sedimentation

The falling of the body consists of two periods:

(1) The period of accelerated fall

- The initial acceleration period is usually very short, of the order of a tenth of a second or so.



(2) The period of constant velocity fall

Set $\frac{dv}{dt} = 0$ and solve the above equation for *v*.

$$m\frac{dv}{dt} = mg - \frac{m\rho g}{\rho_s} - C_D A\frac{\rho v^2}{2} = 0$$

$$\Rightarrow \quad v = v_t = \sqrt{\frac{2(\rho_s - \rho)mg}{\rho_s \rho C_D A}}$$

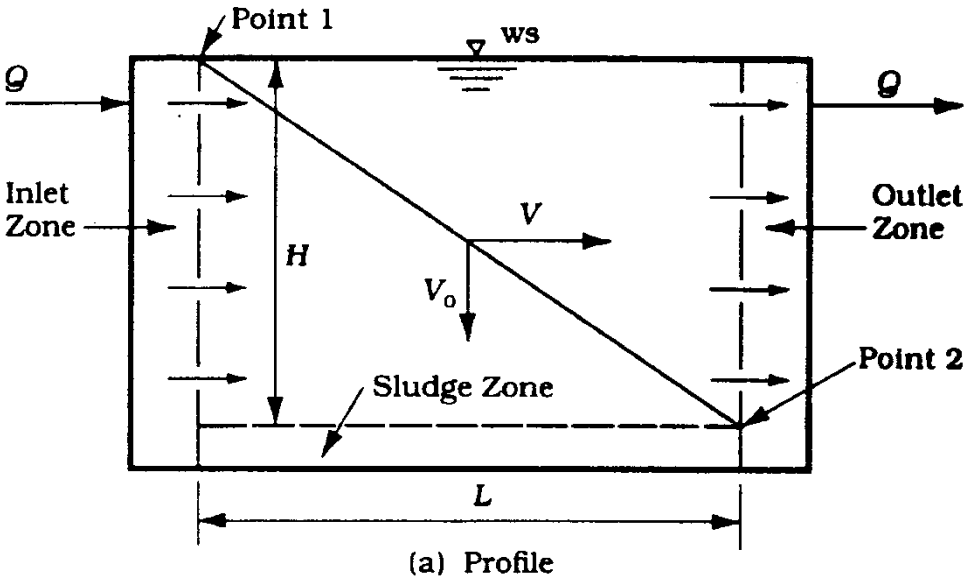
- * v_t is called the free settling velocity or terminal velocity.

Water Treatment Process – Sedimentation

Mechanism of Sedimentation

Terminal velocity of a particle moving in a fluid

$$v = v_t = \sqrt{\frac{2(\rho_s - \rho)mg}{\rho_s \rho C_D A}}$$



Terminal velocity for spherical particles of diameter *d*,

$$m = \frac{\rho_s \pi d^3}{6} \text{ and } A = \frac{\pi d^2}{4}$$

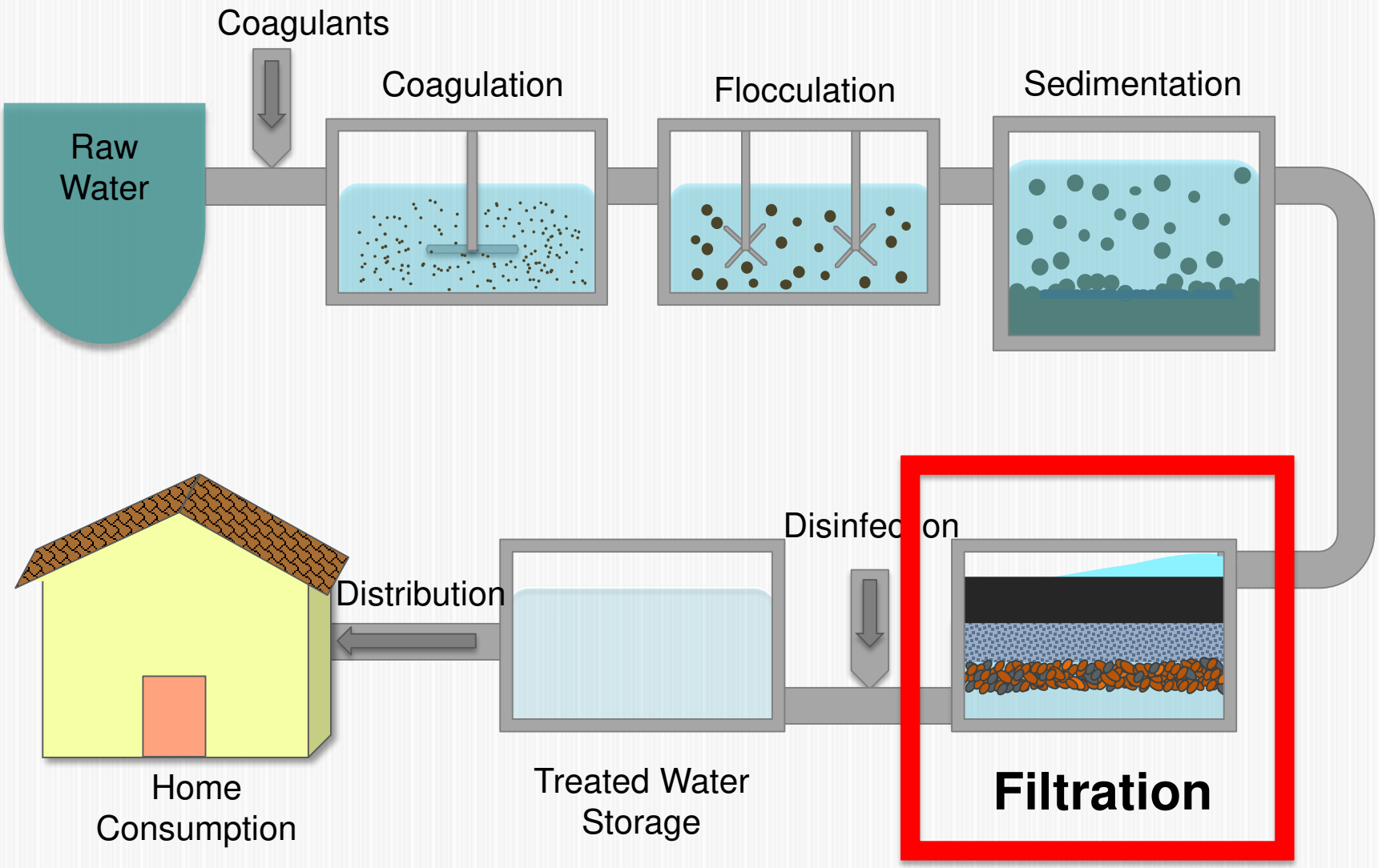
$$\Rightarrow \quad v_t = \sqrt{\frac{4(\rho_s - \rho)dg}{3\rho C_D}}$$

Water Treatment Process – **Sedimentation**

Factors affecting sedimentation and efficiency of sedimentation tank -

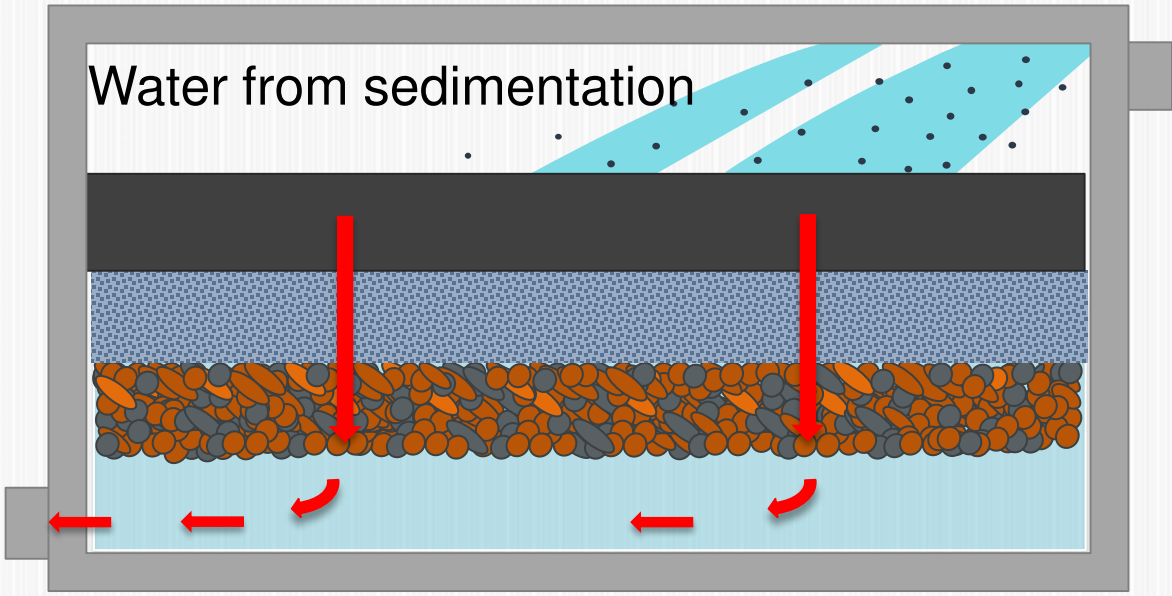
- Horizontal flow velocity of water
- Shape and size of the particle
- Specific gravity of the particle
- Viscosity of water
- Density of water
- Temperature of water

Water Treatment Process - **Filtration**



Water Treatment Process – Filtration

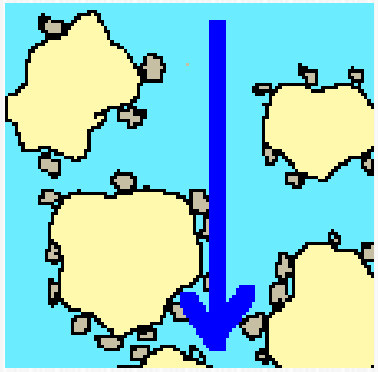
- Once most of the major particles are removed, the water is pushed through layers of activated carbon, sand and gravel to filter out any remaining fine particles and microorganisms.



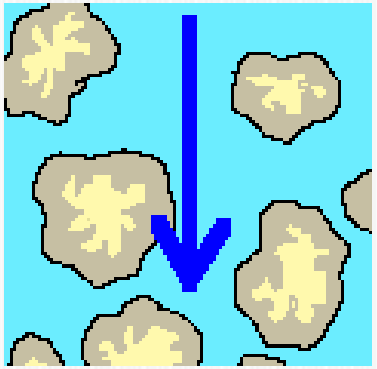
Water Treatment Process – Filtration



Straining



Adsorption



Absorption

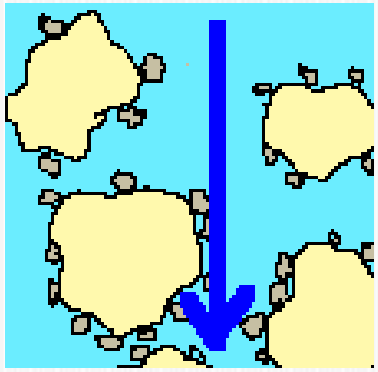
- The primary filtration process used is adsorption, where the particles are attracted to the filter material, such as activated carbon, and are gathered on its surface.

- The secondary process is the straining out of the remaining flocs in the water in a filter.

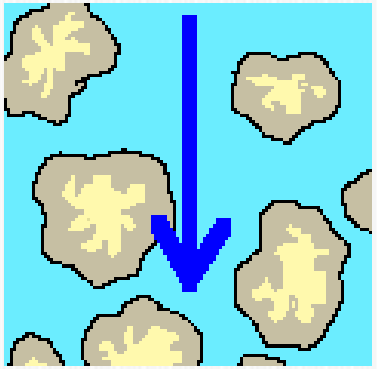
Water Treatment Process – Filtration



Straining



Adsorption



Absorption

- The pores between the filter material, such as sand, are smaller than they are, straining cause trapping of the filter media and preventing them from flowing with the water.

- However, this water is still filled with bacteria, viruses, and other organic matter.

Water Treatment Process – Filtration

Filter Media

- Filter media is the part of the filter which actually removes the particles from the water being treated.



Applying the layer of anthracite (coal) provides a higher filtration rate and a longer filter run time than sand alone.

Water Treatment Process – Filtration

Slow Sand Filters (SSF)/ Biological Filter

Elements of slow sand filter

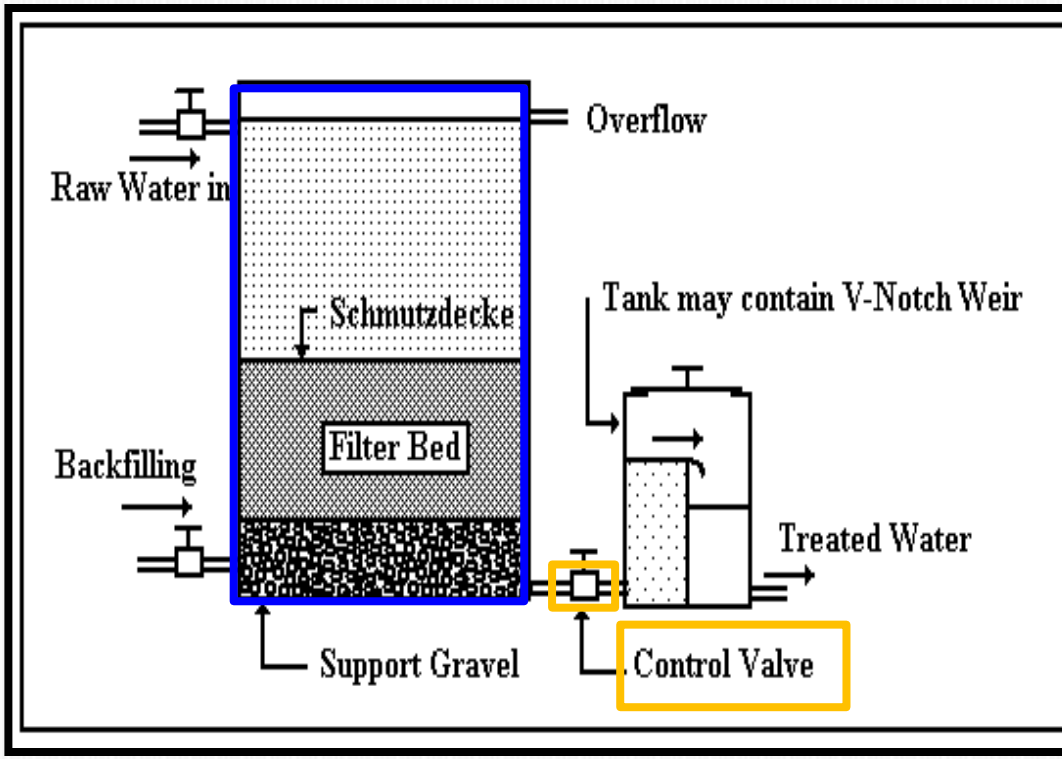
(1) Filter Box

(a) Supernatant water

(b) Sand bed (filter bed)

(c) Under drainage system

(2) Filter control valves



Water Treatment Process – SSF

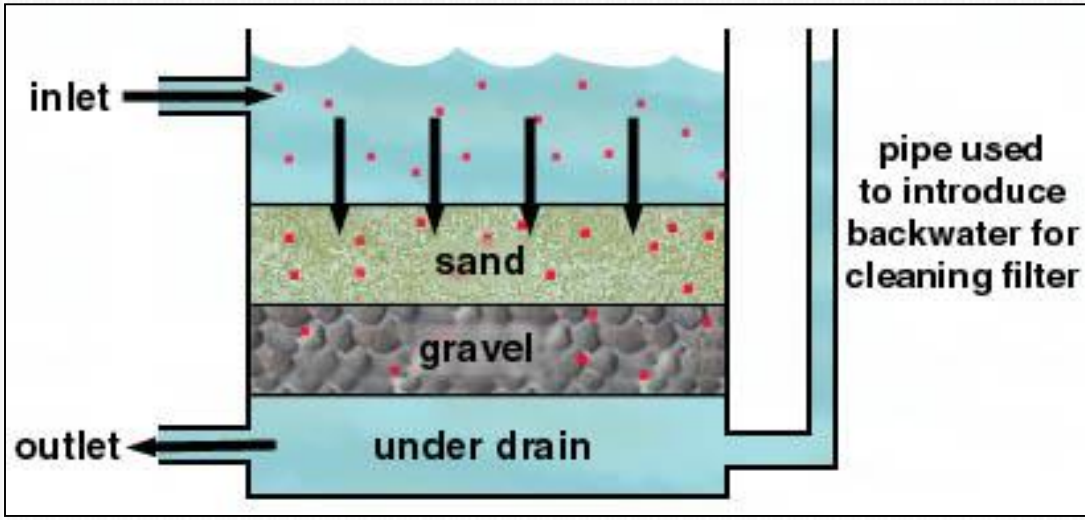
Filter Box Elements

(a) **Supernatant water**

✓depth: 1-1.5 m

✓ promotes downward flow of water through the sand bed

✓ provide waiting time of 3-12 hours for raw water to undergo partial purification by sedimentation and oxidation




Supernatant water in a SSF

Water Treatment Process – SSF

Filter Box Elements

(b) <u>Sand bed supported by gravel:</u>

- ✓ Depth: 1 m, sand (0.2-0.3 mm diameter), supported with 0.3m gravel (0.2-1 cm diameter)



- ✓ Water percolates through the bed and gets filtered by - Mechanical straining, sedimentation, adsorption, oxidation and bacterial action

- ✓Rate of filtration: <u>0.1-0.4 m^3/hour/m^2</u>

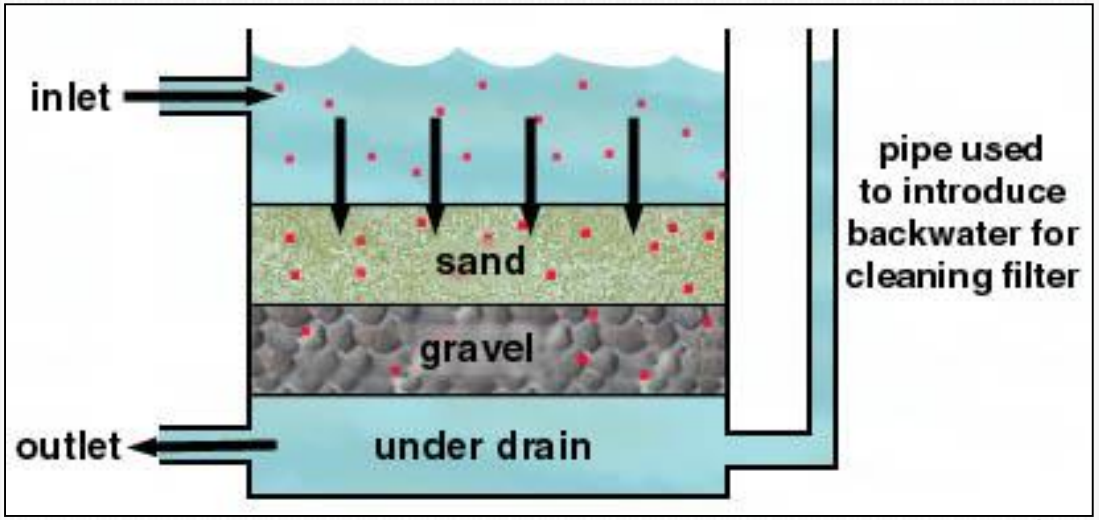
Water Treatment Process – SSF

Mechanism of action of slow sand filter:

1.Sedimentation:

- The supernatant water acts as a settling reservoir.
- Settleable particles sink to the sand surface.

2. Mechanical straining: Particles too big to pass through the interstices between the sand grains are retained.



Water Treatment Process – SSF

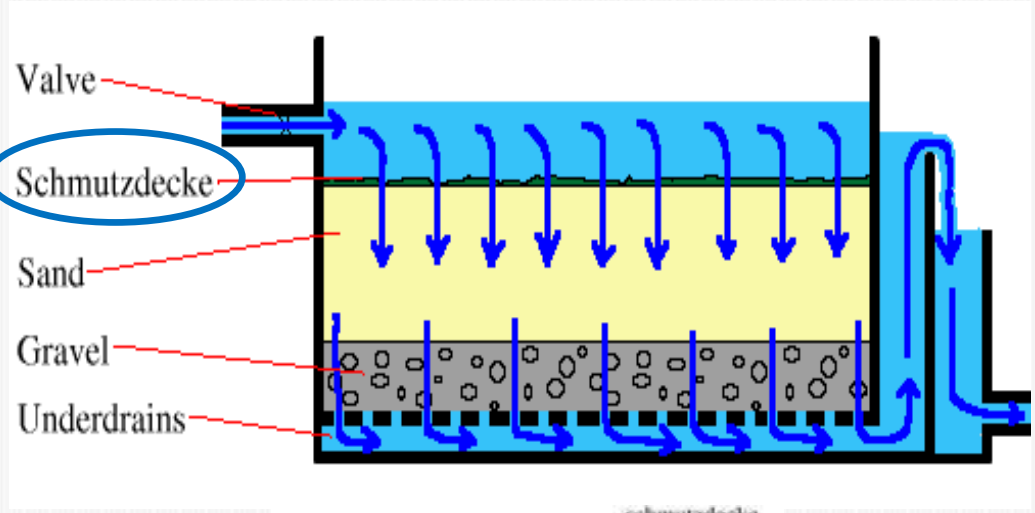
Mechanism of action of slow sand filter:

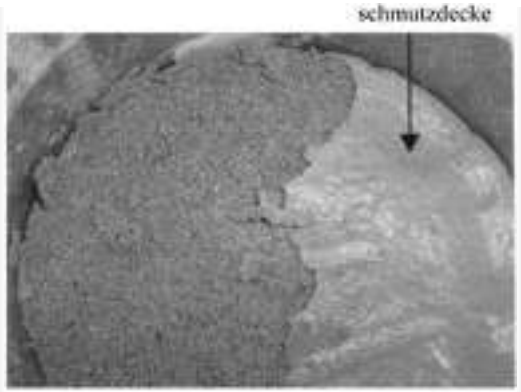
3. Formation of biological layer:

- Surface of the sand bed gets covered with a slimy growth known as vital layer or zoological layer or biological layer.

- It is slimy gelatinous, consists of algae, plankton, diatoms and bacteria.

- The formation of this layer is known as **RIPENING** of the filter, which may take several days to fully develop (2-3 cm)





Water Treatment Process – SSF

Mechanism of action of slow sand filter:

4. Adhesion: The suspended particles that come in contact with the surface of the sand grains are retained by adhesion to the biological layer/ vital layer.

5. Biochemical processes in the biological layer:

- Removes organic matter, holds back bacteria and oxidizes ammonia-nitrogen into nitrates.

Water Treatment Process – SSF

Mechanism of action of slow sand filter:

- Conversion of soluble iron and manganese compounds into insoluble hydroxides which attach themselves to the sand surfaces

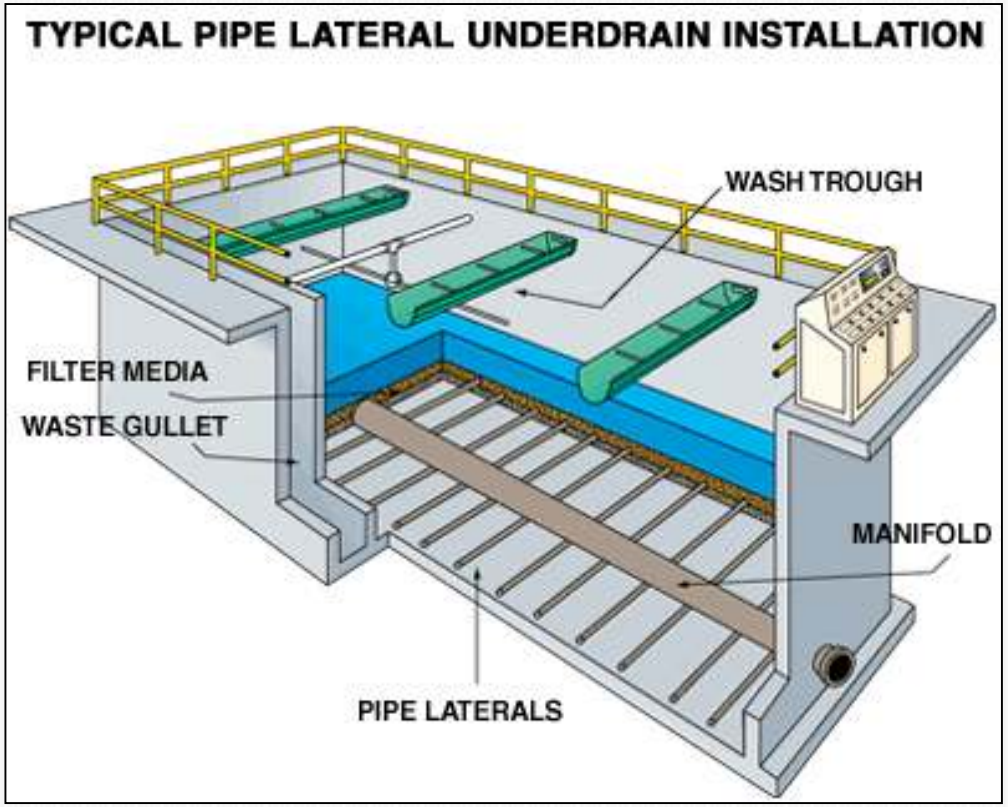
- Until the vital layer is fully formed, filter only worked as a mechanical strainer & so for the first few days filter water run to the waste.

Water Treatment Process – SSF

Filter Box Elements

(c) Underdrain System:

- ✓ Depth: 0.15 m
- ✓ At the bottom of filter bed
- ✓ Porous pipes: Outlet for filtered water as well as support to the filter media above



Filter Control Valve

- ✓ To regulate the flow of water in and out from the filter box.

Water Treatment Process – SSF

Filter Cleaning

- When the bed resistance increases to such an extent that the regulating valve has to be kept fully open, filter bed needs to be cleaned.


Removal of Vital Layer

- Cleaning is done by -

- Draining of supernatant water
- Scrapping of the top portion of the sand bed to a depth of 1-2 cm

- After 20-30 scrapings , new bed (filter) is required to be constructed

Water Treatment Process – SSF

Advantages

- Simple to construct and operate
- Cheaper
- Physical, Chemical & Bacteriological quality of water is very high
- Reduces bacterial count by 99.9% & E. coli by 99%.

Water Treatment Process – SSF

Disadvantages

- Old fashioned and outdated method of water purification (but still in use)
- Initial cost is low but maintenance cost is much more than rapid sand filter
- These filters need a lot of space

Water Treatment Process – Rapid Sand Filter

Types of RSF

- Open/gravity type — **PATERSON FILTER**
- Closed/presure type — Candy's Filter





Water Treatment Process – RSF

Steps of Filtration

- Coagulation
- Rapid Mixing
- Flocculation
- Sedimentation
- Filtration

Coagulation

- Alum is added – 5-40 mg/liter depending upon turbidity, color, pH & temperature

Rapid mixing of Alum

- By violent agitation in a mixing chamber for few minutes

Water Treatment Process – RSF

Flocculation

- Slow & gentle stirring of the treated water for about 30 minutes
- Results in formation of thick, copious, white flocculent precipitate of aluminium hydroxide

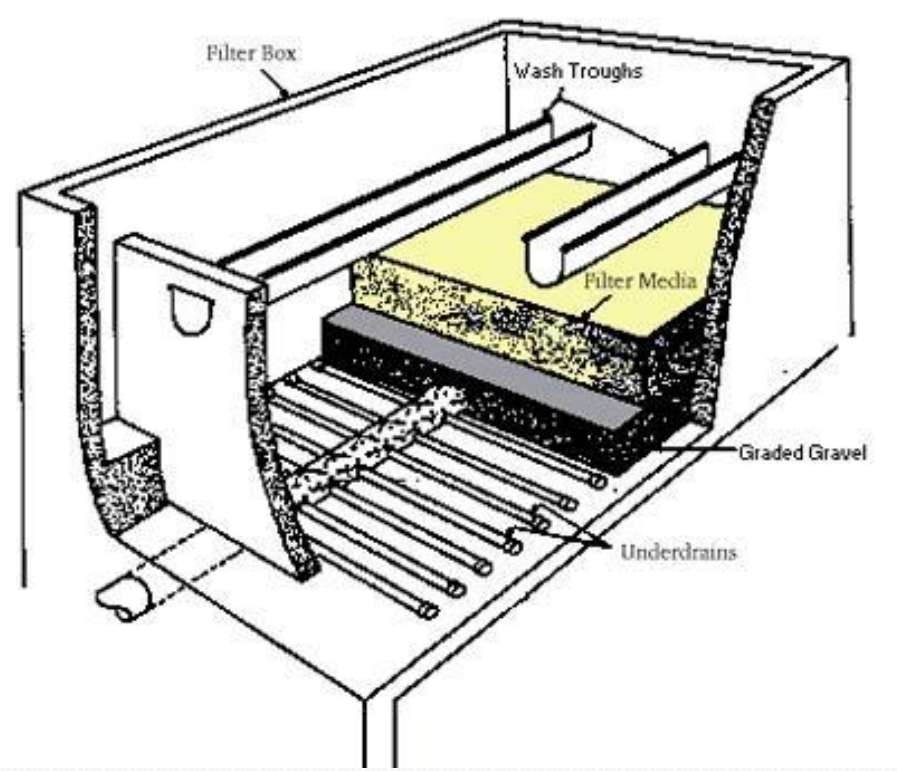
Sedimentation

- For 2-6 hours
- Flocculent precipitate together with impurities and bacteria
- 95% of the flocculent needs to be removed before the water enters the rapid sand filter

Water Treatment Process – RSF

Filter Bed

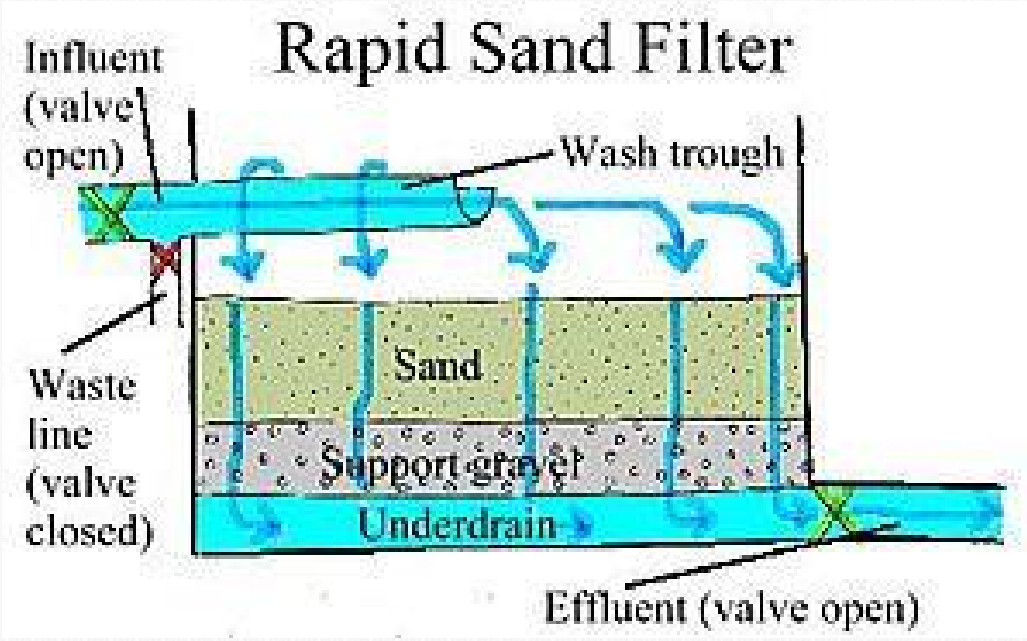
- Each unit has a surface of 80-90 m^2
- Supernatant water – 1 to 1.5 m
- Depth of sand bed – 1 m
- Effective size of sand particle is 0.4-0.7 mm
- Supported graded gravel – 30-40 cm
- Filtration rate – 5-15 m^3 / m^2/ hr



Water Treatment Process – RSF

Filtration

- Retained alum- flocs is held back on sand bed
- Forms a slimy layer [comparable to the zoological layer in slow sand filter]
- adsorbs bacteria from water
- Oxidation of ammonia also takes place during the passage of water



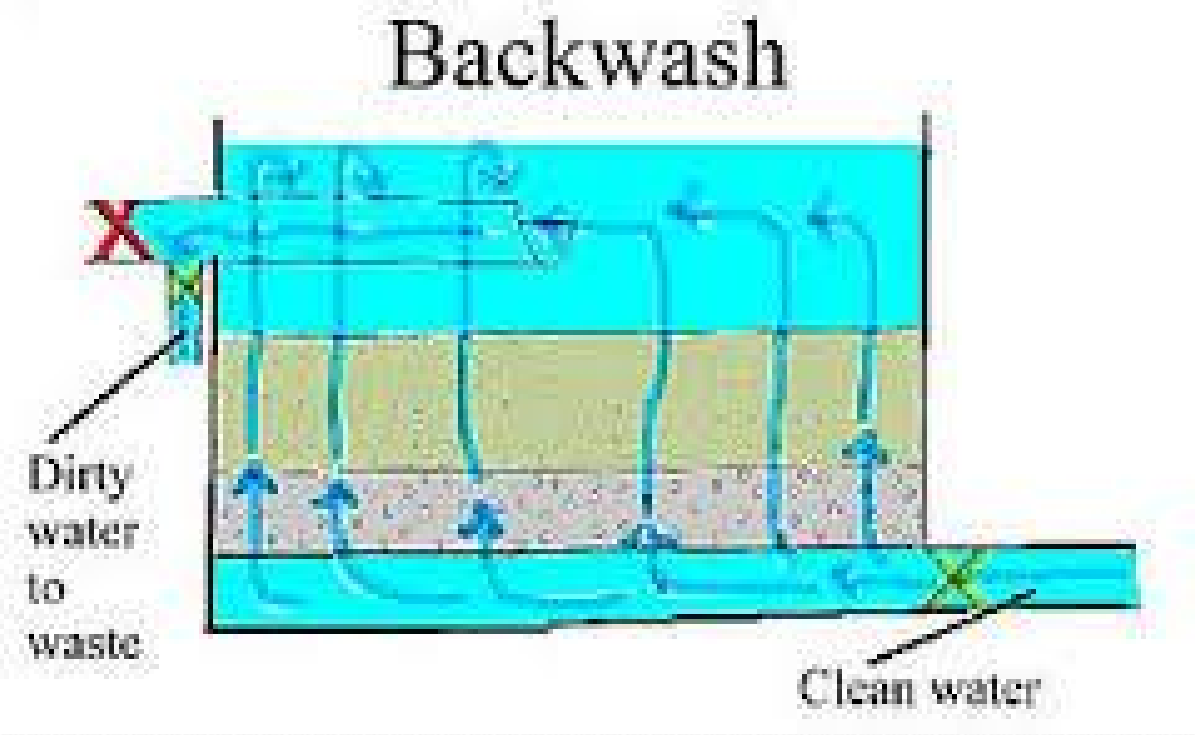


Water Treatment Process – RSF

Cleaning & Maintenance

- When the loss of head reaches 7-8 ft, it needs to be cleaned

- Cleaned by Backwashing.



Water Treatment Process – RSF

Cleaning & Maintenance

- Backwashing is done by reversing the flow of water through the sand bed.

- Upward flow dislodges the impurities trapped in the sand layer and cleans up sand bed.

- Compressed air can be used in back washing



Water Treatment Process – RSF

Advantages

- Deal with raw water directly
- Occupies less space
- Filtration is rapid
- Washing of filter is easy
- More flexibility in operation

Water Treatment Process – RSF

Disadvantages

- Relatively high skill operation
- Costlier
- Removes bacteria by 98-99% (less compared to SSF)

Water Treatment Process – Disinfection

Current Methods

Large-Scale:

- Chlorination
- Ozone
- UV irradiation

Small Scale:

- Boiling
- Iodine tablets
- Filters

Water Treatment Process – Disinfection

Criteria for satisfactory disinfectant

- Not influenced from properties of water within short time
- Should not be toxic and color imparting or leave the water impotable
- Available, cheap, easy to use
- Residual concentration to deal with recontamination
- Detectable by rapid, simple techniques in small concentration

Water Treatment Process – Disinfection

Factors affecting disinfectant efficiency

- Duration
- pH
- Temperature
- Concentration of the disinfectant
- Concentration of organisms
- Nature of the disinfectant
- Nature of the organisms to be inactivated
- Nature of the suspending medium

Water Treatment Process – Disinfection

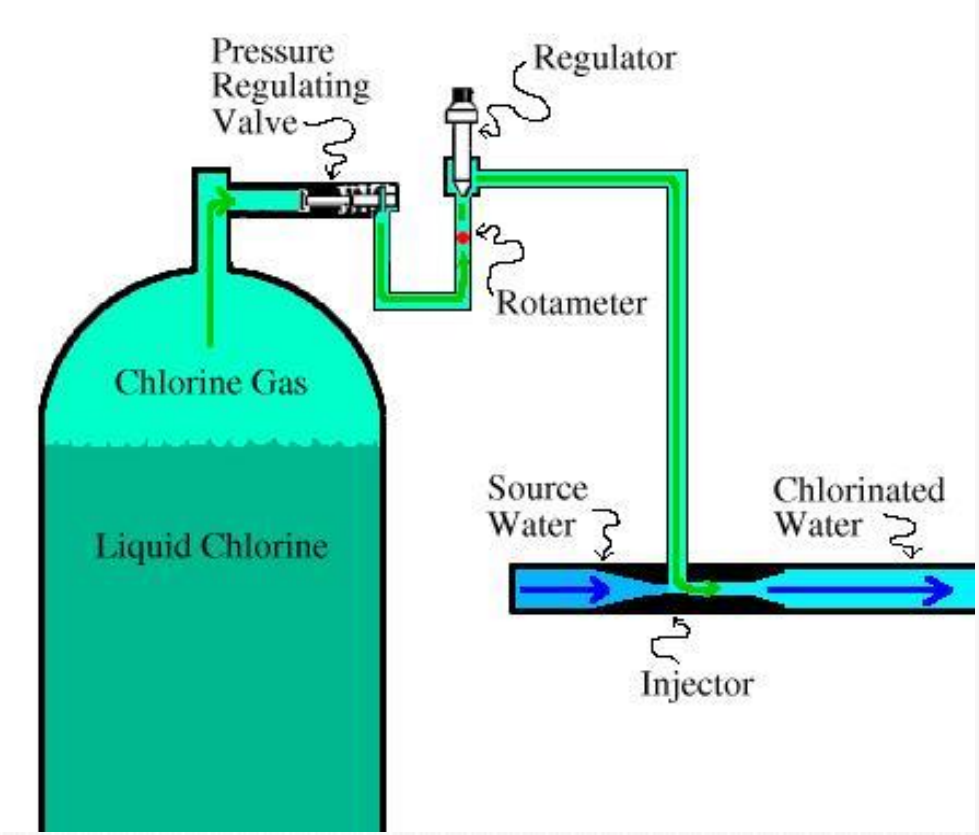
Chlorination

- It is easy to apply chlorine due to its relatively high solubility of about 7000 mg per liter.
- Readily available as gas, liquid or powder.
- Very toxic to most of the micro-organisms.
- Cheap and reliable.
- Chlorine can be applied in water in one of the following ways:
  - as bleaching powder,
  - as chloramines, or
  - as free chlorine gas.

Water Treatment Process – Disinfection

Mechanism of Action of Chlorination

- H_2O+Cl_2 (**at pH 7**) → HCl + HOCl (main disinfectant)
- HOCl (**at pH > 8.5**) → H^+ + OCl^- (minor action)
- $NH_3 + Cl_2$ → NH_2Cl/ $NHCl_2$/ NCl_3+ H_2O (Mono, Di, Tri Chloramines)



Water Treatment Process – Disinfection

Commonly used Chlorine Sources

- Sodium Hypochlorite, NaOCl (common household bleach)

$$NaOCl + H_2O \Rightarrow HOCl + Na^+ + OH^-$$

- Calcium Hypochlorite, $Ca(OCl)_2$

$$Ca(OCl)_2 + 2H_2O \Rightarrow 2HOCl + Ca^{++} + 2OH^-$$

Water Treatment Process – Disinfection

Disinfectant Demand Reactions

- In the presence of ammonium ion, free chlorine reacts in a stepwise manner to form chloramines -

$$NH_4^+ + HOCl = NH_2Cl + H_2O + H^+$$

$$NH_2Cl + HOCl = NHCl_2 + H_2O$$

$$NHCl_2 + HOCl = NCl_3 + H_2O$$

Combined Chlorine

- Monochloramine (NH_2Cl), dichloramine ($NHCl_2$), and trichloramine (NCl_3), each contribute to the total (or combined) chlorine residual in a water.

Water Treatment Process – Disinfection

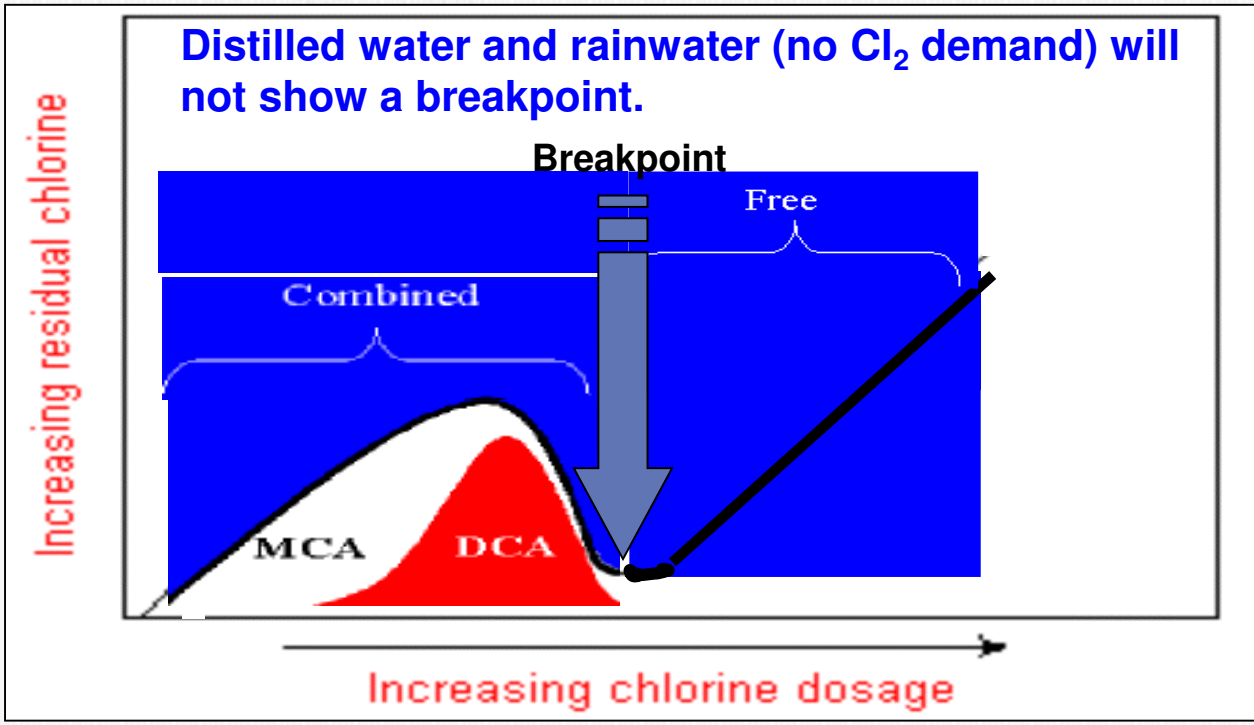
Disinfectant Demand Reactions

- The terms total available chlorine and total oxidants refer, respectively, to the sum of free chlorine compounds and reactive chloramines, or total oxidating agents.

- Under normal conditions of water treatment, if any excess ammonia is present, at equilibrium the amount of free chlorine will be much less than 1 percent of total residual chlorine.

Water Treatment Process – Disinfection

Breakpoint Chlorination

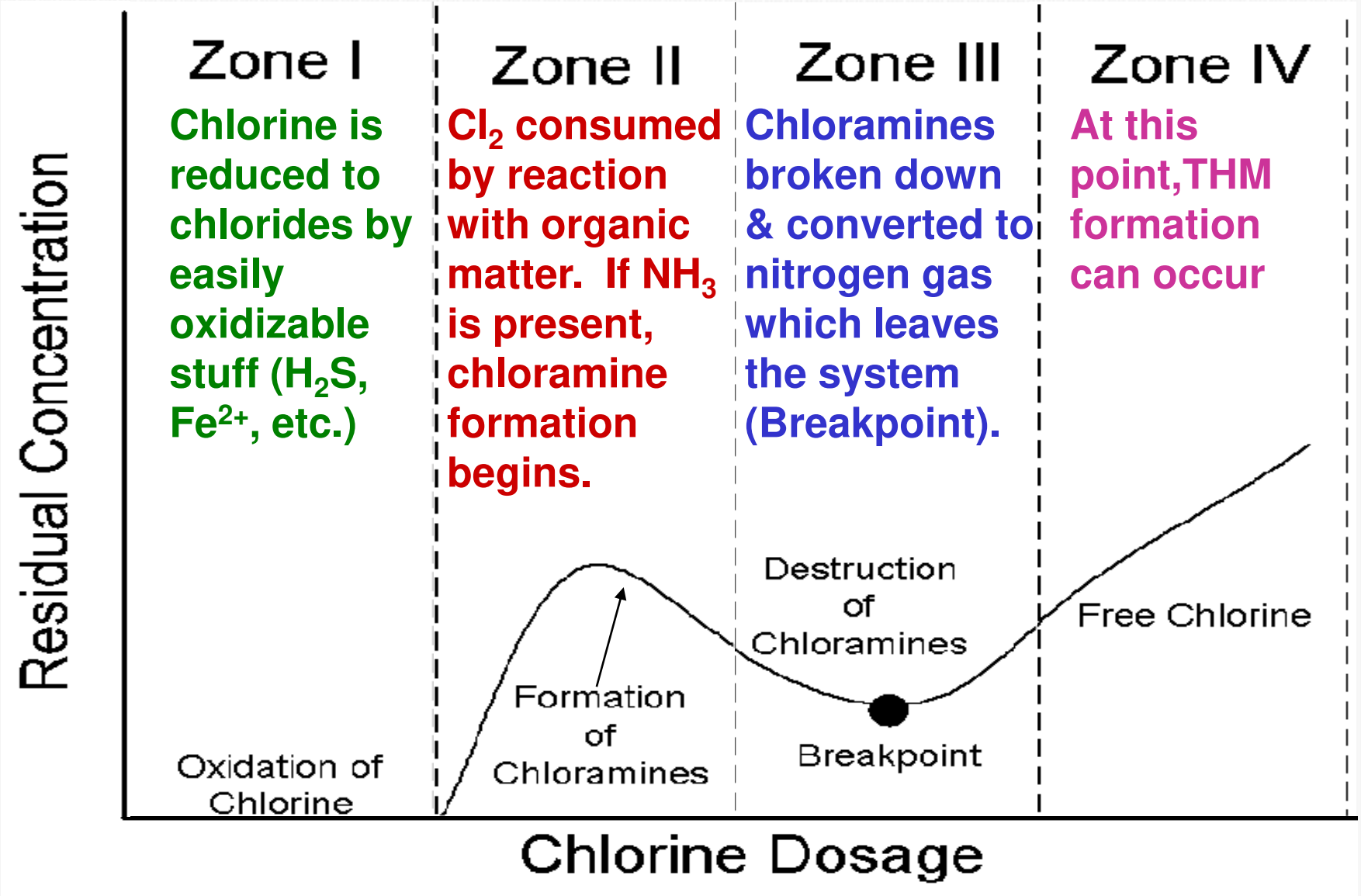


MCA – Mono Chloramine
DCA – Di Chloramine

- The type of chlorine dosing normally applied to piped water supply systems is referred to as breakpoint chlorination.
- Sufficient chlorine is added to satisfy all of the chlorine demand and then sufficient extra chlorine is added for the purposes of disinfection.

Water Treatment Process – Disinfection

Breakpoint Chlorination



Water Treatment Process – Disinfection

Super Chlorination

- Method of choice for highly polluted waters
- High dose of chlorine is added
- After 20 minutes of contact, dechlorination is done with sodium sulphate/ sodium thiosulphate to reduce the taste of excess chlorine

Water Treatment Process – Disinfection

Advantages of Chlorination

- Chloramines are not as reactive with organics as free chlorine in forming DBPs.

- The monochloramine residual is more stable and longer lasting than free chlorine or chlorine dioxide, thereby providing better protection against bacterial regrowth in systems with large storage tanks and dead end water mains. However excess ammonia in the network may cause biofilming.

Water Treatment Process – Disinfection

Advantages of Chlorination

- Because chloramines do not tend to react with organic compounds, many systems will experience less incidence of taste and odor complaints when using chloramines.

- Chloramines are inexpensive.

- Chloramines are easy to make.

Water Treatment Process – Disinfection

Disadvantages of Chlorination

- The disinfecting properties of chloramines are not as strong as other disinfectants, such as chlorine, ozone, and chlorine dioxide.

- Chloramines cannot oxidize iron, manganese, and sulfides.

- When using chloramine as the secondary disinfectant, it may be necessary to periodically convert it to free chlorine for biofilm control in the water distribution system.

Water Treatment Process – Disinfection

Disadvantages of Chlorination

- Excess ammonia in the distribution system may lead to nitrification problems, especially in dead ends and other locations with low disinfectant residual.
- Monochloramines are less effective as disinfectants at high pH than at low pH.
- Dichloramines have treatment and operation problems.
- Chloramines must be made on-site.

Water Treatment Process – Disinfection

Other Disinfection Methods

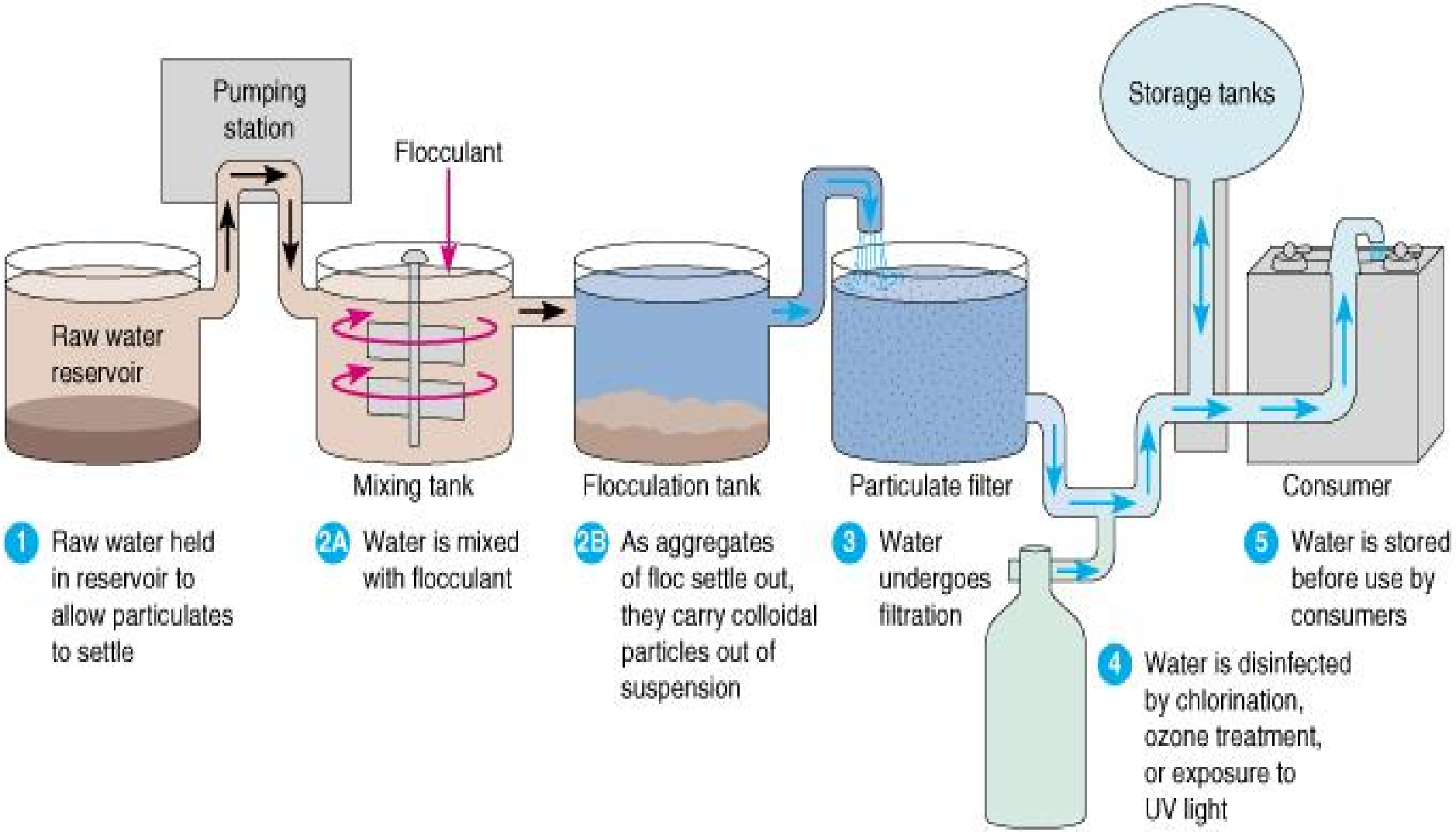
Ozone

- Used in Europe and Canada
- Strong oxidizing agent
- Strong virucidal
- No residual effect
- Should be used with chlorination

UV Rays

- Used in UK
- Water should be clear
- No residual effect
- Expensive

Municipal Water Treatment Plant (WTP)



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EWCE 331
Water Supply Engineering

Lecture 8

Instructor

Lt Col Dr. Kazi Shamima Akter, Engrs

Department of EWCE, MIST

Lecture outline

Water Treatment Methods

Topics	References
• **Advanced water treatment for heavy metal removal** ✓ **Iron and Manganese removal**	**1. Water and Environmental Engineering** Authors: M. Habibur Rahman, Abdullah Al-Muyeed 1st ed., ITN-BUET **2. Environmental Engineering** Authors: Howard S. Peavy, Donald R. Rowe and George Tchobanoglous International Edition, McGraw Hill Companies **2. Water Supply and Sanitation** Authors: M. Feroz Ahmed, Md. Mujibur Rahman 1st ed., ITN-BUET

Advanced Water Treatment

Purposes:

- To take a water treated by standard processes and to improve it to exceptionally high quality as often required by particular industries.

- To treat a water containing specific chemical or microbiological contaminants to an acceptable standard, i.e removal of iron and manganese, the removal of blue-green algae, the removal of specific organics

Advanced Water Treatment

Used Techniques for Advanced Treatment:

- Iron and manganese removal -
  - ✓ iron is removed by pressure filters
  - ✓ manganese is removed by gravity sand filters

- Ion Exchange and inorganic absorption -
  - ✓ water softening by exchanging undesirable calcium and magnesium cations with sodium.
  - ✓ removal of undesirable cations including barium, strontium and radium
  - ✓removing undesirable anions including fluoride, nitrates, silicates and chromates

Advanced Water Treatment

Used Techniques for Advanced Treatment:

- Adsorption of organics – undesirable contaminants are adsorbed on to solid adsorbents.

- Membrane processes – uses microfiltration, ultrafiltration, reverse osmosis, electrodialysis

- Oxidation including chemical oxidation – two or more chemical species are added with the purpose of increasing the oxidation state of one.

Iron and Manganese in Drinking Water

• Water containing excessive amounts of iron and manganese can –

- ✓ stain clothes
- ✓ dis-color plumbing fixtures
- ✓ sometimes add a "rusty" taste and appearance to the water.

• According to Bangladesh Environment Conservation Act, 1997, drinking water standards:

- ✓ **Iron** : **0.3 – 1.0 mg/L**
- ✓ **Manganese**: **0.1 mg/L**

Problem caused by Iron and Manganese in Water

- Small amounts of iron are often found in water because of the large amount of iron present in the soil and because corrosive water will pick up iron from pipes.

- Clothing washed in water containing excessive iron may become stained a brownish color.

- The taste of beverages, such as tea and coffee, may also be affected by iron.

- Manganese produces a brownish color in laundered clothing, leaves black particles on fixtures, and as with iron affects the taste of beverages, including coffee and tea.

Problem caused by Iron and Manganese in Water





Iron Bacteria

Slimy gelatinous material



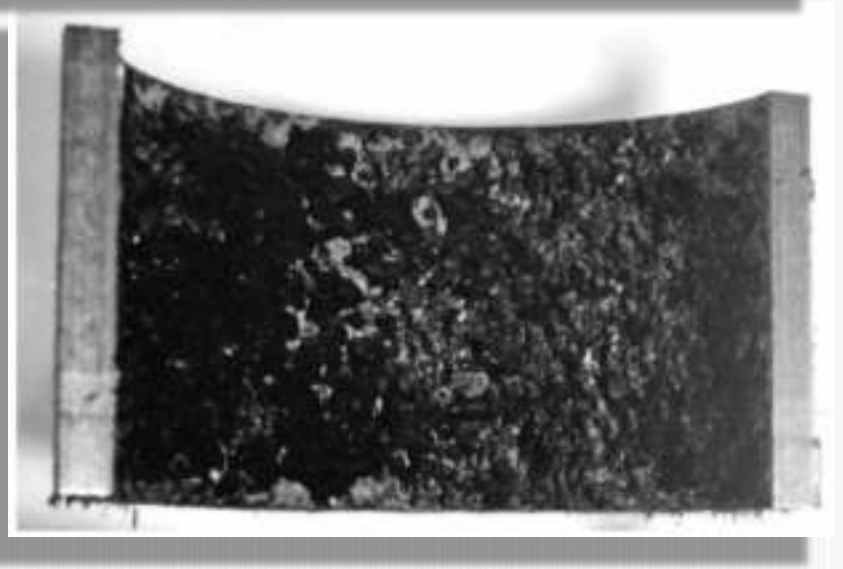




Problem caused by Iron and Manganese in Water







Chemistry of Iron and Manganese in Water

- Iron (Fe) and manganese (Mn) can be present in water in one of three basic forms:

1. Dissolved: ferrous (Fe^{2+}) and manganous (Mn^{2+})
2. Particulate: ferric (Fe^{3+}) and manganic (Mn^{4+}) states
3. Colloidal: very small particles (difficult to settle and filter).

- The predominance of one form over another is dependent on the pH, Eh (redox potential), and temperature of the water.

- Knowledge of the forms or states of iron and manganese can help fine tune a given treatment practice for these metals.

Removal of Iron and Manganese from Water

- The majority of iron and manganese treatment systems employ the processes of oxidation/ filtration.

- The oxidant chemically oxidizes the iron or manganese (forming a precipitate), and kills iron bacteria and any other disease-causing bacteria that may be present.

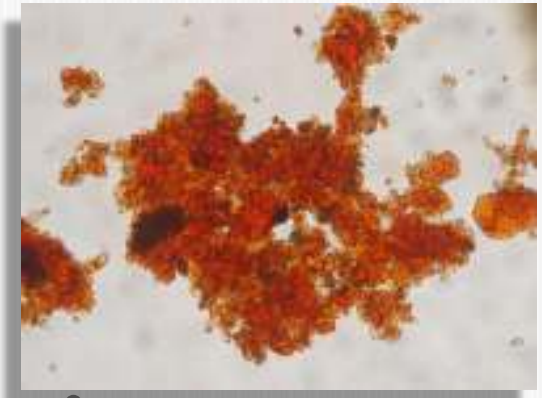
- The filter then removes the iron or manganese precipitates.

Removal of Iron and Manganese – **Chlorination**

- Iron and manganese in water promote the growth of bacteria (including iron bacteria).

- These organisms obtain energy for growth from the chemical oxidation reaction of iron and manganese with dissolved oxygen.

- These bacteria form thick slime growths on the walls of the piping system and on well screens.







Removal of Iron and Manganese – **Chlorination**

- These slimes tend to be are rust-colored from iron and black-colored from manganese.

- Variations in flow can cause these slime growths to separate from pipe walls, resulting in dirty water in the system.





Removal of Iron and Manganese – **Chlorination**

- The growth of iron bacteria can be controlled by chlorination.

- However, when water containing iron is chlorinated, the iron is converted from the ferrous state to the ferric state, producing rust and manganese is converted into black manganese dioxide.

- These materials form a coating on the inside of the water main and when they break loose, a customer will sometimes complain of “dirty” water.

Removal of Iron and Manganese – **Oxidation**

- Before iron and manganese can be filtered, they need to be oxidized to a state in which they can form insoluble complexes.

- Oxidation involves the transfer of electrons from the iron, manganese to the oxidizing agent.

- Ferrous iron (Fe^{2+}) is oxidized to ferric iron (Fe^{3+}), which readily forms the insoluble iron hydroxide complex $Fe(OH)_3$.

- Reduced manganese (Mn^{2+}) is oxidized to (Mn^{4+}), which forms insoluble (MnO).

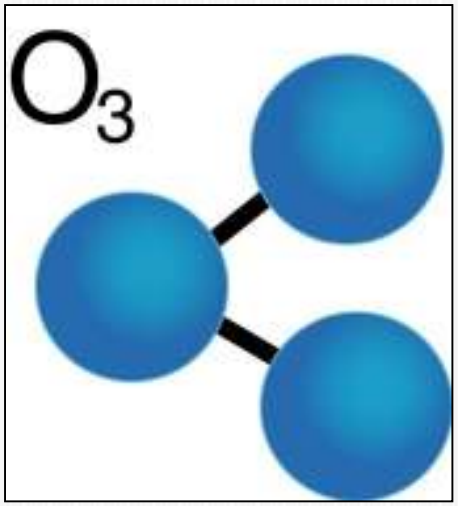
Removal of Iron and Manganese – **Oxidation**

- The most common chemical oxidants in water treatment are chlorine, chlorine dioxide, potassium permanganate, and ozone.





- Oxidation using chlorine or potassium permanganate is frequently applied in small groundwater systems.



- The dosing is relatively easy, requires simple equipment, and is fairly inexpensive.

Removal of Iron and Manganese – **Oxidants**

Chlorine, Chlorine dioxide

- Chlorination is widely used for oxidation of divalent iron and manganese.

Advantages:

- Chlorine feed rates and contact time requirements can be determined by simple jar tests.

Disadvantages/ Limitations:

- Formation of tri-halomethanes (THMs) in highly colored waters may be a problem.

Removal of Iron and Manganese – **Oxidants**

Potassium Permanganate ($KMnO_4$)

Advantages:

- As an oxidant, potassium permanganate ($KMnO_4$) is efficient for iron and manganese removal
- It requires considerably less equipment and capital investment.

Disadvantages/ Limitations:

- Normally more expensive than chlorine and ozone

Removal of Iron and Manganese – **Oxidants**

- The dose of $KMnO_4$ must be carefully controlled, since too little permanganate will not oxidize all the iron and manganese, and too much will allow permanganate to enter the distribution system and cause a pink color.

- Permanganate can also form precipitates that cause mud-ball formations on filters, which are difficult to remove and compromise filter performance.

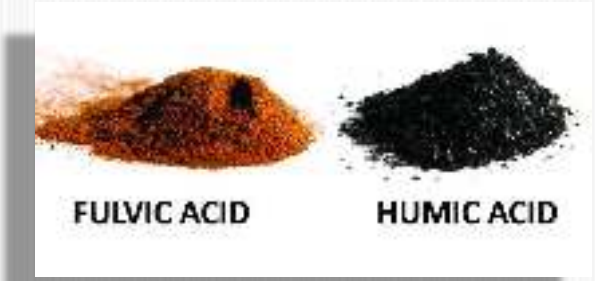
Removal of Iron and Manganese – **Oxidants**

Ozone (O_3)

- Ozone may be used for iron and manganese oxidation.

Disadvantages/ Limitations:

- Ozone may not be effective for oxidation in the presence of humic or fulvic materials.



- If not dosed carefully, ozone can oxidize reduced manganese to permanganate and result in pink water formation as well.

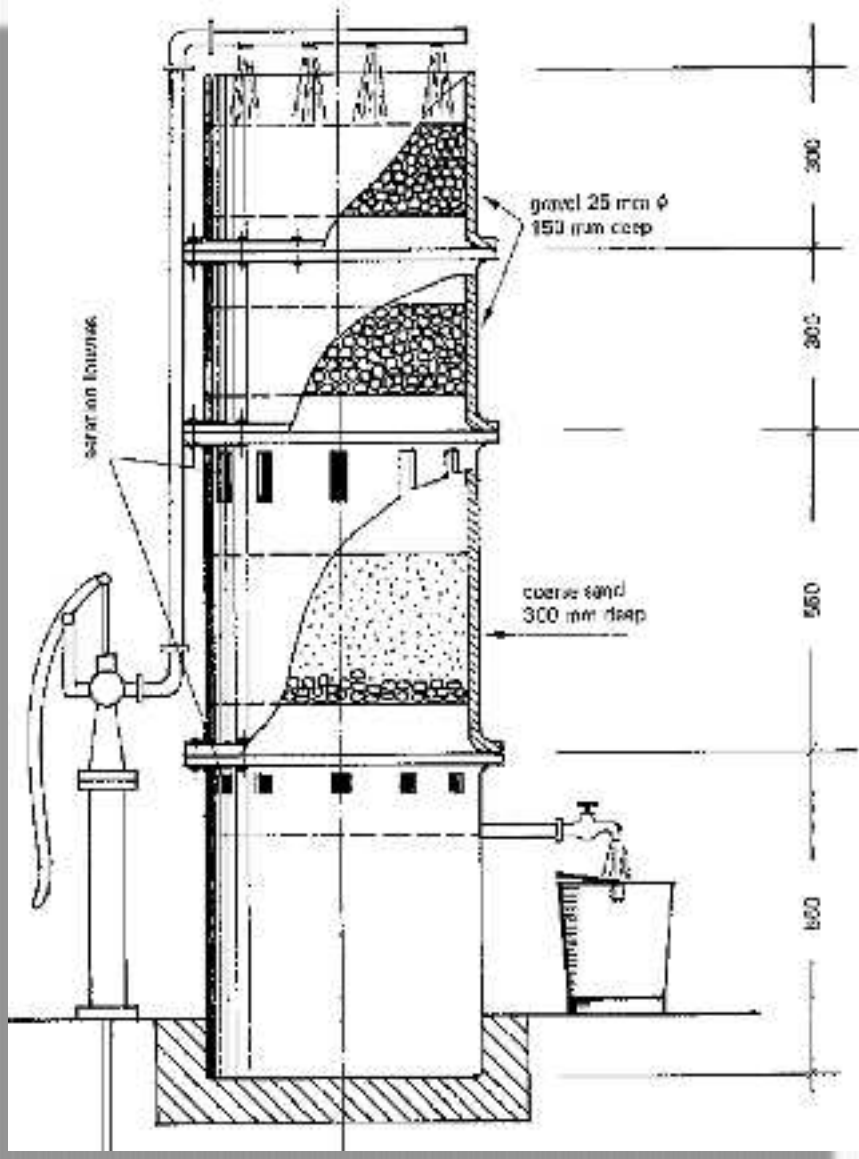
- Manganese dioxide particles, also formed by oxidation of reduced manganese, must be carefully coagulated to ensure their removal.

Removal of Iron and Manganese – **Oxidation**

Aeration

- A low-cost method of providing oxidation is to use the oxygen in air as the oxidizing agent in a tray aerator.

- Water is simply passed down a series of porous trays to provide contact between air and water.



Advantages:

- No chemical dosing is required
- Allows for unattended operation.

Removal of Iron and Manganese – **Oxidation**

Aeration

Disadvantages/ Limitations:

- This method is not effective for water in which the iron is complexed with humic materials or other large organic molecules.
- Oxygen is not a strong enough oxidizing agent to break the strong complexes formed between iron and manganese and large organic molecules.
- The rate of reaction between oxygen and manganese is very slow below pH values of 9.5.

Removal of Iron and Manganese – **Oxidation**

Aeration - Filtration

- High concentrations of iron and manganese can be treated with an aeration- filtration system.
- In this system, air is pulled in and mixed with the passing stream of water.
- The air-saturated water then enters a precipitator/aerator vessel where air separates from the water.
- The water then flows through a filter where various filter media screen out oxidized particles of iron, manganese, and some carbonate or sulphate.

Removal of Iron and Manganese – **Oxidation**

Aeration - Filtration

- Pressure-type aerators are commonly used in household water systems.

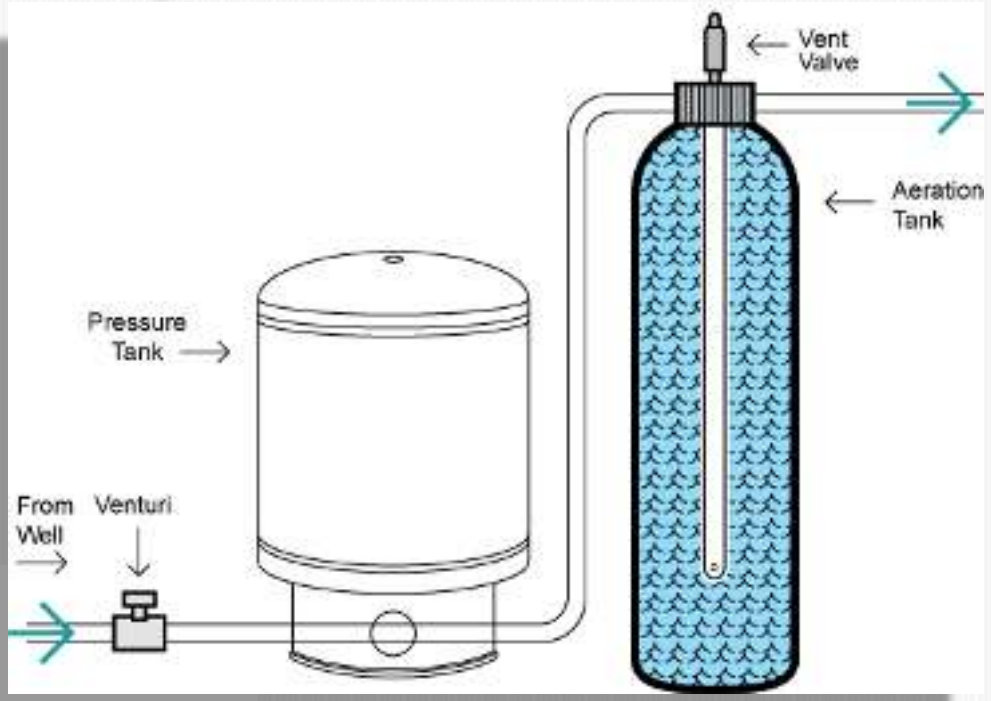
- Backwashing the filter periodically is a very important maintenance step.

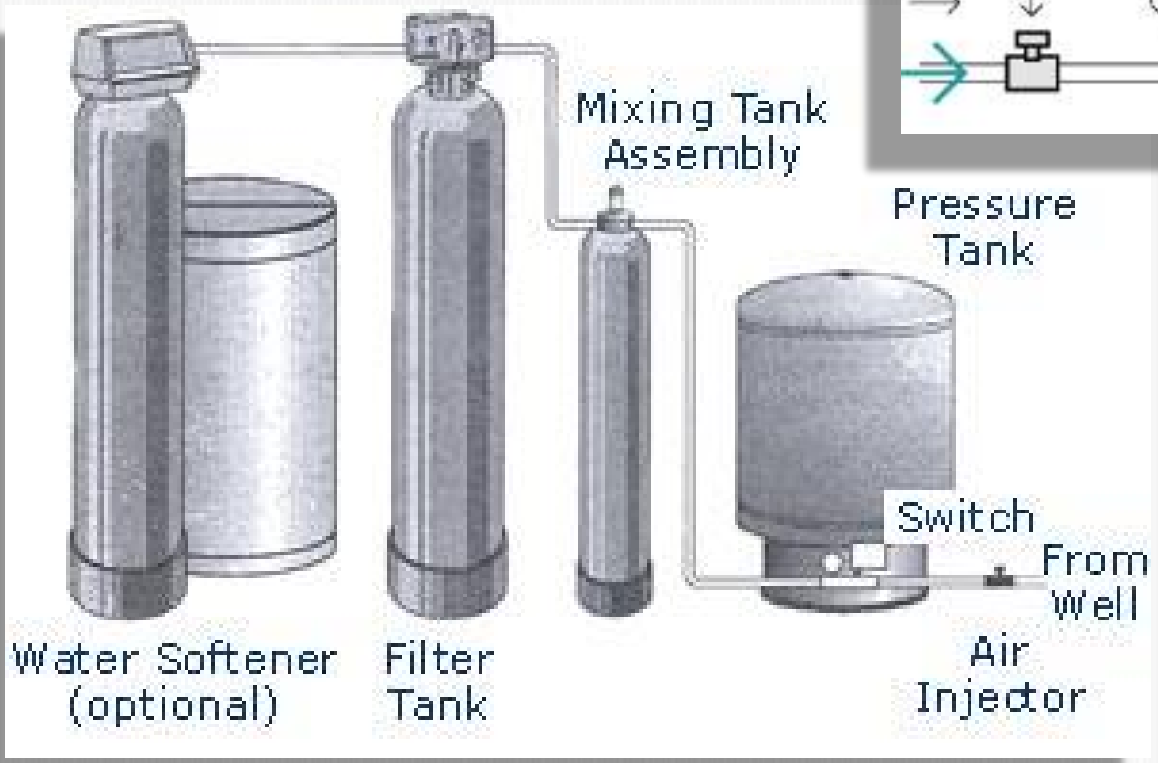
Limitations:

- Aeration is not recommended for water containing iron/manganese bacteria or colloidal (organic complexes of) iron/manganese because they can clog the aspirator and filter.

Removal of Iron and Manganese – **Oxidation**

Aeration - Filtration





Removal of Iron and Manganese – **Oxidation**

Aeration - Filtration

- Iron and manganese in well waters occur as soluble ferrous and manganous bicarbonates.

- In the aeration process, the water is saturated with oxygen to promote the following reactions:

$$4Fe(HCO_3)_2 + O_2 + 2H_2O = 4Fe(OH)_3 + 8CO_2$$

$$2Mn(HCO_3)_2 + O_2 = 2MnO_2 + 4CO_2 + 2H_2O$$

- The oxidation products, ferric hydroxide and manganese dioxide, are insoluble, thus form precipitates.

Removal of Iron and Manganese – **Oxidation**

Aeration - Filtration

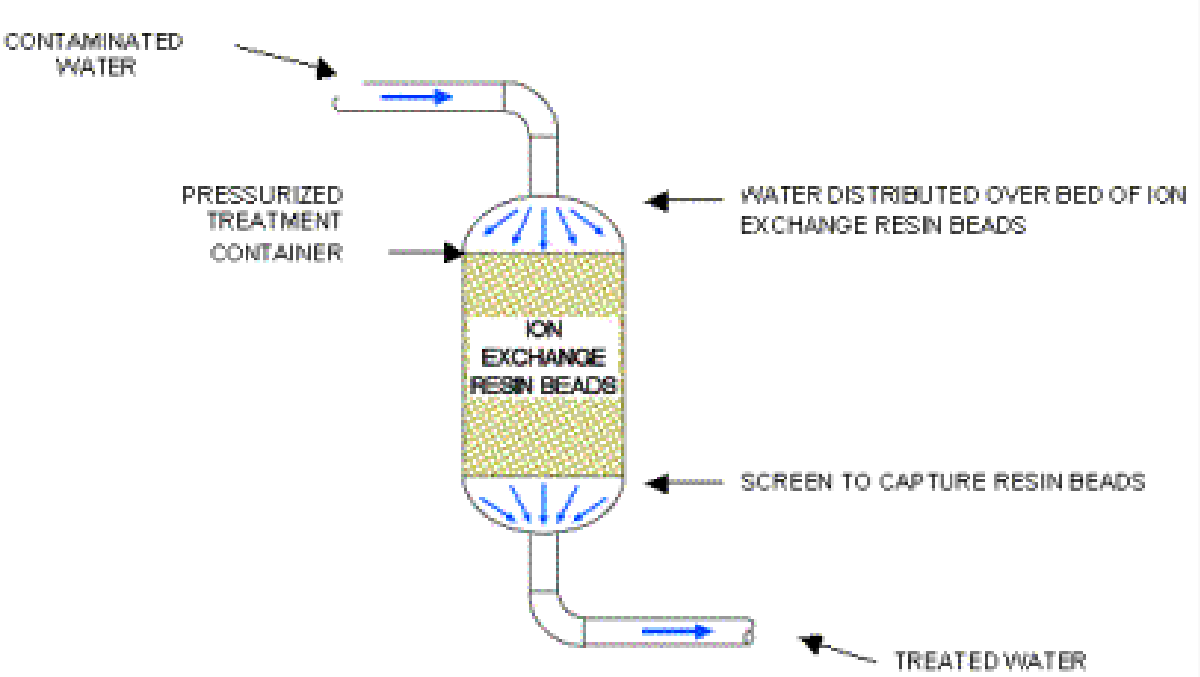
- After aeration, the precipitates are removed by clarification or filtration.

- Occasionally, strong chemical oxidants such as chlorine (Cl_2) or potassium permanganate ($KMnO_4$) may be used following aeration to ensure complete oxidation.

Removal of Iron and Manganese – **Ion Exchange**

- Ion exchange should be considered only for the removal of small quantities of iron and manganese because there is a risk of rapid clogging.

- Ion exchange involves the use of synthetic resins where a pre-saturant ion on the solid phase (the "adsorbent," usually sodium) is exchanged for the unwanted ions in the water.



ION EXCHANGE TREATMENT PROCESS

Removal of Iron and Manganese – **Ion Exchange**

Limitations:

- One of the major difficulties in using this method for controlling iron and manganese is that if any oxidation occurs during the process, the resulting precipitate can coat and foul the media.

- Cleaning would then be required using acid or sodium bisulphate.

EWCE 331
Water Supply Engineering

Lecture 9

Instructor

Lt Col Dr. Kazi Shamima Akter, Engrs

Department of EWCE, MIST

Lecture outline

Water Treatment Methods

Topics	References
• **Advanced water treatment for heavy metal removal** ✓ **Arsenic removal**	**1. Water and Environmental Engineering** Authors: M. Habibur Rahman, Abdullah Al-Muyeed 1st ed., ITN-BUET **2. Environmental Engineering** Authors: Howard S. Peavy, Donald R. Rowe and George Tchobanoglous International Edition, McGraw Hill Companies **2. Water Supply and Sanitation** Authors: M. Feroz Ahmed, Md. Mujibur Rahman 1st ed., ITN-BUET

Removal of Arsenic

- There are several methods available for removal of arsenic from water in large conventional treatment plants.

- The most commonly used technologies include –
  - ✓ oxidation,
  - ✓ co-precipitation and adsorption onto coagulated flocs,
  - ✓ lime treatment,
  - ✓ adsorption onto sorptive media,
  - ✓ ion exchange resin and
  - ✓ membrane techniques

Removal of Arsenic – **Oxidation**

- Arsenic is present in groundwater in Arsenite [As(III)] and Arsenate [As (V)] forms in different proportions.
- Most treatment methods are effective in removing arsenic in As (V) form and hence include an oxidation step as pre-treatment to convert As(III) to As (V) .
- Arsenite can be oxidized by oxygen, ozone, free chlorine, hypochlorite, permanganate, hydrogen peroxide.

Removal of Arsenic – **Oxidation**

- Atmospheric oxygen, hypochloride and permanganate are commonly used for oxidation in developing countries.

$$H_3AsO_4 + \tfrac{1}{2}O_2 = H_2AsO_4^- + 2H^+ \quad (1)$$

$$H_3AsO_4 + HClO = HAsO_4^{--} + Cl^- + 3H^+ \quad (2)$$

$$3\,H_3AsO_4 + 2KMnO_4 = 3HAsO_4^{--} + 2MnO_2^+ + 2K^+ + 4H^+ + H_2O \quad (3)$$

Note: H_3AsO_4: Arsenic Acid
$H_2AsO_4^-$: Dihydrogen Aesenate
$HAsO_4^{--}$: Hydrogen Aesenate

- Air oxidation of arsenic is very slow and can take weeks for oxidation.
- Chemicals like chlorine and permanganate can rapidly oxidize arsenite to arsenate under wide range of conditions.

Removal of Arsenic – **Co-Precipitation and Adsorption**

- Water treatment with coagulants such as aluminium alum, $Al_2(SO_4)_3.18H_2O$, ferric chloride , $FeCl_3$ and ferric sulfate $Fe_2(SO_4)_3.7H_2O$ are effective in removing arsenic from water.

- Ferric salts have been found to be more effective in removing arsenic than alum on a weight basis and effective over a wider range of pH.

- In both cases pentavalent arsenic can be more effectively removed than trivalent arsenic.

Removal of Arsenic – **Co-Precipitation and Adsorption**

- In the coagulation-flocculation process aluminium sulfate, or ferric chloride, or ferric sulfate is added and dissolved in water under efficient stirring for one to few minutes.
- Aluminium or ferric hydroxide micro-flocs are formed rapidly.
- During this flocculation process all kinds of micro-particles and negatively charged ions are attached to the flocs by electrostatic attachment.

Removal of Arsenic – **Co-Precipitation and Adsorption**

- Arsenic is also adsorbed onto coagualted flocs.

- As trivalent arsenic occurs in non-ionized form, it is not subject to significant removal.
- Oxidation of As(III) to As(V) is thus required as a pretreatment for efficient removal.

- This can be achieved by addition of bleaching powder (chlorine) or potassium permanganate as shown in Equations 2 and 3.

$$\mathbf{H_3AsO_4} + HClO = HAsO_4^{--} + Cl^- + 3H^+ \quad (2)$$

$$\mathbf{3\ H_3AsO_4} + 2KMnO_4 = 3HAsO_4^{--} + 2MnO_2^{+} + 2K^+ + 4H^+ + H_2O \quad (3)$$

Removal of Arsenic – **Co-Precipitation and Adsorption**

- The possible chemical equations of alum coagulation are as follows:

Alum dissolution:

$$Al_2(SO_4)_3.18H_2O = 2Al^{+++} + 3SO_4^{++} + 18H_2O \quad (4)$$

Aluminium precipitation(acidic):

$$2Al^{+++} + 6H_2O = 2Al(OH)_3 + 6H^+ \quad (5)$$

Co-precipitation (Non-stoichiometric, non-defined product):

$$H_2AsO_4^- + Al(OH)_3 = \text{Al-As (complex)} + \text{Other Products} \quad (6)$$

- Arsenic adsorbed on aluminiun hydroxide focs as Al-As complex is removed by sedimentation.

- Filtration may be required to ensure complete removal of all flocs.

Removal of Arsenic – **Co-Precipitation and Adsorption**

- Similar reactions take place during the coagulation – precipitation process using ferric chloride and ferric sulfate.
- Fe-As complex is formed as the end product, which is removed by sedimentation and filtration.
- Arsenic removal is dependent on pH.
- In alum coagulation, the removal is most effective in the pH range 7.2 -7.5.
- In iron coagulation, efficient removal is achieved in a wider pH range usually between 6.0 and 8.5.

Removal of Arsenic – **Co-Precipitation and Adsorption**

- The principles of arsenic removal by alum coagulation, sedimentation and filtration have been employed in a compact unit for water treatment in the village level in West Bengal, India.

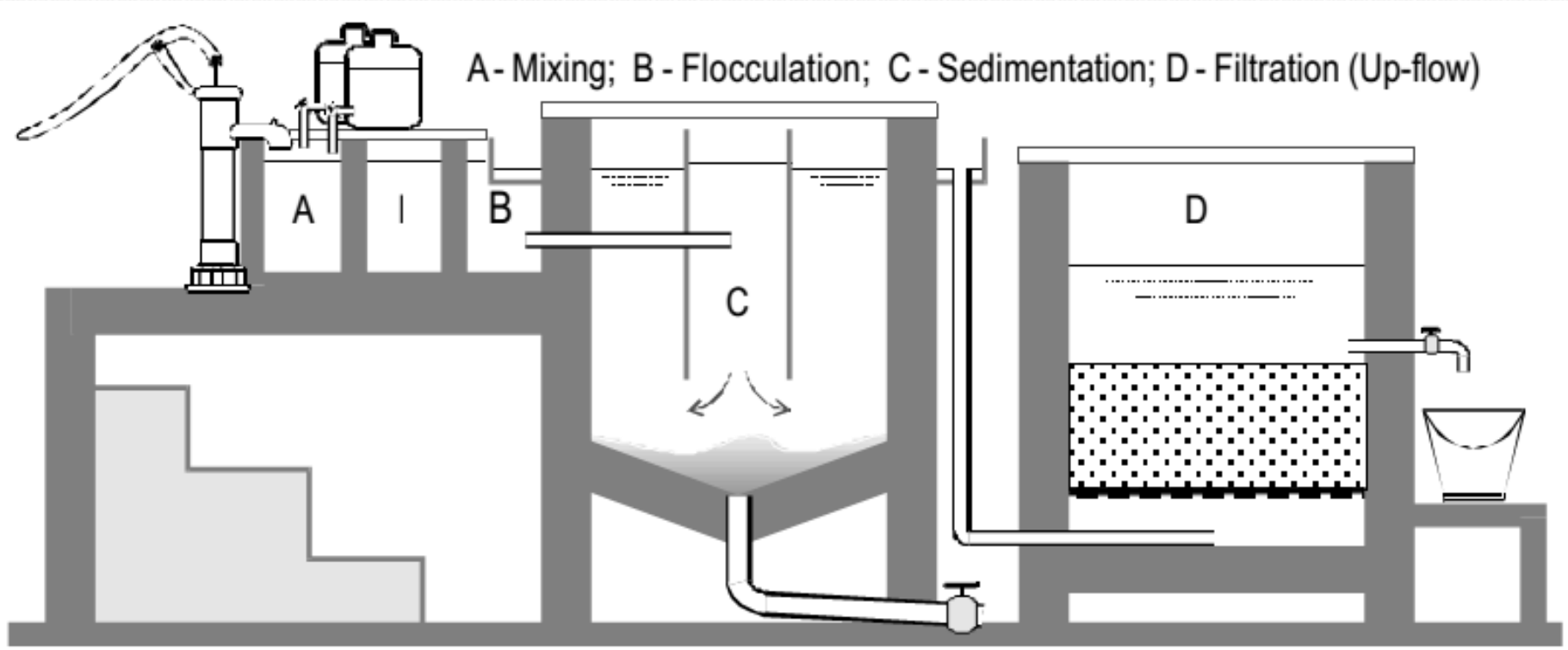


Fig 1: Arsenic removal plants attached to tubewell (designed and constructed in India)

Removal of Arsenic – **Co-Precipitation and Adsorption**

- The arsenic removal plant attached to hand tubewell as shown in Figure 1 has been found effective in removing 90 percent arsenic from tubewell water having initial arsenic concentration of 300 mg/L.

- The treatment process involves in the As removal plant (Figure 1) –
  ✓addition of sodium hypochloride (NaOCl) and alum in diluted form,
  ✓mixing,
  ✓flocculation,
  ✓sedimentation and
  ✓up flow filtration ------ in a compact unit.

Removal of Arsenic – **Co-Precipitation and Adsorption**

Bucket Treatment Unit

- The Bucket Treatment Unit (BTU), developed by DPHE-Danida Project is based on the principles of coagulation, co-precipitation and adsorption processes.

- These units are based on chemical doses of 200 mg/L aluminum sulfate and 2 mg/L of potassium permanganate supplied in crushed powder form.

- The units were reported to have very good performance in arsenic removal in both field and laboratory conditions.

- In many cases of rapid assessment, the units under rural operating conditions fails to remove arsenic to the desired level of 0.05 mg/L in Bangladesh.

Removal of Arsenic – Co-Precipitation and Adsorption

Bucket Treatment Unit

- Poor performance in rapid assessment is due to –
  - ✓ Poor mixing
  - ✓ Variable water quality (specially pH) of groundwater in different locations of Bangladesh

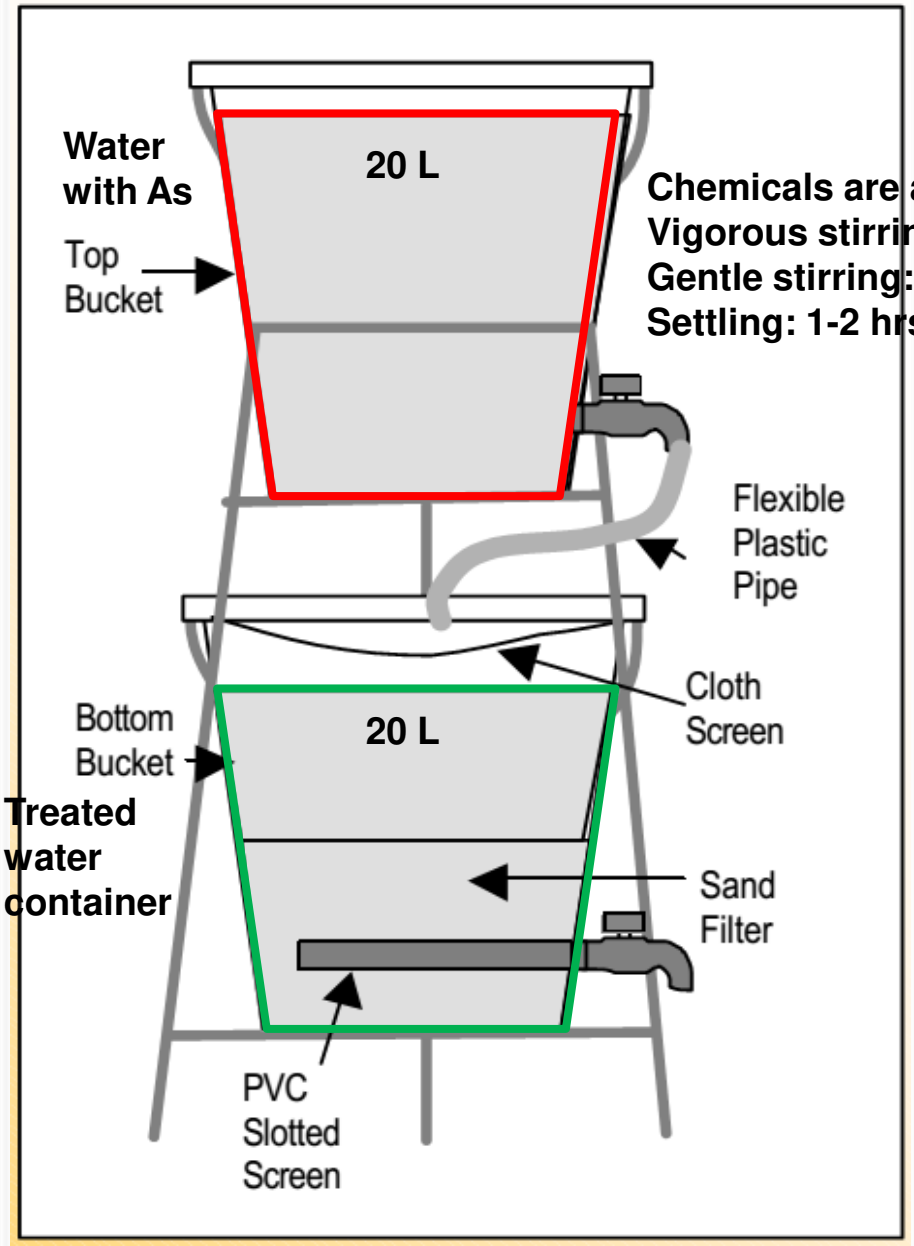


Fig 2: Bucket treatment unit

Removal of Arsenic – **Co-Precipitation and Adsorption**

Steven Institute Technology

- Rapid assessment showed that the technology was effective in reducing arsenic levels to less than 0.05 mg/L in case of 80 to 95% of the samples tested.

- The sand bed used for filtration is quickly clogged by flocs and requires washing atleast twice a week.

Removal of Arsenic – Co-Precipitation and Adsorption

Steven Institute Technology

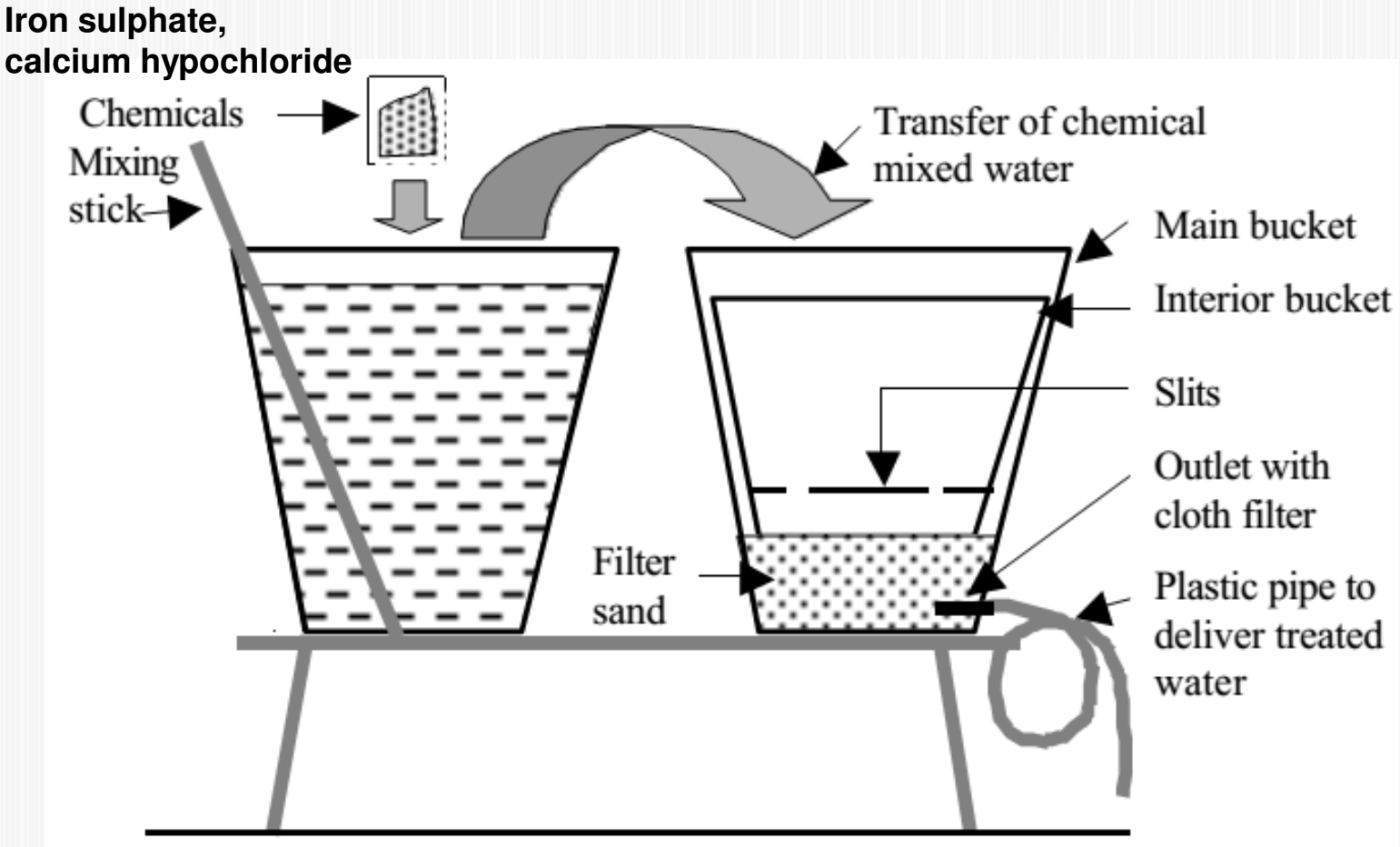


Fig 3: Steven Institute Technology

Removal of Arsenic – **Co-Precipitation and Adsorption**

Steven Institute Technology

- This technology also uses two buckets –
  - ✓one to mix chemicals (iron sulphate and calcium hypochloride) supplied in packets and
  - ✓ the other to separate flocs by the processes of sedimentation and filtration.

- The second bucket has a second inner bucket with slits on the sides as shown in Figure 3 to help sedimentation and keeping the filter sand bed in place.

Removal of Arsenic – **Co-Precipitation and Adsorption**

Naturally Occurring Iron

- The use of naturally occurring iron precipitates in ground water in Bangladesh is a promising method of removing arsenic by adsorption.

- Although no good correlation between concentrations of iron and arsenic has been derived, iron and arsenic have been found to co-exist in ground water.

- Most of the tubewell water samples satisfying Bangladesh Drinking Water Standard for Iron (1 mg/L) also satisfy the standard for Arsenic (0.05 mg/L).

Removal of Arsenic – **Co-Precipitation and Adsorption**

Naturally Occurring Iron

- The iron precipitates [$Fe(OH)_3$] formed by oxidation of dissolved iron [$Fe(OH)_2$] present in groundwater, have the affinity for the adsorption of arsenic.

- Only aeration and sedimentation of tubewell water rich in dissolved iron has been found to remove arsenic.

Removal of Arsenic – **Co-Precipitation and Adsorption**

Naturally Occurring Iron

- The Iron Removal Plants (IRPs) in Bangladesh constructed on the principles of aeration, sedimentation and filtration in a small units have been found to remove arsenic without any added chemicals.

- The conventional community type IRPs, depending on the operating principles, more or less work as Arsenic Removal Plants (ARPs) as well.

Removal of Arsenic – **Co-Precipitation and Adsorption**

Sorptive Filtration Media

- Several sorptive media have been reported to remove arsenic from water.

- These are activated alumina, activated carbon, iron and manganese coated sand, kaolinite clay, hydrated ferric oxide, activated bauxite, titanium oxide, and many natural and synthetic media.

- The efficiency of all some sorptive media depend on the use of oxidizing agent as aids to sorption of arsenic.

Removal of Arsenic – **Co-Precipitation and Adsorption**

Sorptive Filtration Media - Activated Alumina

- Activated alumia, (Al_2O_3) having good sorptive surface is an effective medium for arsenic removal.

- When water passes through a packed column of activated alumina, the impurities including arsenic present in water are adsorbed on the surfaces of activated alumina grains.

- Eventually the column becomes saturated, first at its upstream zone and later the saturated zone moves downstream towards the bottom end and finally the column get totally saturated.

- Then the media requires to be regenerated.

Removal of Arsenic

Other Methods of Arsenic Removal

- Ion Exchange
- Membrane Filtration
- Nano Filtration
- Reverse Osmosis
- Microbial process

EWCE 331
Water Supply Engineering

Lecture 10

Instructor

Lt Col Dr. Kazi Shamima Akter, Engrs

Department of EWCE, MIST

Lecture outline

Water Treatment Methods

Topics	References
• **Advanced water treatment for heavy metal removal** ✓ **Taste and Odor control** ✓ **Hardness removal – water softening**	**1. Water and Environmental Engineering** Authors: M. Habibur Rahman, Abdullah Al-Muyeed 1st ed., ITN-BUET **2. Environmental Engineering** Authors: Howard S. Peavy, Donald R. Rowe and George Tchobanoglous International Edition, McGraw Hill Companies **2. Water Supply and Sanitation** Authors: M. Feroz Ahmed, Md. Mujibur Rahman 1st ed., ITN-BUET

Control of Taste and Odor – **Aeration**

- Aeration is effective in removing tastes and odors that are caused by volatile materials.
- Volatile materials (e.g Methane and hydrogen sulfide) have low boiling point and will vaporize very easily.
- Many taste and odor problems in surface water could be caused by oils and by-products that algae produce.
- Since oils are much less volatile than gases, aeration is only partially effective and requires oil separation techniques to be applied.

Control of Taste and Odor – **Aeration**

Hydrogen Sulfide:

- A poisonous gas, having rotten-egg odor.

- H_2S occurs mainly in groundwater supplies, caused by the action of iron or sulphur reducing bacteria in the well.

- H_2S in a water supply will disagreeably alter the taste of coffee, tea, and ice.

- H_2S is corrosive to piping, tanks, water heaters, and copper alloys that it contacts.

Control of Taste and Odor – **Aeration**

Hydrogen Sulfide:

Operational problems:

- Disinfection of the water can become less effective because of the chlorine demand exerted by the hydrogen sulfide.

$$H_2S + Cl_2 + O^{2-} \rightarrow S + H_2O + 2Cl^-$$

$$H_2S + 4Cl_2 + 4\ H_2O \rightarrow H_2SO_4 + 8\ HCl$$

- There could be corrosion of the piping systems and the water tanks.

Control of Taste and Odor – **Aeration**

Removal of Hydrogen Sulfide:

• H_2S is physically removed by agitating the water via bubbling or cascading and then separating or stripping the hydrogen sulfide in a container.

$$H_2S + O_2 = \text{water } (H_2O) + \text{elemental sulfur}$$

• Aeration is most effective when H_2S concentration is lower than 2.0 mg/l.

• At higher concentrations, this method may not remove all of the offensive odor unless the air is used to oxidize H_2S chemically into solid sulfur, which is then filtered.

Removal of Hardness

- Hardness in water is principally caused by the solution in water of carbonate, bicarbonate and sulfate of calcium and magnesium.

- Sometimes iron and aluminium cause hardness to a lesser degree.

- The general methods used for water softening are:
  - ✓ Boiling
  - ✓ Lime process
  - ✓ Lime and soda-ash process
  - ✓Base-exchange process

Removal of Hardness

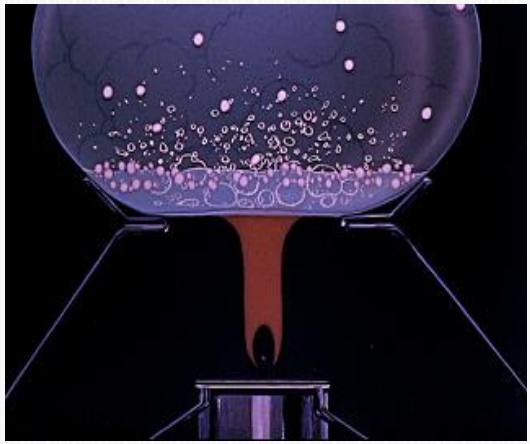
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  - ✓ Lime process
  - ✓ Lime and soda-ash process
  - ✓Base-exchange process

Removal of Hardness – **Heating/ Boiling**

- Heating is only effective for removal of bicarbonate hardness.



- Heating of water breaks down the bicarbonate into carbonate, water and carbon dioxides.

$Ca(HCO_3)_2$ + Heat = $CaCO_3$ + H_2O + CO_2

- $CaCO_3$ is insoluble and settles down.
- Excess CO_2 escapes from water.
- Similarly, hardness due to $Mg(HCO_3)_2$ can also be removed by simple heating.

Removal of Hardness – **Lime Process**

- Also known as Clark process, reduces only carbonate hardness.

- The principle involved is to neutralize with milk of lime, i.e $Ca(OH)_2$, forming normal carbonates which precipitate out when present in excess amounts.

$$\mathbf{Ca(HCO_3)_2 + Ca(OH)_2 = 2CaCO_3 + H_2O}$$

$$\mathbf{Mg(HCO_3)_2 + Ca(OH)_2 = CaCO_3 + MgCO_3 + H_2O}$$

- The precipitated carbonates are removed by sedimentation and filtration.

Removal of Hardness – **Lime & Soda Ash Process**

- Lime has no effect on sulfate of calcium and magnesium, which are responsible for causing most of the non-carbonate hardness found in natural waters.

- Non-carbonate hardness is removed by the addition od soda ash (Na_2CO_3).

$$\mathbf{CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4}$$

$$\mathbf{Ca(HCO_3)_2 + Na_2CO_3 = CaCO_3 + NaHCO_3}$$

Removal of Hardness – **Lime & Soda Ash Process**

- Some of the insoluble materials formed here may remain in the water in a finely divided state.
- These may be found deposited on the filter sand or in the distribution pipelines at a later time.
- This difficulty may be overcome by treating the water with CO_2, process called recarbonation.

Removal of Hardness – **Base Exchange Process**

- Hard water is passed through a bed of zeolite sand (complex silicates of aluminium and sodium).
- The water exchanges its calcium and magnesium for sodium in the zeolite bed until the sodium becomes exhausted.
- The lost sodium from the bed is then restored by regenerating the zeolite with a solution of common salt (NaCl).
- The zeolite or base-exchange process of water softening is applicable only to clear water, since the presence of turbidit causes clogging of zeolite material.

Removal of Hardness – **Base Exchange Process**

- The chemical reactions are as follows:

$$\left.\begin{array}{l} CaSO_4 \\ MgSO_4 \\ CaCO_3 \\ MgCO_3 \\ CaCl_2 \\ Etc \end{array}\right\} + Na_2Al(SiO_3)_2 = \underset{\text{(zeolite)}}{\left.\begin{array}{l} Ca \\ \\ Mg \end{array}\right\}} Al(SiO_3)_2 + \left\{\begin{array}{l} Na_2CO_3 \\ Na_2SO_4 \\ 2NaCl \\ \text{etc.} \end{array}\right.$$

- **Regeneration:**

$$\left.\begin{array}{l} Ca \\ \\ Mg \end{array}\right\} Al(SiO_3)_2 + 2NaCl = \underset{\text{(regenerated zeolite)}}{Na_2Al(SiO_3)_2} + \left\{\begin{array}{l} CaCl_2 \\ \\ MgCl_2 \end{array}\right.$$