EWCE 331



WATER SUPPLY ENGINEERING

Course Contents

- Introduction to Water Supply Engineering; Water requirement in urban and rural communities; Sources of water supply; Ground water exploration, types of wells and pumps; design, drilling, construction and maintenance of wells.
- Rain water harvesting system and alternative water supplies for water stressed areas;
- **Surface water collection, transportation, treatment and distribution systems; analysis and design of distribution network; Fire hydrants;** Water meters; Water loss control.
- **Water quality requirements; Bangladesh and international standards; Water treatment methods**, climate resilient water safety plan (CRWSP).

Course References

- **Water Supply and Sanitation**

  M. Feroze Ahmed & Md. Mujibur Rahman (ITN-Bangladesh)

- **Water Supply Engineering**

  M. A. Aziz

What is Water Supply Engineering?

- A branch of civil engineering concerned with the development of sources of supply, transmission, distribution, and treatment of water.
- The term is used most frequently in regard to municipal water works, but applies also to water systems for industry, irrigation, and other purposes.

History and Development of Water Supply

- Structures of water supply, drainage , sewerage and swimming pools of Mohenjo-Daro civilianization in the Indus Valley.
- Also Egypt, Babylonia and Assyria-flat countries used open canals with large storage basins
- Wells were also used in many countries in ancient times to utilize underground water
- Italy, Greece , India and Egyptian used wells in 2100 BC.
- Artesian wells were sunk in China in early times.

History and Development of Water Supply

- Lake Mories in Egypt – built in 2000 BC –Supplied water for 2,00,00,000 people
- Numerous conduits – water supply in ancient Jerusalem –600 to 900 BC
- Water supply in Rome –Surrounding aqueducts and hills –616 km
- London –at end of 16th century-first modern city to use lead pipe for conveyance of water
- European countries -Wood pipes bored out of logs

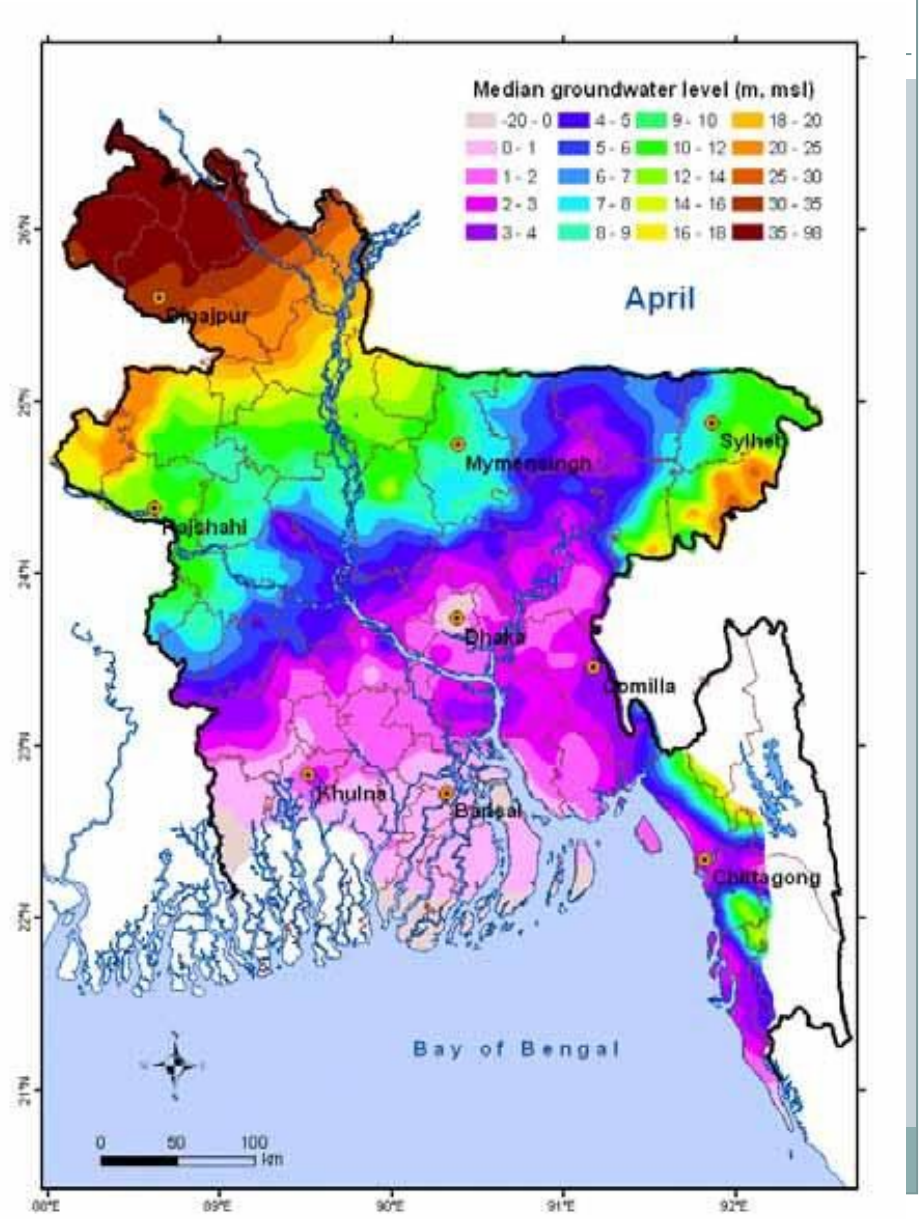
Purification attempts of the supplied water

- John Gibb -first water filter at Paisley in Scotland, **UK in 1804**.
- James P. Kirkwood - also designed the first sizeable water filter (New York, in **1871**).
- In **1849 Dr. John Snow**, a medical researcher in England demonstrated the role of fecal pollution of drinking water in the epidermicity of cholera.
- From **1857onward** Dr. William Budd investigated the water-borne diseases.

Bangladesh Scenario

Around 700 rivers in Bangladesh

- Annual Average Rainfall approx. 2500 mm
- Groundwater available within a depth of 1.0 m–60.0 m



Bangladesh Scenario

- In late 1960s and early 1970s about 3 to 4 million hand tube wells in Bangladesh have been sunk to provide drinking water to 97% of the rural population.
- In the context of very high prevalence of diarrheal diseases in Bangladesh, groundwater being usually free from disease producing micro-organisms, received priority as a source of water supply.

Water Supply system of Dhaka City

- Piped water supply in Dhaka in 1876
- 1963 demand was 150 million liters per day.
- Today demand 2000 mld considering per capital consumption rate 160lit/person/day
- DWASA supply 1500 million litre per day
- DWASA has pipeline of 2358.86 km

Water Supply system of Dhaka City

- from surface water 310 mld (225 mld from Saidabad, 39 from Chandni Ghat, and 46 from Narayangonj),rest from ground water.

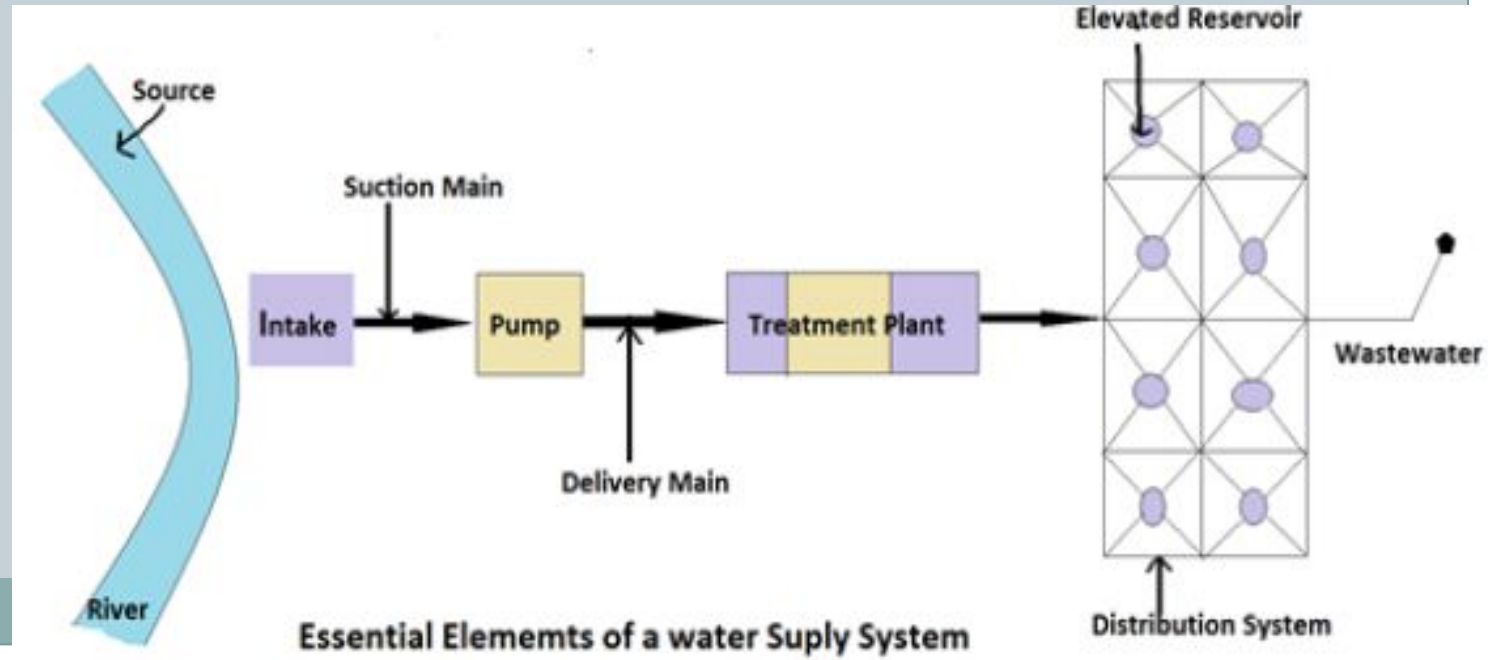
- There are 406 deep tube well of which 332 are functioning and produced 1330 mld.

Objectives of Water Supply

- supply water in adequate quantity
- supply safe and wholesome water to the consumers
- make water easily available to consumers

Elements of Water Supply

- Source of supply
- Collection system
- Treatment and
- Distribution system



Essential Elememts of a water Suply System

Source of Supply

- Surface water
- Ground water
- Rainwater

Selection of source depends on –

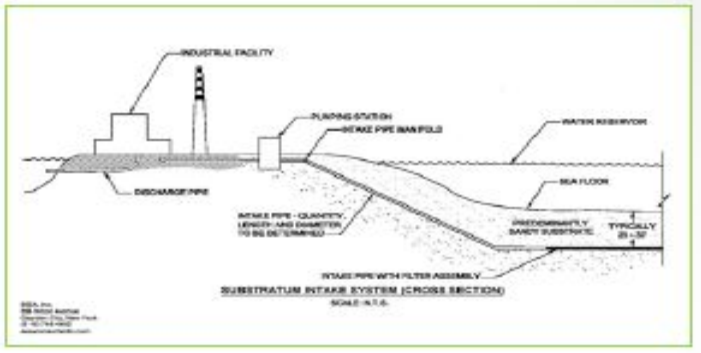
- Quantity
- Quality
- Cost

Choice of Source for Water Supply

- **Quantity:** The quantity of water available at all time s of the year should meet all the requirements of the community.
- **Quality:** the quality of water at the source should be such that the requirement for treatment is minimum.
- **Cost:** The cost involved in development, operation and maintenance of the water supply system should be reasonably affordable to the consumers.

Collection System

- Surface water – Intake with pumping facility required



- Ground water – Dugwells or tube wells are common devices



- Rainwater – A permanent roof or uncontaminated ground surface



Treatment

- Surface water
  - Turbidity
  - Color
  - Taste
  - Odour
  - Pathogens
- Ground water
  - Mineral substances
  - Iron
  - Arsenic
  - Fluoride
  - hardness

Methods:

- **Screening**
- **Sedimentation**
- **Aeration**
- **Chemical treatment**
- **filtration**
- **demineralization**
- **Disinfection**

Distribution System

- Urban -Piped Water supply
  - Storage reservoirs
  - Pumping devices
  - Standposts
  - Valves
  - Other appurtenances
- Rural -Unpiped Water supply –manually operated tubewells
  - Location
  - Accessibility
  - Serving distance and extent

Planning and Design Considerations

- Quality of water should not deteriorate below WHO standard
- Water in adequate quantity in convenient location
- Traditional sources should be selected for water supply development
- Construction, operation, maintenance and repair should be within reach of the available skills
- The equipment should be robust, reliable and locally available
- Construction and operation cost should be minimum
- Use of pumping and chemicals should be minimum
- System should be planned together with the community
- Women should be involved and consulted to address their needs
- In built system for monitoring of performance
- Provision for preventing deterioration of water quality
- Sustainability should be preferred in planning, designing and pricing the water supply

Water Requirement

Per Capita Water Consumption

- The per capita consumption of water is the total consumption divided by the population and the number of days in the year. It is generally expressed as liter per capita per day (lpcd).

Water Requirement

Factors affecting per capita demand:

- **Size of the city**: Per capita demand for big cities is generally large as compared to that for smaller towns as big cities have sewered houses.
- **Presence of industries**: industry uses large volumes of water in its manufacturing and supporting operations.
- **Climatic conditions**: water consumption on a summer day is 30 to 50% higher than the average daily demand.
- **Habits of people and their economic status**: per capita use of water is much less in slum areas than that in the high class residential areas due to gardening, car washing, air conditioning etc.

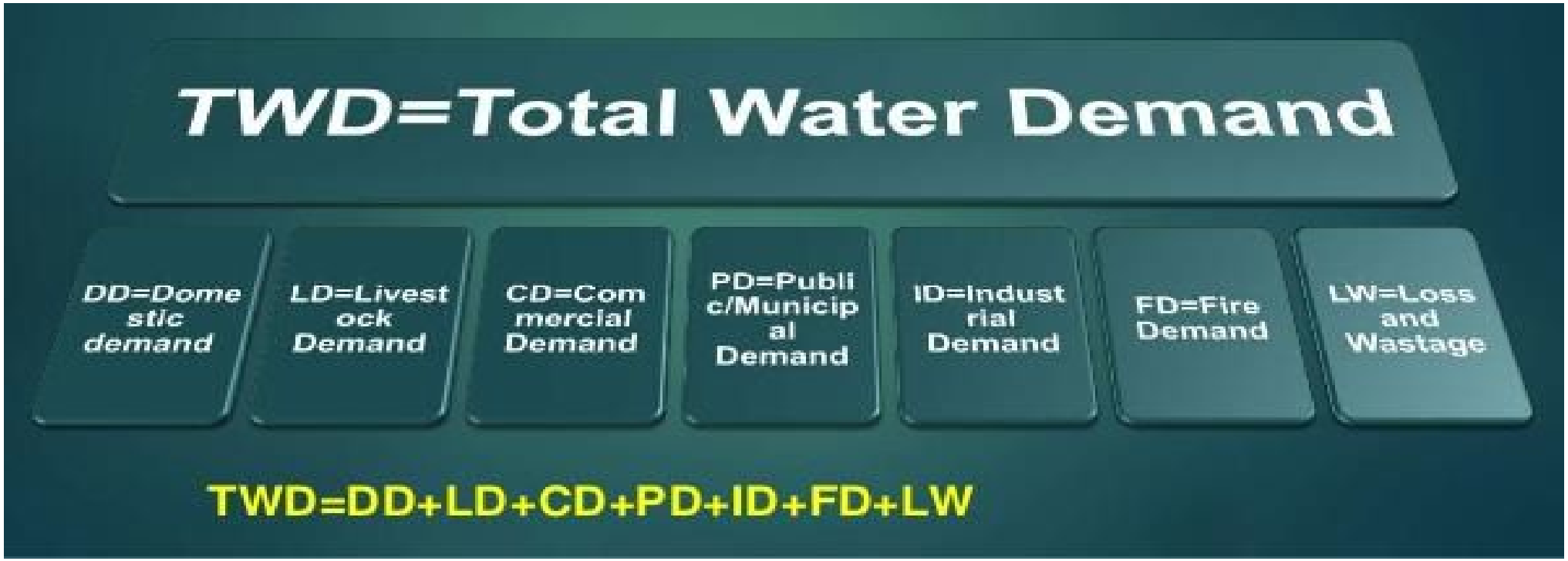
Water Requirement

- **Quality of water**: If water is aesthetically and medically safe, the consumption will increase.
- **Pressure in the distribution system**: incase of piped system the rate of water use increases with pressure.
- **Efficiency of waterworks administration**: Leaks in water mains and services; and unauthorized use of water can be kept to a minimum by surveys.
- **Cost of water**: if the cost is high people become more conservative in water use.
- **Policy of metering and charging method**: Water tax is charged in two different ways: on the basis of meter reading and on the basis of certain fixed monthly rate.

Water Consumption

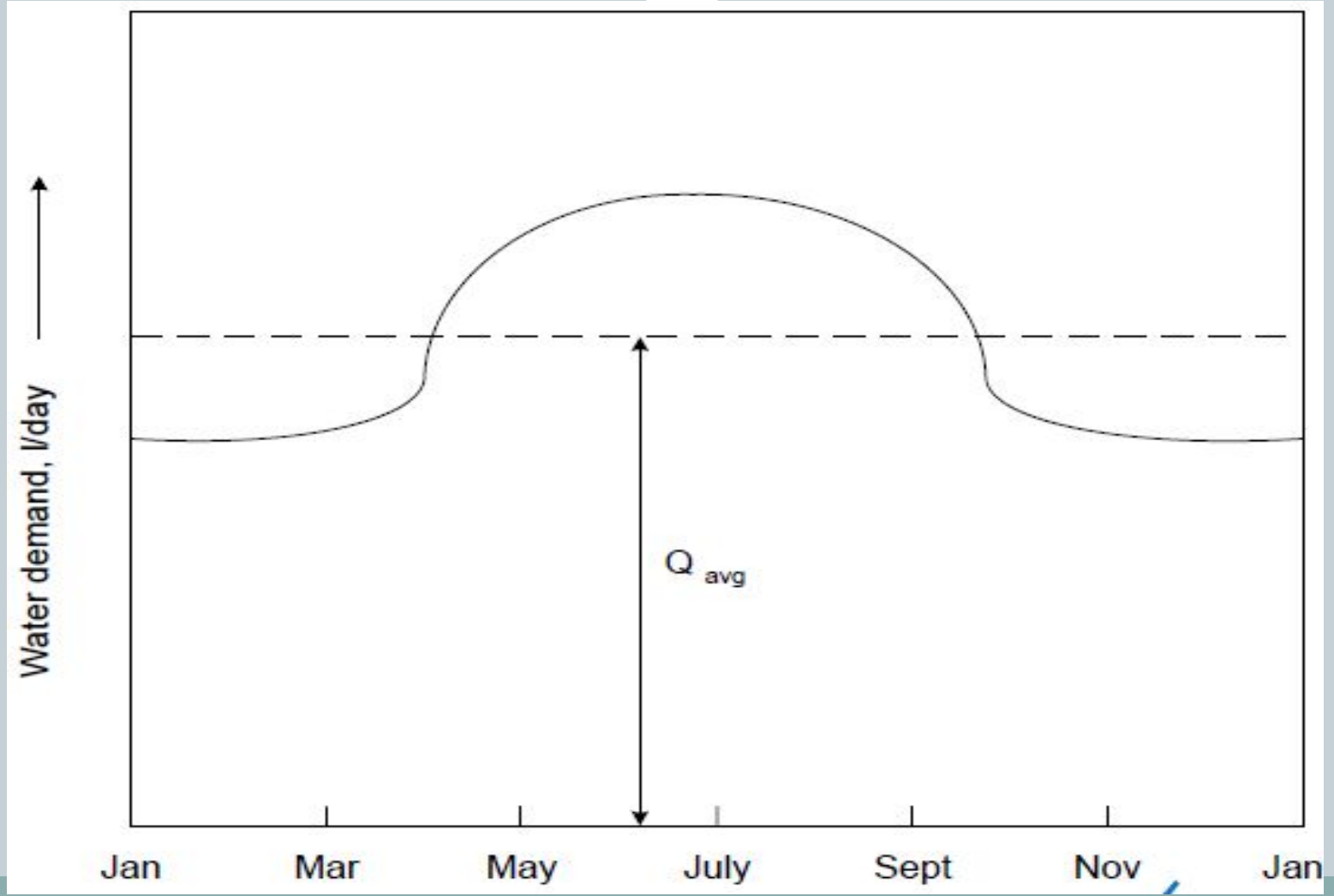
Water Consumption for Various Purposes:

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

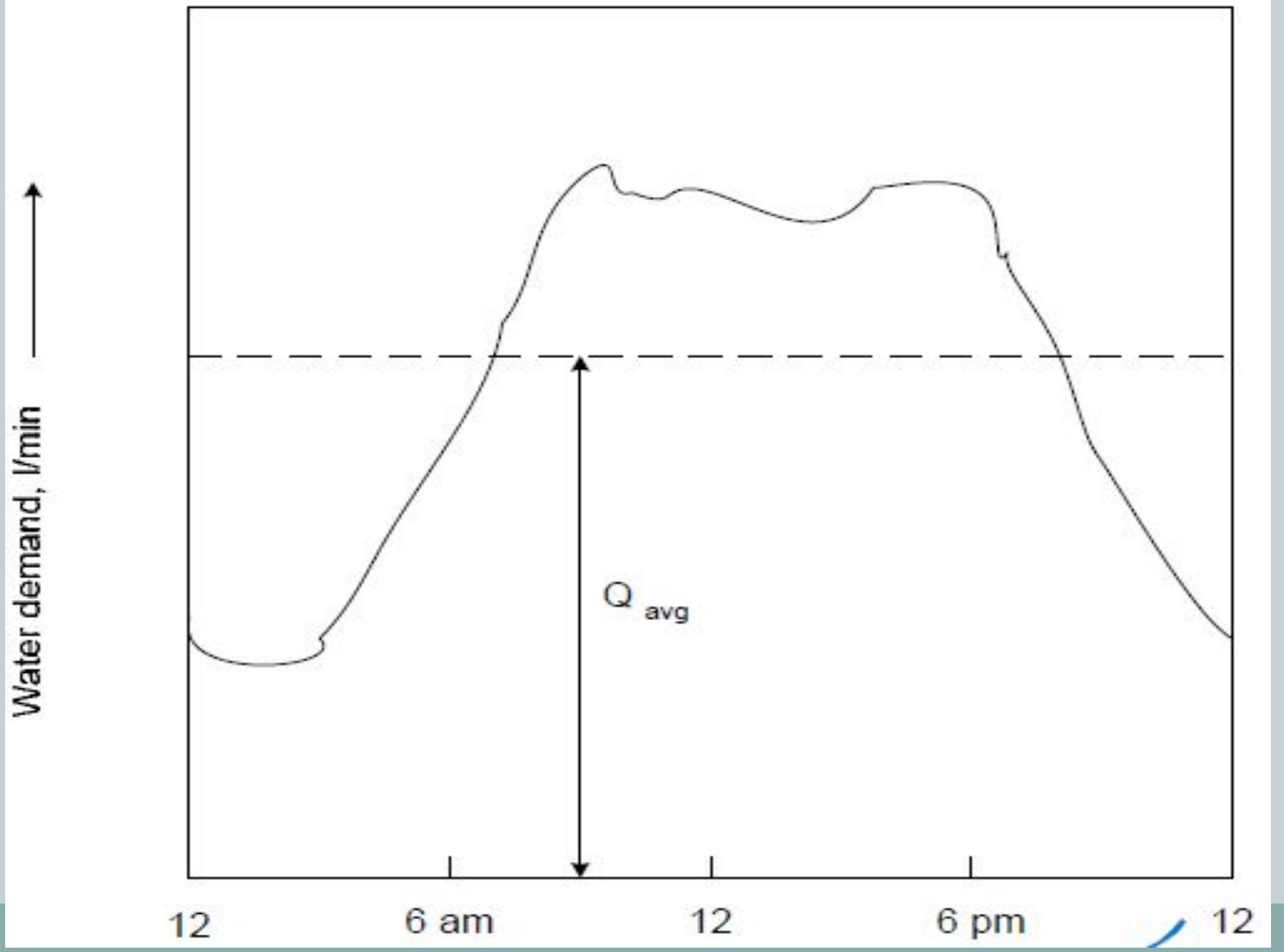

TWD=Total Water Demand
DD=Domestic demand
LD=Livestock Demand
CD=Commercial Demand
PD=Public/Municipal Demand
ID=Industrial Demand
FD=Fire Demand
LW=Loss and Wastage
TWD=DD+LD+CD+PD+ID+FD+LW


Variation in Demands of Water
Seasonal Variation
Variation in Demands of Water
Hourly Variation
Daily Variation

Seasonal Variations



Hourly Variations



Water Demand

Estimation of water requirement is important for designing a water supply system, which is designed for a future population. Total quantity of water required:

$$Q_f = P_f \times q$$

Where,

Q_f : water requirement per day

P_f : Projected population estimated at the end of the design period

q : rate of water consumption per capita per day.

Population Prediction

Methods for population projection

- Uniform growth rate method
- Uniform percentage growth rate method
- Decreasing growth rate method
- Graphical extension or curvilinear method
- Graphical comparison method
- **Geometric progression method**
- **Least square parabola method**

Population Prediction

1. Uniform growth rate method:

A constant increment of growth is added for a period based on the population growth of the same period in the recent past.

Example:

If population increased from 10,000 to 11,000 during last 5 years, the population will increase from 11,000 to 12,000 during next 5 years.

2. Uniform percentage growth rate method:

A constant percentage of growth is added for an equal period of time.

Example:

If population increased from 10,000 to 11,000 (10% increase) during 5 years, the population will increase to 12,100 during next 5 years.

Population Prediction

3. Decreasing growth rate method:

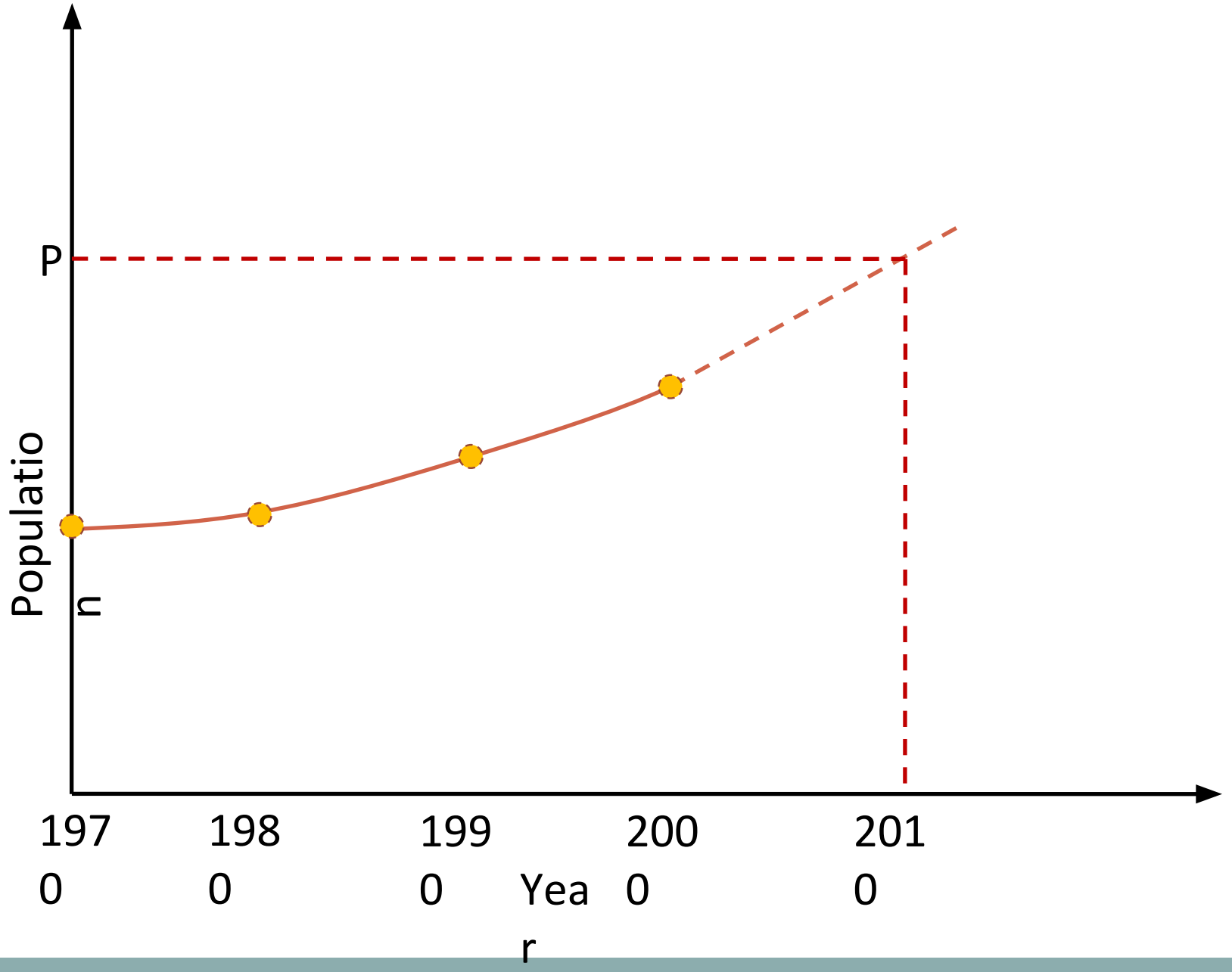
Similar to uniform growth rate method but the growth rate is decreasing.

Example:

If population increased from 10,000 to 11,000 during 2005 to 2009, the population will increase from 11,000 to 11,900 during 2009 to 2013.

4. Graphical extension or curvilinear method:

In this method the population time curve is extended by eye estimation to obtain the future population.


P
Populatio
n
197
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Population Prediction

5. Graphical comparison method:

This method involves the extension of the population-time curve of the community under study into the future based on a comparison of population-time curves of similar communities instead of projection by estimation. This method is also known as **modified curvilinear method.**

6. Geometric Progression Method:

Future population can be estimated using the following equation:

$$P_f = P_p (1 + r)^n$$

The rate of population growth can be estimated from population data of two years of n year interval in the recent past using the expression:

$$r = \sqrt[n]{\frac{P_2}{P_1}} - 1$$

Population Prediction

6. Geometric Progression Method:

Example - 1

The population of a town was 180,000 in 1980 and 220,000 in 1990. What will the population be in 2000?

Solution: $P_{1980} = 180.000$; $P_{1990} = 220,000$; $n = 10$

$$r = (P_{1990} / P_{1980})^{1/10} - 1 = (220.000/180,000)^{0.1} - 1 = 0.0203$$

$$P_{2000} = P_{1990} (1 + 0.0203)^{10} = 220,000 (1 + 0.0203)^{10} = 268,969$$

Population Prediction

7. Least Square Parabola method:

In this method the ***equation*** of the ***population-time curve*** is determined by the least square method using the available ***statistical data***.

Let the variables:

- X denote the years
- Y denote population of each year (X)

The equation of the least square parabola fitting the time population data is given by:

$$Y = a + bX + cX^2 \text{ ------- (1)}$$

Population Prediction

7. Least Square Parabola method:

$$Y = a + bX + cX^2 \text{ ------- (1)}$$

Where a, b, c are constants to be found from ***normal equations*** by applying the actual population data:

$$\sum Y = aN + b\sum X + c\sum X^2 \quad \text{--------- (2)}$$

$$\sum XY = a\sum X + b\sum X^2 + c\sum X^3 \quad \text{--------- (3)}$$

$$\sum X^2Y = a\sum X^2 + b\sum X^3 + c\sum X^4 \text{ ------- (4)}$$

Where ***N* = number of observations** or sets of data.

Example 2

The population of a community in 1950, 1960, 1970, 1980 and 1990 was 200, 230, 280, 350 and 450 respectively. Estimate the population of the community in the year 2000 and 2010.

Solution:

Year	X	Y	X^2	X^3	X^4	XY	X^2Y
1950	-2	200	4	-8	16	-400	800
1960	-1	230	1	-1	1	-230	230
1970	0	280	0	0	0	00	0
1980	1	350	1	1	1	350	350
1990	2	450	4	8	16	900	1800
Sum	ΣX=0	ΣY=1510	ΣX2=10	ΣX3=0	ΣX4=34	ΣXY=620	ΣX2Y=3180

In the above table 1970 has been taken as base year and a decade has been taken as 1 unit in X–Ordinate to eliminate some of the terms and make the computation simpler.

Using the data in the table the equations (17.2), (17.3), and (17.4) become

$$1510 = 5a + 0 + 10c \quad (17.7)$$
$$620 = 0 + 10b + 0 \quad (17.8)$$
$$3180 = 10a + 0 + 34c \quad (17.9)$$

Solving the equations (17.7), (17.8) and (17.9), the following values of a, b, and c are obtained:

$$a = 279.14; \quad b = 62; \quad c = 11.43$$

Thus the equation fitting the population data is given by :

$$Y = 279.14 + 62X + 11.43X^2$$

Population of the year 2000. $Y_{2000} = 279.14 + 62 \times 3 + 11.43 \times 3^2 = 568$

Population of the year 2010. $Y_{2010} = 279.14 + 62 \times 4 + 11.43 \times 4^2 = 710$

Population Prediction

Least square method of population projection

It is common to fit a straight line to the past observations.

y= a+bx

$$\Sigma Y = Na + b.\ \Sigma X$$
$$\Sigma XY = a.\ \Sigma X + b.\ \Sigma X^2$$

Example

Given Data

Year	population (in million)
1997	51.99
1998	52.49
1999	55.12
2000	54.07
2001	57.56

Population Prediction

Year	Population (in million) (Y)	S. No. of Col. 1 (X)	Square of 'X'	X.Y
1997	51.99	1	1	51.99
1998	52.46	2	4	104.92
1999	55.12	3	9	165.36
2000	54.07	4	16	216.23
2001	57.56	5	25	287.80
Total	(ΣY) 271.20	(ΣX) 15	(ΣX^2) 55	ΣXY) 826.35

$\Sigma Y = Na + b\Sigma X = 271.20 = 5a + 15b$ 1

$\Sigma XY = a \Sigma X + b \Sigma X^2 = 826.33 = 15a + 55b$ 2

$Y = 50.43 + 1.27 X$ (with 1997 as X=1)

population in 2002 (Y) = 50.43 + 1.27 x 6 = 58.05, X = 6

FIRE FIGHTING

- Fire fighting requires sufficient quantity of water, so as to throw it over the fire at high speeds .
- The quantity of water required extinguishing fires should be easily available and kept always stored in storage reservoirs.
- High rate of water consumption during a fire considerably affects the design of distribution system ,hence while designing public water supply schemes, the rate of fire demand is sometimes treated as function of population .

Fire Water Demand

- At least four streams should be available at all points within the area protected.
- Each stream should be capable of delivering at least 175 gpm of water in low risk areas and 250 gpm in high risk areas for 5 hours.
- Water pressure should be around 80 psi.

Fire Water Demand

- The number of fire streams based on Kuchling's formula will be:
- F= 2.8 $\sqrt{P}$; F= number of simultaneous fire streams and P= population in thousands.

Calculate the total stream flow in gpm for a town having a population of 10,000. Assume that each stream will spray 250 gpm on the fire simultaneously.

Answer: number of stream, F = 2.8 $\sqrt{10}$ = 9

Total stream flow = 250 × 9 = 2250 gpm. However, according to National board of Fire Underwriters, for population of 10,000, the stream flow will be 3000 gpm

Fire Hydrant





- Fire hydrants are usually fitted in the water mains at about 100 to 150m apart and firefighting pumps are immediately connected into them by fire brigade personnel.

Fire Hydrant





Fire Demand

1) **Kuichling"s formula**

$$Q = 3182 \sqrt{P}$$

2) **Freeman formula**

$$Q = 1136 [P/5+10]$$

3) **National board of fire under writers formula**

$$Q = 4637\sqrt{P} [1-0.01 \sqrt{P}]$$

4) **Buston formula**

$$Q = 5663\sqrt{P}$$

P – population in thousands

Q – Water Required in litres/ minute

Example 5.5. *Compute the 'fire demand' for a city having population of 1,40,000 using various formulae.*

Solution. P = population in thousands = 140.

1. ***Kuichling's formula***

$$Q = 3182\sqrt{P} = 3182\sqrt{140} = 37650 \text{ litres/min.}$$
$$= 0.627 \text{ cumecs.}$$

2. ***Buston's formula***

$$Q = 5663\sqrt{P} = 5663\sqrt{140} = 67000 \text{ litres/min.}$$
$$= 1.117 \text{ cumecs.}$$

3. ***Freeman's formula***

$$Q = 1136\left(\frac{P}{5} + 10\right) = 1136\left(\frac{140}{5} + 10\right)$$
$$= 43168 \text{ litres/min} = 0.719 \text{ cumecs}$$

4. ***National Board of Fire Underwriter's formula***

$$Q = 4637\sqrt{140}\,(1 - 0.01\sqrt{140})$$
$$= 48,374 \text{ litres/min.} = 0.806 \text{ cumecs.}$$

EWCE 331



SOURCE OF WATER SUPPLY

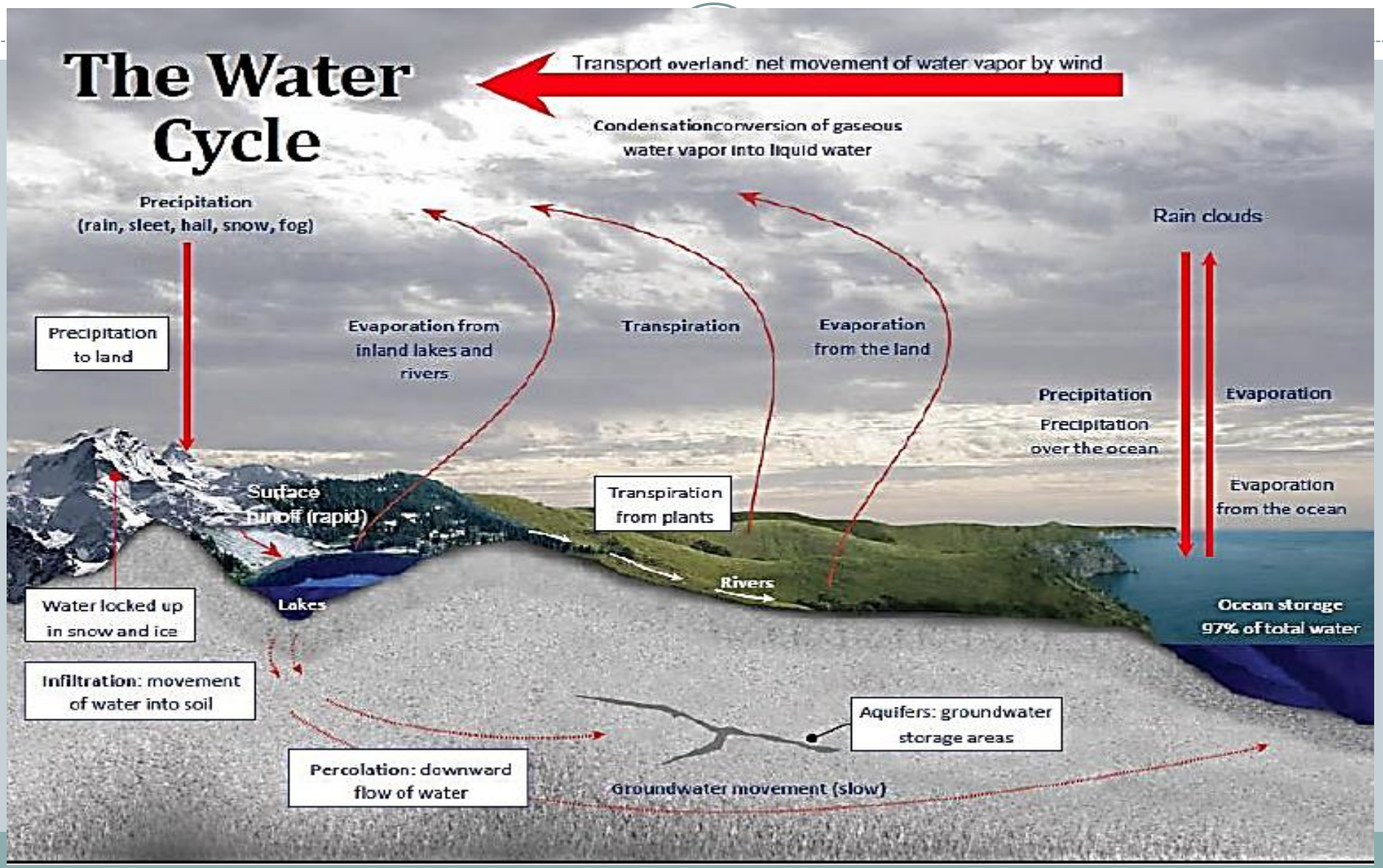
World Water Distribution

Location-land areas	Volume, (10^{12} m^3)	% of total
Freshwater lakes	125	0.009
Saline lakes and inland seas	104	0.008
Rivers	1.25	0.0001
Soil moisture	67	0.005
groundwater	8350	0.61
Ice caps and glaciers	29200	2.14
Total land area	37800	2.8
Atmosphere(water vapor)	13	0.001
Oceans	1,320,000	97.3
Total all locations	1,360,000	100

Hydrologic cycle/Water Cycle

- Role of Water?
  - Terrestrial ecosystems: major factor determining distribution of organisms
  - Aquatic ecosystems: literally matrix that surrounds & serves as environment of aquatic organisms
  - Water Is critical for human activities: agriculture, industry, and municipal use

Hydrologic cycle/Water Cycle



Water Cycle: Main Processes

- **Evaporation**: conversion from liquid to vapor(surface to atmosphere)
- **Transpiration**: evaporation of water from leaves.
- **Condensation**: conversion of vapor to liquid(droplets of water)
- **Precipitation**: movement as rain, sleet, hail, snow(atmosphere to surface)
- **Infiltration**: movement into soil.
- **Percolation**: downward flow through soil to aquifers.
- **Runoff**: surface flow down slope to ocean, lake or river.

Sources of Water Supply

- Surface water
  - Ponds and lakes
  - Streams and rivers
  - Storage reservoirs
  - Oceans
- Sub-surface water
  - Springs
  - Infiltration galleries
  - Infiltration wells
  - Wells and tubewells
- Groundwater

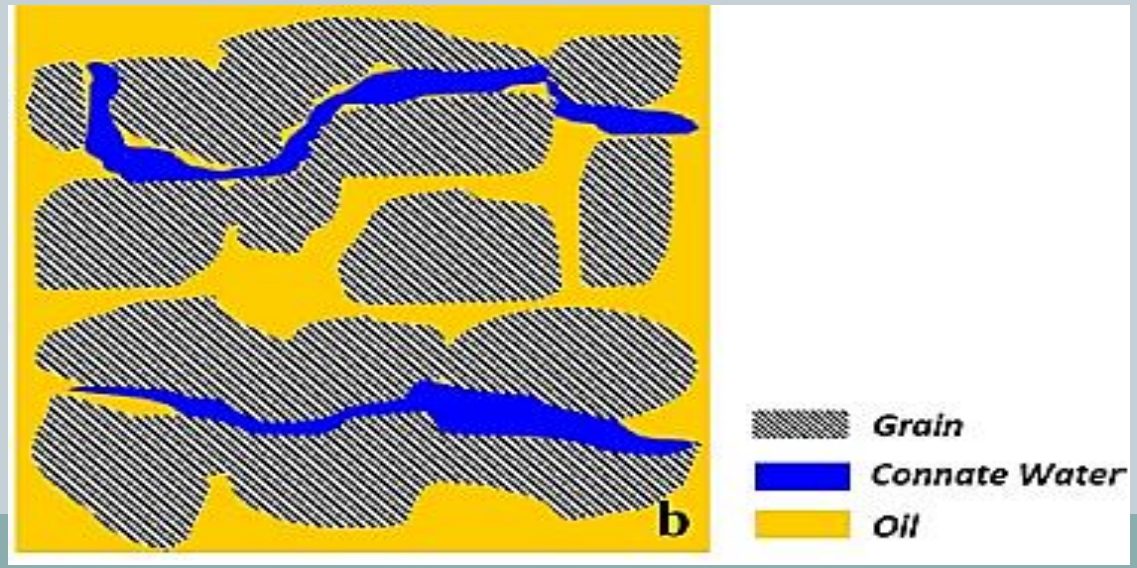
Surface water

- **Surface water**: categorized as rainfall, transboundary flow, water on standing water bodies (reservoir, river, lake and pond),water on seasonal wetlands, and in-stream storage.
- Average annual rainfall of the country is about **2360 mm**.
- Bangladesh shares **57 transboundary rivers** with India and Myanmar. Total annual volume of this water is about **1000 billion m^3**.
- Total volume of standing waterbodies (beels / baors) is about **0.61 billion m^3**.
- Estimated volume of water stored in seasonal wetlands/floodplains is about **2.69 billion m^3**.
- Estimated volume of channel storage is **0.5 billion m^3**.

Groundwater

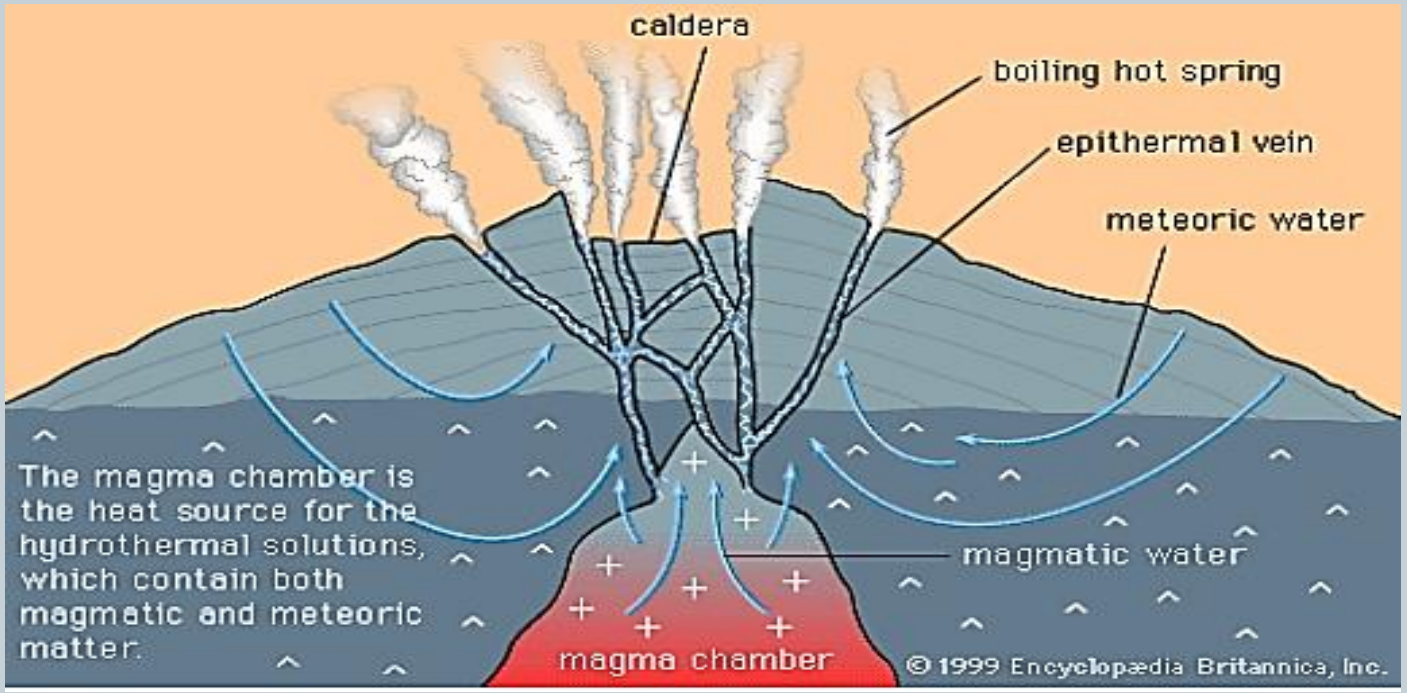
The main source of groundwater is the recharge from surface water. Three major sources are:

- **Meteoric water**: includes rain, sleet, snow, hail and other forms of precipitation.
- **Connate Water**: sea water or freshwater trapped in sediments when deposited on sea bottoms or lakes.



Groundwater

- **Juvenile Water (magmatic water):**produced from volcanic and magmatic activity and during crystallization of rock molecules.

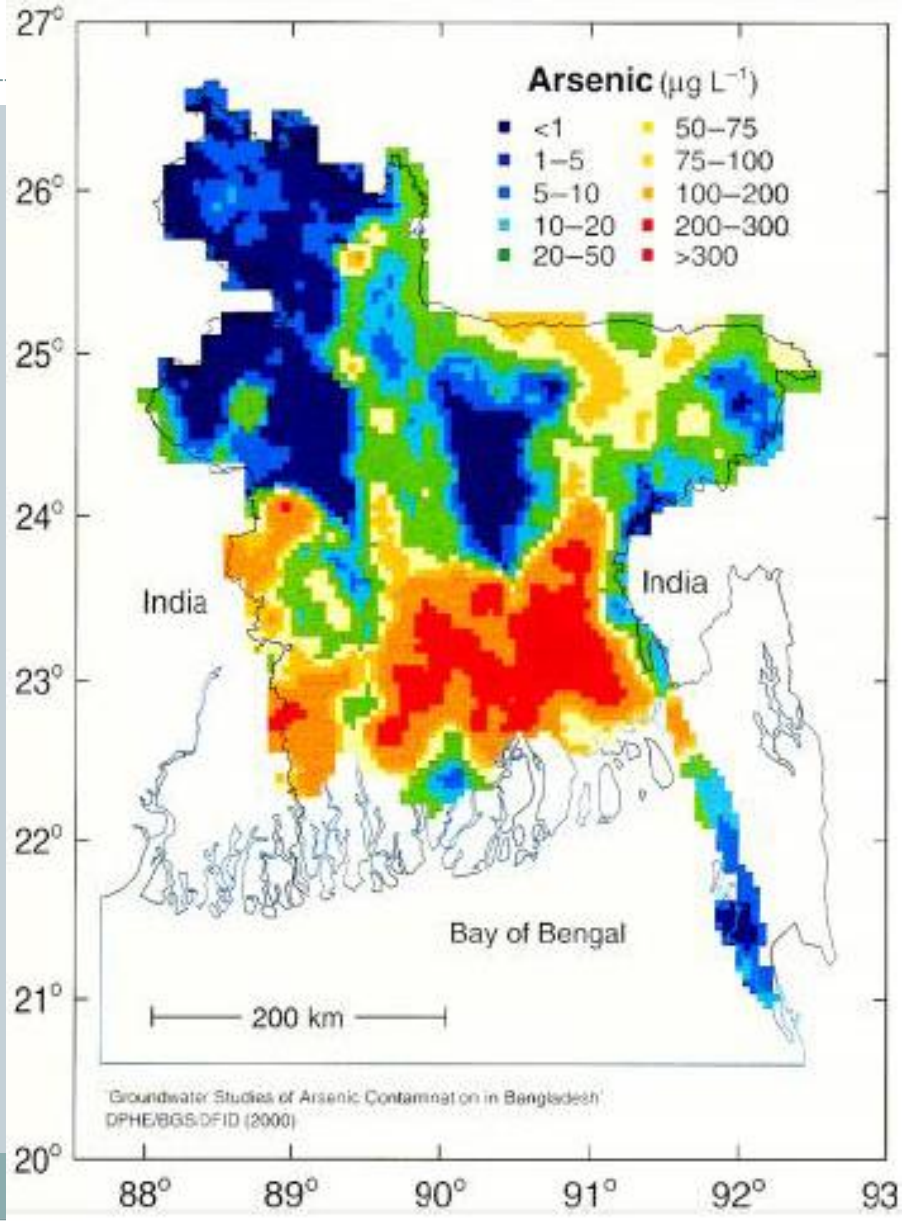


Problems in GW development

- Arsenic in groundwater
- Excessive dissolved iron
- Salinity in the coastal areas
- Lowering of groundwater level
- Rock/stony layers in hilly areas

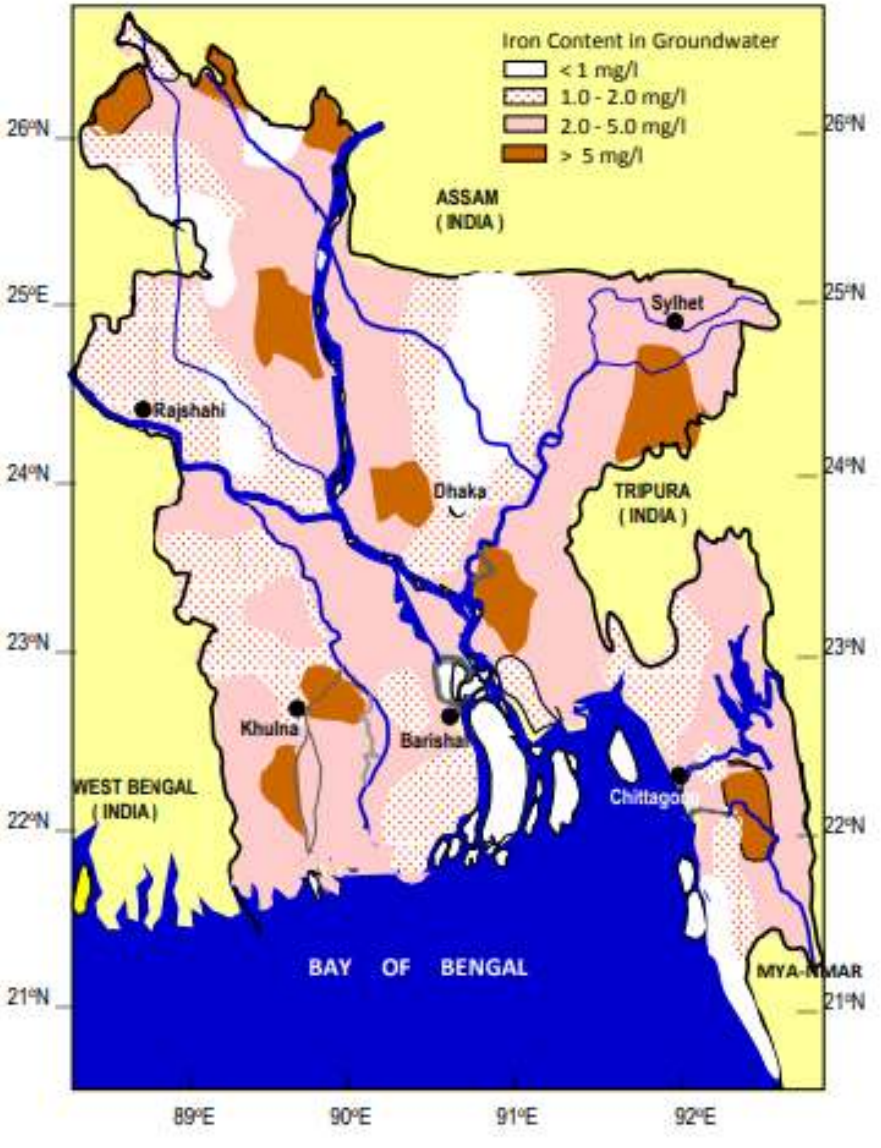
Arsenic (As)

- WHO guideline for maximum desirable arsenic concentration in drinking water– 0.01mg/L
- In Bangladesh–maximum acceptable concentration in drinking water– 0.05mg/L
- Arsenic toxicity leading to cancer occurs due to excessive intake over a longer period of time.
- Presence of arsenic in Bangladesh was first detected in 1993 at Chapai Nawabganj.
- One in every three shallow tubewells was found to produce arsenic contaminated water above acceptable limits.



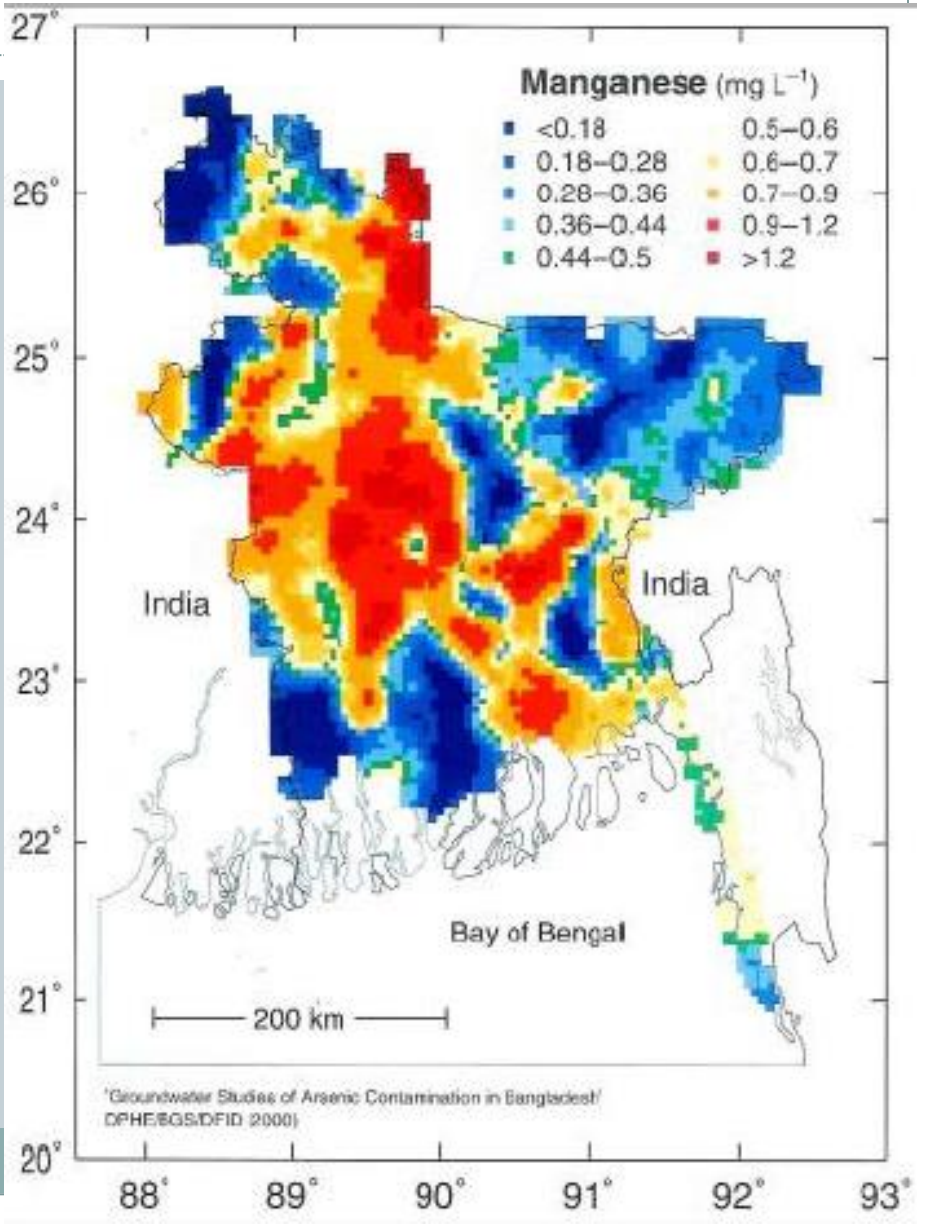
Excessive Dissolved Iron (Fe)

- In Bangladesh, the permissible limit of iron in ground water is 1 mg/l
- Iron content upto 5 mg/L is acceptable for rural water supply
- Dissolved iron in shallow tubewell water in about 67% areas of Bangladesh is in excess of 2 mg/l.
- Iron content in deep tubewell water is comparatively lower.



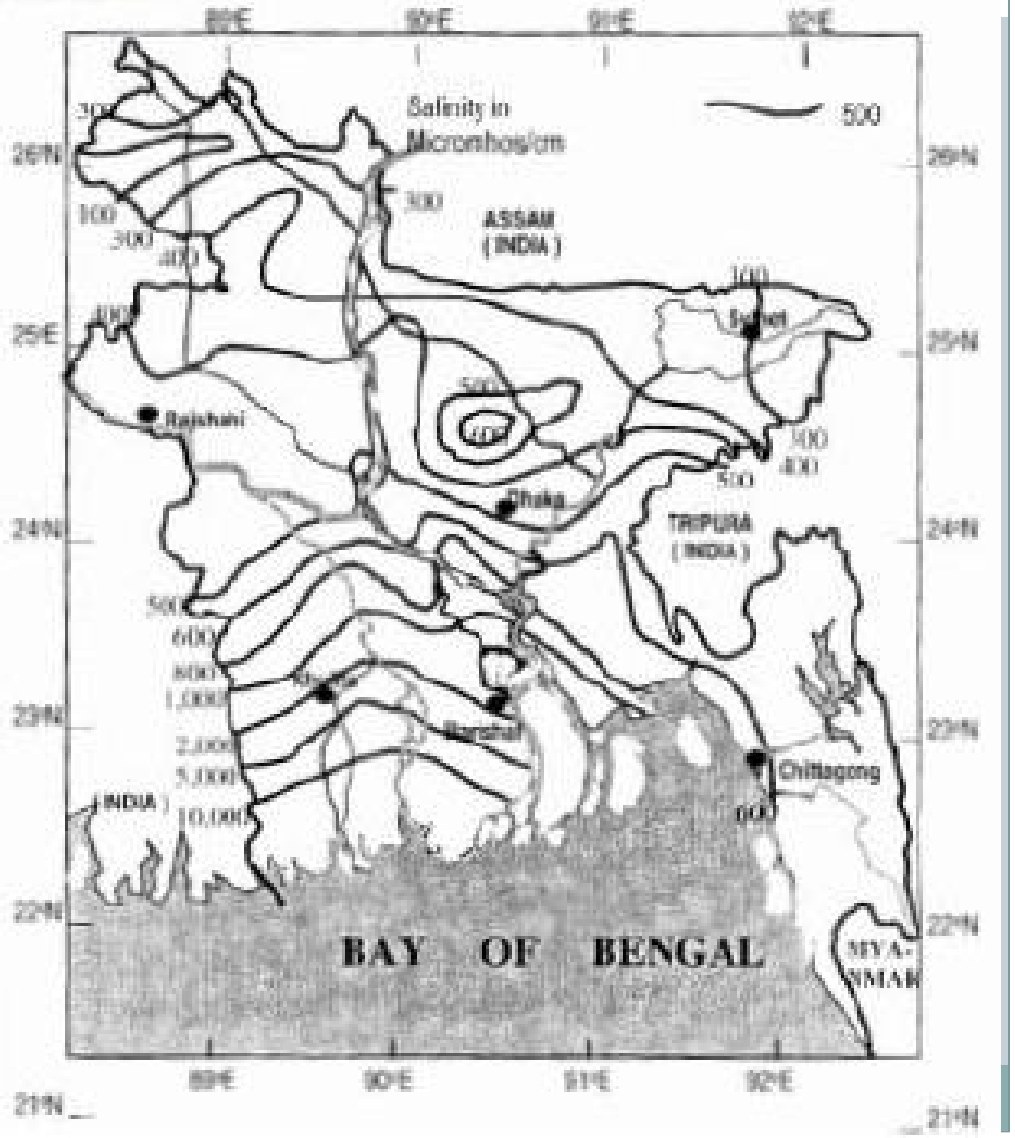
Manganese (Mn)

- Manganese in groundwater is very high.
- About 35% of the drinking water samples had manganese in excess of WHO health-based Guideline Value of 0.4 ppm;
- Bangladesh Standard for manganese in drinking water is 0.1 ppm and few samples meet this requirement



Salinity in Coastal Areas

- Concentration of dissolved minerals in ground water is higher than that in surface water
- The coastal belt of Bangladesh is identified as a problem area
- Scarcity of ground water of acceptable quality at coastal area from shallow depth
- Low salinity ground water is not available in many areas at coastal belts within a depth of 1100ft



Lowering of Groundwater Level

- A considerable area of the country faces scarcity of ground water within suction limit in the dry season
- Water level declines due to the over-exploitation of ground water for human consumption as well as irrigation purposes

Groundwater depletion situation in the capital

Year	Bellow the surface
1996	26.60m
1997	28.15m
1998	30.45m
1999	31.86m
2000	34.18m
2001	37.78m
2002	42.00m
2003	46.24m
2004	50.6m
2005	57.42m
2006	59.72m
2007	61.18m

Source: Groundwater monitoring survey project, BADC

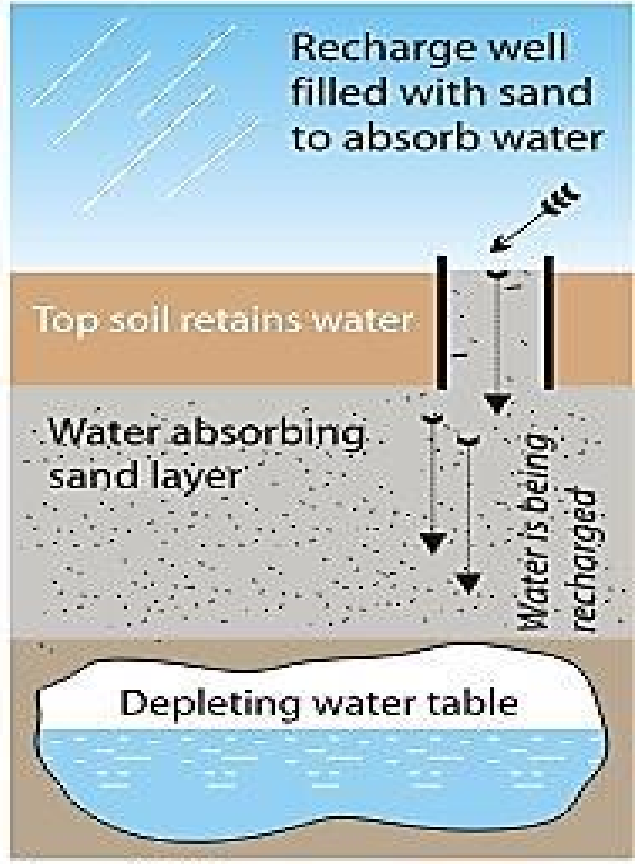


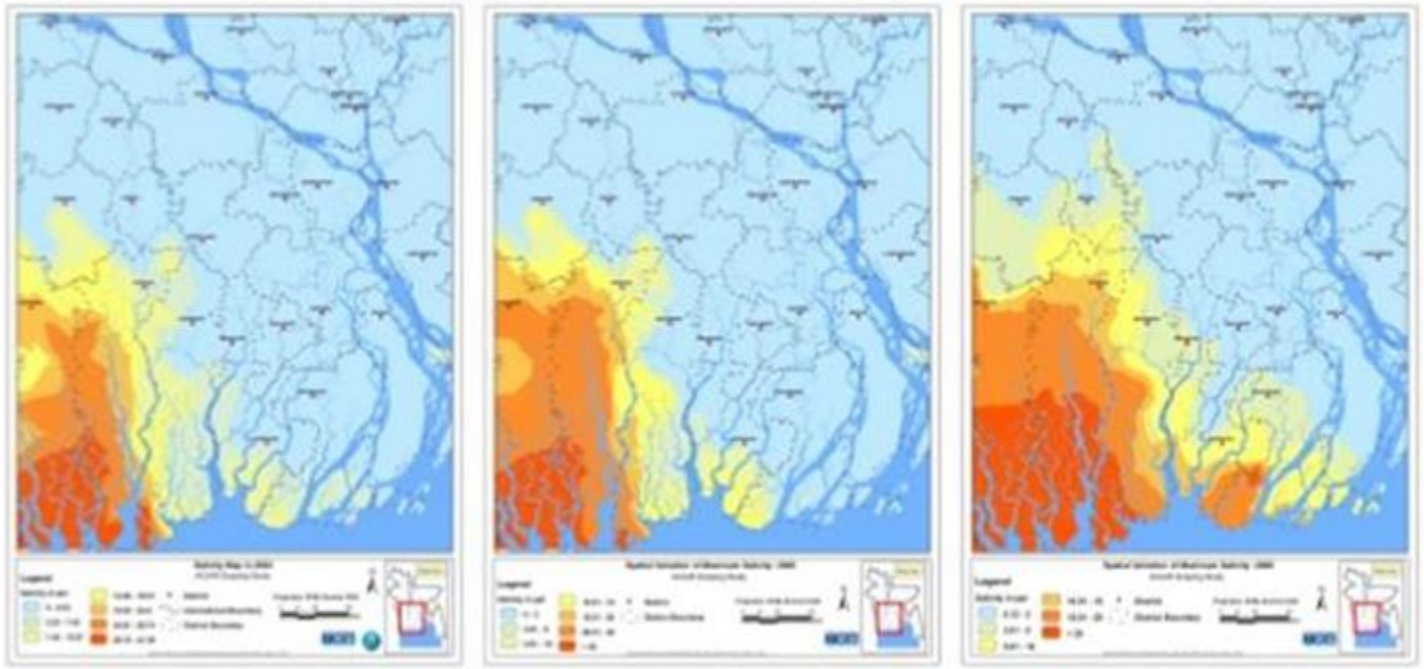
Diagram by Sharier

Rock/stony Layers in Hilly Areas

- Presence of hard formations in the subsurface of hill tracts districts make it difficult to drill tubewells
- Areas–Chittagong, Cox'sbazar, Sylhet, north of Mymensingh, Netrokona, Panchagar districts
- Mechanical drilling rigs are used to overcome the problem and provide potable water
- Installation cost increases of a water point

Water in Bangladesh (salinity problem)

Surface water salinity



Considerable increase in salinity over time both in concentration and area; saline front moved further inland through the stream

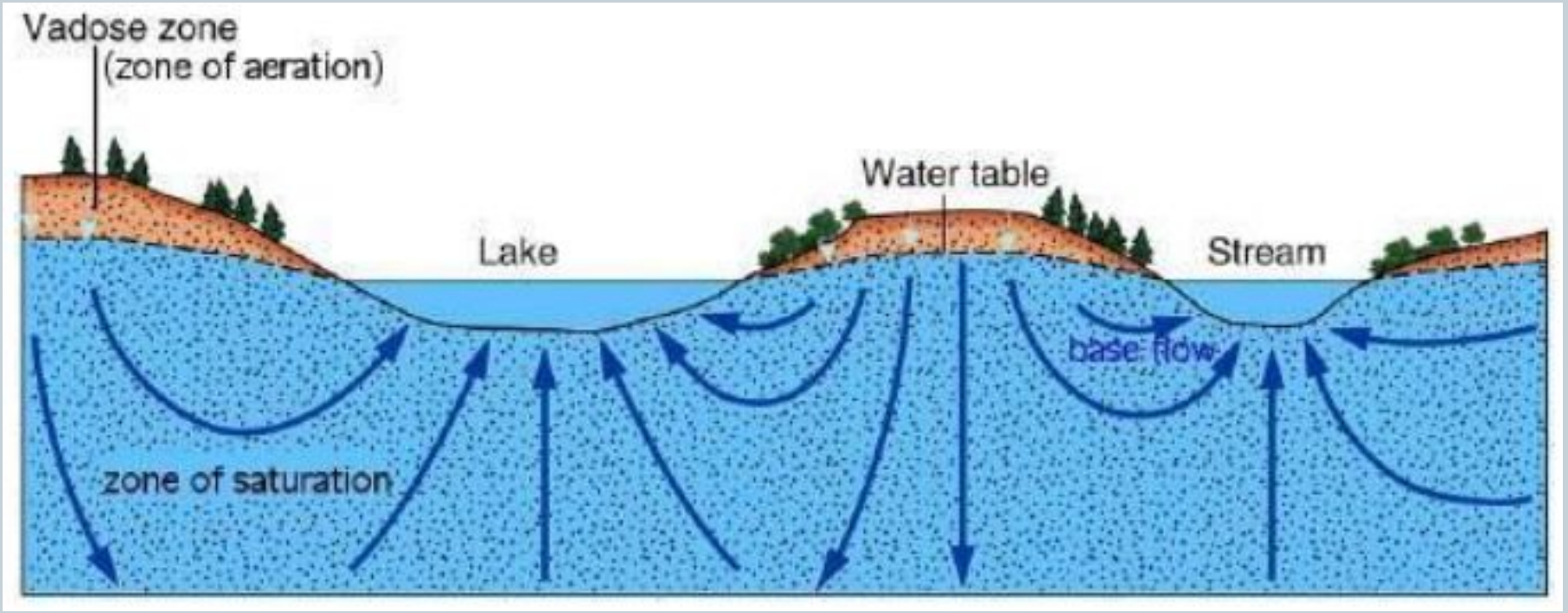
EWCE 331

GROUNDWATER

Groundwater

- Water available in the saturation zone is known as groundwater.
- Constitute the most important source of fresh water supply.
- Amount of groundwater depends on the characteristics of the underlying aquifer and the extent and frequency of recharge.

Groundwater



Forms of Subsurface Water

Zone of Saturation

This zone, also known as *groundwater zone,* is the space in which all the pores of the soil are filled with water. The water table forms its upper limit and marks a free surface, *i.e.* surface having atmospheric pressure.

Zone of Aeration

In this zone the soil pores are only partially saturated with water. The space between the land surface and the water table marks the extent of this zone.

Forms of Subsurface Water

The zone of aeration has three subzones:

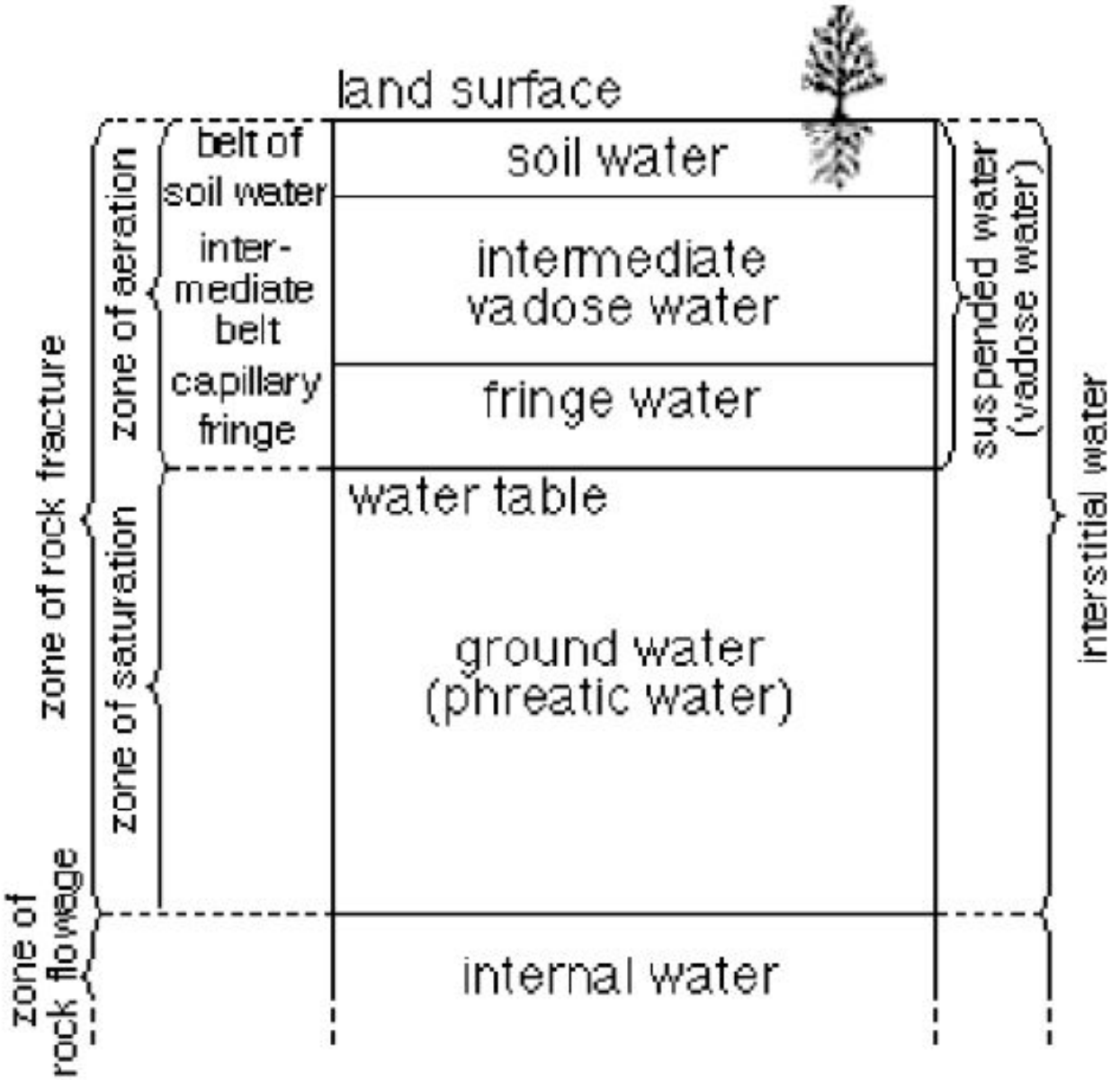
i) Soil water zone : This lies close to the ground surface in the major root band of the vegetation from which the water is lost to the atmosphere by evapotranspiration.

ii) Capillary fringe: In this the water is held by capillary action. This zone extends from the water table upwards to the limit of the capillary rise.

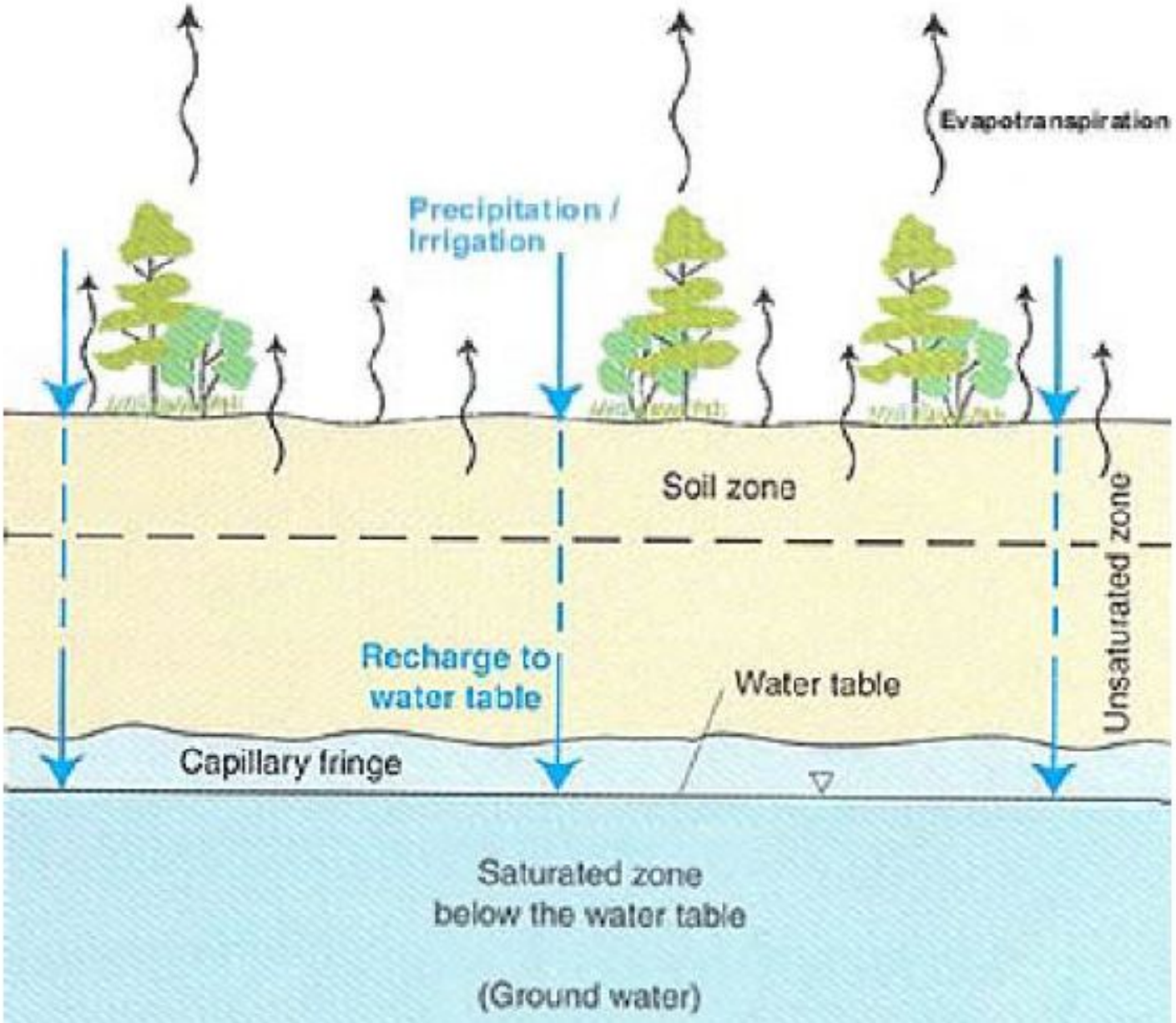
iii) Intermediate zone *:* This lies between the soil water zone and the capillary fringe.

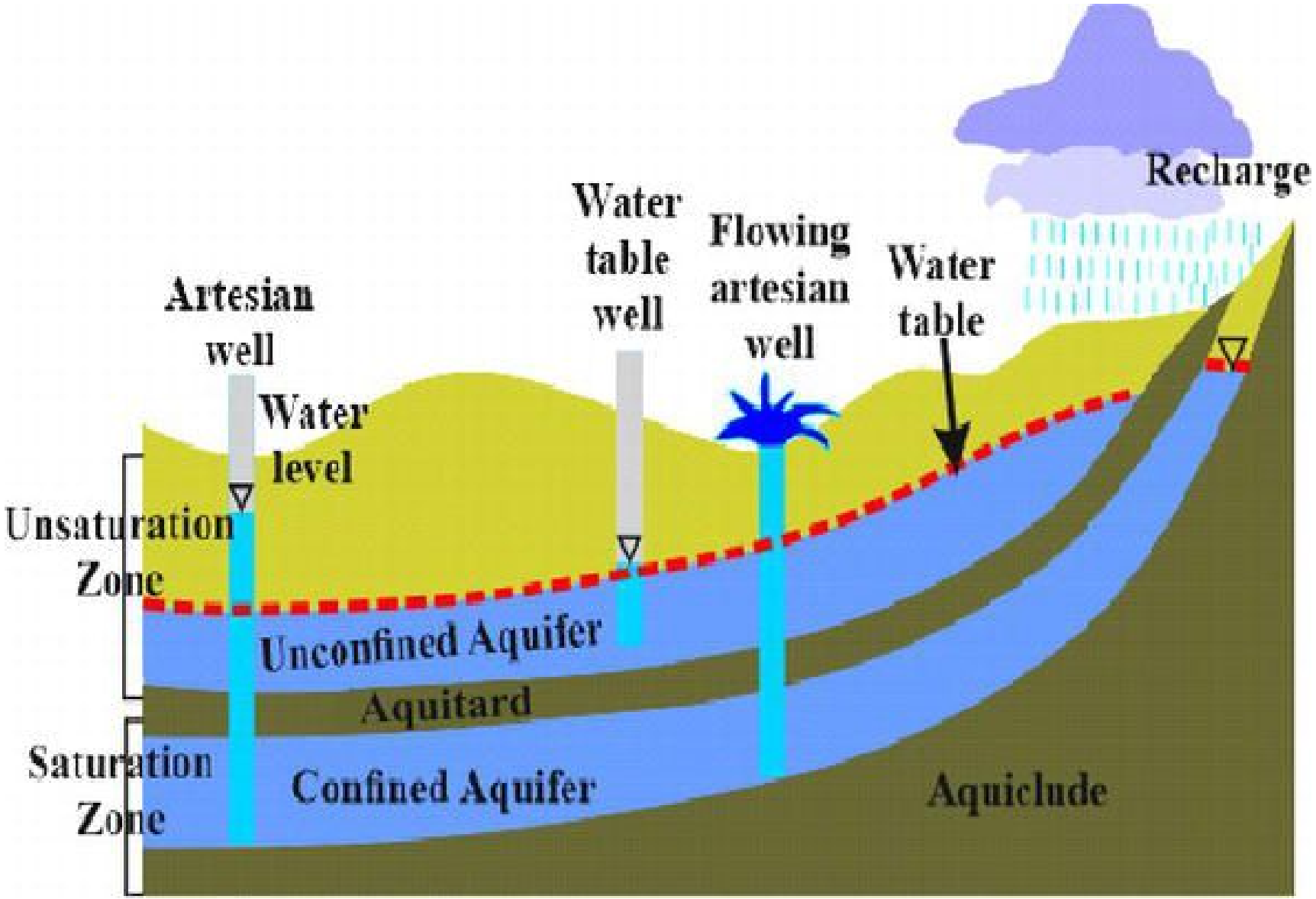
The thickness and its constituent subzones depend upon the soil texture and moisture content and vary from region to region. The soil moisture in the zone of aeration is of importance in agricultural practice and irrigation engineering.

Groundwater



Groundwater




Recharge
Water table well
Flowing artesian well
Water table
Artesian well
Water level
Unsaturation Zone
Unconfined Aquifer
Aquitard
Saturation Zone
Confined Aquifer
Aquiclude

Aquifer

- An underground layer of rock that holds groundwater which is rain or melted snow that has seeped into the ground and is held there.
- Filled slowly and can dry up when people drain them faster than they can be refilled—a process called aquifer depletion.
- Drained by man-made wells or they can flow out naturally in springs.
- The impervious formation or strata containing very little groundwater are termed Aquiclude.

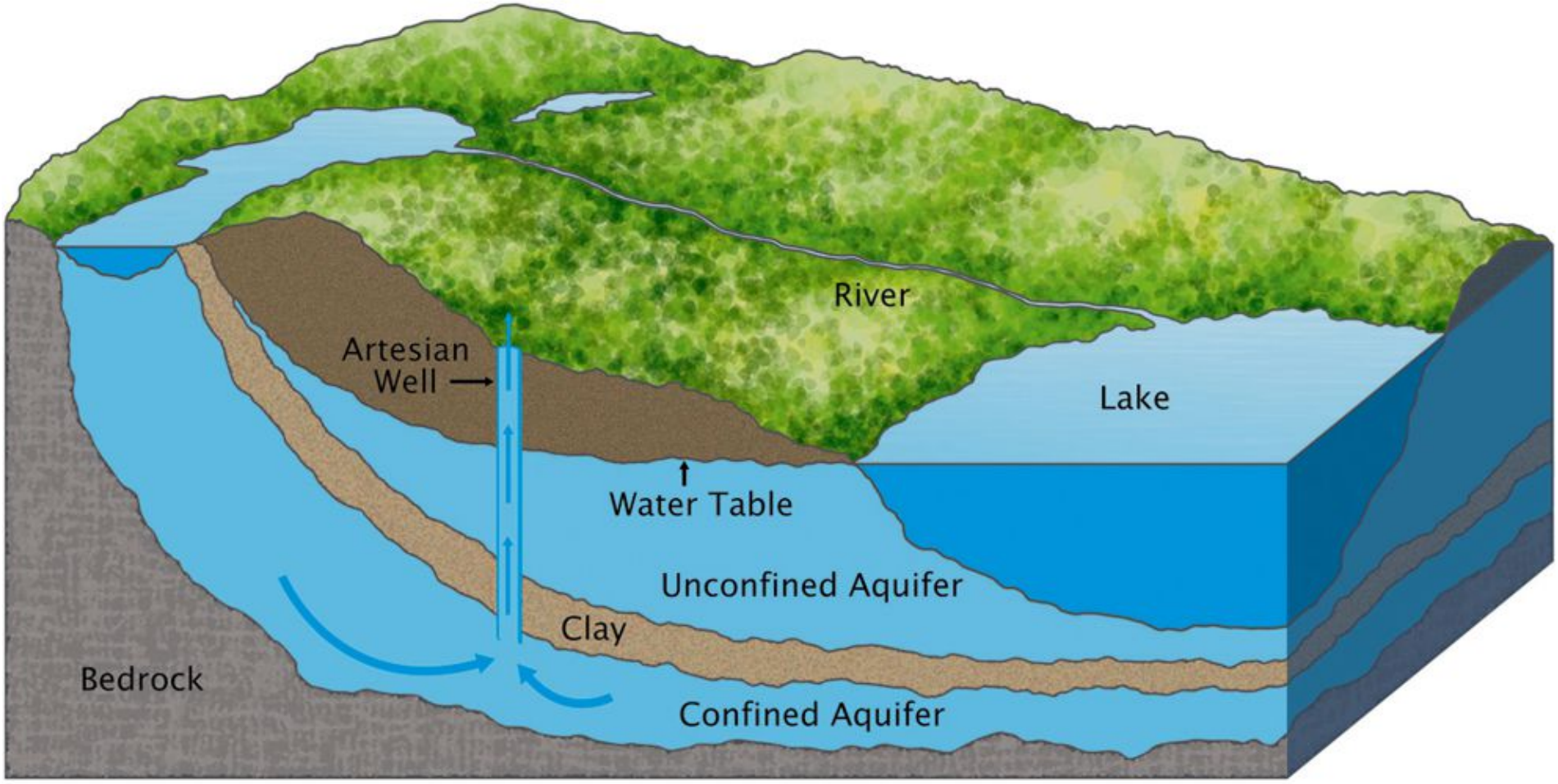
Aquifer

- An aquifer has interconnected pores filled with water. Interconnected pores provide both storage and flow functions in an aquifer.
- Capacity of an aquifer to contain water is measured by porosity of the formation.
- But high porosity does not indicate that it will yield large volume of water and only the water which flow by gravity can be obtained from the aquifer.

Types of Aquifer

- An unconfined aquifer can receive water directly from the surface, while a confined aquifer is trapped between two layers of rock.
- Water-table or unconfined aquifer is one which is not confined by an upper impermeable layer and is at under atmospheric pressure. Water seeps into it directly from the ground surface.
- Artesian or confined aquifer is one which is confined under a pressure greater than atmospheric and overlay by an impermeable layer that prevents water seeping into it from the ground surface.

Aquifer


River
Artesian Well
Lake
Water Table
Unconfined Aquifer
Clay
Bedrock
Confined Aquifer

Factors governing the occurrence of groundwater

- **Aquifer functions** : aquifer has an interconnected pores filled with water and it works as a network of pipes through which water flows at a very slow rate.
- Two functions are considered in an aquifer:
  - Storage function
  - Conduit function

Factors governing the occurrence of groundwater

Storage function: porosity and specific yield are important properties of storage function.

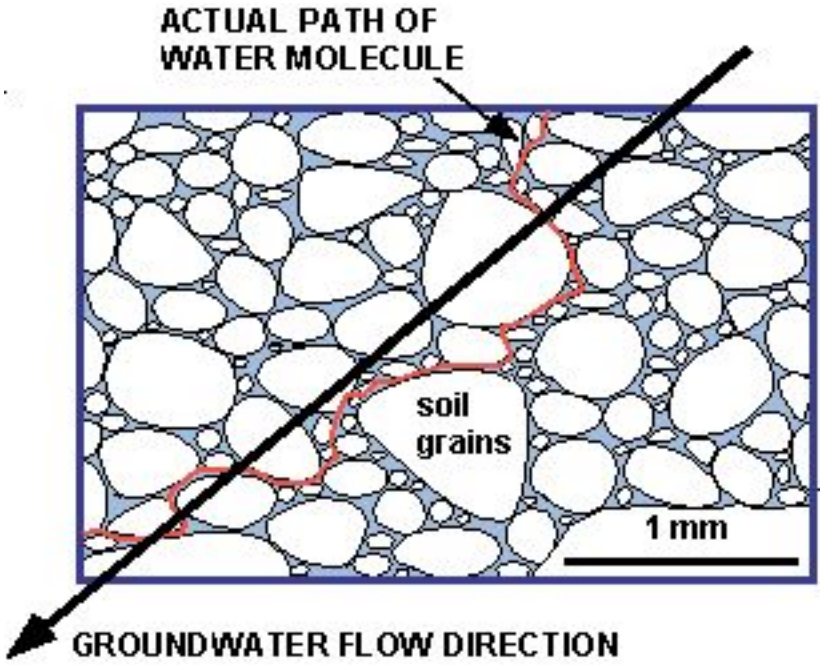
- **Porosity of soil** ={(total volume of voids in the soil or the volume of water required to saturate the dry sample (V_v))/total volume of soil aggregate (V)} x 100

$$\eta = V_v/V \times 100$$

- **Specific yield** is the volume of water released freely or by gravity from a unit volume of aquifer.

Sp. Yield = {(volume of water obtained by gravity drainage)/(total volume of the material drained or dewatered)} x 100

$$S_y = W_y/V$$



Soil type	Porosity (%)	Specific yield (%)
Clay	45	3
Gravel and sand	20	16
Sand	35	25
Gravel	25	22

Factors governing the occurrence of groundwater

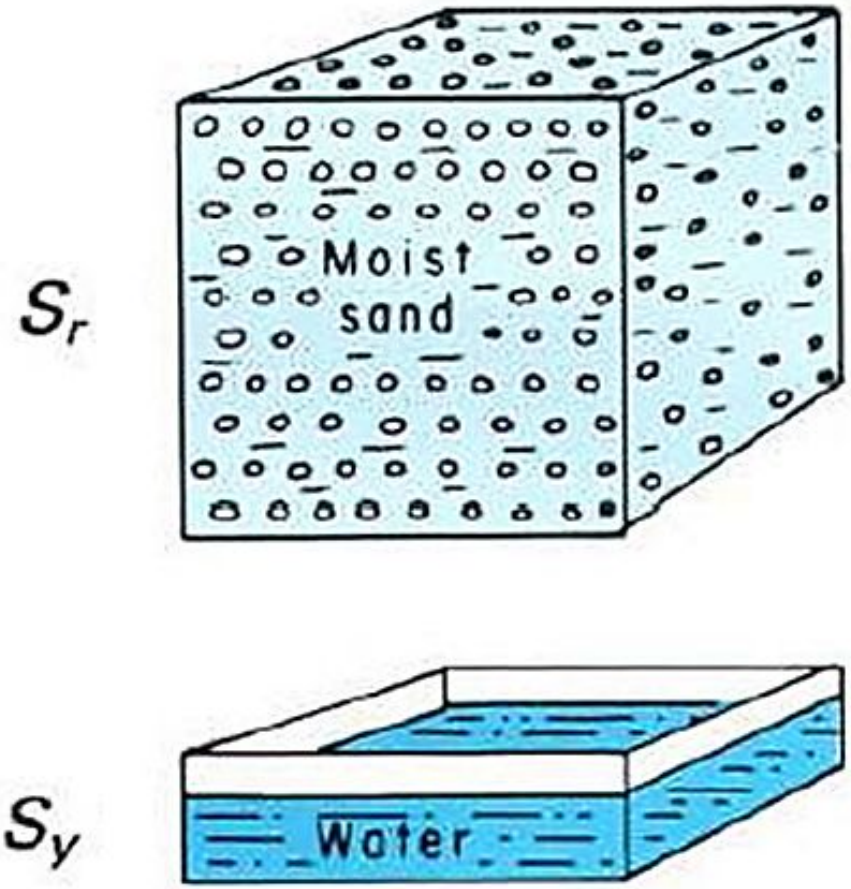
- **Specific retention** is the volume of water held up by capillary or other attraction forces.

Sp. retention or field capacity={(volume of water held against the gravity drainage)/total volume of the material drained} x 100

$$S_r = W_r / V$$

- Sum of the specific yield and the specific retention is equal to its porosity.

$$\eta = S_r + S_y$$



$$n = S_y + S_r$$

The table below shows the properties of four types of soil. Mention which type of soil is capable of retaining most of the water and which one is capable of discharging most of the water. Also calculate the maximum amounts retained and discharged respectively if the aquifer bearing the soil layer has a total volume of 1000 m^3.

Soil type	Porosity (%)	Specific yield (%)
Clay	45	3
Gravel and sand	20	16
Sand	35	25
Gravel	25	22

Factors governing the occurrence of groundwater

- **Conduit function**: permeability is a property of conduit function. It is the measure of the capacity of an aquifer to transmit water.
- Velocity of flow is related to the slope of the hydraulic gradient by Darcy's law equation:

  $V=K(h_1-h_2)/l$

  The equation can be modified as $V=Ki$

  $i=(h_1-h_2)/l$ and is called the hydraulic gradient
- Quantity of flow per unit time Q, through a given cross-sectional area A is $Q=AV=K\ A\ i$
- The flow per unit width of the aquifer having thickness of m is

  $q=K\ m\ i$

Factors governing the occurrence of groundwater

- The value of K can be determined experimentally or can be estimated by empirical formula.

$$K = cd_{10}^{2}$$

where, d=effective grain size and

c = constant, values vary from 100-120

Important terms

- **Coefficient of permeability or hydraulic conductivity** defined from Darcy's law, as the rate of flow of water through a unit cross-sectional area of the water bearing material under a unit hydraulic gradient and at temperature of 20^0C.
- **Water table** is the surface at which water pressure is equal to atmospheric pressure. It is depicted on maps as a line across an aquifer.
- **Drainage of groundwater** means extracting the water from below the water table through wells, infiltration galleries, springs etc. The water drained under a natural phenomenon (like-spring) or it can be drained artificially by constructing wells and lifting the water from them.

Important terms

Transmissivity (T)

- ✓ Rate at which water is transmitted through its unit width under a unit hydraulic gradient.
- ✓ Co-efficient of transmissivity or transmissibility.
- ✓ Characterizes the ability of aquifer to transmit the water.

$$T = K \times b \times i$$

Where,

K=hydraulic conductivity(m/day),

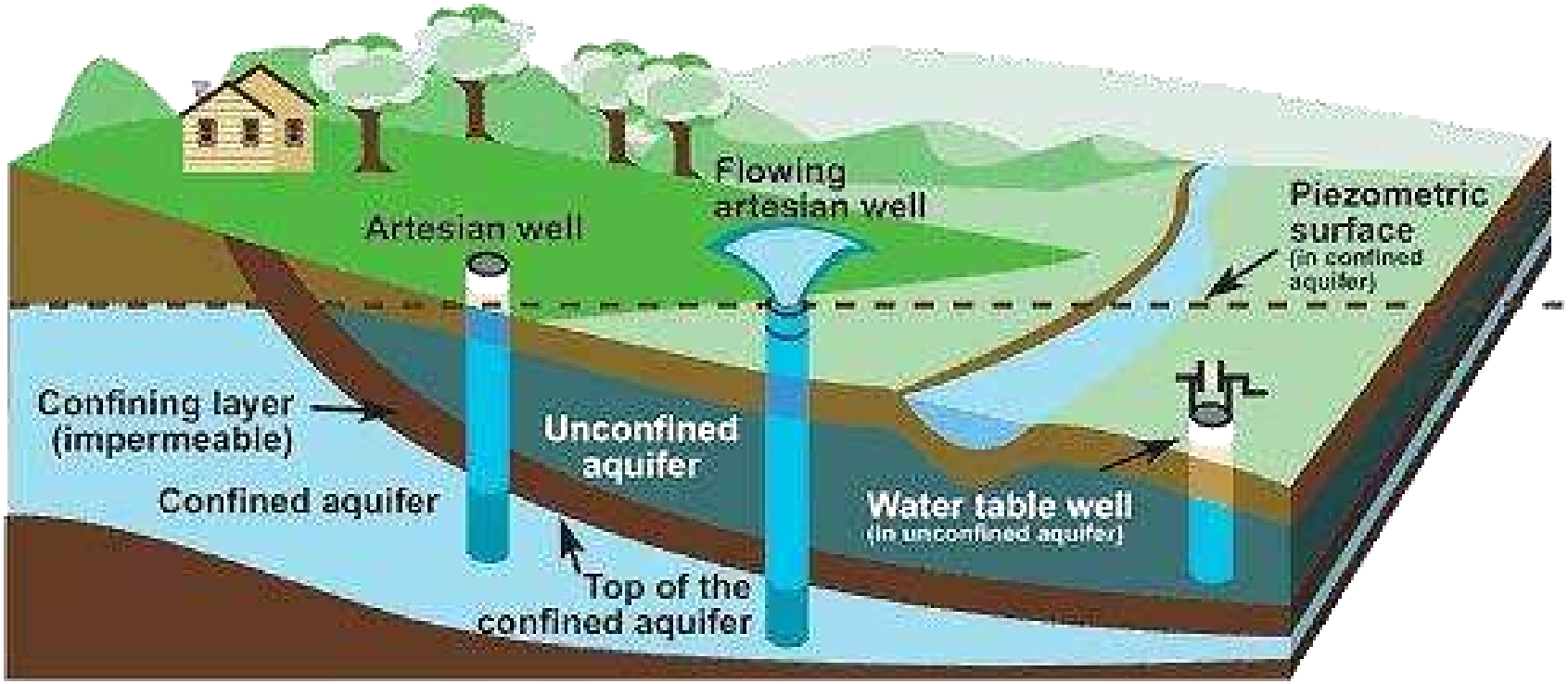
b=thickness(m),

i=hydraulic gradient.

Piezometric Surface

- Imaginary surface to which water will rise to wells located throughout a confined or artesian aquifer is Piezometric surface (the surface coincides with the piezometric head of the water in the aquifer).
- May be either above and below the ground surface at different parts of the same aquifer.
  - If piezometric surface lies above the ground level is referred as flowing artesian wells.
  - If piezometric surface is below the ground surface a non-flowing artesian wells results, pump must be provided to obtain water.

Aquifers and wells



Groundwater Situation in Dhaka

Depth of Groundwater in Different Areas of Dhaka City (in feet)

Year	Mirpur	Mohammadpur	Dhanmondi	Gulshan	Cantonment	Lalbag	Sabujbag	Sutrapur
1980	8.36	9.3	10.12	9.91	-	1.67	3.13	5.88
1985	13.57	13.5	12.76	9.95	-	16.06	13.63	8.93
1990	15.3	14.52	15.4	10	-	17.71	21.49	11.08
1995	20.76	20.48	24.27	24.25	18.46	19.78	26.43	15.67
2000	35.2	20.87	40.12	27.59	27.88	36.57	46.45	18.79
2005	63	32.21	60.85	37.3	27.8	44.77	54.4	20.12
2010	65.97	31.24	66.32	42.66	27.81	44.77	54.4	21.1

Source: *Bangladesh Water Development Board, 2014*

Recharge of Groundwater

General hydrologic equation

$\Sigma R = \Sigma D + \Delta S$

Where ΣR=hydrologic factors contributing to recharge

ΣD=hydrologic factors contributing to discharge

ΔS=Associated change in storage volume

Recharge of Groundwater

Recharge is composed of:

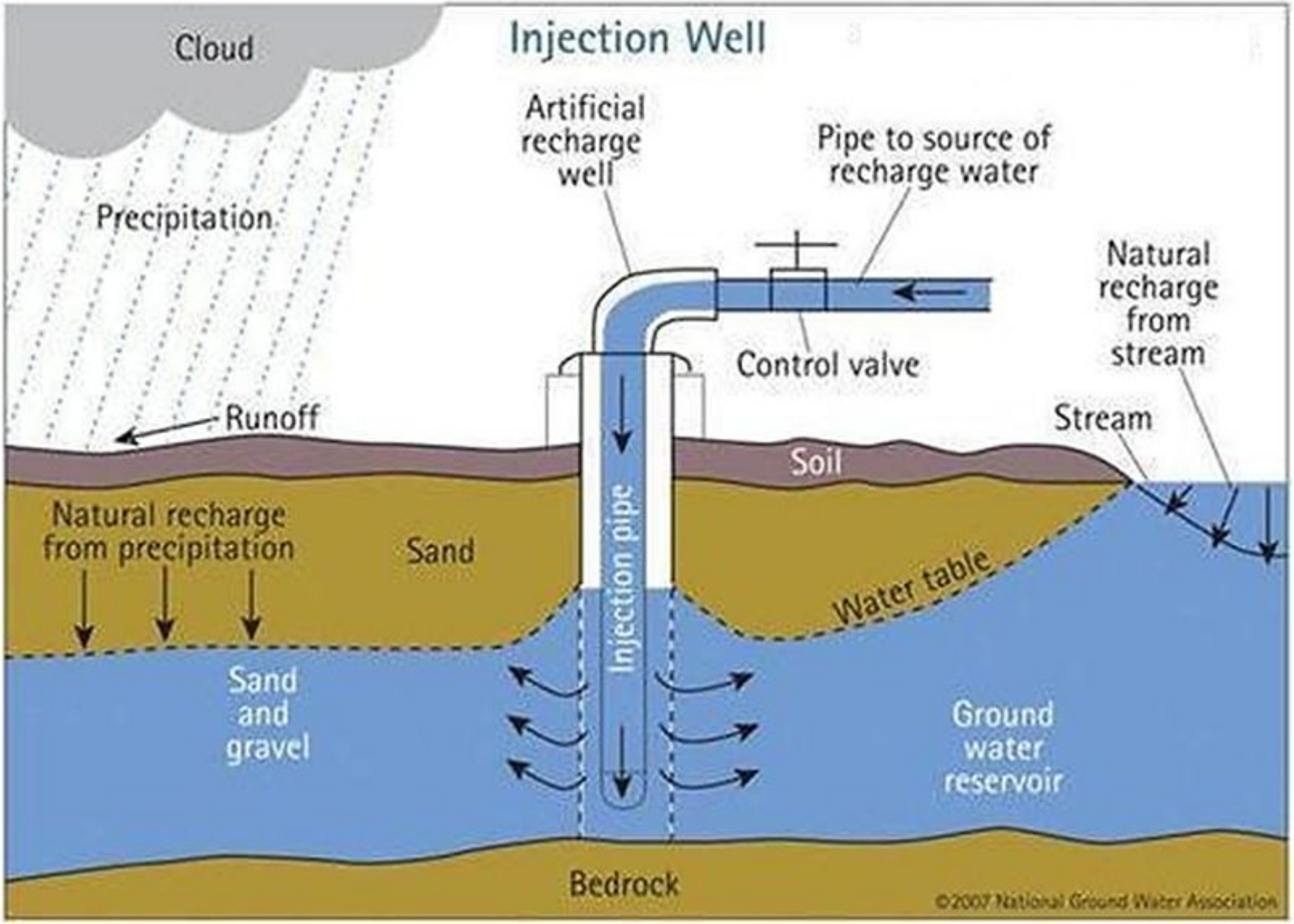
- Natural infiltration derived from rainfall and snowmelt
- Infiltration from surface bodies of water
- Underflow — Subsurface inflow of groundwater from one region to another
- Leakage through confining layers or water displaced from them by compression
- Water derived from diffusion, charging and water spreading operation

Artificial replenishment of aquifer by methods like injection wells, recharge pits, etc.

Recharge of Groundwater

Conversely discharge includes:

- Evaporation and transpiration
- Seepage in to surface bodies of water
- Underflow
- Leakage through confining layers or absorbed by them through the reduction of compression
- Water withdrawn through wells and infiltration galleries


Injection Well
Cloud
Artificial recharge well
Pipe to source of recharge water
Precipitation
Natural recharge from stream
Control valve
Runoff
Stream
Soil
Natural recharge from precipitation
Sand
Injection pipe
Water table
Sand and gravel
Ground water reservoir
Bedrock
©2007 National Ground Water Association

Aquifer Characteristics in Bangladesh

- A shallow aquifer (main aquifer) lies between 100m from the surface with an overlying clay/silt blanket (2m thick) in northwest and increases southward to more than 50m.
- Deep aquifers occur at depths between 300 and 2500m.
- Groundwater (GW) of shallow aquifer flows from north to south without flow into the major rivers.
- Gradient of GW varies from 1:1,000 in the northwest to 1:13,000 in central Bangladesh and less than 1:20,000 in the coastal area.

Aquifer Characteristics in Bangladesh

- Permeabilities are very high and vary from 10 to 200m/day.
- Transmissibilty of the main aquifer has an average value of 2000 m^2/day.
- Horizontal flow of groundwater is very low because of the low hydraulic gradient.
- Storage capacity of the aquifer increases with depth because of increase in the size of aquifer materials.
- The specific yield varies from 0.02 to 0.25.

Aquifers and Water supply Wells

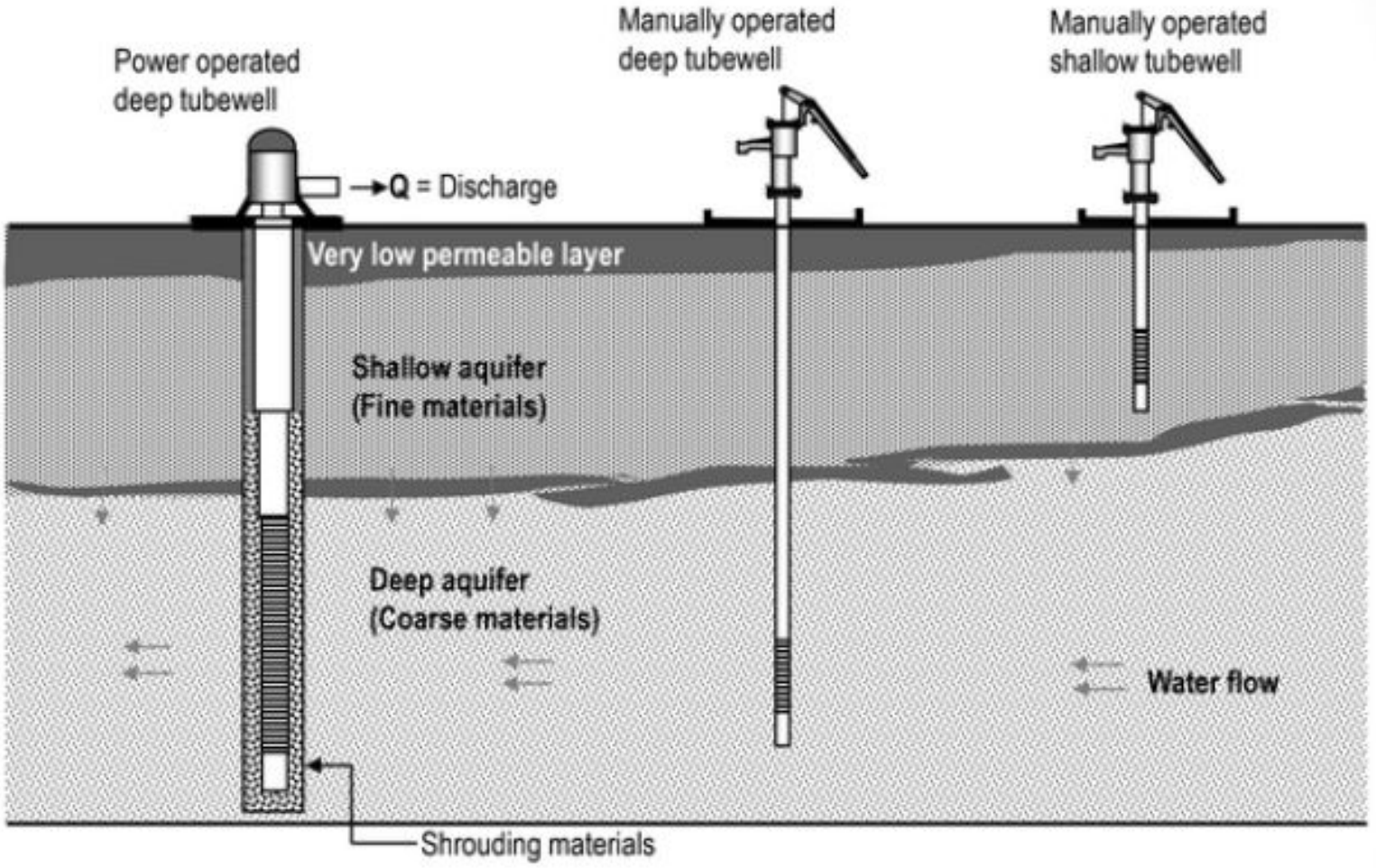
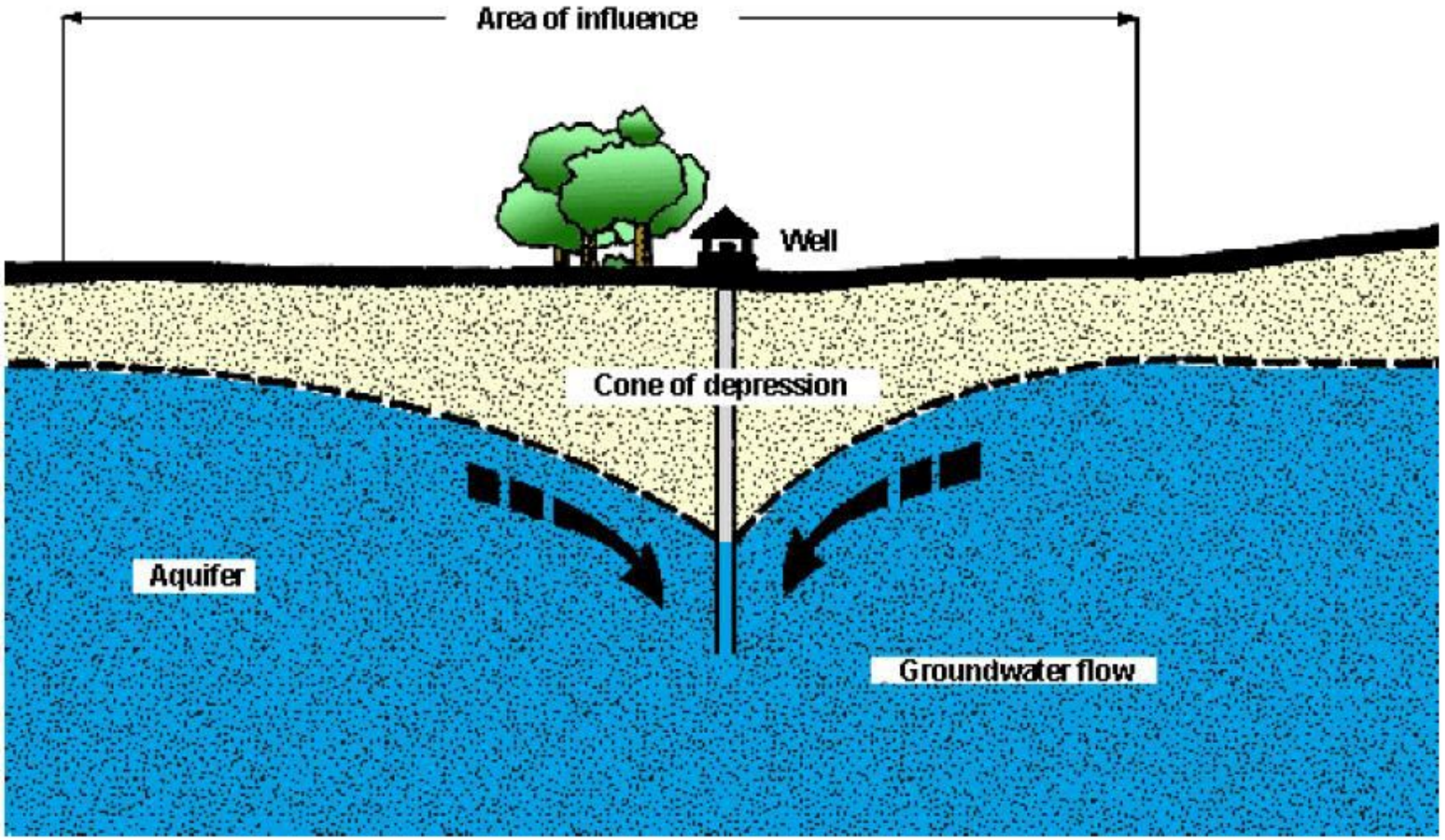


Fig-The main aquifers and the wells for water supply

Well Hydraulics



Pumping a well lowers the fluid pressure at that point. The resulting lower hydraulic head causes water flow towards the well from all directions. A cone of depression is formed.

Flow Towards Wells

When well is at rest→ static water level

Pumping →converging flow

Q=AV=KAi

Where, Q=quantity of flow per unit of time

A=cross-sectional area

K=coefficient of permeability

i=hydraulic gradient]

The velocity close to the well is higher than the velocity at a greater distance from the well.

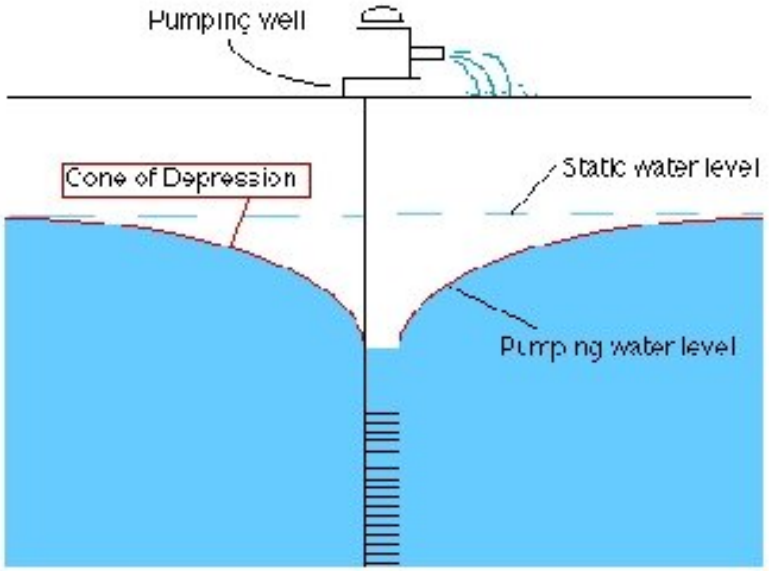
Flow Towards Wells

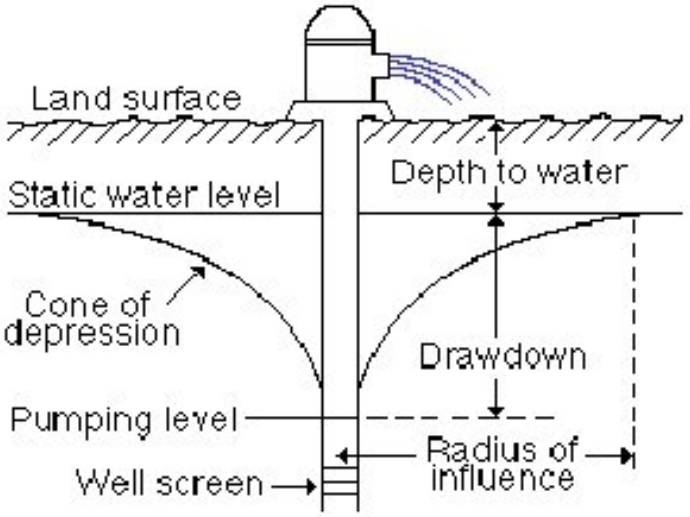
- Static water level (when well at rest) coincides with the water table of the aquifer and the Piezometric surface.
- Pumping causes lowering of the pressure and induces flow from all directions into the well which is known as converging flow.
- In a converging flow velocity close to the tube well is higher than the velocity at a distance from the tube well.
- Darcy's law explains that the hydraulic gradient varies directly with the velocity. So, the increasing velocity towards well is accompanied by an increasing hydraulic gradient.

The hydraulic gradient is the slope of the water table or potentiometric surface, that is, the change in water level per unit of distance along the direction of maximum head decrease.

Flow Towards Wells

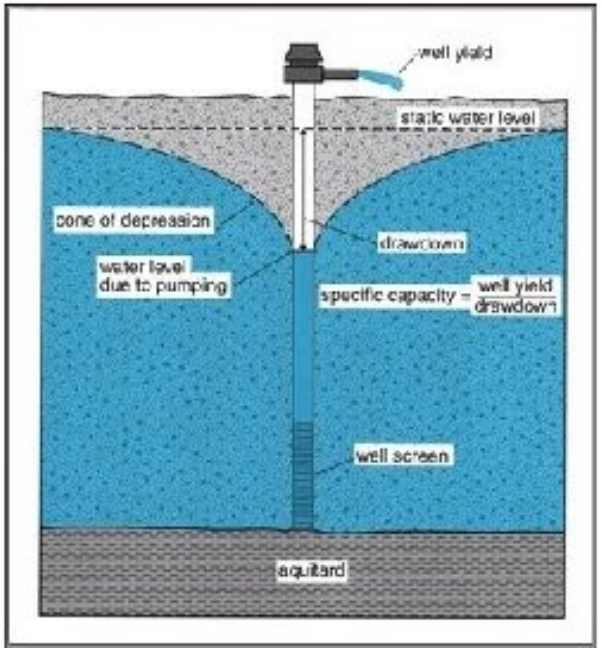
- The water surface develops a steeper slope towards the well and takes the form of an inverted cone called cone of depression.
- The difference between the static water level and the surface of the cone of depression is called the drawdown.



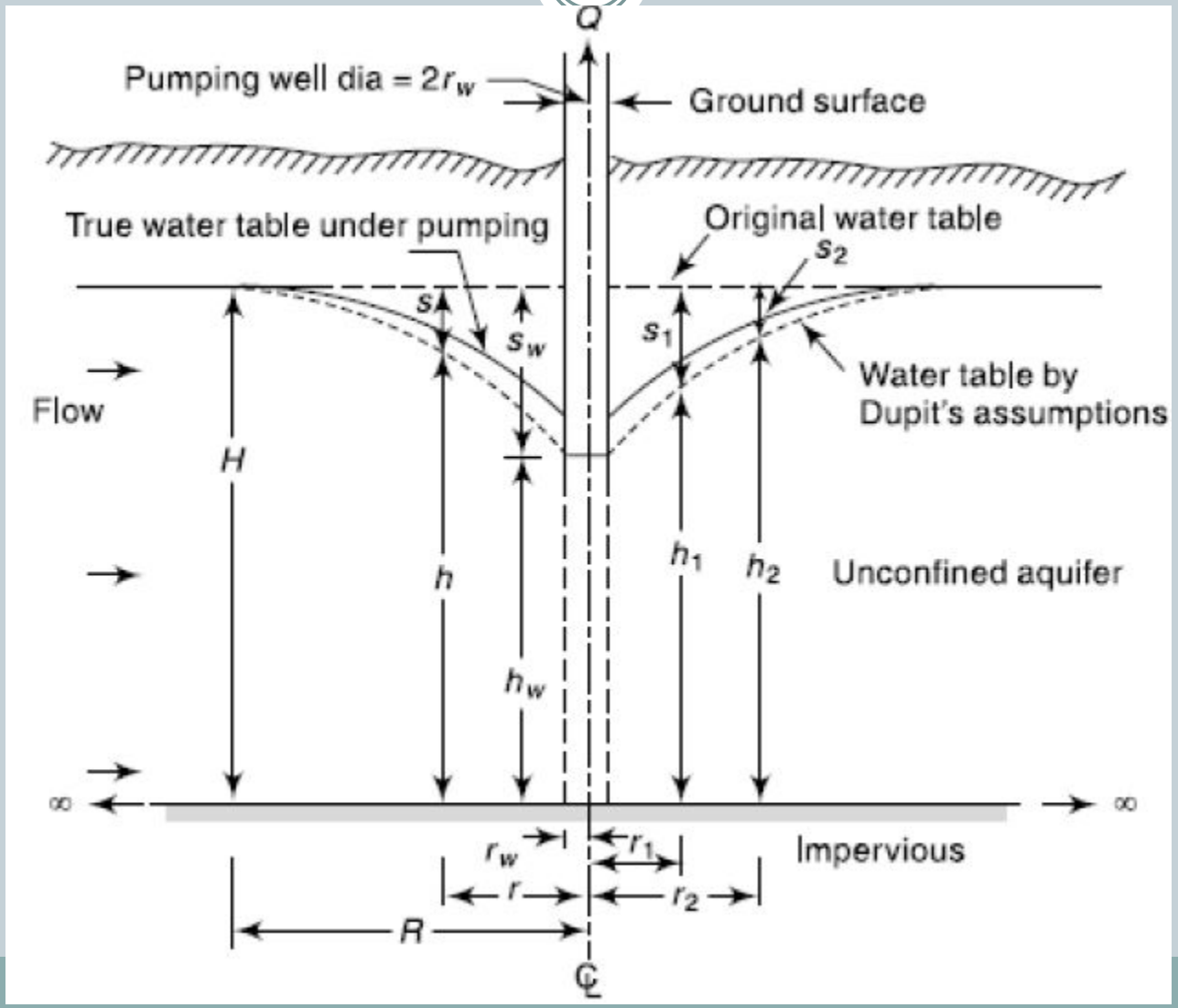


Some useful terms to know:

- ✓ Cone of depression
- ✓ Drawdown
- ✓ Radius of influence
- ✓ Specific capacity



Unconfined Steady Flow



Unconfined Steady Flow

Consider the well of radius r_w penetrating completely an extensive unconfined horizontal aquifer as shown in Fig. The well is pumping a discharge Q. At any radial distance r, the velocity of radial flow into the well is; $V_r = K\left(\frac{dh}{dr}\right)$, where h is the height of the water table above the aquifer bed at that location.

For steady flow, by continuity:

$$Q = (2\pi rh)V_r = (2\pi rh)K\left(\frac{dh}{dr}\right) \quad or; \quad \frac{Q}{2\pi K}\frac{dr}{r} = h\,dh$$

Integrating between limits r_1 and r_2 where the water-table depths are h_1 and h_2, respectively and on rearranging:

$$Q = \frac{\pi K(h_2^2 - h_1^2)}{ln\frac{r_2}{r_1}}$$

This is the equilibrium equation for a well in an unconfined aquifer. As at the edge of the zone of influence of radius R. H= saturated thickness of the aquifer, Eq.can be written as:

$$Q = \frac{\pi K(H^2 - h_w^2)}{ln\frac{R}{r_w}}$$

where h_w = depth of water in the pumping well of radius r_w.

Example-1

A 100 mm diameter tubewell is sunk 35 m below static groundwater level. The depth of water in the tubewell while pumping is 33 m. The radius of drawdown is 30 m and the coefficient of permeability of the aquifer is 0.5 l/s/m^2. Calculate the probable discharge of the well.

Solution: $$Q = \frac{\pi K(D^2 - d^2)}{\text{Log}_e(\frac{R}{r})}$$

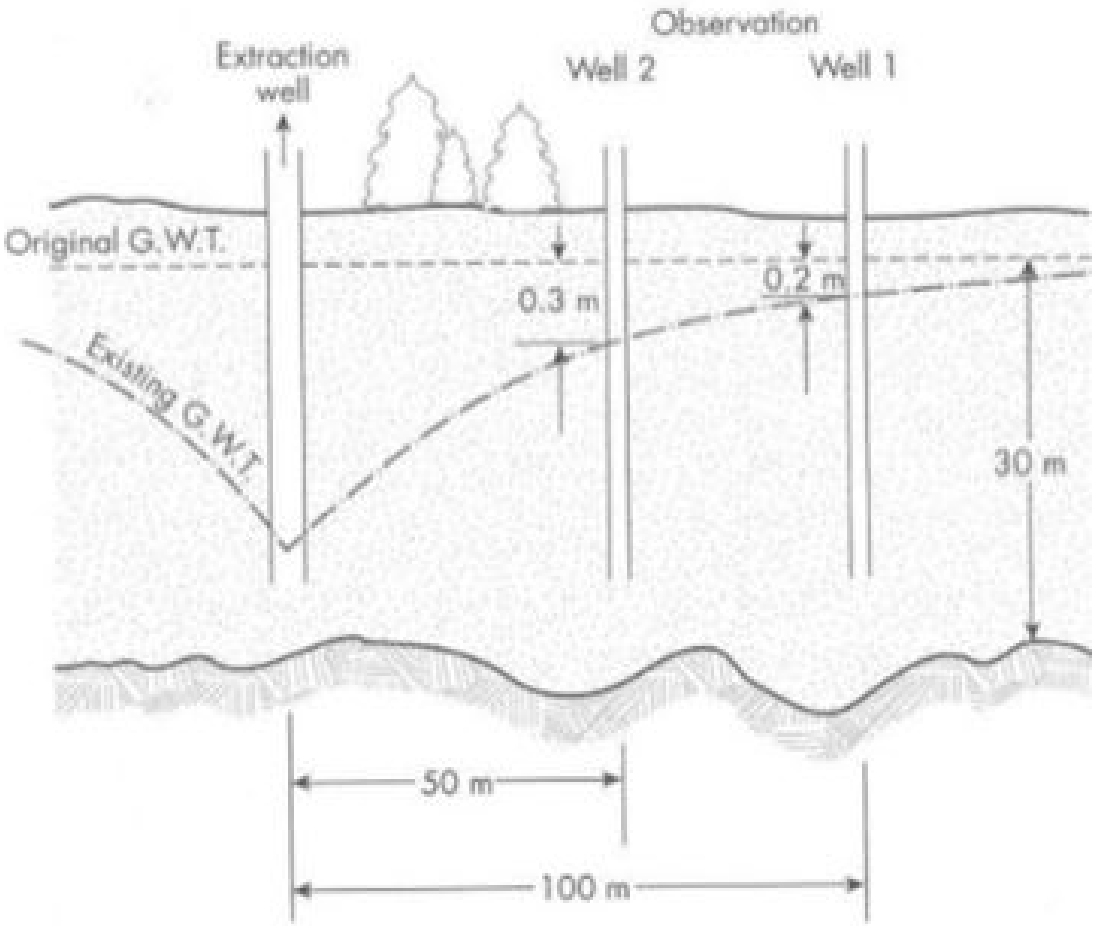
$K = 0.5$ lps/m^2; $D = 35$m; $d = 33$m; $R = 30$m; $r = 0.05$m

Substituting the values in the above equation:

$Q = 3.14 \times 0.5 \times (35^2 - 33^2) / \text{Log}_e (30/0.05)$

$Q = 3.14 \times 0.5 \times 136/6.3969 = 33.4$ lps

A well is 0.2 m in diameter and pumps from an unconfined aquifer 30 m deep at an equilibrium rate of 1000 m^3/day. Two observation wells are located at distances of 50 and 100 m and have drawdowns of 0.3 and 0.2 m, respectively. What is the coefficient of permeability (hydraulic conductivity, K)



A 30-cm well completely penetrates an unconfined aquifer of saturated depth 40 m. After a long period of pumping at a steady rate of 1500 *Lpm*, the drawdown in two observation wells 25 and 75 m from the pumping well were found to be 3.5 and 2.0 m, respectively. Determine the transmissivity of the aquifer. What is the drawdown at the pumping well?

Solution:

(a)

$$Q = \frac{1500 \times 10^{-3}}{60} = 0.025 m^2/S$$

$h_2 = 40.0 - 2.0 = 38.0$ $\quad r_2 = 75\ m$

$h_1 = 40.0 - 3.5 = 36.5\ m$ $\quad r_1 = 25\ m$

From Eq. (28),

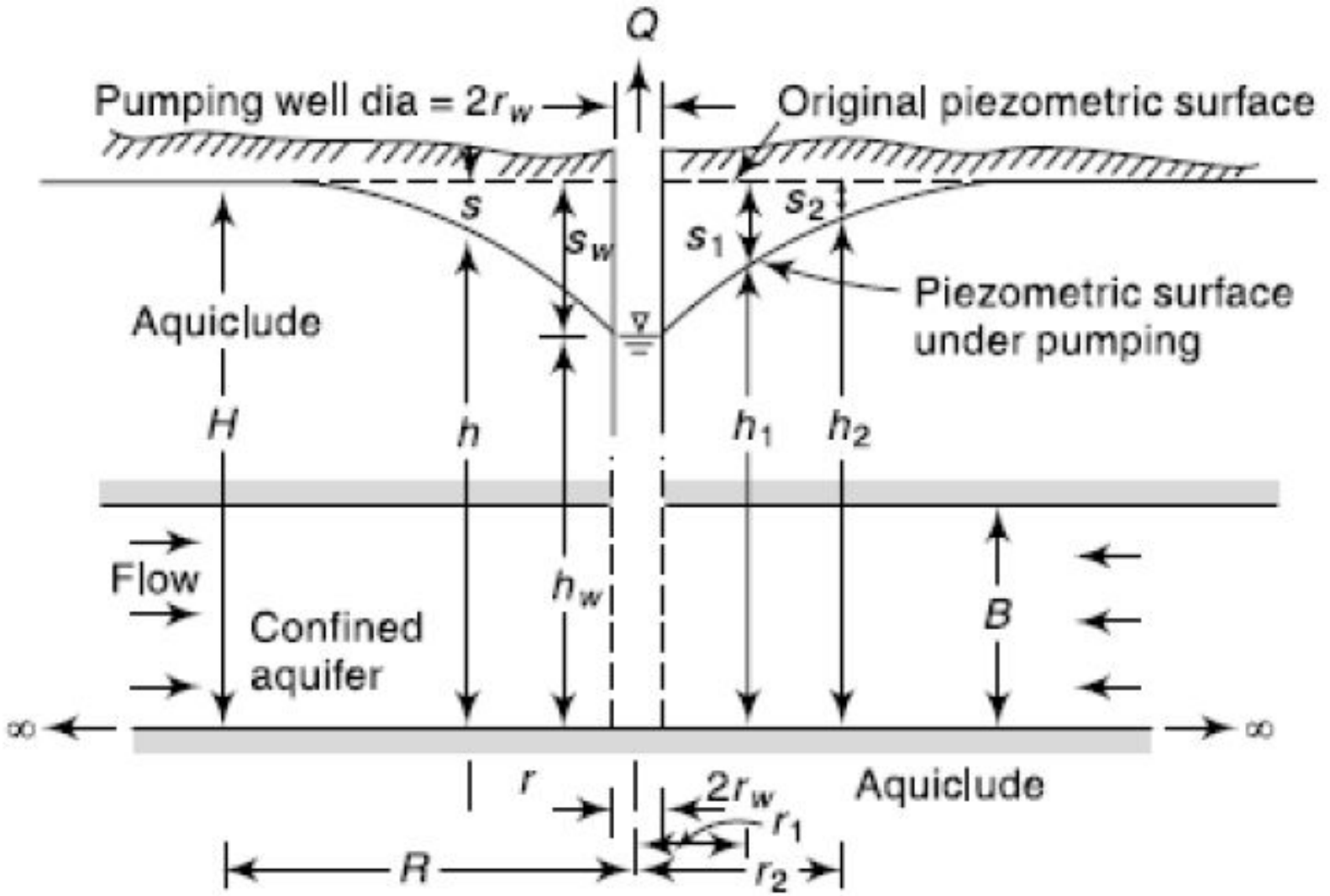
$$Q = \frac{\pi K(h_2^2 - h_1^2)}{ln\frac{r_2}{r_1}} = \frac{\pi K(38^2 - 36.5^2)}{ln\frac{75}{25}} = 0.025 \quad ; \quad K = 7.823 \times 10^{-5}\ m/s$$

$T = KH = 7.823 \times 10^{-5} \times 40 = 3.13 \times 10^{-2}\ m^2/s$

$$Q = \frac{\pi K(H^2 - h_w^2)}{ln\frac{R}{r_w}}$$

At the well,($r_1 = r_w$; $h_1 = h_w$)

Confined Steady Flow



Confined Steady Flow

Figure shows a well completely penetrating a horizontal confined aquifer of thickness *B*. Consider the well to be discharging a steady flow, *Q*. The original piezometric head (static head) was H and the drawdown due to pumping is indicated in Fig The piezometric head at the pumping well is hw and the drawdown s_w.

At a radial distance r from the well, if h is the piezometric head, the velocity of flow by Darcy's law is:

$$V_r = K\left(\frac{dh}{dr}\right)$$

The cylindrical surface through which this velocity occurs is 2π r B . Hence by equating the discharge entering this surface to the well discharge, yields:

$$Q = V_r A_s = 2\pi r B\, K\left(\frac{dh}{dr}\right) \qquad or\ ; \qquad \frac{Q}{2\pi KB}\frac{dr}{r} = dh$$

Integrating between limits r_1 and r_2 with the corresponding piezometric heads being h_1 and h_2 , respectively,

$$\frac{Q}{2\pi KB}\ln\frac{r_2}{r_1} = (h_2 - h_1) \qquad or;$$

$$Q = \frac{2\pi KB(h_2 - h_1)}{\ln\frac{r_2}{r_1}}$$

Example - 2

A 100 mm diameter tubewell is sunk to withdraw water from a 10 m thick confined aquifer having coefficient of permeability equal to 0.75 lps/m². The depth of water below the piezometric level is 30 m and it falls 2 m in the tubewell while pumping. Calculate the discharge of the tubewell when the radius of the circle of influence is 30 m.

Solution: $$Q = \frac{2\pi Km(D-d)}{\log_e(\frac{R}{r})}$$

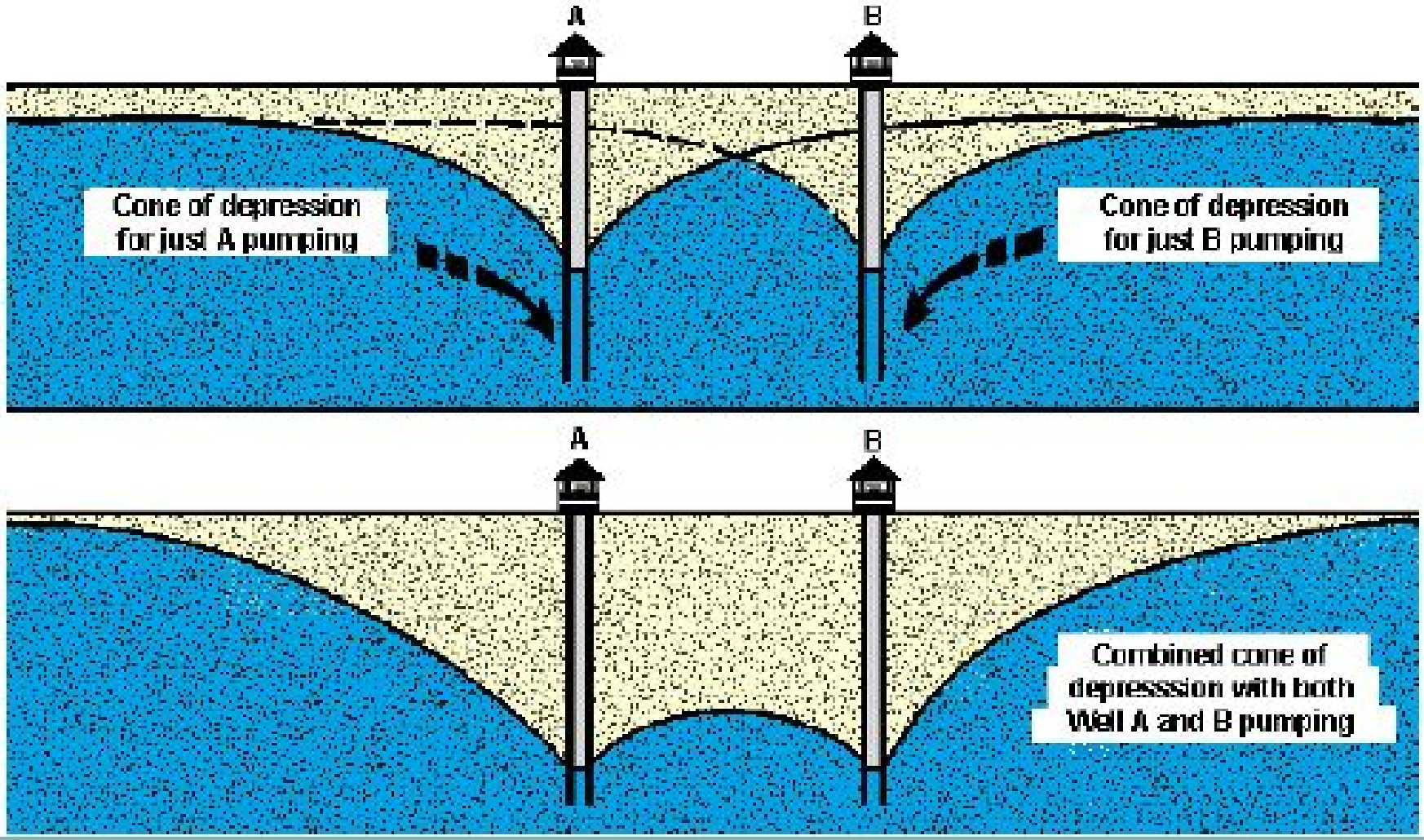
$K = 0.75$ lps/m²; $m = 10$m; $D = 30$m; $d = (30\text{-}2)$m $= 28$m; $R = 30$m; $r = 0.05$m

$Q = 2 \times 3.14 \times 0.75 \times 10\ (\ 30 - 28\ ) / (\ \log_e\ 30/0.05)$

$Q = 94.2 / 6.3969 = 14.73$ lps

A 150 mm diameter tubewell produces 100 lps with a drawdown of 3 m and a circle of influence of 120 m in diameter. The static depth of water in the well is 40 m. Calculate the coefficient of permeability of the aquifer in which the tubewell is sunk.

Interference of Well



Interference of Well

- Occurs when the pumping of one well lowers the water level in another nearby well, reducing the amount of water available to the affected well.
- Cones of depression between wells overlap.
- Tubewells should be spaced enough to avoid interference. Spacing of 250 to 500 ft is found to be satisfactory.
- Small diameter tubewells installed in fine sand will produce too little drawdown to cause interference.

Interference of Well

For two similar wells drawing water from the same aquifer situated at w ft apart, their rate of discharge shall be

$$Q_1 = Q_2 = \frac{\pi K (D^2 - d^2)}{log_e \left(\frac{R^2}{rw}\right)}$$

Interference of Well

Example: At what rate could water be pumped from the two wells 24 inch diameter each, static depth of water 200 ft and drawdown 30ft, if both wells were being pumped together at a distance of 24ft?

Assume: R=1025ft, K=0.099 gpm/sft.

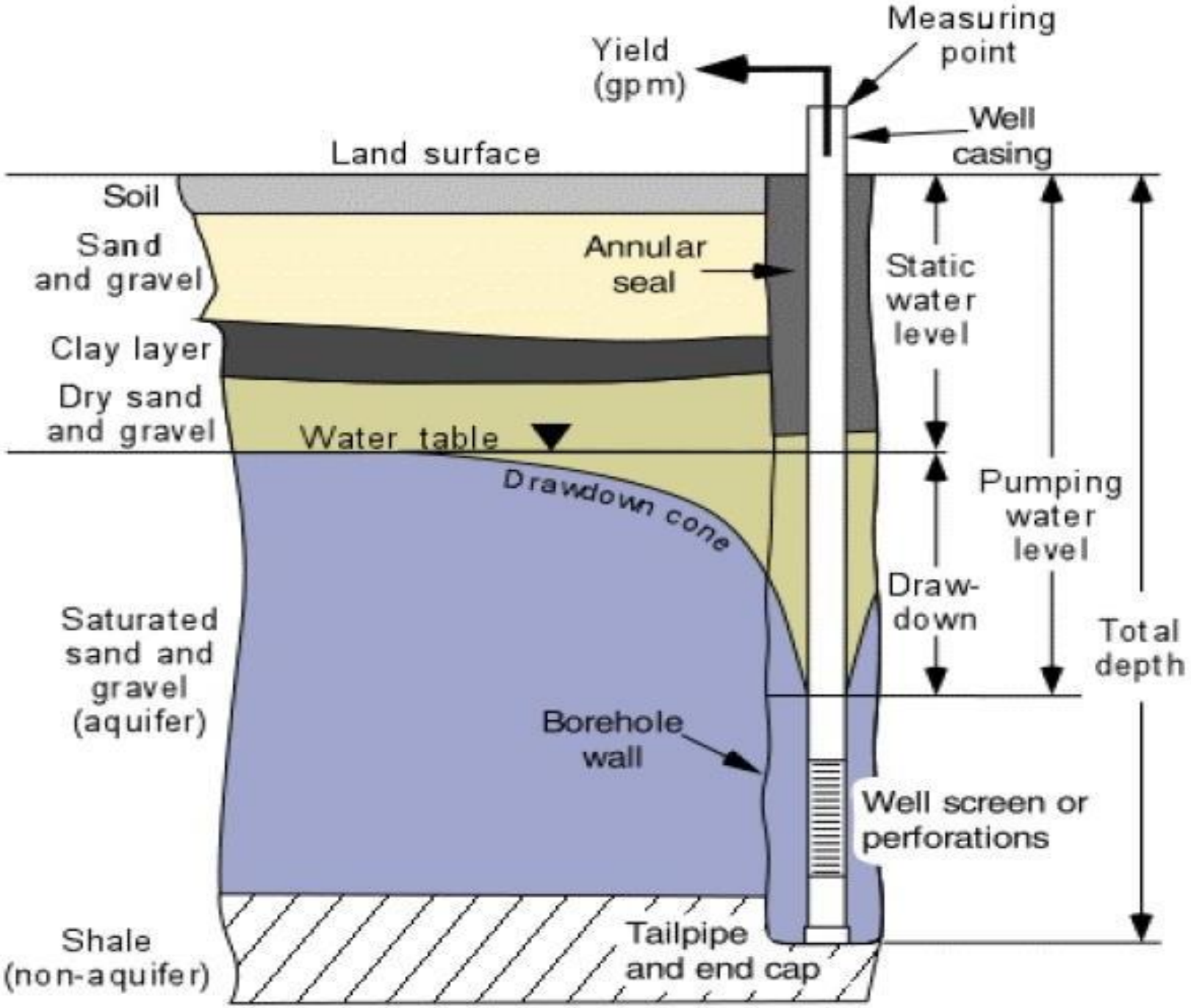
Solution: from the equation above

Given, D=200ft, d=200-30=170ft, r=1ft, w=24 ft

So, $Q_1 = Q_2 = \frac{\pi(0.099)(200^2-170^2)}{log_e\left(\frac{1025^2}{1x24}\right)}$=323 gpm

Combined rate of flow from two wells=2x323=646 gpm.

WELL DESIGN


Yield
(gpm)
Measuring
point
Well
casing
Land surface
Soil
Sand
and gravel
Annular
seal
Static
water
level
Clay layer
Dry sand
and gravel
Water table
Drawdown cone
Pumping
water
level
Draw-
down
Saturated
sand and
gravel
(aquifer)
Total
depth
Borehole
wall
Well screen or
perforations
Shale
(non-aquifer)
Tailpipe
and end cap

Important terms

- Annular seal
- Aquifer
- Borehole
- Casing
- Drawdown
- Cone of depression
- Measuring point
- Pumping water level
- Screen or perforations
- Static water level
- Tailpipe and end cap
- Water table
- Total depth
- Yield

Water Well Design

- Well design means selecting the proper dimensional factors for well structure and choosing the materials to be used in its construction
- Prime considerations of well design are:
  - a) Service life
  - b) Cost and
  - c)Performance
- A properly designed well serves the following:

a) Allows the water to enter at low velocity

b) Prevents the entry of sand

c) Serve as the structural retainer to support the loose formation material

Water Well Design

- Length of screen
- Diameter of screen
- Slot openings of the screen
- Gravel pack material
- Yield of Tubewell

Water Well Design

Well Screen or Strainer: Well screen is the part of well pipe which contains slot openings for extraction of water from water bearing strata.

A properly constructed well screen should –

- allow water to enter the well freely at low velocity,
- prevent sand from entering with the water, and
- serve as the structural retainer to support the loose formation material.

Water Well Design

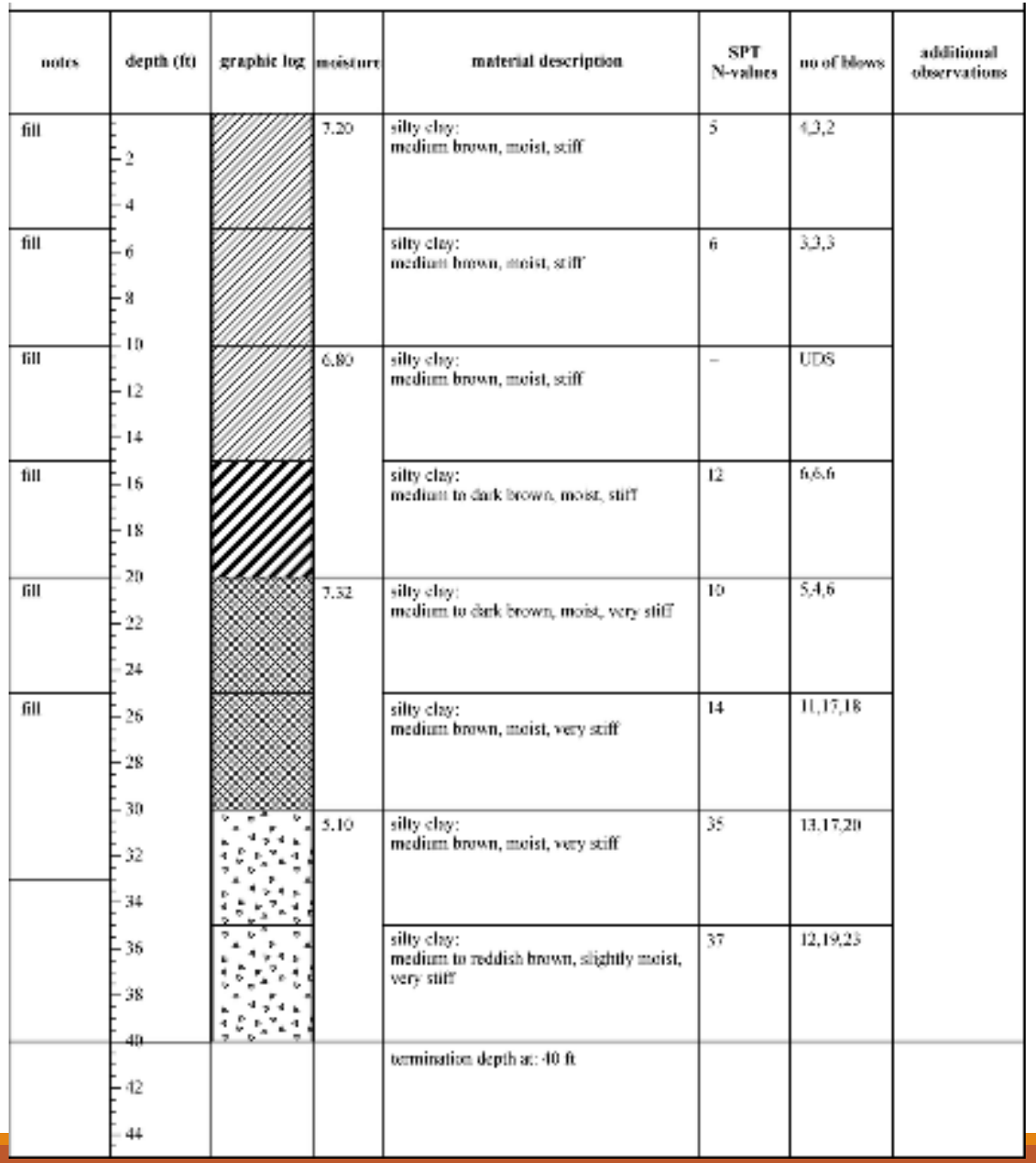
The length and position of the strainer must be evaluated carefully.

Following four factors to be considered while determining the position of the well screen

1. Existing static water level at present
2. Assumed drawdown of 10-20 ft while pumping
3. Average rate of water level declination per year x design period
4. Extra allowance of 10-15 ft depth for safety

That means the position of the screen should start after providing blank casing up to the extent equal to the sum of the above four values

Bore Log



notes	depth (ft)	graphic log	moisture	material description	SPT N-values	no of blows	additional observations
fill	2–4		7.20	silty clay: medium brown, moist, stiff	5	4,3,2	
fill	6–8			silty clay: medium brown, moist, stiff	6	3,3,3	
fill	10–12		6.80	silty clay: medium brown, moist, stiff	–	UDS	
fill	14–16			silty clay: medium to dark brown, moist, stiff	12	6,6,6	
fill	18–20		7.32	silty clay: medium to dark brown, moist, very stiff	10	5,4,6	
fill	22–24			silty clay: medium brown, moist, very stiff	14	11,17,18	
	26–28		5.10	silty clay: medium brown, moist, very stiff	35	13,17,20	
	30–32			silty clay: medium to reddish brown, slightly moist, very stiff	37	12,19,23	
	34–36						
	38–40			termination depth at: 40 ft			
	42–44						

Most Productive Aquifer

The intake portion of the well must be placed in those zones having the highest hydraulic conductivity which is determined using following technique:

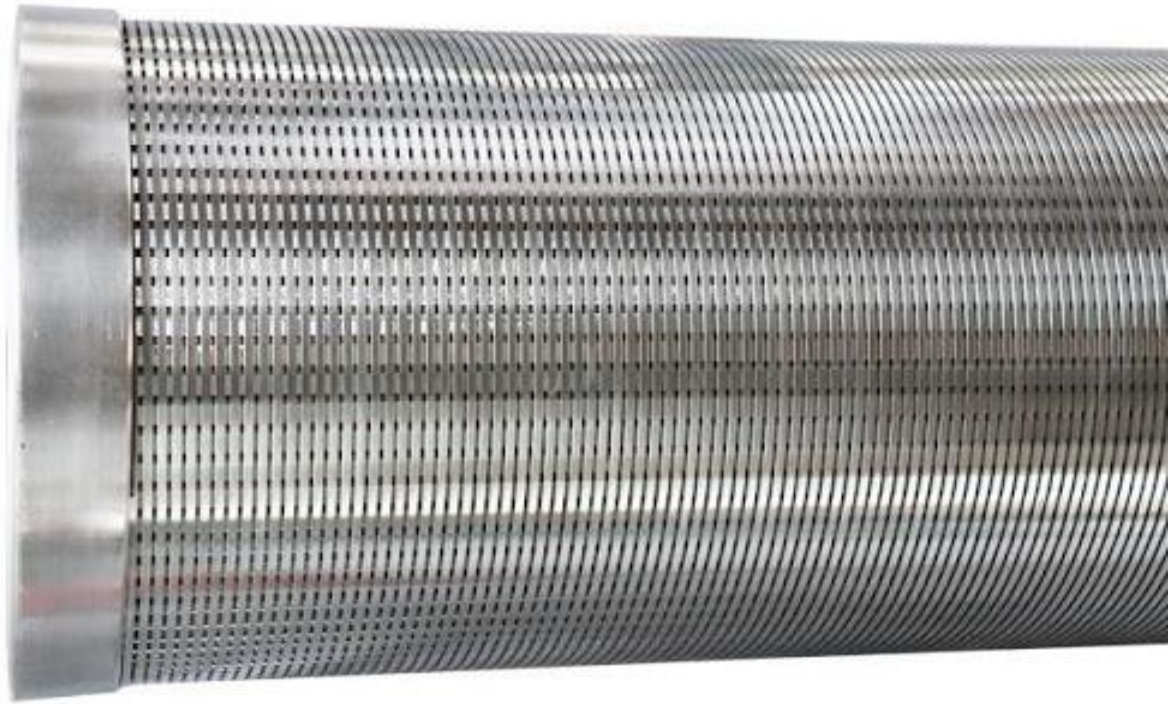
- Aquifer materials at definite intervals undergo sieve analysis.
- Particle size distribution curve is prepared.
- Effective size (d_{10}) and uniformity coefficient($C_U=d_{60}/d_{10}$).
- Aquifer materials having high effective size d_{10} and low uniformity coefficient C_U will have high hydraulic conductivity.
- Best aquifer for screening is determined by comparison of the grain size analysis curve of the materials along the depth of the borehole.

Well Screen Slot Openings

- Oversized slots will pump finer materials indefinitely and become difficult to obtain clear water. Undersized slots will provide more resistance to flow of groundwater into the well, resulting in more head loss and corrosion.
- Screen slot openings for the same formation can be different depending on whether the well is naturally developed or filter packed.
- Coarse-grained non-homogeneous material can be developed naturally, whether fine-grained homogeneous materials are best developed using a filter pack.



PVC screens available from 33mm diameter to 630mm diameter

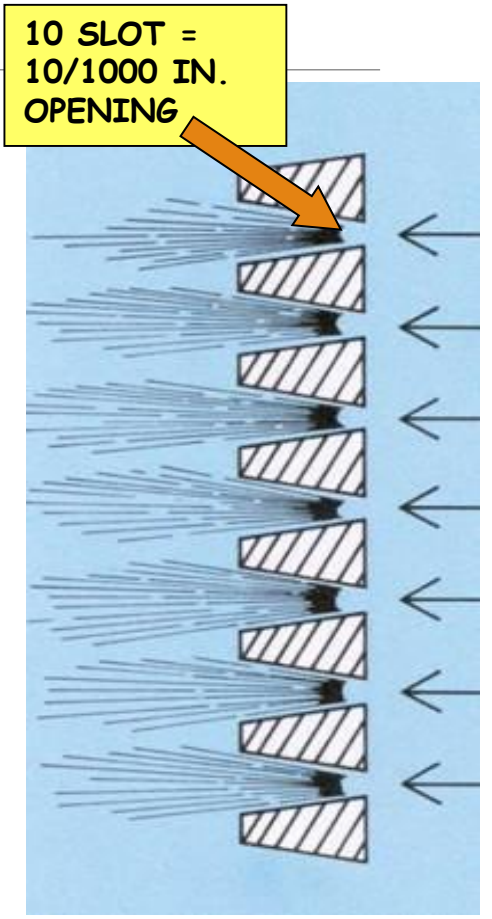


Stainless Steel Water Well Screen

Screen Slot Size

Screen Slot Sizes are measured in thousandths of an inch

- Slot No. 5 = 5/1000 inch = 0.005 inch
- Slot No. 10 = 10/1000 inch = 0.010 inch
- Slot No. 20 = 20/1000 inch = 0.020 inch
- Slot No. 30 = 30/1000 inch = 0.030 inch
- Slot No. 40 = 40/1000 inch = 0.040 inch
- Slot No. 60 = 60/1000 inch = 0.060 inch
- Slot No. 80 = 80/1000 inch = 0.080 inch



CROSS-SECTION
OF SCREEN WIRE

Well Screen Diameter

- Increasing screen length is generally more effective than increasing screen diameter for enhancing well yield.
- Doubling the screen diameter, for instances, will only result in increasing 10% to 15 % in the yield. On the other hand, doubling the screen length will result in the yield being almost doubled.
- It is much more better to use screen length as a controlling factor on well rather than screen diameter in thick aquifer.
- Enough open area must be provided so that the entrance velocity of water generally does not exceed the design standard of **0.1 ft/s**.

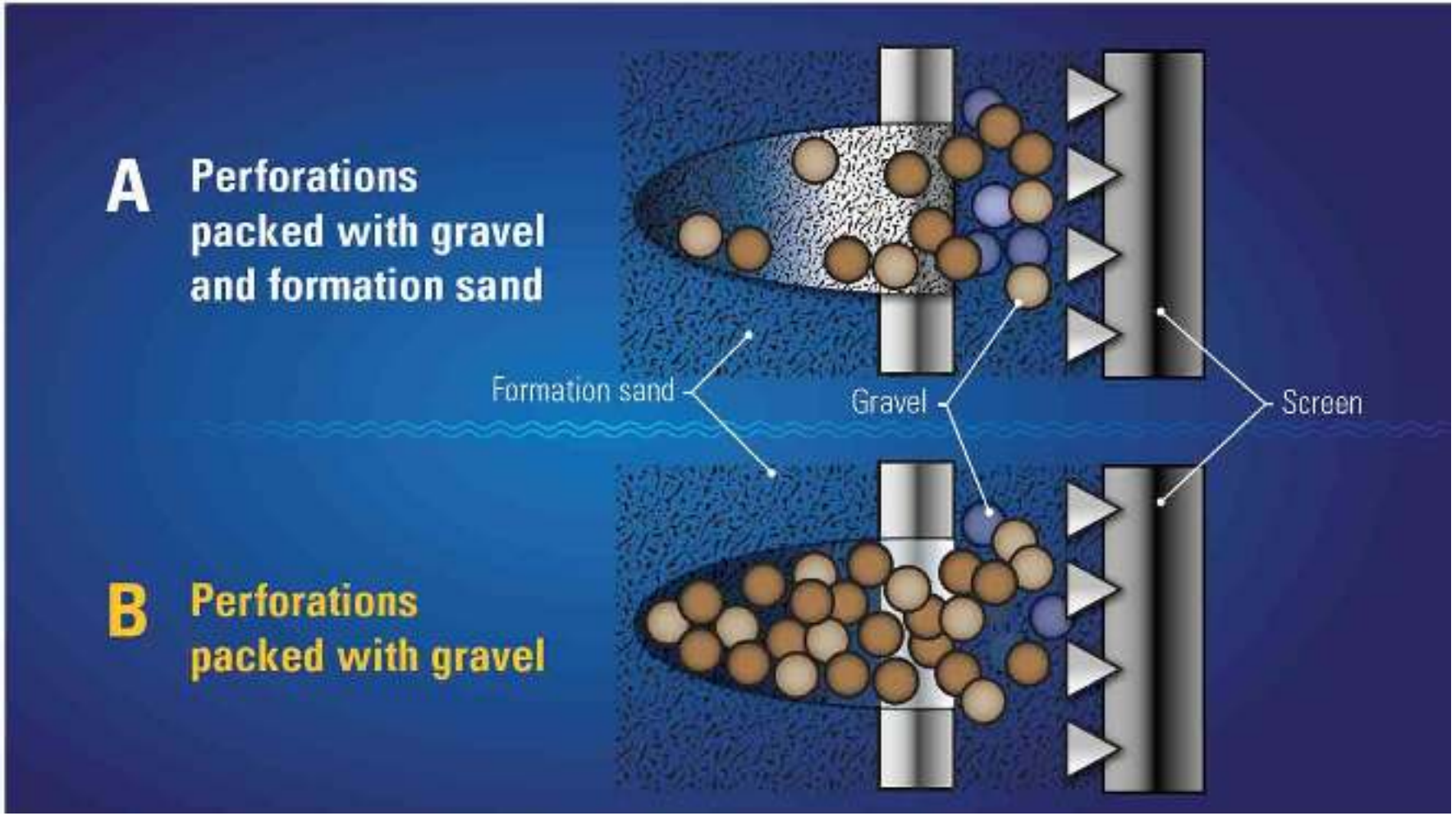
Gravel Pack Design

- Gravel pack materials should be well sorted to assure good porosity and hydraulic conductivity of the materials near the screen.

Gravel packing is required when:

- The sediments are highly uniform and fine grained (d_{10}<0.25mm).
- The sediments are highly laminated.
- The borehole diameter may be much larger than required for the installation of a screen.

Selecting a screen slot size that will retain 90% or more of the filter pack material. The thickness of the filter pack should be within 3 to 8 inches .


A
Perforations
packed with gravel
and formation sand
Formation sand
Gravel
Screen
B
Perforations
packed with gravel



Natural Garvel Pack Material

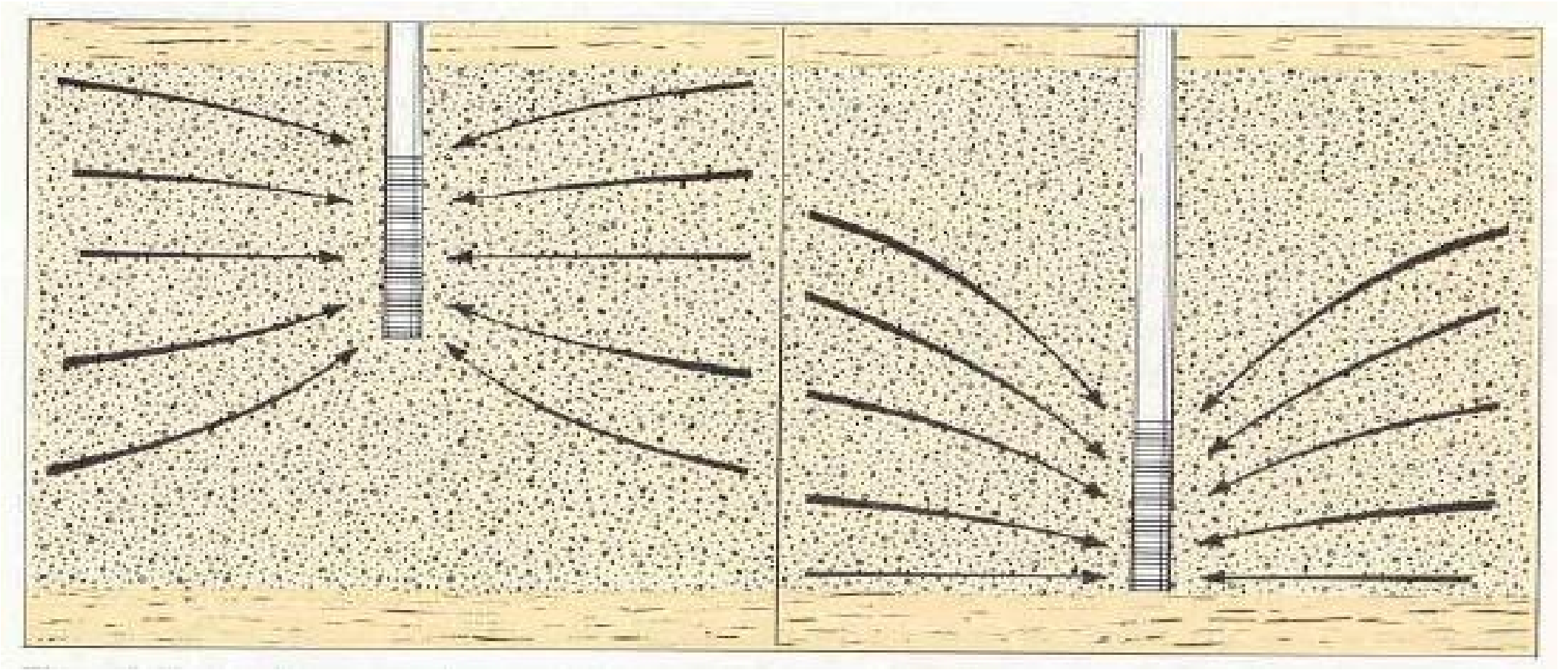
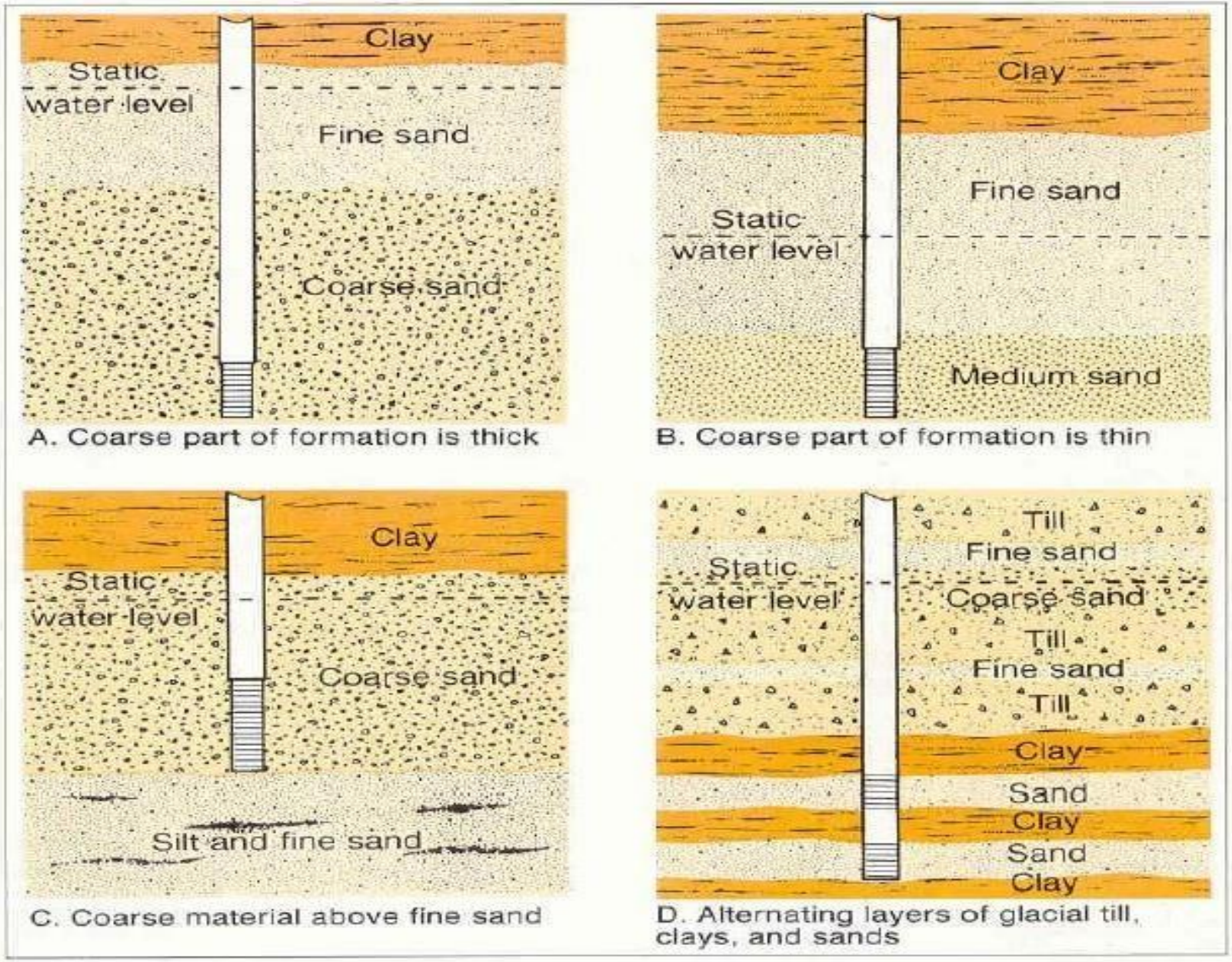


Figure partial penetrations when the intake portion of the well is less than the full thickness of the aquifer. This causes distortion of the flow lines and greater head losses.



Suggested positioning of well screens in various stratified water-bearing formations

Entrance Velocity

- Field experience and laboratory tests show that the average entrance velocity of water moving into the screen should not exceed **0.1ft/s**.
- At this velocity, the friction losses in the screen openings will be negligible and the rates of incrustation and corrosion will be minimal.

Screen Transmission Capacity

The transmitting capacity of a well is given by,

- $Q=\pi DL(0.01p)v_c$

Where, Q=screen transmitting capacity

D=diameter of the screen

L=length of the screen

p=percent opening area of the screen

v_c=permissible entrance velocity

The discharge of a tubewells should not exceed the transmitting velocity.

Example - 1

Design a strainer for a 38 mm diameter tubewell to be operated by a No.6 handpump at the rate of 40 lpm. Slot No.10 strainer having a 40% open area is to be used. The entrance velocity should be around 0.01 m/sec.

Solution: The open area per metre of 38 mm strainer = $\pi d \times 1 \times 0.04 = 3.14 \times 0.038 \times 1 \times 0.4 = 0.0477\ m^2/m$

$Q = 40$ lpm $= (40/60) \times 10^{-3}\ m^3/sec. = 0.67 \times 10^{-3}\ m^3/sec.$

Entrance Velocity, $v_e = 0.01$ m/sec.

Entrance area required $= Q/v_e = 0.67 \times 10^{-3}/0.01 = 0.067\ m^2$

Length of the strainer required $L = 0.067/0.0477 = 1.4$ m

Strainer length of 1.5 m may be provided.

Steps for well design

1. Grain size distribution for different soil layers
2. Locating the aquifer and water bearing strata
3. Determination of strainer length and position
4. Design of gravel pack material
5. Selection of strainer size
6. Yield of well

1. Grain size distribution for different soil layers

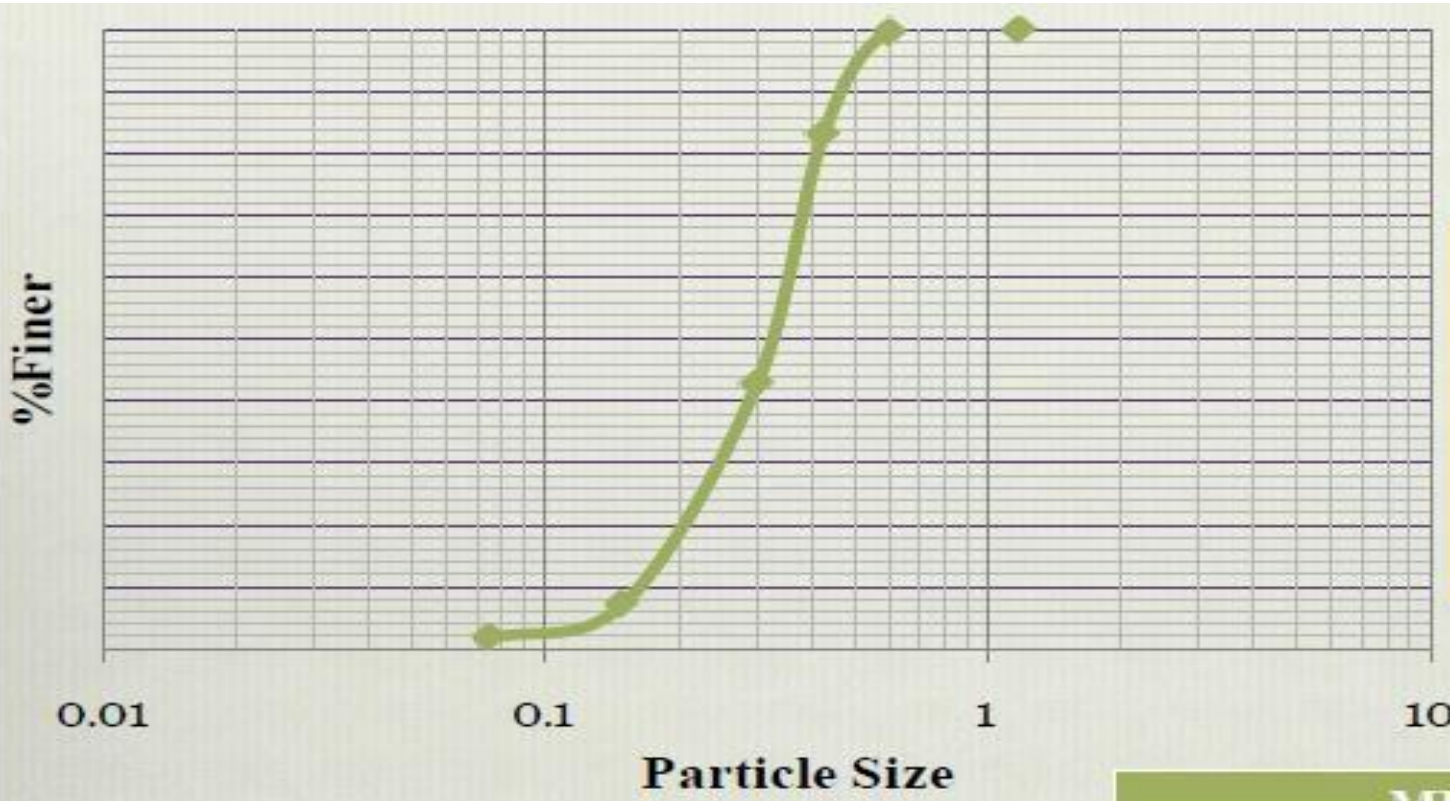
- Grain size distribution curves are drawn for different soil layers using soil data
- Effective grain size ($D_{10,}$ $D_{30,}$ D_{60}) and uniformity coefficient are found for each layer
- From the grain size distribution curves relative percentage of different particles are found using MIT classification of soil

1. Grain size distribution for different soil layers

Sample Calculation

Sieve No	Seive Size (mm)	Material Retained	% Retained	Cumulative % Retained	%Finer	FM
16	1.18	0	0	0	100	
30	0.6	0.2	0.2	0.2	99.8	
40	0.425	16.4	16.47	16.67	83.33	
50	0.3	40.4	40.56	57.23	42.77	1.5
100	0.15	35.4	35.54	92.77	7.23	
200	0.075	5.6	5.62	98.39	1.61	
Pan	0.0001	1.6	1.61	100	0	
Total		99.6				

- $FM = \frac{\sum(\text{Cumulative \% retained of standard sieves})}{100}$



Fine Sand 20%
Medium Sand 79%
Course Sand 1%

MIT Classification	
Silt/Clay	< 0.06 mm
Fine Sand	0.06 – 0.20mm
Medium Sand	0.20 – 0.60 mm
Course Sand	0.60 – 2.00mm
Fine Gravel	> 2.00 mm

2. Locating the aquifer and water bearing strata

- All soil sample data are summarized in a table to find available water bearing soil strata

Factors to be considered for locating water bearing strata

- Greater uniformity coefficient increases permeability
- Higher fineness modulus means bigger soil particle
- Higher percentage of course and medium sand indicates higher water carrying capacity
- FM<1 → Clay and silt

  FM=1 → Fine sand with silt

  FM>1→ Medium to course sand which has potential to good permeability and presence of water

1. Locating the aquifer and water bearing strata

Summary of Grain Size Distribution

Sample Depth (ft)	D_{10}	D_{30}	D_{60}	$U = D_{60} / D_{10}$	FM	% Course Sand	% Medium Sand	% Fine Sand
130-170	0.15	0.195	0.27	1.80	1.18	1	66	33
170-210	0.12	0.195	0.3	2.50	1.26	3	67	30
210-220	0.15	0.21	0.33	2.20	1.41	4	70	26
220-270	0.17	0.28	0.3	1.76	**1.63**	**6**	**77**	17
270-310	0.17	0.28	0.31	1.82	**1.69**	**11**	**72**	17
310-370	0.17	0.24	0.38	2.24	**1.5**	**5**	**75**	20
370-410	0.17	0.29	0.395	2.32	**1.63**	**5**	**80**	15
410-430	0.15	0.22	0.37	2.47	1.47	5	71	24

***Higher %of coarse and medium sand**
***Higher FM means bigger particle**

Location of water bearing soil layer 220' to 410'

3. Determination of strainer length and position

Primary factors:

1. Length of casing pipe must be selected first
2. Casing pipe must be sufficient enough so that submersible pump always remain below water

Length of the casing pipe is the summation of four lengths:

1. Static water level at present
2. Assumed drawdown of 10' to 15' while pumping each time
3. Average rate of water level declination (per year) x Design life
4. Safety distance of 10' to 15'

- After the length of the casing pipe and depth of the submersible pump being ensured, we can think about strainer position
- Limitation of strainer length

Aquifer Thickness	Recommended Screening
< 25'	70% Screening
25' – 50'	75% Screening
> 50'	80% Screening

- As it is very difficult to maintain the vertical alignment of a long strainer, it will not be practical to go beyond 100' screening
- Strainer should not be extended up to the bottom of the aquifer to allow the upward converging flow of water during pumping

Necessity of a blank pipe

1. Between two strainers of a discontinuous aquifer
2. 10’ blank pipe is placed at the bottom of the strainer to trap particles that may enter into the pipe through upward converging flow

Sample Calculation

Let, the static water level at 230’

Average rate of water level declination (per year) = 2’

Design period= 20 years

Drawdown of 15’ while pumping each time

Safety distance of 15’

So length of the casing pipe= (230+40+15+15)= 300’

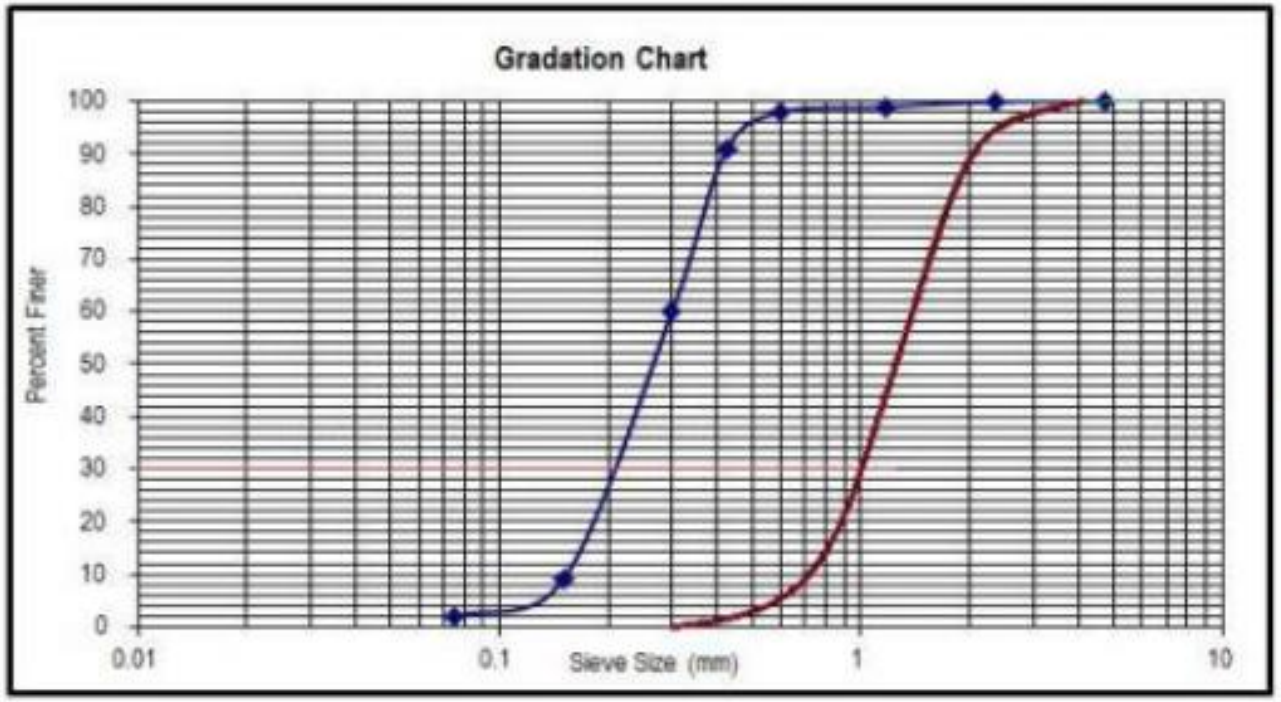
Aquifer depth= (410-220) = 190’ which is more than 50’.

So 80% of the aquifer screening can be made which gives the strainer length of = (190 * 0.80) = 152’

But as we know that maximum safe length of the strainer is 100’, so we can choose a strainer of 100’

4. Design of gravel pack material

- To design the gravel pack material, the grain size distribution curve of the comparatively finest layer within the aquifer is drawn on a semi log paper
- 70% (D_{30}) size of the finest sand is multiplied by a factor 4-6 depending on the sand type. This is the first point on the curve that represents the grading of the artificial gravel pack material.
- Through this initial point on the gravel pack curve, a smooth curve nearly parallel with the aquifer material curve is drawn by trial and error method, representing a material with a uniformity coefficient 2.5 or less.



As Cu of the finnest layer in between 1.5 & 2.5, assume multiplying factor = 4.5
D30 of gravel pack = 1.0 mm
Cu = 2.1 < 2.5, OK

Gravel Pack Material:

Sieve Number	Sieve Opening (mm)	Cumulative % Retained	Pertinent Values
8	2.36	0-12	
16	1.18	2-18	FM = 3.65
30	0.6	28-42	D_{10} = 0.73
40	0.425	90-100	D_{60} = 1.5
50	0.3	100	U= 1.75

4. Design of Gravel Pack Material
5. Selection of Strainer Size

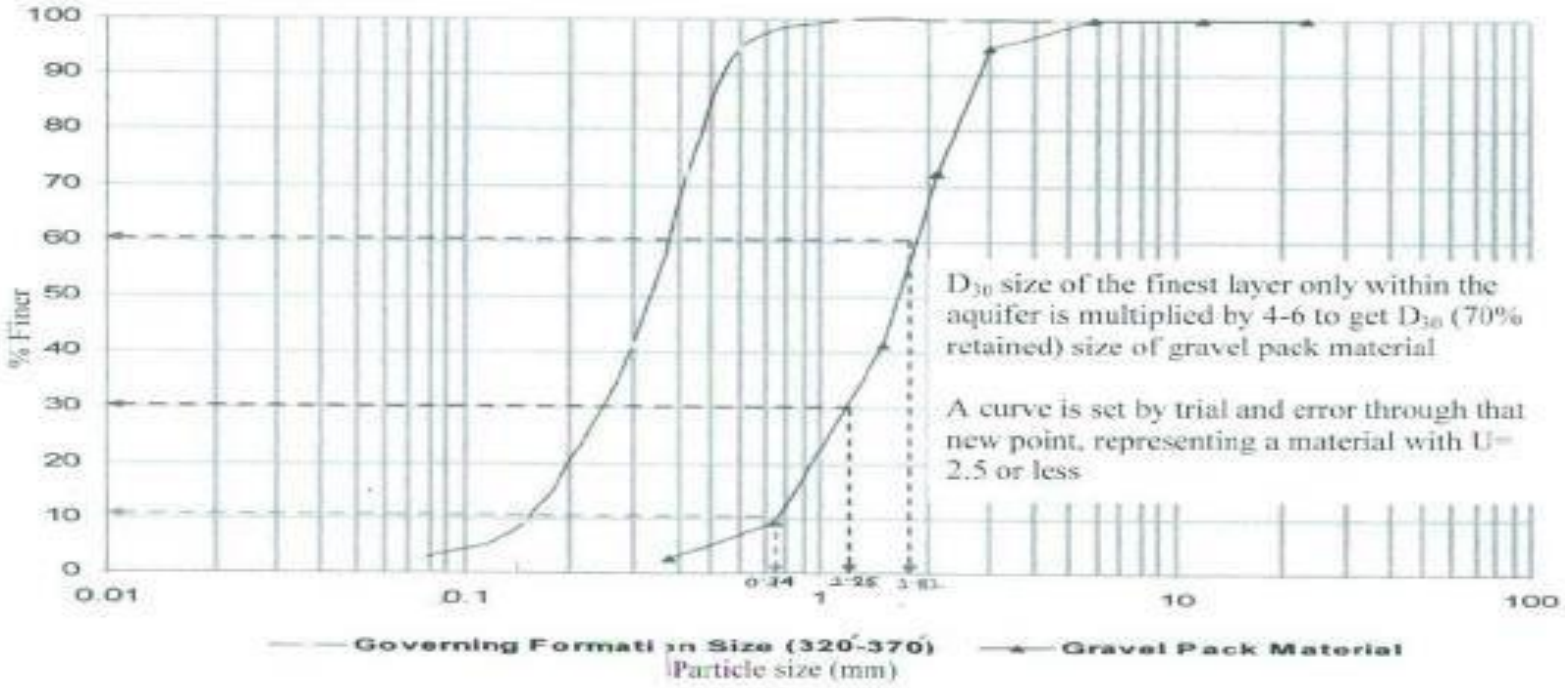
Gravel Pack Material

Sieve No.	Size(mm)	% Finer from Graph	Cumulative % Retained	% reatained	Range of % reatained
4	4.75	98	2	2	0-6
8	2.36	80	20	18	14-22
16	1.18	28	72	54	50-58
30	0.6	5	95	23	19-27
40	0.425	3	97	2	0-6
50	0.3	0	100	3	0-7
100	0.15	0	100	0	-
200	0.075	0	100	0	-

Strainer Size

To retain 90% of gravel pack materials, slot= D_{10} /25.4*1000
=0.74/25.4*1000
=29.13

4-6 inch dia 30 slot strainer is selected having each opening area of 30/1000 inch



D_{30} size of the finest layer only within the aquifer is multiplied by 4-6 to get D_{30} (70% retained) size of gravel pack material

A curve is set by trial and error through that new point, representing a material with U= 2.5 or less

3-8 inch diameter envelop of gravel will surround the entire screen

Specification for the gravel pack material is prepared by

- first selecting 4 to 5 sieve sizes that cover the spread of the curve and then
- set down a permissible range (±8%) for the percent retained on each of the selected sieves.

Gravel pack material should be clean and well rounded.

To ensure that an envelope of gravel will surrounded the entire screen, a thickness from 3- 8 inch can be maintained.

5. Selection of strainer size

To retain 90% of the gravel pack materials,

Slot = D_{10} / 25.4 * 1000 ; here D_{10} will be of the gravel pack material

If, D_{10} = 0.74 mm

Slot= 0.74/ 25.4 * 1000 = 29.13

So 4-6 inch diameter 30 slot strainer is selected having each opening area of 30/1000 inch

3 to 8 inch diameter envelop of gravel pack material will surround the entire screen

6. Yield of well

- Well yield is calculated using strainer opening area
- Yield = (area of strainer x flow velocity) / factor of safety
- The factor of safety is considered assuming blockage while operation
- Different slot size have different opening area
- For PVC screen, opening area is considered to be half of the mentioned areas below

Slot size	Assumed opening (Steel screening)
40 slot	20%
30 slot	15%
20 slot	10%

Sample calculation

For 30 slot strainer,

Strainer area= 15% of strainer surface area

= 0.15 x 3.14 x Diameter x Strainer length

Here, Diameter = 6”

Length = 100’

Assume, flow velocity = 0.10 fps

Screen blockage factor = 0.4

So, Yield of a well = (0.15 x 3.14 x 6/12 x 100 x 0.1) x 0.4

= K x $(0.3048)^3$ x 3600 x 1000

= 96,028 lph

Design considerations:

- For one pump
- In one day
- 10 hour pumping in two shifts

As pumping is for 10 hour per day, Yield = 96,028 x 10

= 960, 280 lpd

- More than one well may be required if one well can't meet the demand
- Water demand for that area = 1470800 lpd

No. of tubewells required = 1470800 / 960280 = 1 . 5 ≈ 2

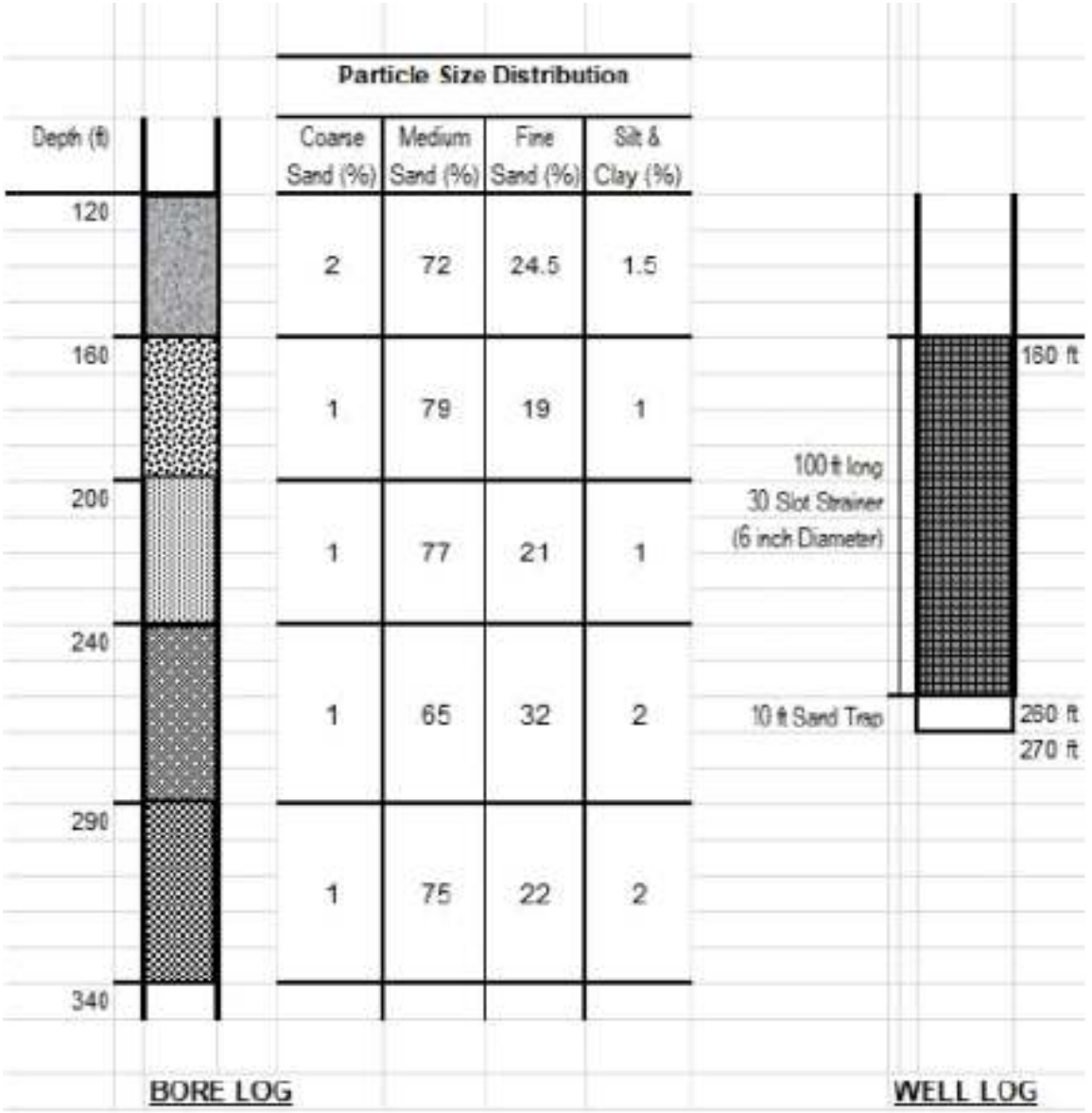
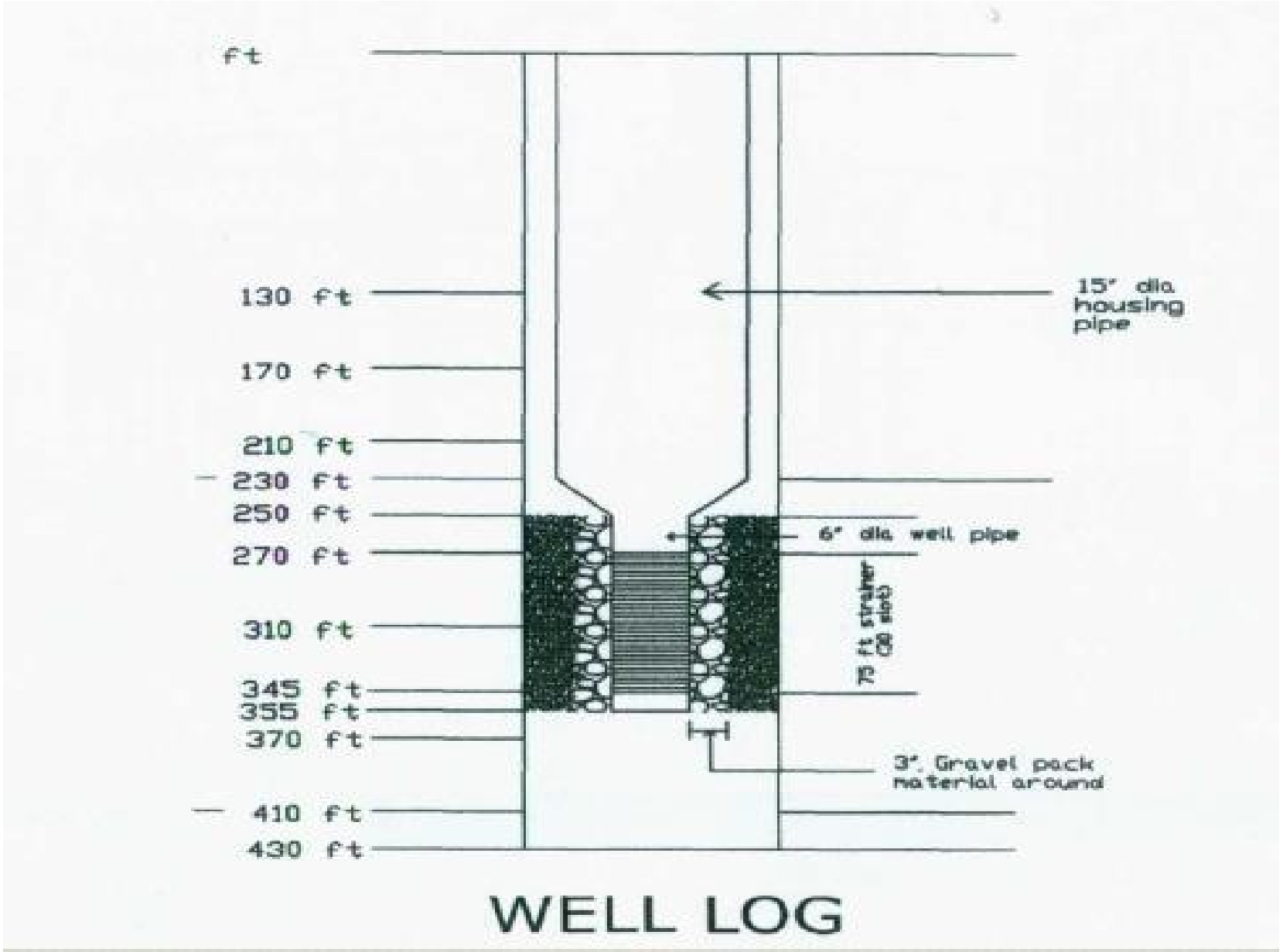


Figure-3: Typical Bore Log and Well Log Presentation

(NB - this log is not for the tubewell data shown in sample calculation, it is provided as sample format only)


ft
130 ft
170 ft
210 ft
230 ft
250 ft
270 ft
310 ft
345 ft
355 ft
370 ft
410 ft
430 ft
15" dia. housing pipe
6" dia. well pipe
75 ft strainer (50 slot)
3". Gravel pack material around
WELL LOG

EWCE 331



Water Well Installation and Maintenance

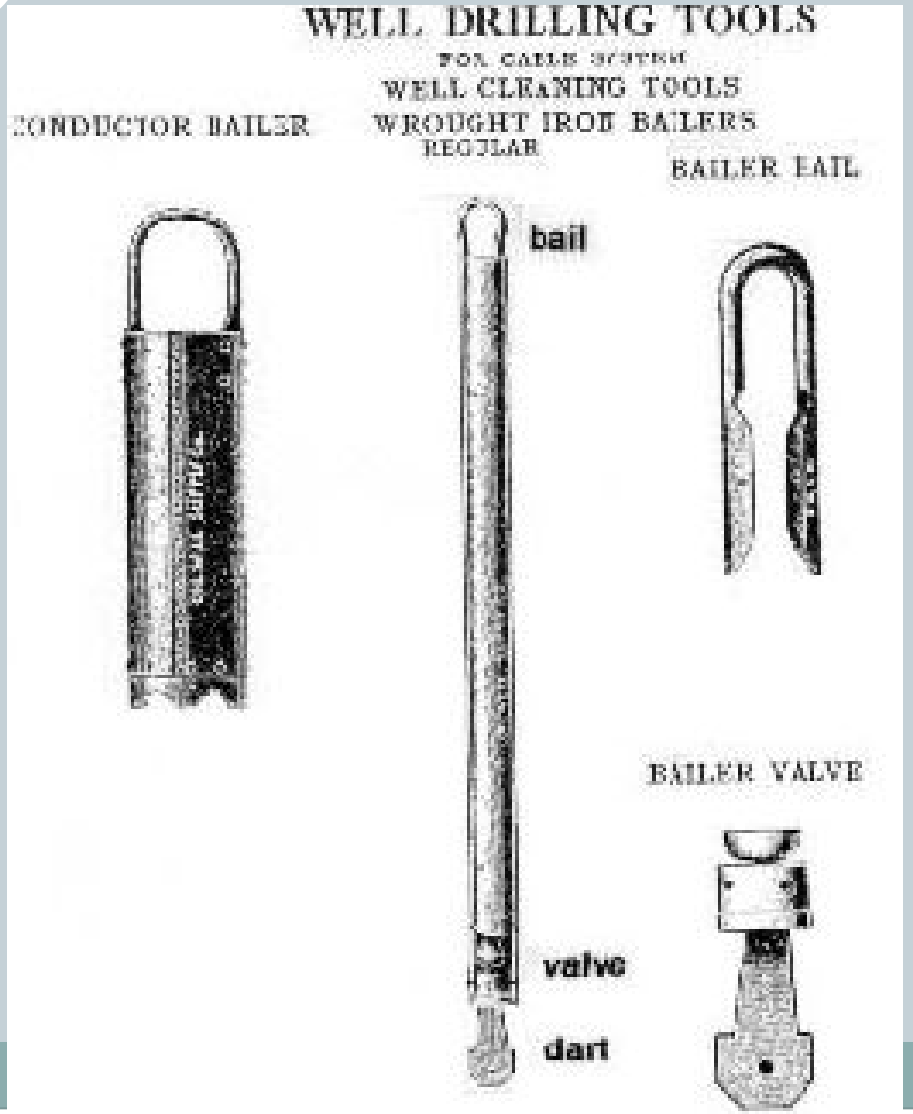
Methods of Drilling of Tubewells

Deep tubewells are constructed by drilling. Methods for drilling deep tubewells are as follows:

1. **Cable tool/percussion/standard method**
2. California stove pipe method
3. **Jetting method**
4. **Direct rotary method**
5. **Reverse-circulation rotary method**

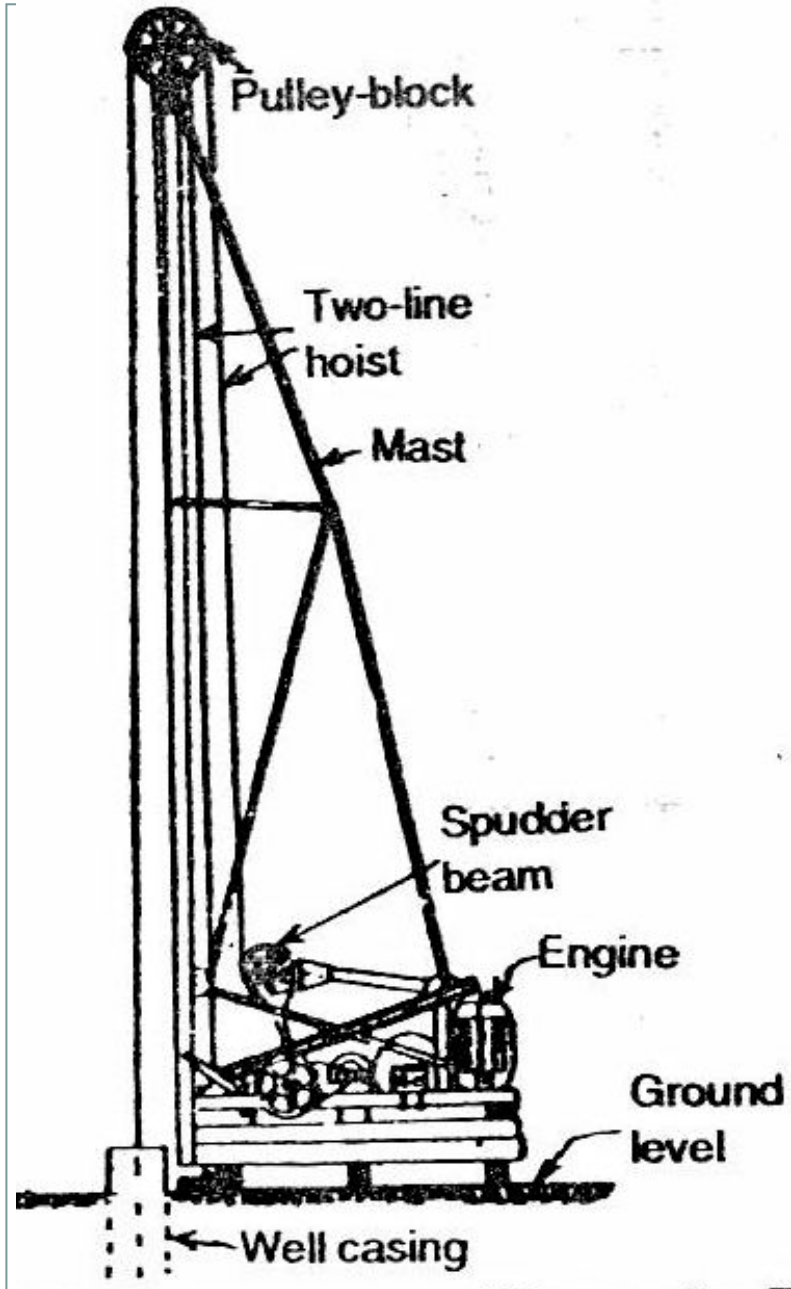
Cable Tool Method





Cable Tool Method

- Useful for cutting consolidated rocks from soft clay to hardest rocks.
- Wells drilled by this method are constructed with a standard well- drilling rig, percussion tools and a bailer.
- Drilling is accomplished by regular lifting and dropping of a string of tools (falling and rising arrangements)into the borehole.
- The string of tools is suspended by a cable from a spudder beam(truck mounted).



) Basic components of Percussion Drilling Rig.

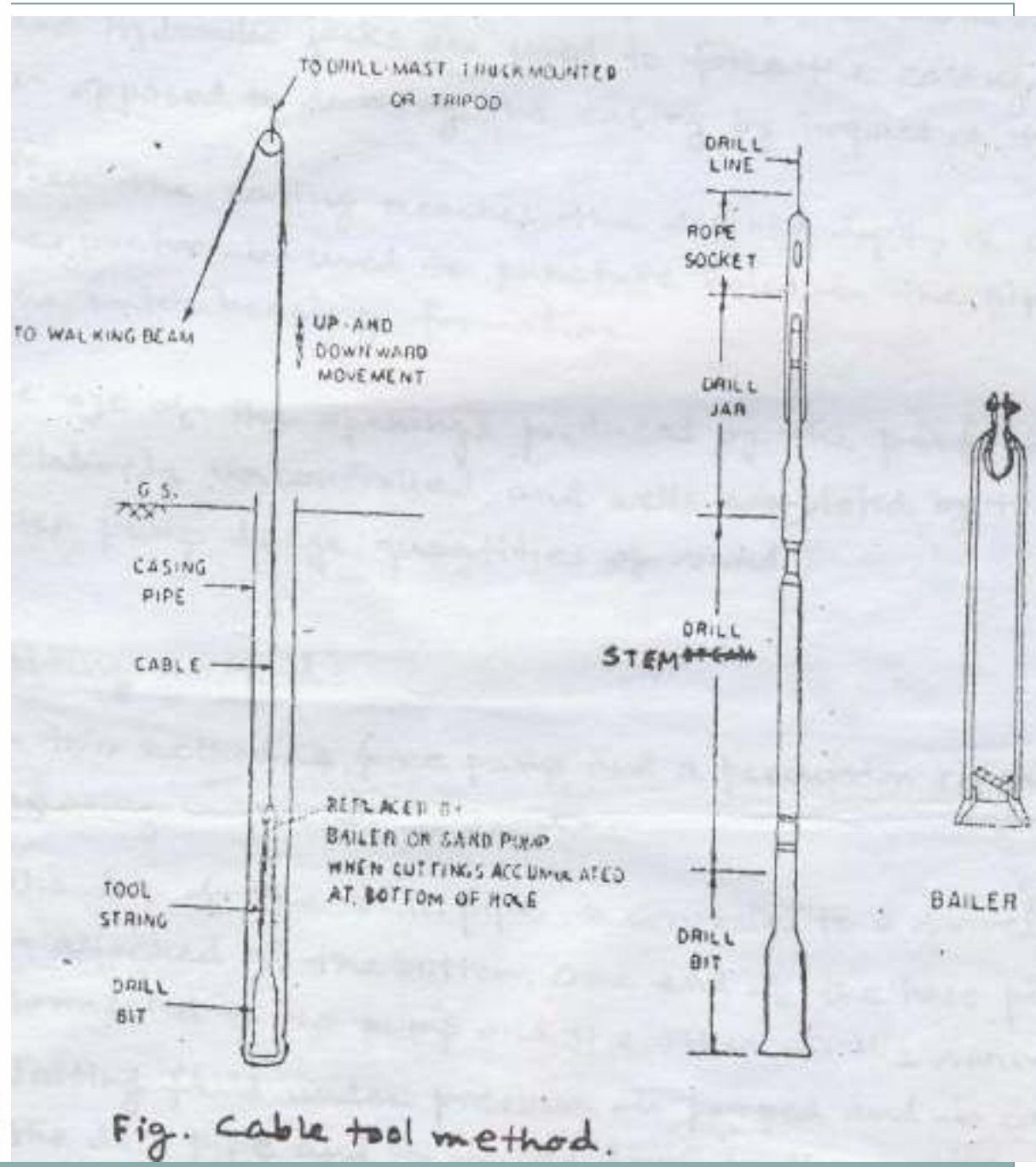


Fig. Cable tool method.

Cable Tool Method

- From top to bottom, the string of tools consists of a swivel socket, a set of jars, a drill stem and a drilling bit.
- The drill bit break the crushes consolidated rock into small fragments, whereas the bit primarily loosens the particles with water to form a slurry at the bottom of the borehole.
- The reciprocating action of the tools mixes the crushed or loosened particles with water to form a slurry.
- If little or no water is present, water is added to form a slurry. The slurry is removed at intervals from the borehole by a sand pump or a bailer.

Cable Tool Method

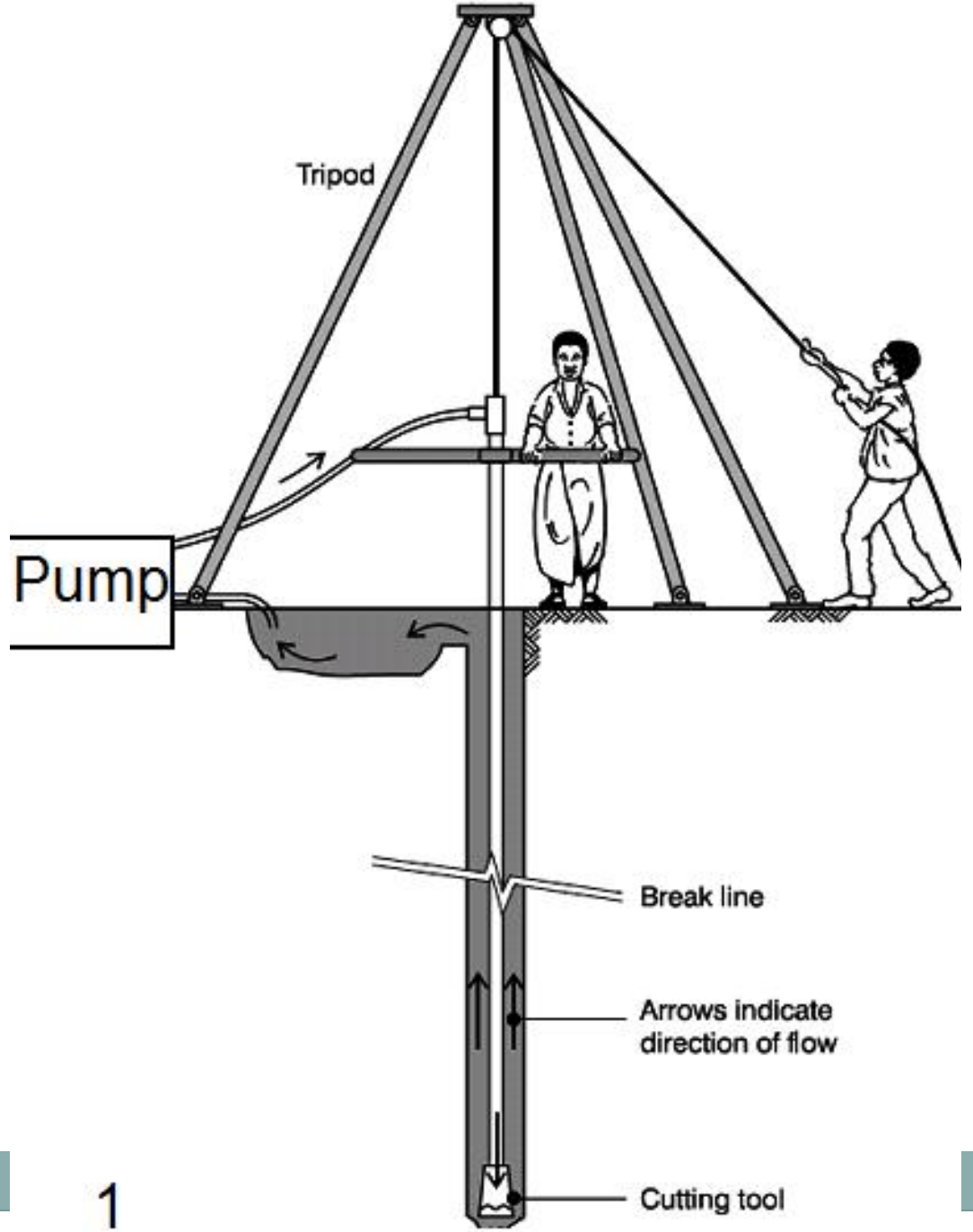
- In unconsolidated formations, the casing closely follows the drilling bit, adding length of casing as the hole is deepened, to prevent caving.
- Usually drilling is started with a large diameter and diameter is reduced telescopically after drilling certain depth.

Jetting Method

- In this method, a force pump and a percussion rig machine with spudding mechanism is desirable.
- The top of the drill pipe is connected to a swivel and a bit is attached at the bottom. One end of the hose pipe is connected to the pump and the other to the swivel.
- Jetting fluid under pressure is pumped and is carried into the drill pipe and is forced down to the nozzle in the jetting bit against the bottom of the borehole.
- The jet stream of water loosens the soil, in form of slurry, rise to the surface through the annular space between drill pipe and casing pipe and discharges into a settling tank. Clear water over flows into a second pit from where it is recirculated down the drill pipe

Jetting Method

- The casing pipe usually sinks by its own weight or extra weight added to it at the top.
- Slow rotation can also be imparted to the casing pipe to expedite its sinking.
- If a layer of hard material is encountered, the drill pipe is attached to the spudding mechanism on the rig and a special drill bit is attached at the bottom of the drill pipe.


Tripod
Pump
Break line
Arrows indicate
direction of flow
Cutting tool

Direct Rotary Method

- In this method, the borehole is drilled by a bit attached to a hollow drill rod rotating rapidly by an engine driven rotary table.
- A drilling fluid is pumped down through the drill pipe and out through the port or jets in the bit, the fluid then flows upward in the annular space between the hole and the drill pipe, carrying the cuttings in suspension to the surface.
- At the surface, the fluid is channeled into a setting pit where most of the cuttings drop out.
- Clean fluid is then picked up by the pump from the second pit and is recirculated down the drill pipe.

Direct Rotary Method

- The properties of the drilling fluid are such as to provide adequate support for the wall of the hole and are usually viscous mixture of water and bentonite.
- No casing is ordinarily required during drilling because the drilling fluid forms a clay lining or mud cake or the wall of the well by filtration. This seals the walls thereby preventing cavity entry of groundwater and loss of drilling fluid.

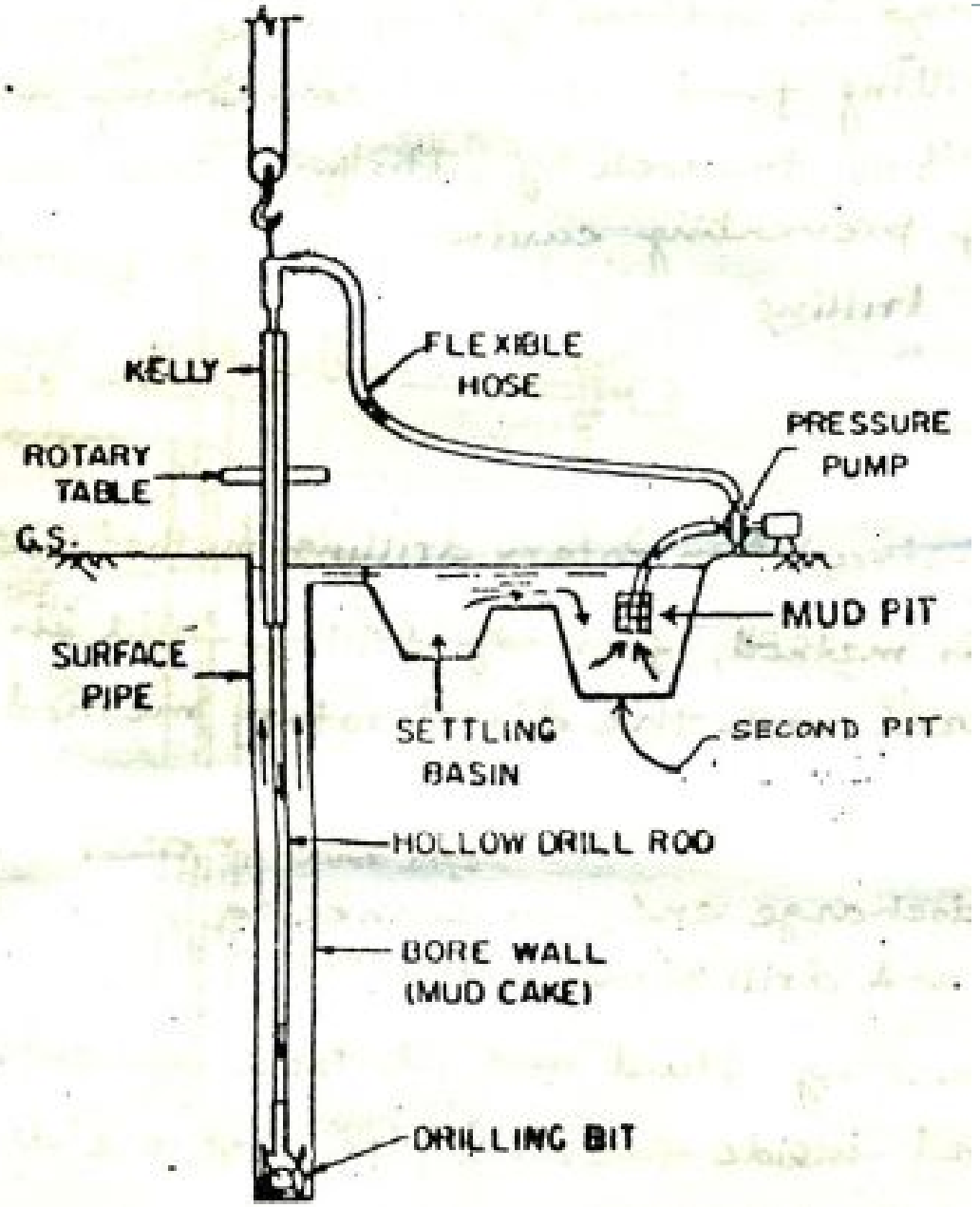


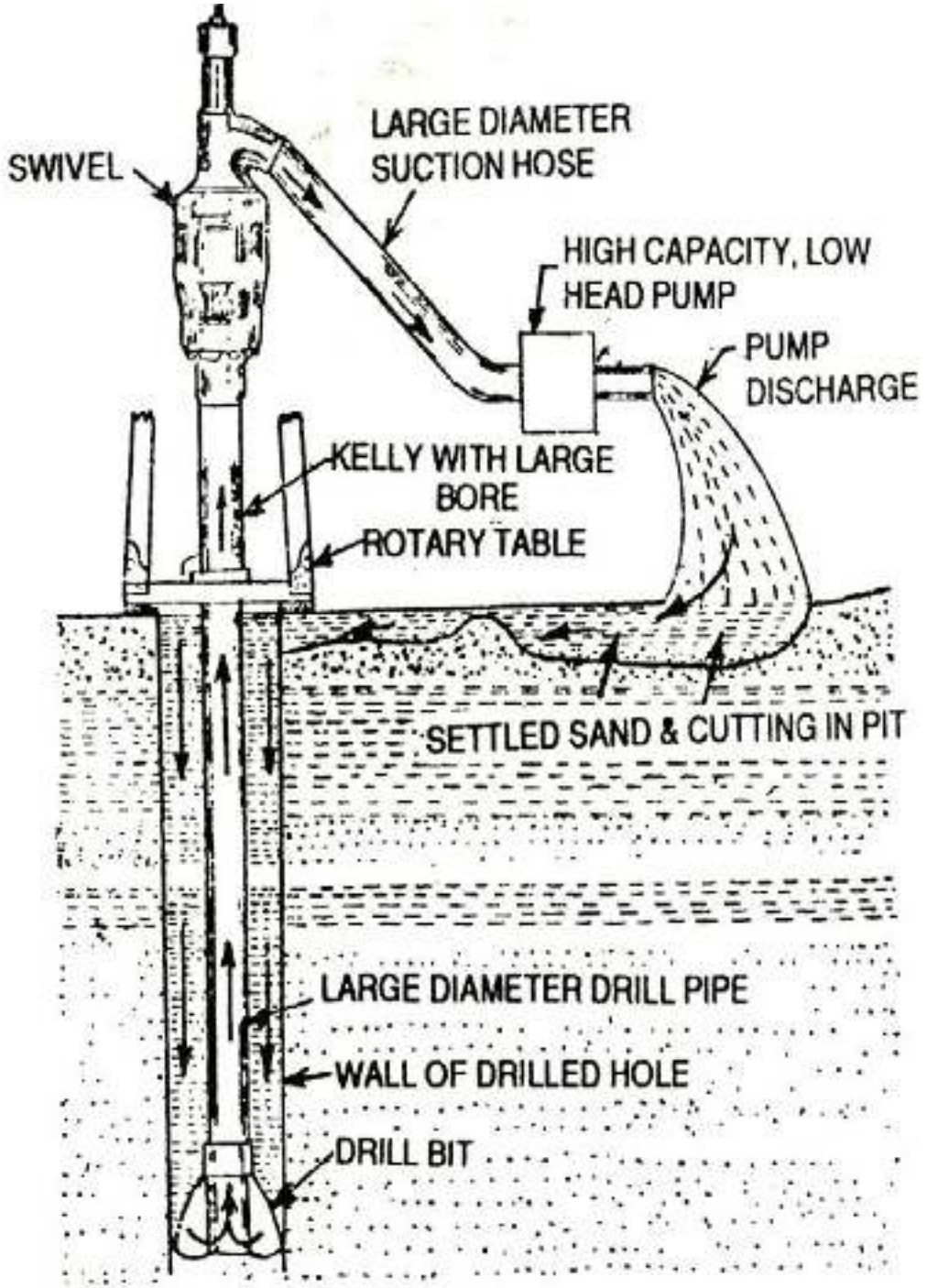
Fig. Direct rotary method.

Reverse–circulation Rotary Method

- In this method, flow of drilling fluid is reversed compared with the direct rotary method.
- The drilling fluid and its load of cuttings move upward inside the drill pipe and are discharged by the pump into the settling pit.
- The clean fluid returns to the bore hole by gravity flow.
- Relating high velocity of the fluid in the drill pipe enables the cuttings to be carried to the surface without the deliberate use of clay or other additives to increase the viscosity.

Reverse–circulation Rotary Drilling Method

- The boring is done without a casing and the hydrostatic pressure is used to support the walls of the borehole during construction.


SWIVEL
LARGE DIAMETER
SUCTION HOSE
HIGH CAPACITY, LOW
HEAD PUMP
PUMP
DISCHARGE
KELLY WITH LARGE
BORE
ROTARY TABLE
SETTLED SAND & CUTTING IN PIT
LARGE DIAMETER DRILL PIPE
WALL OF DRILLED HOLE
DRILL BIT

Installation of Tubewells

- When a borehole is completed to the desired length, the tubewell assembly is to be lowered and fixed in position as soon as possible.
- The borehole is usually drilled a little more than the installed depth of the tubewell to accommodate the materials which may cave in or settle in the borehole before installation of the tubewell.
- The sandtrap, strainers, blind pipe, housing pipe etc. are assembled near the borehole and marked serially.
- The components of the tubewell is to be properly screwed or welded to another and slowly lowered vertically with the help of clamps, wire rope, pulley, tripod and crab winch.

Installation of Tubewells

- When the lowering of the tubewell is completed, it is kept suspended and the annular space between the strainer and wall of the borehole shall be filled immediately by gravel pack material.
- **The gravel pack material is filled to at least 10 to 15m above the top of the strainer. The remaining space of the borehole is filled with clayey materials and plain concrete to prevent percolation of contaminated water from the surface.**
- These materials grip the whole assembly of pipes on the outside and hold the tubewell in position.

Installation of Tubewells

- It is important that the entire tubewell is installed straight and vertically. Centralizers are placed at a certain distance apart for concentric installation of the tubewell, to permit uniform filling of gravel pack materials around the well and satisfactory operation of the pumping unit and without damage.

Well Development

The act of cleaning out the clay and silt introduced during the drilling process as well as the finer part of the aquifer directly around the well screen prior to putting the well into service is called "**Well Development**".

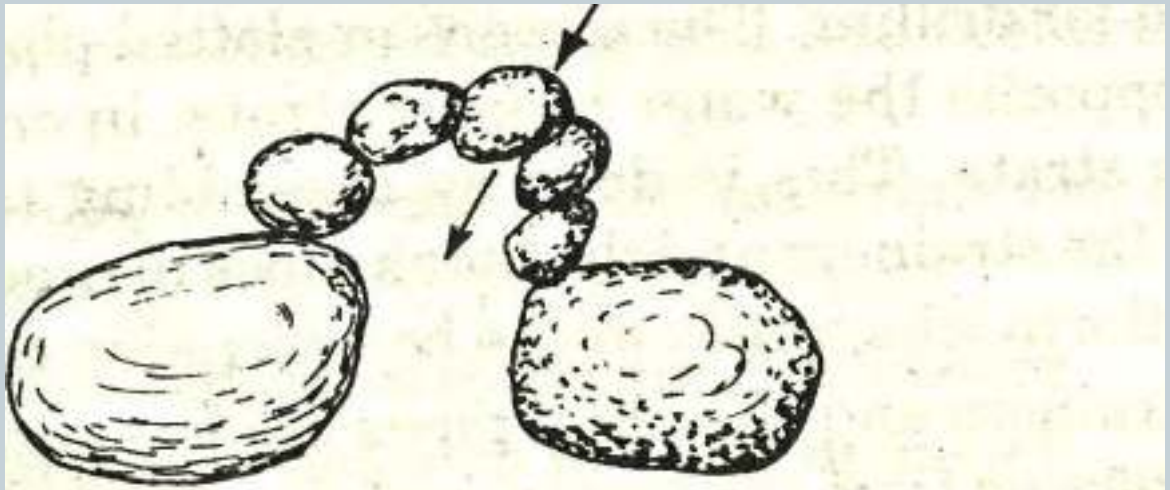
Effective well development:

- Increases the rate of water movement from the aquifer into the well.
- Stabilizes the aquifer to prevent sand pumping, thereby producing better quality water and increasing the service life of the pump cylinder and well.
- Removes organic and inorganic material which may inhibit effective well disinfection.

Methods of Well Development

Over pumping

Over pumping means pumping the well at a higher rate than the designed yield to create excess drawdown to washout the fine particles. But since there is no reversals of flow, bridging of sand can occur.



Bridging action caused by one directional flow

Methods of Well Development

Backwashing

This is a relatively simple method of development which requires a water lifting device and a container in which water can be stored and then from which it will be allowed to flow easily back into the well.

Mechanical surging

A surge block attached to the bottom of a drill stem is moved up and down in the screen resulting in a surging action to the water. The down stroke causes back wash to breakup any bridging which may occur, while the up stroke pull displayed sand grains into the well.

Methods of Well Development

Surging with air

This process involves combination of surging and pumping. By means of sudden release of a large volume of air, a strong surge is produced. Pumping is done with an ordinary airlift pump.

Hydraulic jetting

A high velocity of water is directed horizontally through the screen openings with the tip of the nozzle from the inner wall of the screen. The jetting tool is slowly rotated and gradually raised or lowered so that the entire surface of the screen receives the jetting action.

Methods of Well Development

Dispersing agents

Sometimes it is necessary to add a chemical agent to disperse clay particles in the mud cake or in the formation to avoid their sticking to sand grains and to speed up the development process. **For this purpose, several polyphosphates are used. About 600g of the chemical is added to every 100 litres of water in the well. The mixture is allowed to stand for about an hour before starting development.**

Well Maintenance

- The sudden pressure drop and increase in the entrances velocity near the screen due to high pumping rate, releases carbon-di-oxide and cause precipitation of calcium carbonate and iron deposits near the screen. The presence of oxygen in the well can change soluble ferrous iron in soluble ferric hydroxide.
- The perforations can be cleaned by adding **hydrochloric acid** followed by agitation and surging which remove the incrusting deposits. Normally the volume of acid required for a single treated will be about 1.5 to 2.0 times the volume of water in the screen.

Well Maintenance

- The yield of the well may decrease due to the deposition of incrustation of fine particles of silt and clay near the screen. This can be removed by the use of a dispersing agent such as **polyphosphates**. For effective treatment, 15 to 30 kg of polyphosphates is added to every 1000 liters of water in the well. The solution of polyphosphates is poured into the well and a surge plunger is used to agitate the water. The well may be treated 2-3 times for better results.
- The perforations may become plugged with bacterial growths. Chlorine treatment of well has been found more effective than acid treatment in loosening bacterial growth sand slime growth which often accompany the deposition of iron oxide. Calcium or sodium hypochlorite may be used and the chlorine solution in the well must be agitated by using a surging plunger.

Well Maintenance

- Depletion of ground water supply can sometimes be remediated by decreasing pumping draft sand resetting the pumped into greater depth.

Alternative Water Supply Technology

Introduction

- Type of handpump technology suitable for a particular area depends on the **groundwater level**, **water quality** and **Hydrogeological conditions**.
- Some areas like the **coastal belt** in the southern part of Bangladesh, where the conventional shallow and deep tubewell technologies are not successful due to the **high salinity**.
- Alternative water supply options are needed for those areas.

Alternative Technologies

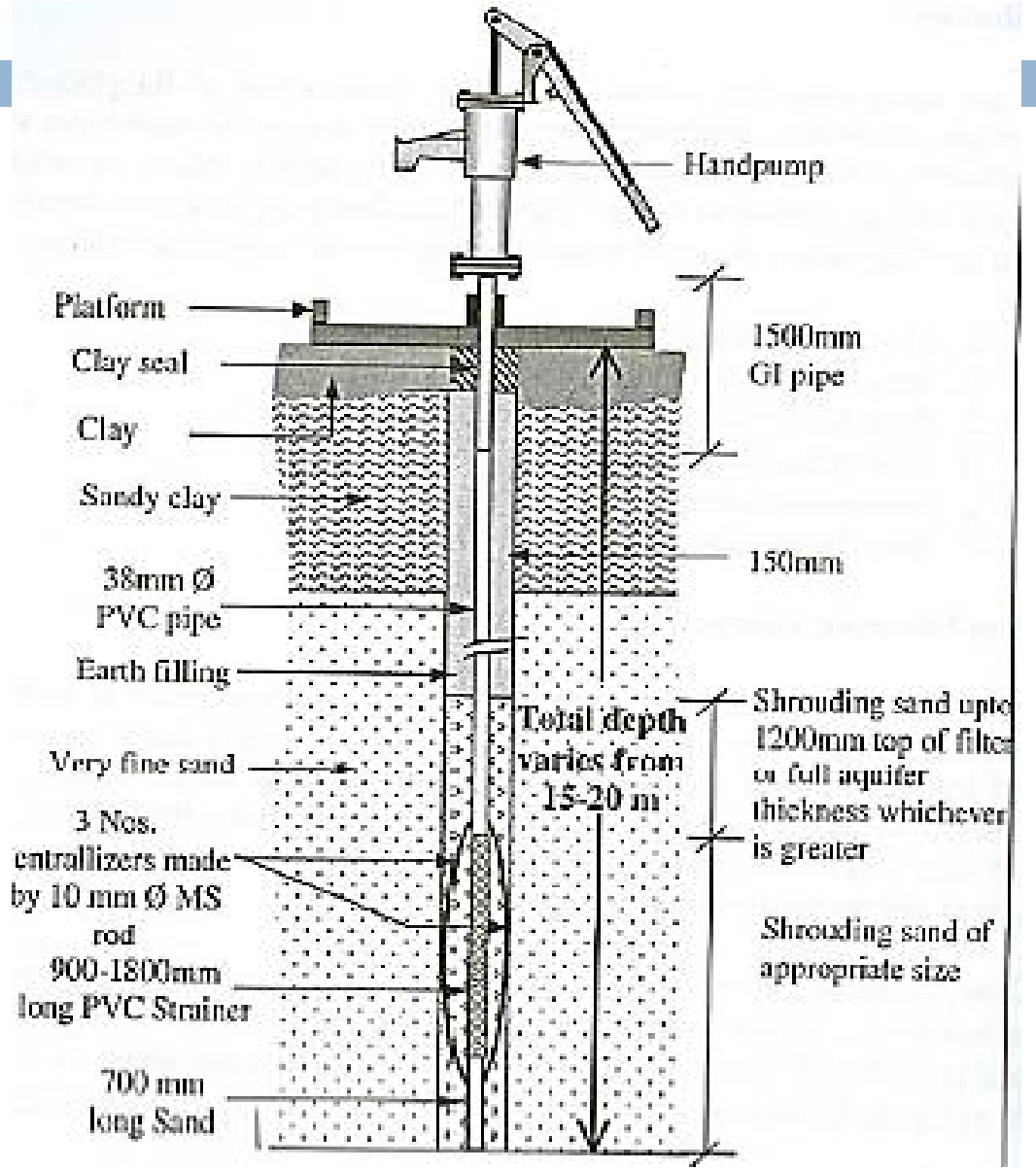
- Shallow shrouded tubewell (SST)
- Very shallow shrouded tubewell (VSST)
- Pond sand filter (PSF)
- Household filters
- Infiltration galley
- Solar desalination
- Rain water harvesting

Shallow Shrouded Tubewell (SST)

- In the high **salinity coastal** areas fresh water is available in **shallow aquifers** composed of fine sand at **15 to 20 m** depth.
- **Accumulation of rainwater** in the topmost aquifer.
- Particle size of soil and the depth of the aquifer are **not suitable** for installing a normal tubewell.
- To get water through these **very fine grained aquifers**, an artificial sand packing is required around the screen of the tubewell.

Shallow Shrouded Tubewell (SST)

- Artificial sand packing, called shrouding, increases the yield of the tubewell and prevents entry of fine sand into the screen.
- 15 to 20 m deep tubewells, installed with this technology are called shallow shrouded tubewells (SST).The SSTs are fitted with NO.6 handpumps



Very Shallow Shrouded Tubewell (VSST)

- A low-cost handpump tubewell about 8m in depth with a 2 m strainer shrouded with coarse sand.
- VSST is designed to collect water from very shallow aquifers formed by displacement of saline water by a continuous flow of accumulated fresh water.
- Lenses of fresh water formed by this process are found beneath old ponds in coastal areas.
- In many places, ponds dry up but fresh water in shallow aquifers remains beneath the pond.

Very Shallow Shrouded Tubewell (VSST)

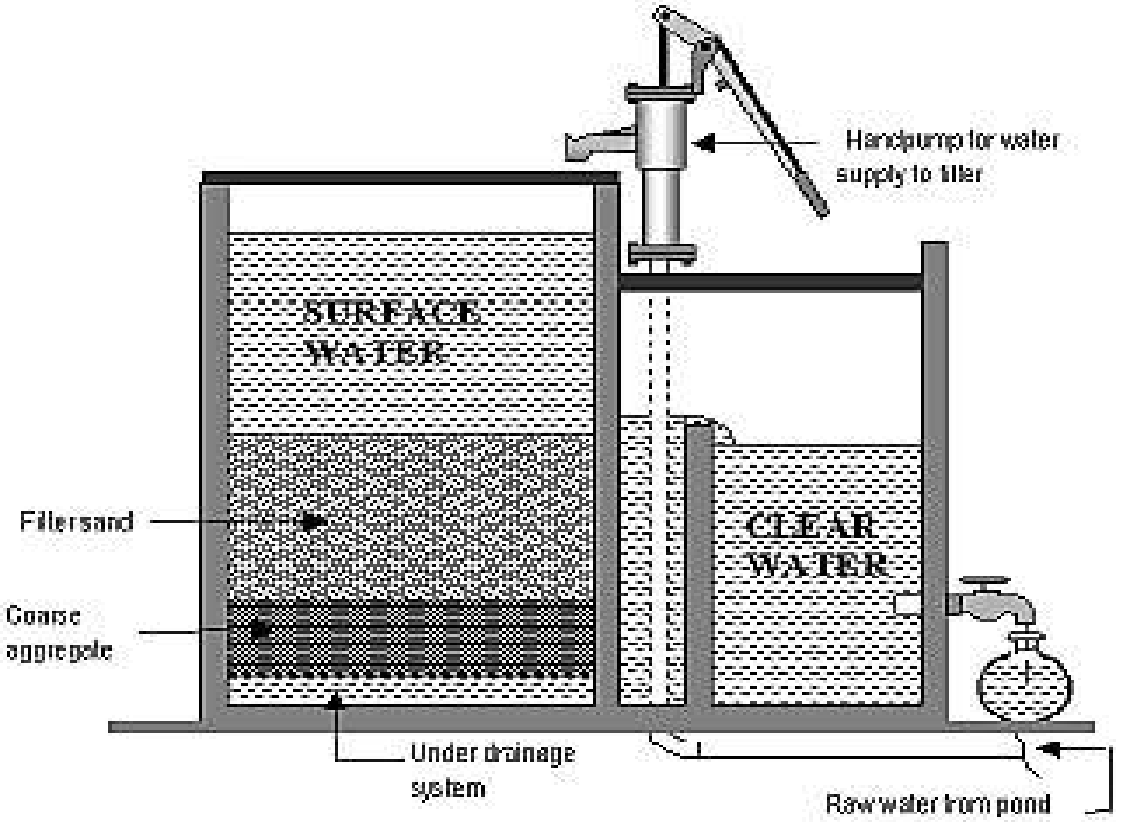
- A VSST is a convenient method for withdrawal of fresh water in limited quantities.
- In many places, the water produced by VSSTs becomes saline due to rising of water caused by over-pumping.
- Installation of low capacity pumps may prevent over exploitation of shallow aquifers.
- Suitable for drinking water supply of small settlements where water demand is low.
- A VSST is not different from an SST except in the depth of well.

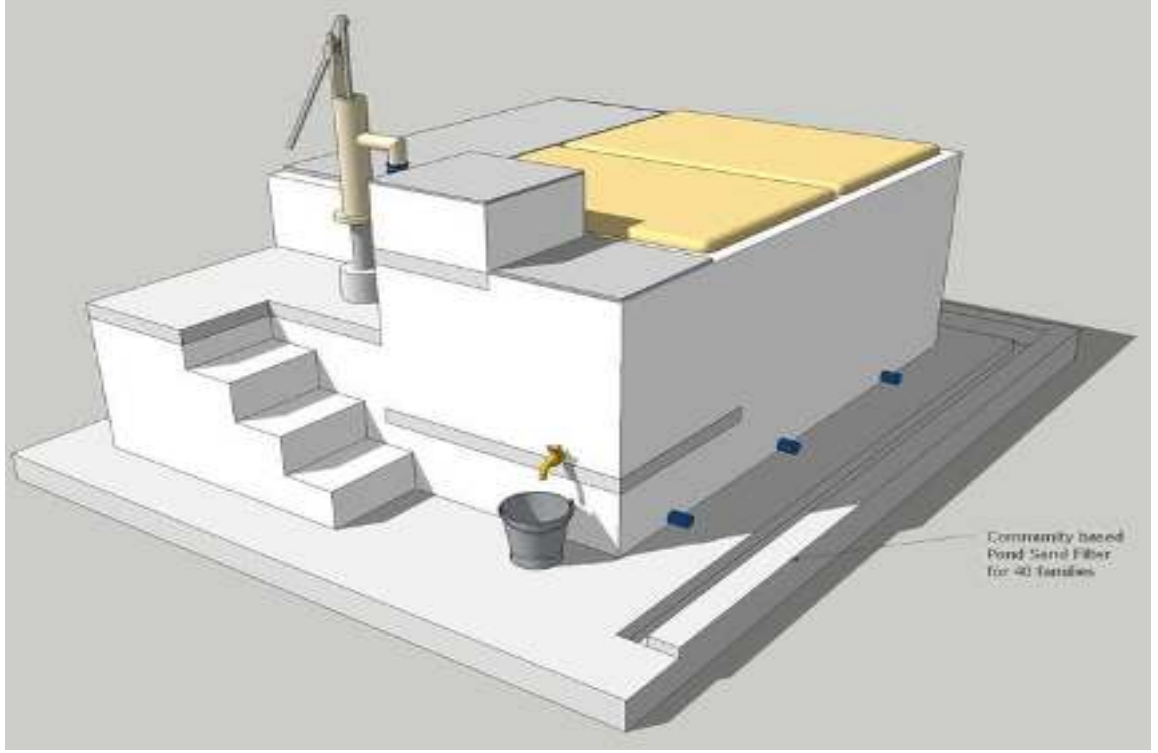
Pond Sand Filter (PSF)

- An alternative and popular option of potable water in coastal problem areas is the pond sand filter (PSF).
- Package type slow sand filter unit developed to treat surface water, usually low-saline pond water, for domestic water supply in coastal areas.
- Slow sand filters are installed near or on the bank of a pond, which does not dry up in the dry season.
- Water from the pond is pumped by a **manually operated hand tubewell** to feed the filter bed, which is raised from the ground, and the treated water is collected through tap(s).

Pond Sand Filter (PSF)

- It has been tested and found that the treated water from a PSF is normally **bacteriologically safe** or within tolerable limits.
- On an average the operating period of a PSF between cleaning is usually two months, after which the sand in the bed needs to be cleaned and replaced.


Handpump for water supply to filter
SURFACE WATER
CLEAR WATER
Filter sand
Coarse aggregate
Under drainage system
Raw water from pond


Community based Pond Sand Filter for 40 families



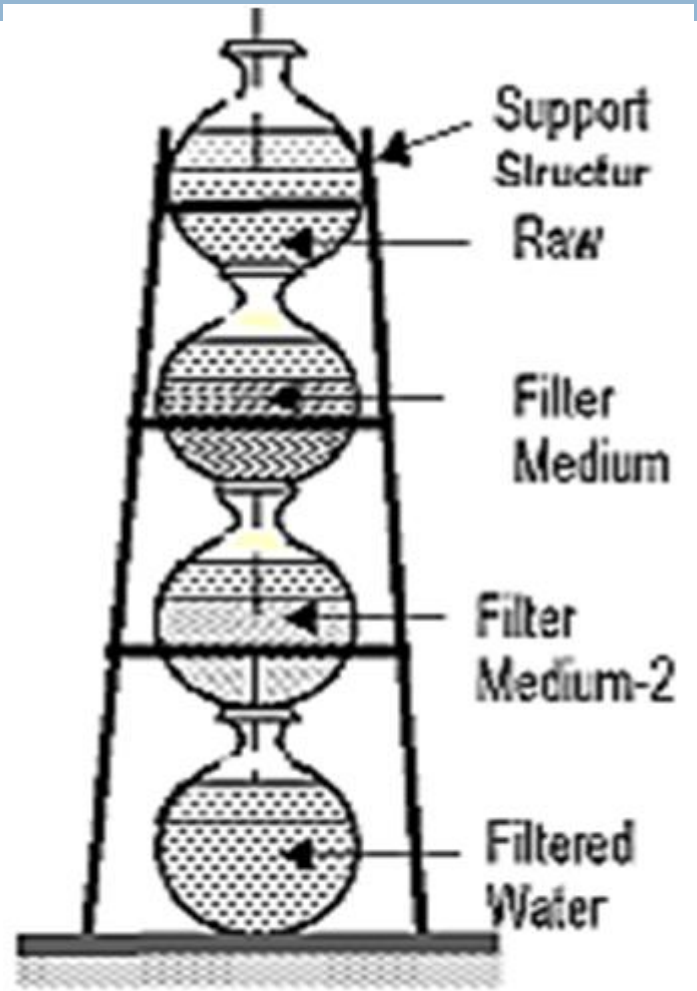
Pond Sand Filter (PSF)

Disadvantage

- cannot reliably eliminate all viruses, bacteria, and other microorganisms
- Ineffective against dissolved pollutants
- a slow filtration rate, potential for clogging
- high initial setup costs
- requirements for large land areas
- labor-intensive maintenance

Household Filters

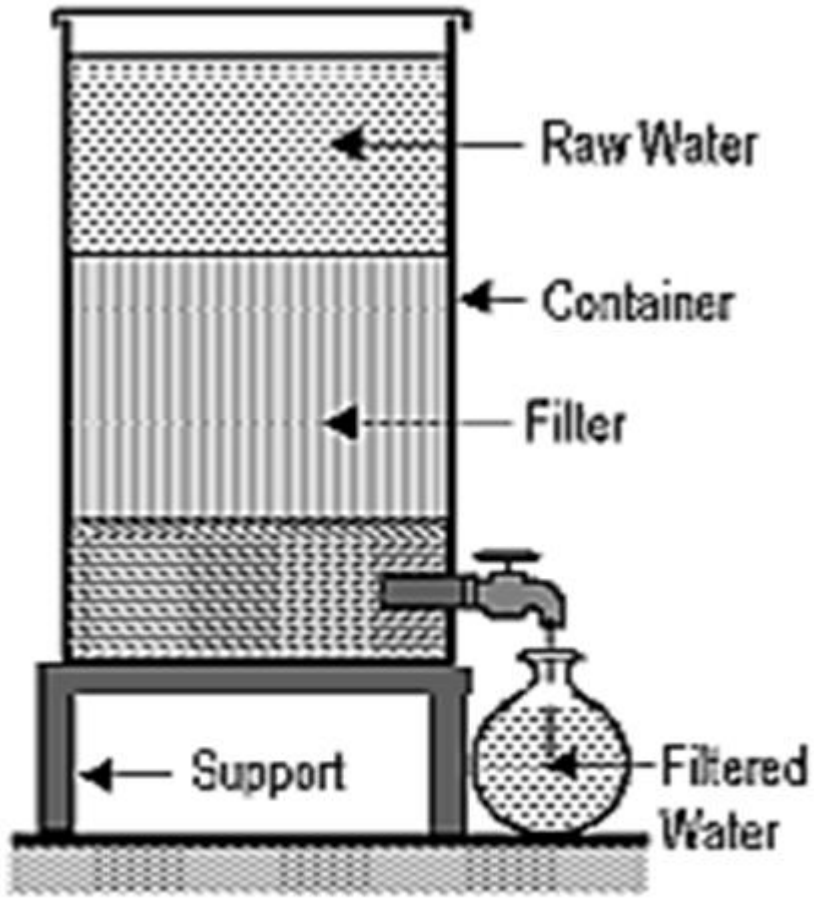
- Water treatment at household level have been phased out with the introduction of tubewells for village water supply.
- Pitcher filters are constructed by stacking a number of pitchers (Kalshi), one above the other, containing different filter media.
- Surface water containing impurities can be clarified by a pitcher filter unit or a small sand filter at the household level.
- It is an old method of water purification, once widely used in rural areas of Bangladesh.



Pitcher (Kalshi) filter

Household Filters

- Raw water is poured in the top Kalshi and filtered water is collected from the bottom one.
- In this process, water is mainly clarified by the mechanical straining and adsorption depending on the type of filter media used.



Small household filter

Household Filters

The important characteristics of household filters are:

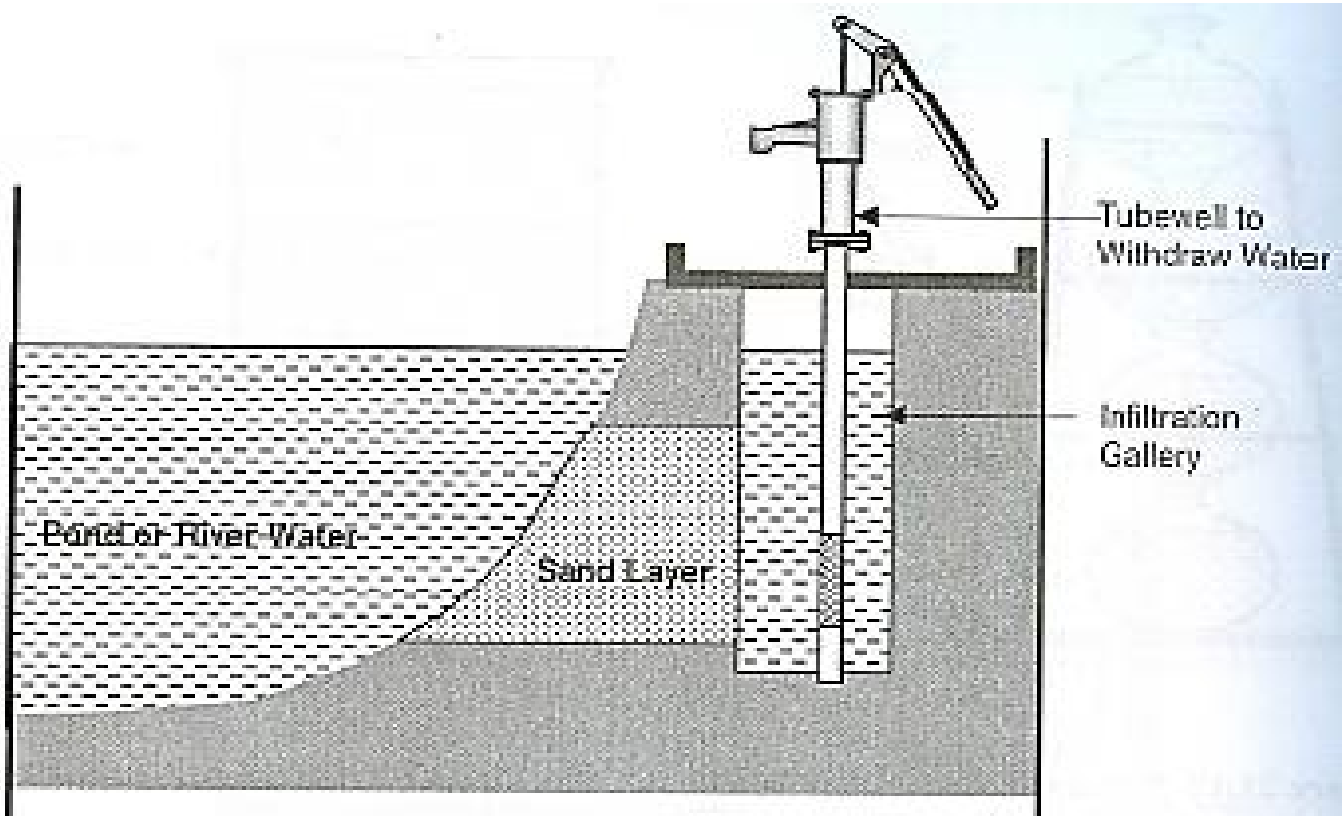
- suitable for surface water treatment;
- remove turbidity, color and microorganisms;
- complete removal of pathogenic microorganisms is not guaranteed;
- not suitable for high-turbid water;
- difficulty in cleaning and keeping the system operational.

Infiltration Well/Gallery

- Installation of infiltration wells/galleries along the banks of rivers and ponds provides clean water for domestic purposes.
- Rivers or ponds with sandy soils are suitable for construction of infiltration well/galleries.
- Sometimes, sand beds are placed between the source and infiltration well/gallery for the filtration of water.
- Main problem encountered with infiltration galleries is the sanitary protection of water and without it becomes soon contaminated.

Infiltration Well/Gallery

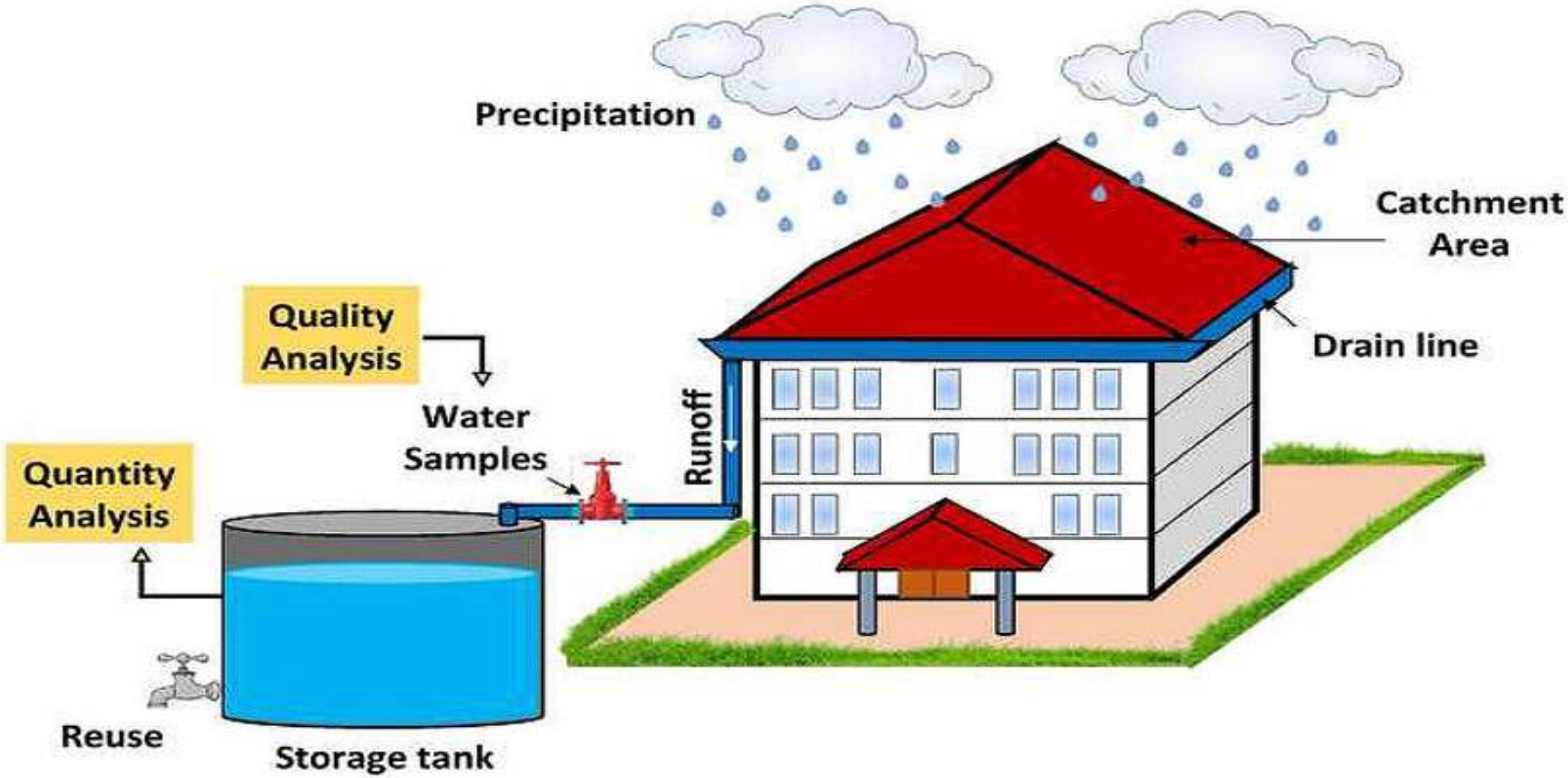
- Installation of handpump tubewell for collection of water from a sealed infiltration well/gallery can provide good sanitary protection.
- Sometimes, permeability at the entrance of surface water from the source is greatly reduced by entrapped suspended particles and deposited clay materials.



Rainwater Harvesting



Rainwater Harvesting



Rainwater Harvesting

- To harness good quality water resource now being wasted
- To augment the expensive piped water supply
- To save expenditure on water
- To prevent soil erosion and urban flooding
- Inexpensive and simple technology
- Aids ecological conservation
- To prevent groundwater depletion

Rainwater Harvesting

There are **two main constraints** in the development of a completely rainwater based water supply system:

- **The need for larger storage tank.**
- **A large catchments area for rainwater collection is needed if the total water supply is based on rainwater.**

Rainwater Harvesting



Rainwater Harvesting from Roof Catchment



Plastic Sheet Catchment

Rainwater Harvesting



Rainwater Harvesting

Advantage	Disadvantage
The quality of rainwater is comparatively good.	The initial cost may prevent a family from installing a rainwater harvesting system.
The system is independent and therefore suitable for scattered settlements.	The water availability is limited by the rainfall intensity and available roof area.
Local materials and craftsmanship can be used in construction of rainwater system.	Mineral-free rainwater has a flat taste, which may not be liked by many.

Rainwater Harvesting

Advantage	Disadvantage
No energy costs are incurred in running the system	Mineral-free water may cause nutrition deficiencies in people who are on mineral deficient diets.
Ease in maintenance by the owner/user	The poorer segment of the population may not have a roof suitable for rainwater harvesting.
The system can be located very close to the consumption points.	

ROOFTOP RAINWATER HARVESTING?

Components

1.Catchment
2. GUTTER AND DOWNTAKE PIPE
3.First flush & Filter
4.Delivery system
5.Storage

Example -1

Calculate the rainwater available for a family having a roof area of 20 m^2 in the central region of Bangladesh, where rainfall intensity is 2.0 m per year. Assume a runoff coefficient of 0.75.

Solution : Quantity of rainwater available, $Q = C\,I\,A$

$C = 0.75$; $I = 2.0$ m/yr; $A = 20$ m^2

$Q = 0.75 \times 2.0 \times 20 = 30$ m^3/yr

Example - 2

The average rainfall intensity in Bangladesh is 2.4 m/yr. and the runoff coefficient is 0.70. Calculate the minimum catchment area required for a family of 7 persons to be supplied with 15 lpcd of water.

Solution: The catchment are required is, $A = 0.365\,q\,N/(C\,I)$

$q = 15$ lpcd; $N = 7$; $C = 0.7$; $I = 2.4$ m/yr

$A = 0.365 \times 15 \times 7/(0.70 \times 2.4) = 22.8$ m^2

Example - 3

Calculate the minimum capacity of the storage tank required for a family of 8 persons to be supplied with 10 lpcd of rainwater. The yearly rainfall intensity is 2.5 m and the rainfall distribution is such that at least 35% of the rainwater must be stored for uninterrupted water supply throughout the year. Also calculate the minimum catchment area required when the coefficient of runoff is 0.7.

Solution: Storage volume required $V = 0.365\, f\, q\, N$

$f = 0.4$; $q = 10$ lpcd; $N = 8$; $C = 0.7$; $I = 2.5$ m

$V = 0.365 \times 0.4 \times 10 \times 8 = 11.68\ m^3$

$A = 0.365\, q\, N/(C\, I)$

$A = 0.365 \times 10 \times 8/(0.7 \times 2.5) = 29.2/1.75 = 16.69\ m^2$

Example - 4

Calculate the per capita water available and the capacity of the storage tank required for a family of 6 persons having a roof area of 20 m^2 with a runoff coefficient of 0.8. The family lives in a part of Bangladesh having a yearly rainfall of 2.5 m. The distribution demands 40% storage requirement for full utilization of rainwater.

Solution: Available rainwater, $Q = C\ I\ A$

$C = 0.80$; $I = 2.5$ m/yr; $A = 20\ m^2$; $f = 0.4$

Available rainwater = 20 x 2.5 x 0.8 = 40 m^3

Storage volume required = 40 x 0.4 = 16 m^3

Available rainwater per capita per day = 40 x 1000/(6 x 365)
= 18.26 lpcd.

Example 1:

For a building with a flat roof of size 10 m x 12 m in a city with the average annual rainfall of 800 mm

Roof Area (A) = 10 x 12 = 120 m^2

Average annual rainfall (R) = 800 mm = 0.80 m

Total annual volume of rainfall over the roof

= A * R = 120 m^2 x 0.80 m = 96 m^3 = 96,000 litres

If 70% of the total rainfall is effectively harvested,

Volume of water harvested = 96,000 x 0.7 = 67,200 litres

Average water availability = 67,200 / 365 ~ 184 litres/ day

Storage capacity

Method 1 – Storage required for dry period

- A rough estimate of the maximum storage requirement can be made based on the (i) per capita consumption (ii) no of users and (iii) length of the longest dry period

- For a household with 5 people, assuming water use of 20 lpcd and if longest dry period is 30 days and rainwater is the only water source, storage required = 5 x 20 x 30 = 3000 litres

Storage capacity

Example 2:

Calculate the size of the storage tank required for a school with 65 students and 5 staff, assuming average water consumption of 5 litres/day.

Roof area = 200 m^2

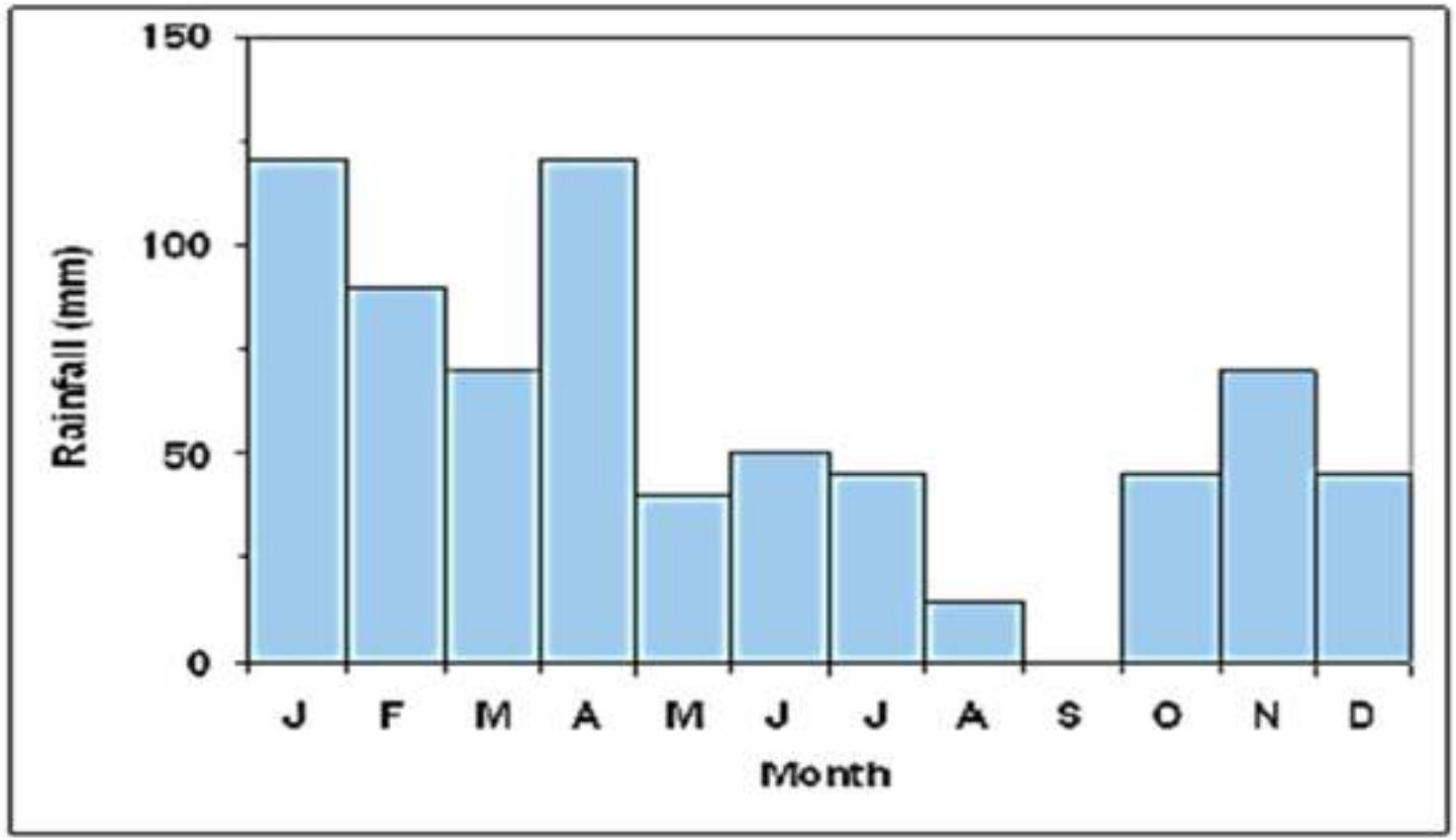
Assume runoff coefficient of 0.9

The rainfall pattern in the area is given in the table

Storage capacity calculations

(a) Rainfall pattern - 1

Month	Rainfall mm
Jan	120
Feb	90
Mar	70
Apr	120
May	40
June	50
July	45
Aug	15
Sep	
Oct	45
Nov	70
Dec	45



Average daily demand = 70 x 5 = 350 litres

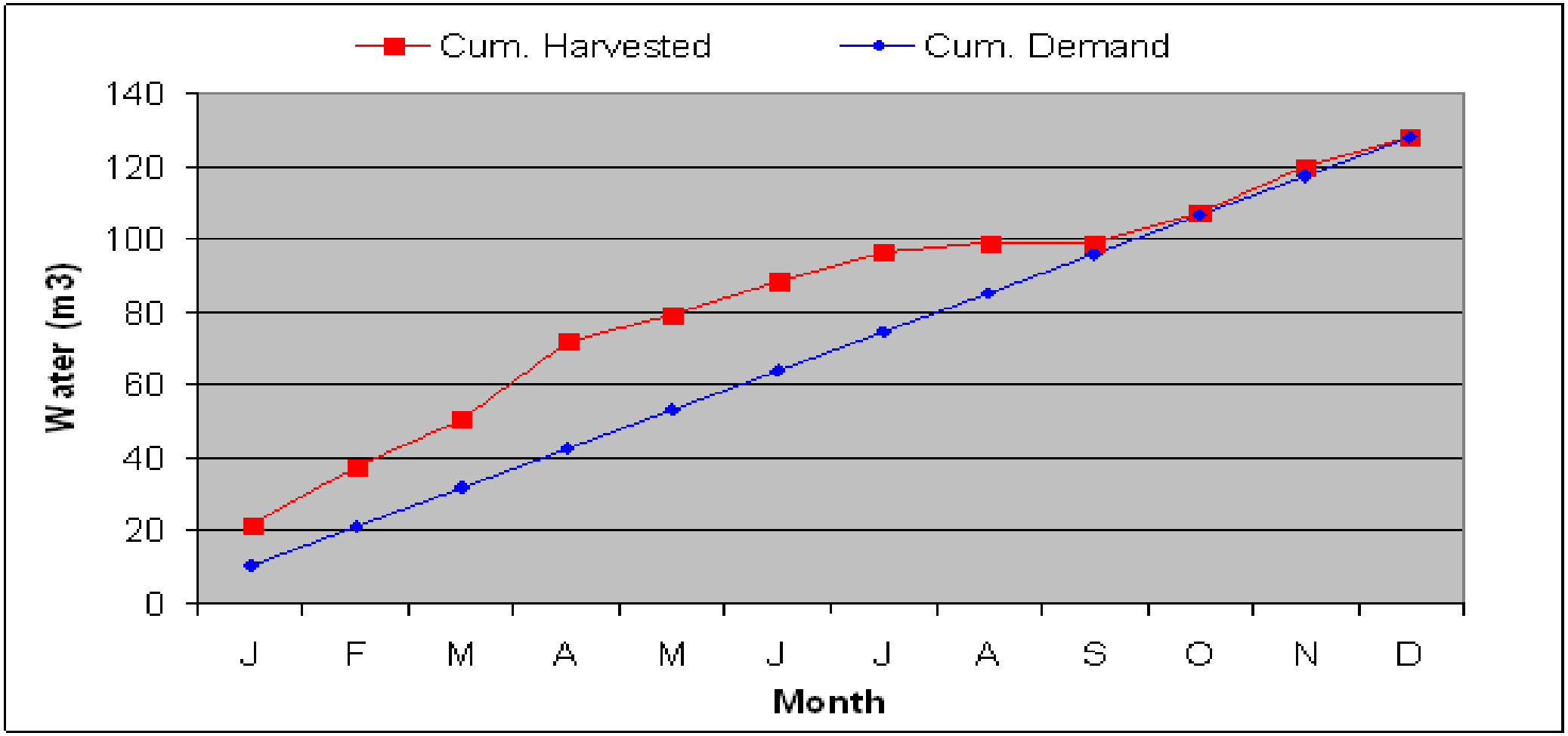
Yearly demand = 350 * 365 = 127750 litres = 127.75 m^3
Average monthly demand = 127.75/12 ~ 10.65 m^3

Calculation of required storage capacity (1)

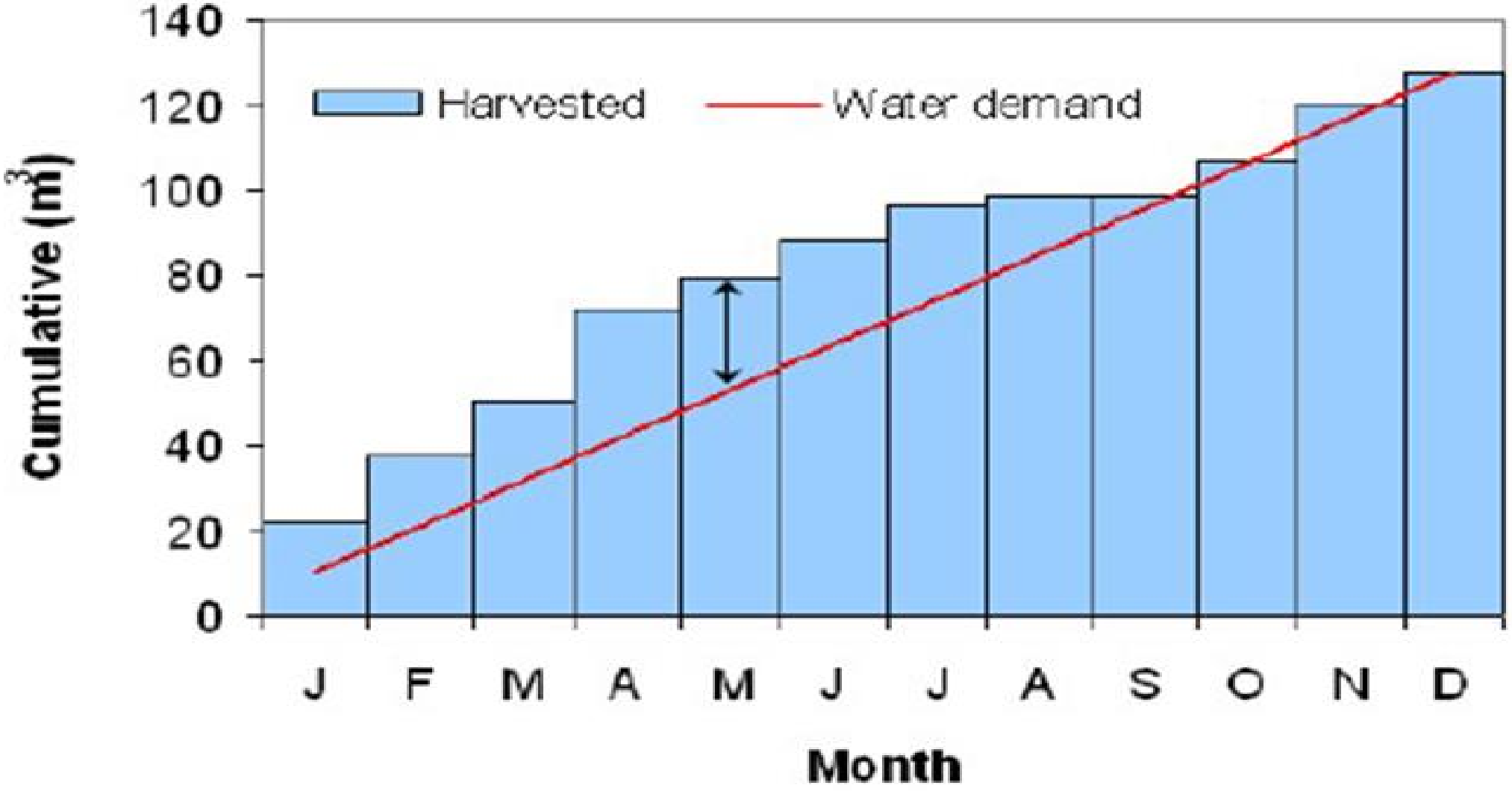
Month	Rainfall mm	Rainfall harvested m^3	Water Demand m^3	Cum. Rainfall harvested CH m^3	Cum. Water Demand CD m^3	Difference CH - CD m^3
J	120	21.6	10.65	21.6	10.65	10.95
F	90	16.2	10.65	37.8	21.3	16.5
M	70	12.6	10.65	50.4	31.95	18.45
A	120	21.6	10.65	72	42.6	**29.4**
M	40	7.2	10.65	79.2	53.25	25.95
J	50	9	10.65	88.2	63.9	24.3
J	45	8.1	10.65	96.3	74.55	21.75
A	15	2.7	10.65	99	85.2	13.8
S		0	10.65	99	95.85	3.15
O	45	8.1	10.65	107.1	106.5	0.6
N	70	12.6	10.65	119.7	117.15	2.55
D	45	8.1	10.65	127.8	127.8	0

Required storage capacity = 29.4 m^3 say 30 m^3

Mass Curve for Calculation of Storage capacity



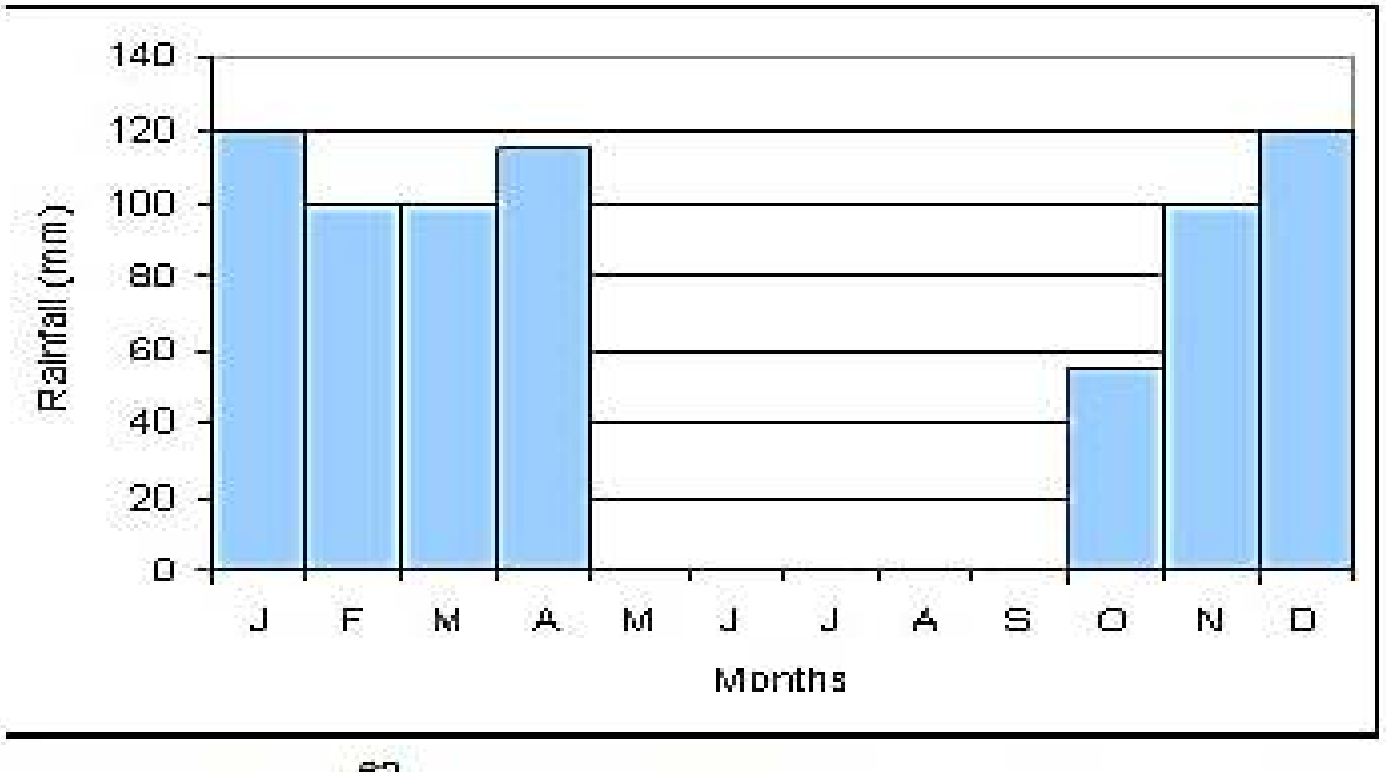
Mass Curve for Calculation of Storage capacity



Storage capacity calculations

(b) Rainfall pattern - 2

Month	Rainfall mm
Jan	120
Feb	100
Mar	100
Apr	115
May	
June	
July	
Aug	
Sep	
Oct	55
Nov	100
Dec	120



Calculation of required storage capacity (2)

Month	Rainfall mm	Rainfall harvested m^3	Water Demand m^3	Cum. Rainfall harvested CH m^3	Cum. Water Demand CD m^3	Difference CH - CD m^3
J	120	21.6	10.65	21.6	10.65	10.95
F	100	18	10.65	39.6	21.3	18.3
M	100	18	10.65	57.6	31.95	25.65
A	115	20.7	10.65	78.3	42.6	**35.7**
M		0	10.65	78.3	53.25	25.05
J		0	10.65	78.3	63.9	14.4
J		0	10.65	78.3	74.55	3.75
A		0	10.65	78.3	85.2	-6.9
S	0	0	10.65	78.3	95.85	-17.55
O	55	9.9	10.65	88.2	106.5	**-18.3**
N	100	18	10.65	106.2	117.15	-10.95
D	120	21.6	10.65	127.8	127.8	0

Required storage capacity = 35.7 + 18.3 = 54 m^3

Rainwater Harvesting Problem

- Calculate the size of storage tank required for a school campus with 734 students and staffs, assuming average water consumption of toilet flushing is 10 lpcd. Water is constantly being used throughout the year except during the vacation period in July and August. Total roof area is 4242 m^2, runoff coefficient is 0.9 and there is additional 15% losses in the piping, collecting and storage system. Monthly rainfall pattern is given in the table below:

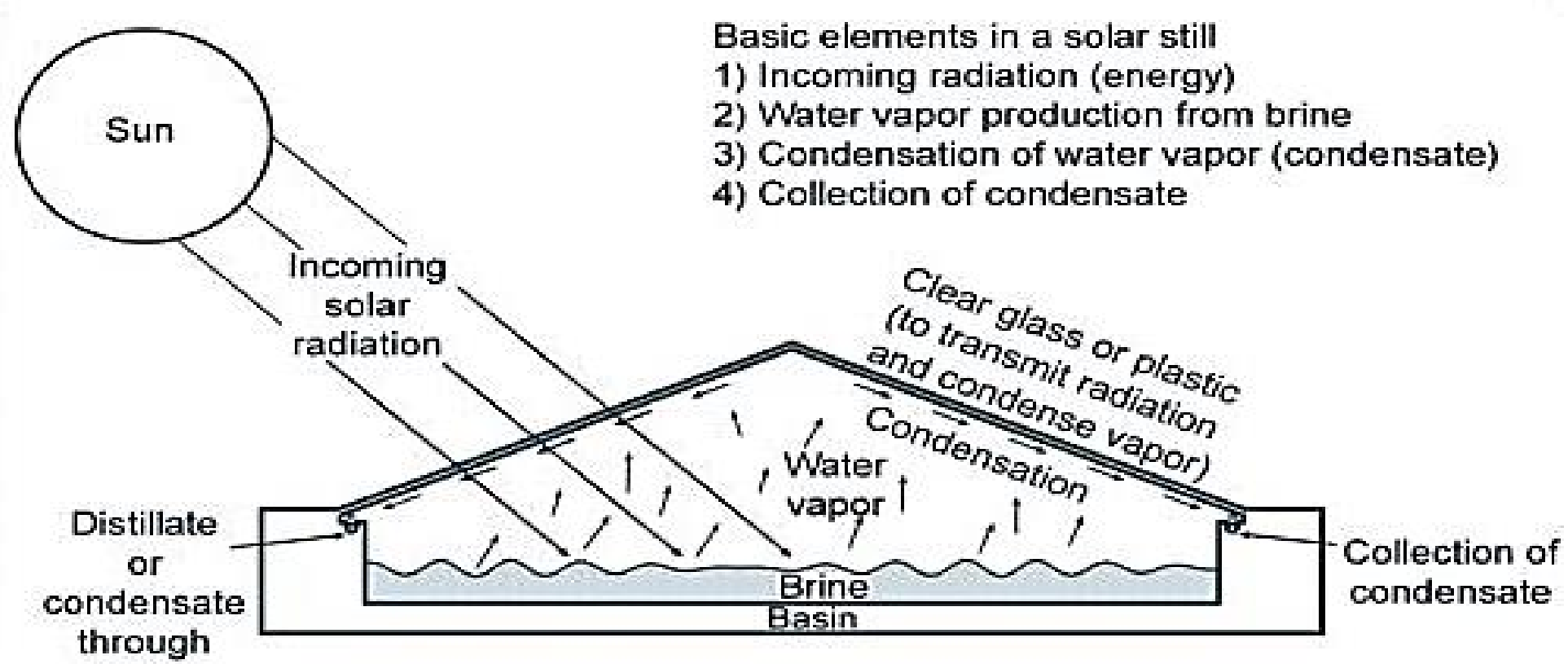
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (mm)	87	72	62	44	32	25	23	28	44	70	86	105

Solar Desalination

- Solar desalination units based on conventional evaporation and condensation facilitates can be installed for drinking water supply.
- Experimental units constructed in the coastal areas of Bangladesh have produced 0.6 - 2.4 l/m^2/d of water with an average yield of 1.41 l/m^2/d.
- The water produced by solar desalination is completely free of salinity and can be mixed with tubewell water to increase the volume of water for drinking water supply.

Solar Desalination

- The technology cannot produce an adequate quantity of water at a reasonable cost. The system requires further development for use in water supply in rural areas.



Summary

Technology	Inst. Cost (TK.)	Adv.	Disadv.
Pond sand Filter	20000-30000	Utilize surface water	Low discharge
SST	4000-6000	sweet water from shallow aquifers	Identification is difficult
VSST	3000-5000	sweet water from very shallow aquifers	Lifespan is short
Rainwater Harvesting	3000-4500	Usable in coastal/saline areas	Rainfall distribution is uneven

COMMON GROUNDWATER SUPPLY SYSTEMS

Sources of Drinking Water

(1) Ground Water

- the main source of water supply in urban and rural areas
- Free from Pathogens and requires no treatment

- **Urban Area**: power driven production wells, access to safe drinking water-99%, Public water supply-47%
- **Rural Area**: Hand pumps, 90% have access to tubewell within 150 m

(2) Surface Water: Pond sand filter (suitable for coastal belt)

(3) Rain Water: Rain water harvesting (suitable for arsenic affected areas)

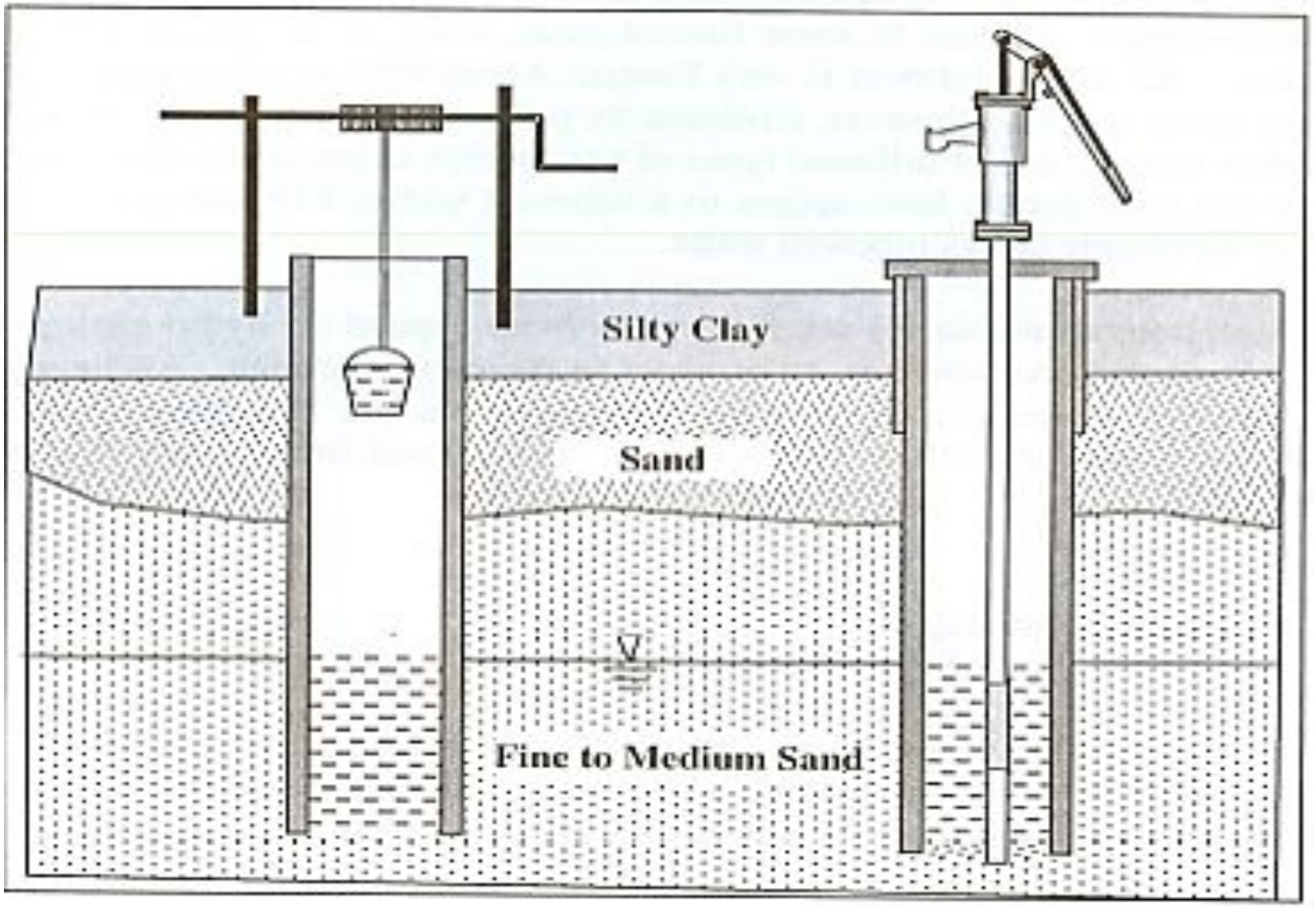
Water Supply Technologies

- **Dug well** (h<10m)
- **Tubewell**
  - Shallow Tubewell (h<7.5m)
  - Deep-set Intermediate Tech (h<30m)
  - Deep tubewell (h>75m)
- **Alternative technologies**
  - Pond sand filter
  - Rain water harvesting etc.

Open Well/Dug well

- Oldest method, low cost, no special equipment or skill necessary.
- A hole is dug to a depth below the GWT(<10m) and dia >1.2m
- Depth of Community dug well: 20~30 m
- Walls are lined to prevent water seeping, prevent caving and collapse of soil during construction

Open Well/Dug well



Open Well/Dug well



Open Dug well



Closed Dug well by tubewell

Bacterial contamination of well water

Can be Protected by sealing the well top with water tight concrete slab

Application areas:

In acute Arsenic and Iron problem areas, because Dug well water is free from Arsenic and Iron.

Tubewell Technology

- Shallow Tubewell
- Deep-set Intermediate Technology
- Deep tubewell

Shallow Tubewell

- Draw water from shallow depth by creating vacuum in the suction pipe
- Extract water from a depth of 7.5m

Category

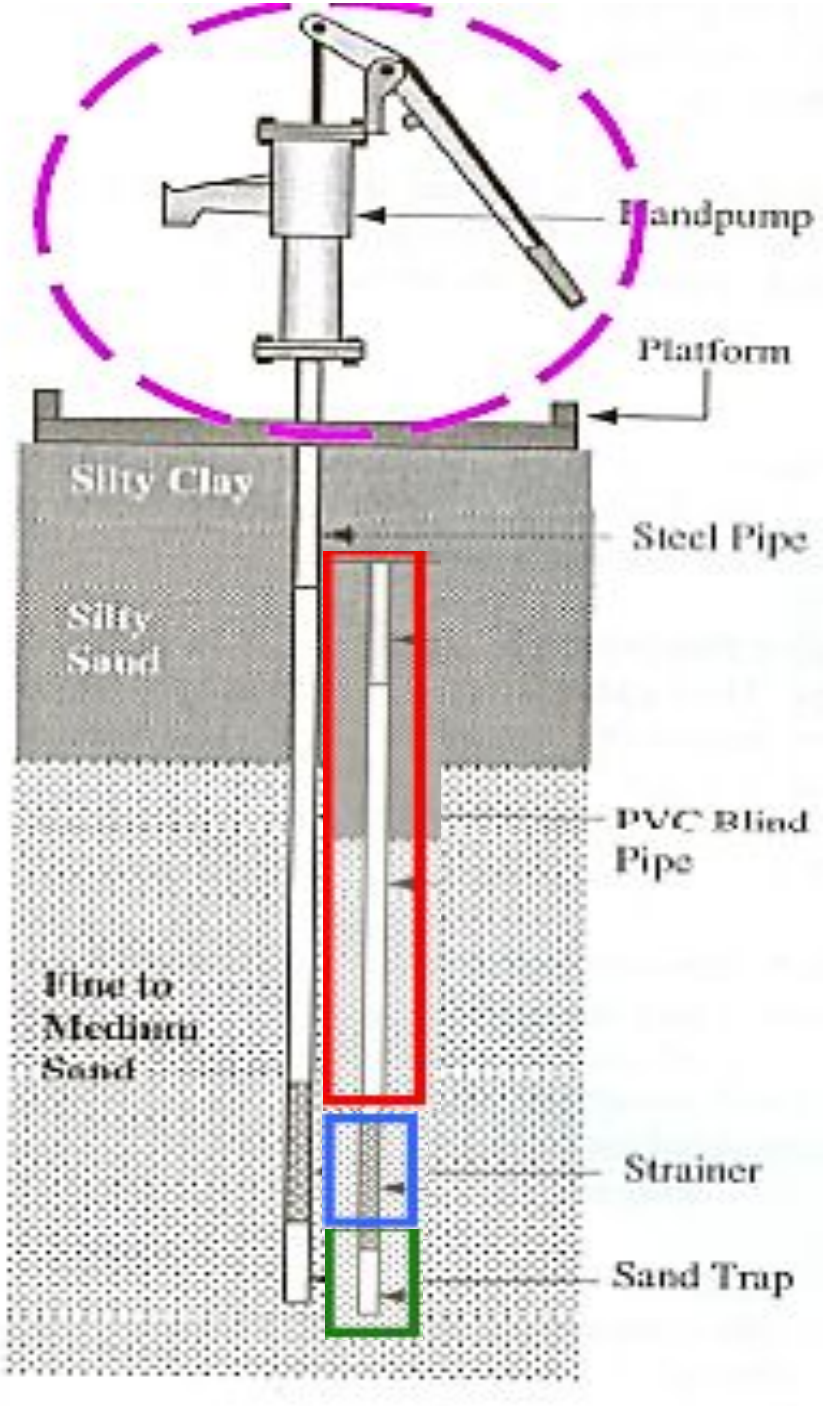
1. No. 6 handpump tubewell
2. Rower pump tubewell
3. Disco pump tubewell

No. 6 Handpump Tubewell

- Barrel diameter is 6 inch
- Theoretical lifting capacity 32.8 ft
- Average Discharge 30~40 liters /min
- Design Life: 15 ~20 years or more

Components:

- Handpump
- Blind pipe (rising pipe)
- Strainer/screen: 38mm dia PVC
- Sand trap



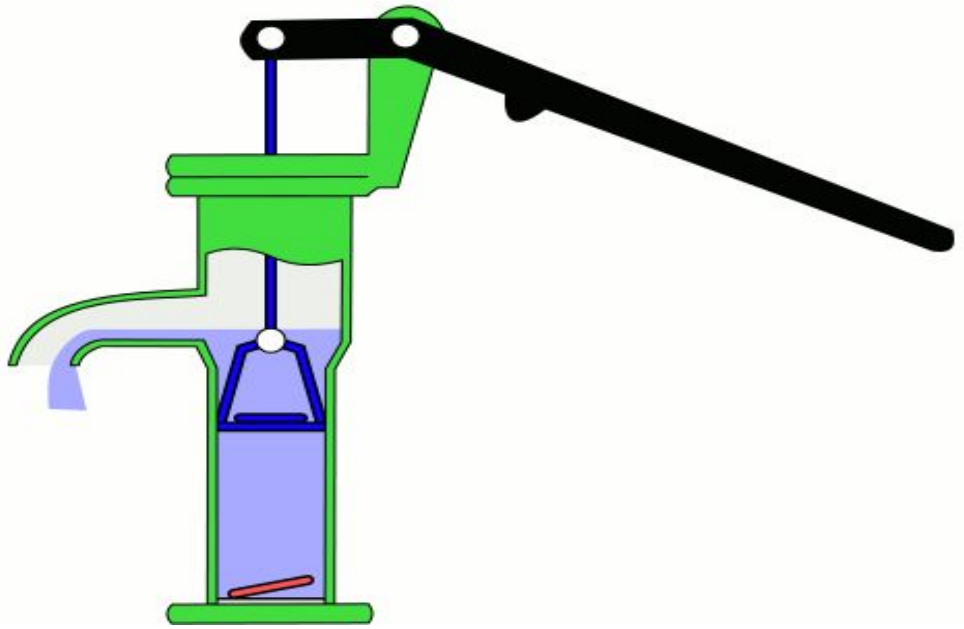
No. 6 Handpump Tubewell

- Components
  - **Handpump**: base, barrel, head cover, handle, piston rod, plunger, valve weight, bolts and nuts are component parts which are made of cast iron. Bucket and seat valve are made of leather or PVC.
  - **Blind pipe**: pipe between screen and the handpump. 38 mm diameter pipes are the most common and top five feet GI and remaining are PVC.
  - **Strainer (screen):** 38 mm diameter strainers are used, 2 m long and made of PVC. Openings used are 0.008 inch (slot no. 8), 0.010 inch (slot no. 10 and 0.012 inch (slot no. 12).
  - **Sand trap:** about 4 to 6 ft long an extension of a blank pipe, fixed at the bottom of the filter. Open end is sealed with a cap and generally PVC sand traps are used. It prevents blocking of the strainer.

No. 6 Handpump Tubewell

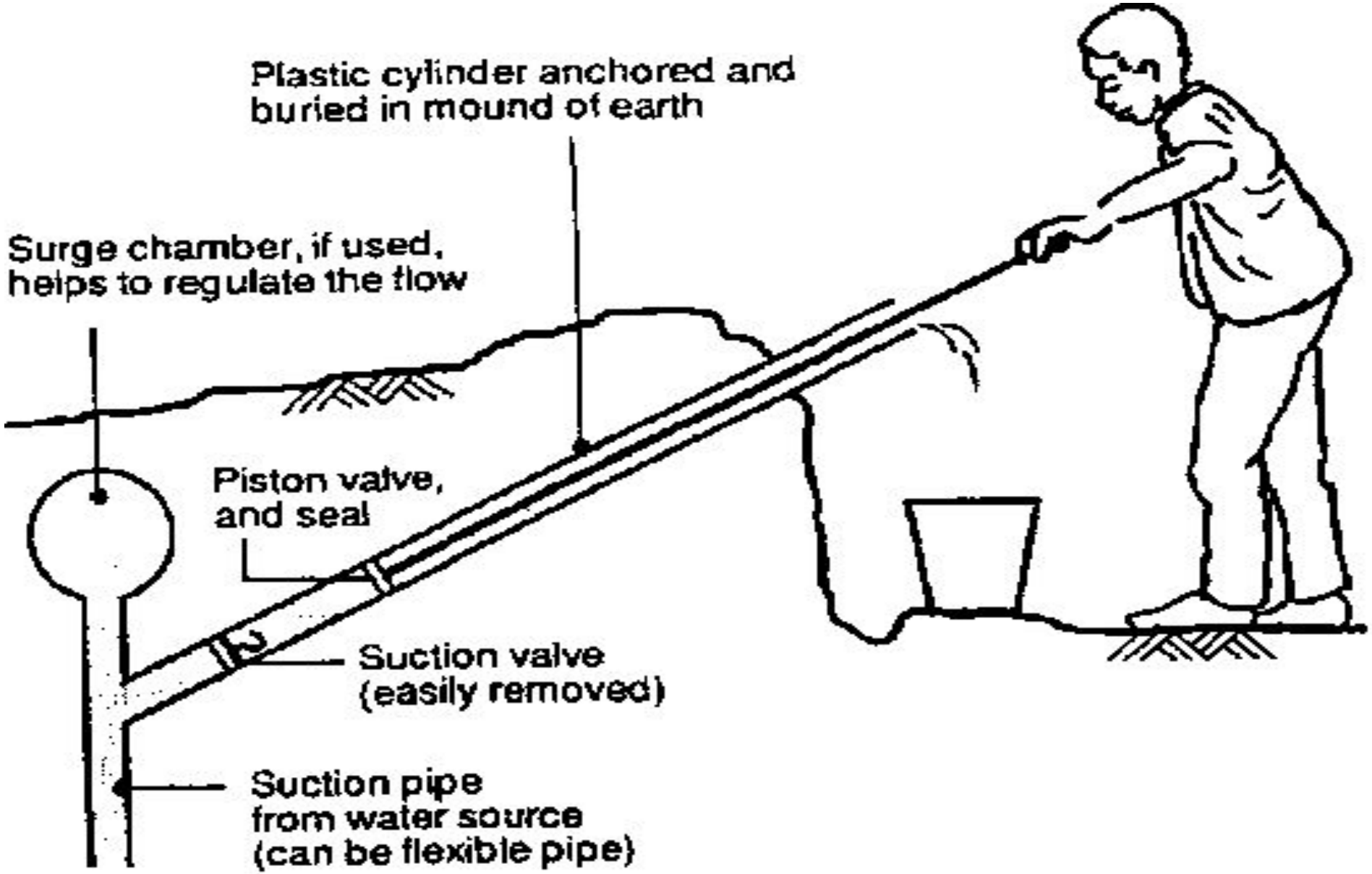
Working principle:

- In the first stroke vacuum is created within the cylinder of the pump by raising the piston and water entered into it.
- In the second stroke piston is lowered down and water enters in the upper chamber and comes out of the spout when the piston is raised to create vacuum again.



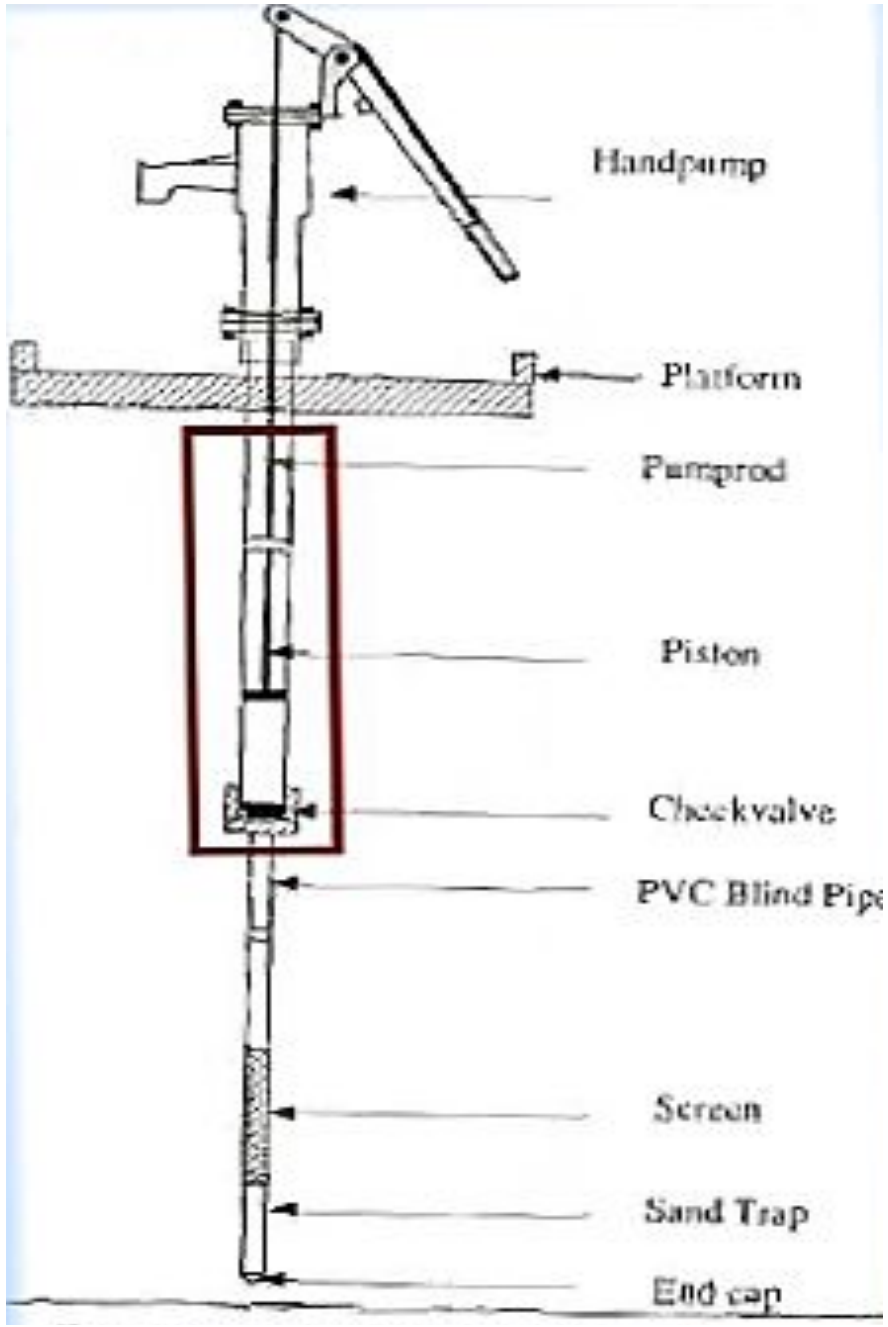
Rower Pump Tubewell

- A simple manually operated pump for small scale irrigation.
- A suction pump in which the piston is directly activated.
- A surge chamber (an air vessel just downstream of the foot valve, makes the pumping operation smoother).
- Simple and reliable with a very few moving parts thus wear is reduced.
- Limited use for drinking water as the spout is relatively low.
- Typically, pumps are installed in collapsible tubewells with the screen extending to the coarse sand aquifer.
- Average Discharge 75 liters /min

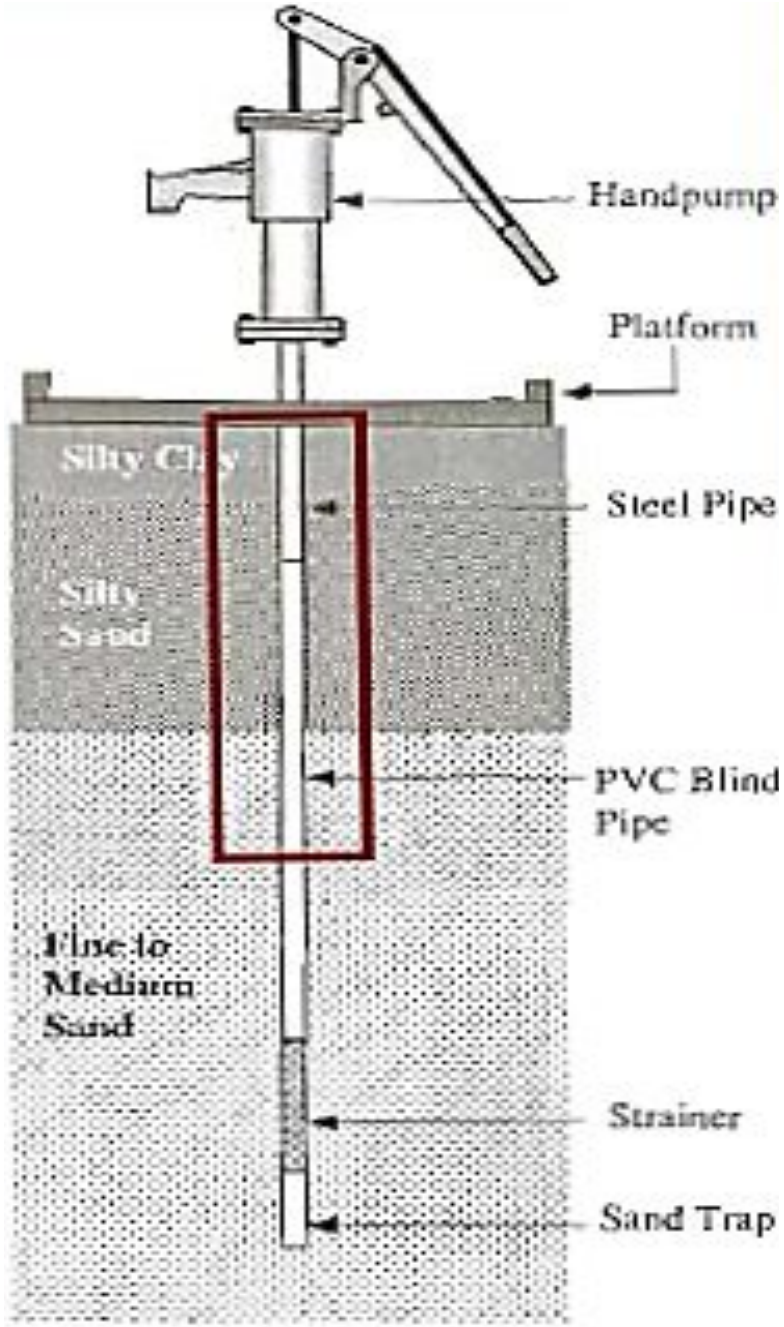

Plastic cylinder anchored and buried in mound of earth
Surge chamber, if used, helps to regulate the flow
Piston valve, and seal
Suction valve (easily removed)
Suction pipe from water source (can be flexible pipe)

Disco Pump Tubewell

- Modified No.6 hand pump
- Suction action is extended by extending the suction rod about 1-3 m.
- About 75 mm diameter GI pipe is used as casing.
- h = 7-10m



Disco Pump Well



No. 6 Handpump Well

Deep-set Intermediate Technology

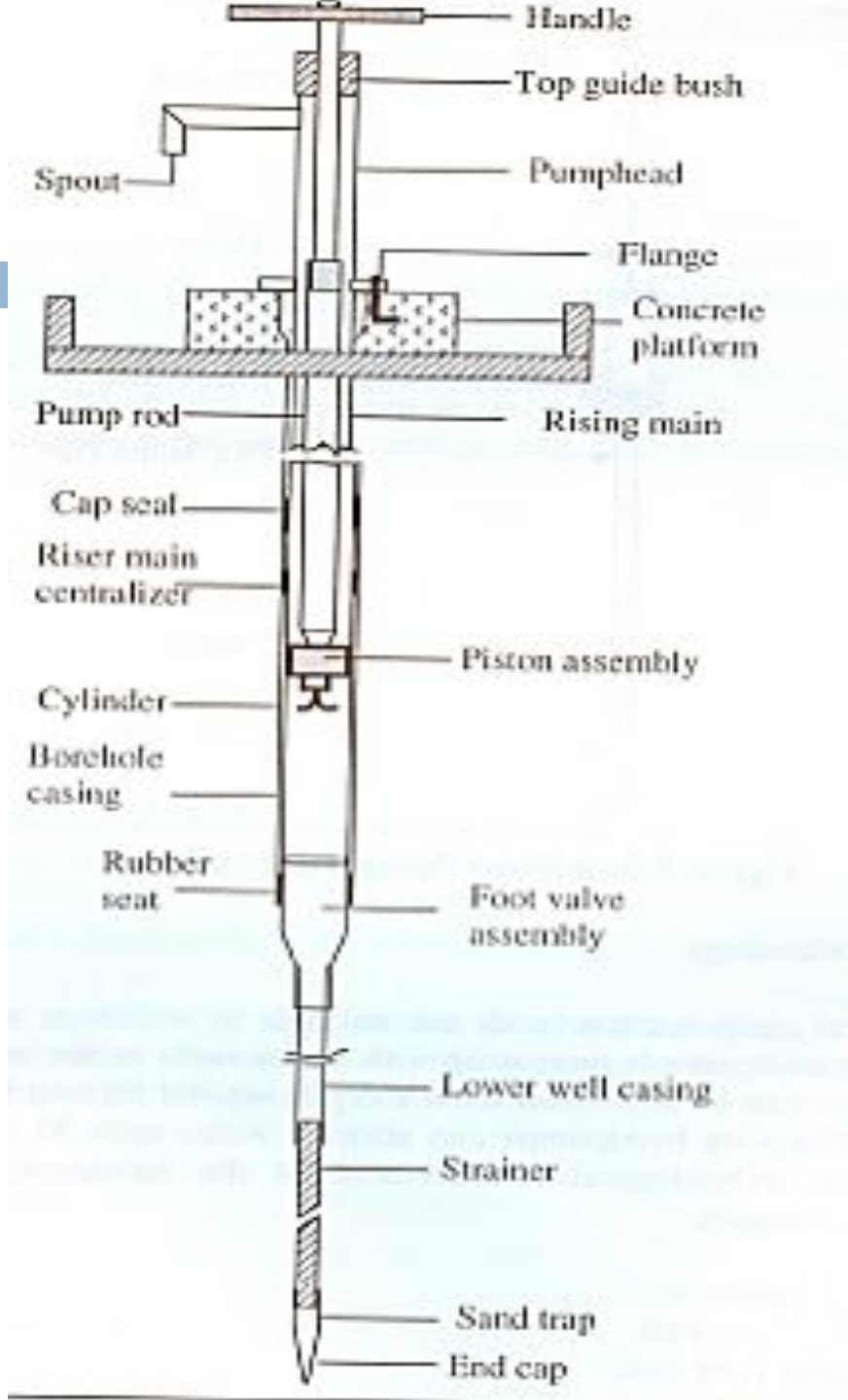
- Due to irrigation in dry season WT goes down
- No. 6 hand pumps go out of operation
- h = 15 - 30m

Category

- **Tara** Handpump tubewell
- **Moon** Handpump tubewell
- **Bangla** Handpump tubewell
- **Mark-II** Handpump tubewell

Tara Hand Pump Tubewell

- h = 15 m
- expected life 3 to 5 years
- Average discharge 24 litres /min
- Main components: pump head, handle, pump rod, piston assembly, foot valve assembly and cylinder.
- The lower part is similar to No. 6 hand pump.

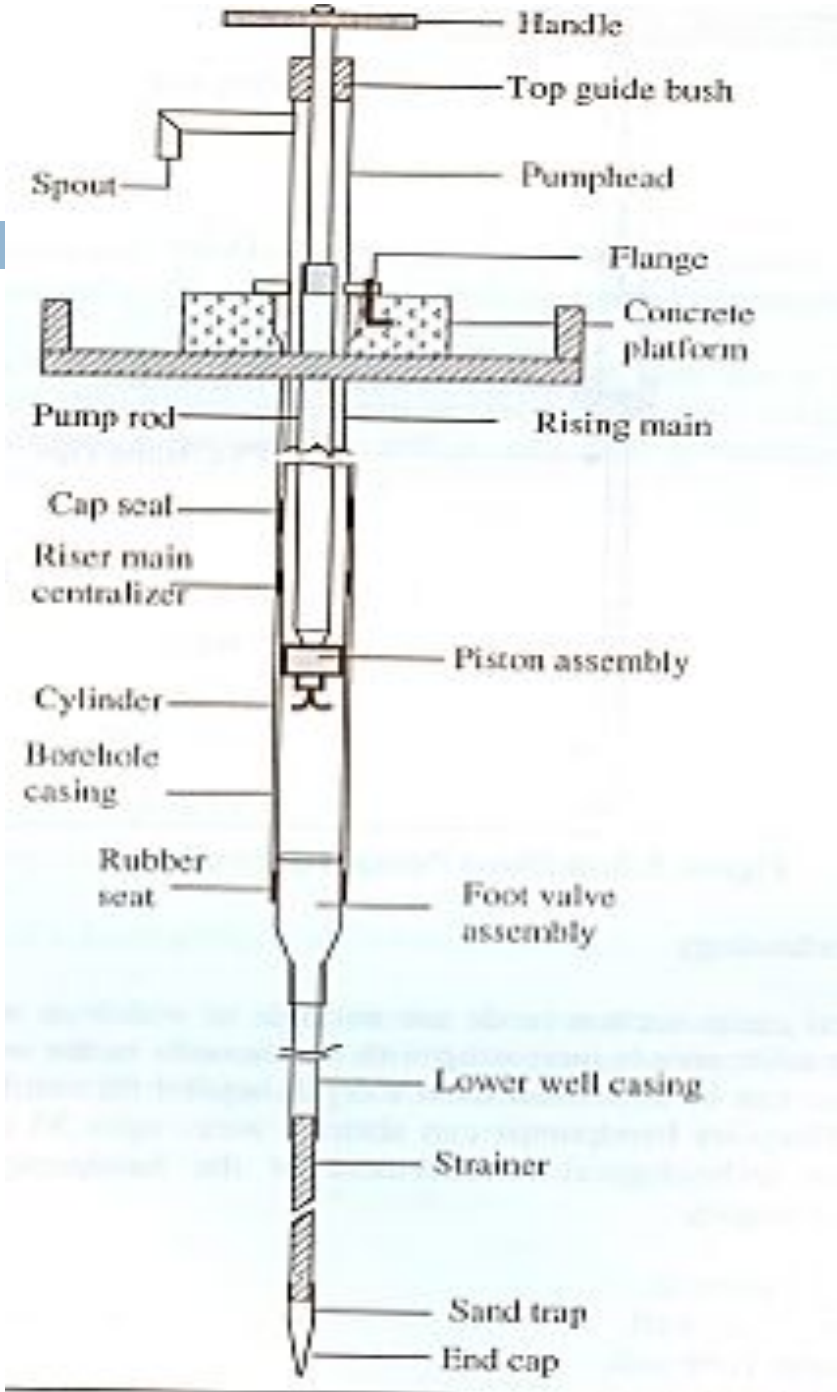


Tara Hand Pump Tubewell

This pump does not proved to be user friendly.

Problems:

- Because of direct actions, more force is required even at low head
- Buoyancy forces is not always available due to leakage
- Moderate output for 7m lift and very low output for 12m lift.
- Repairing is inconvenient



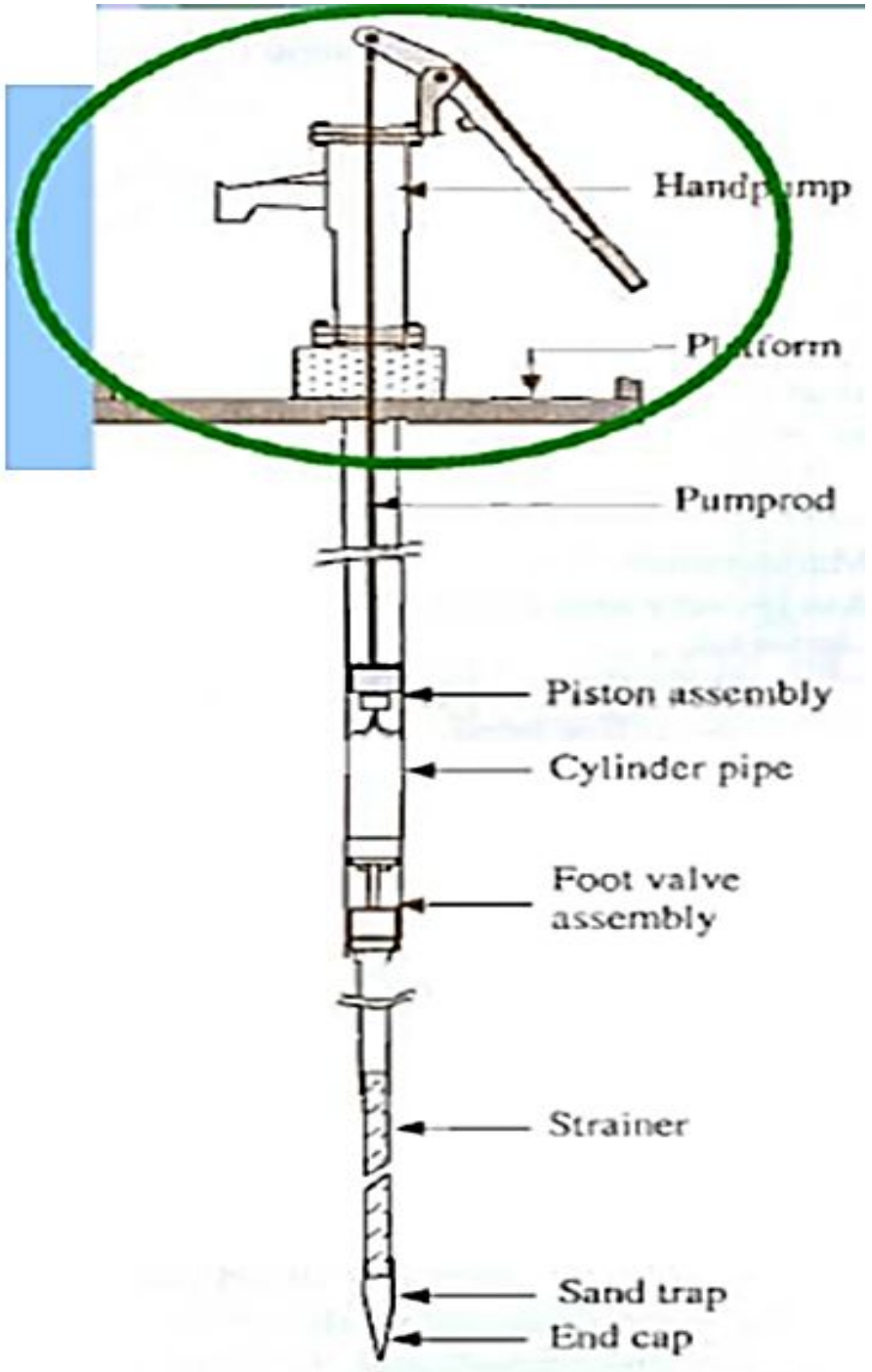
Tara Hand Pump Tubewell

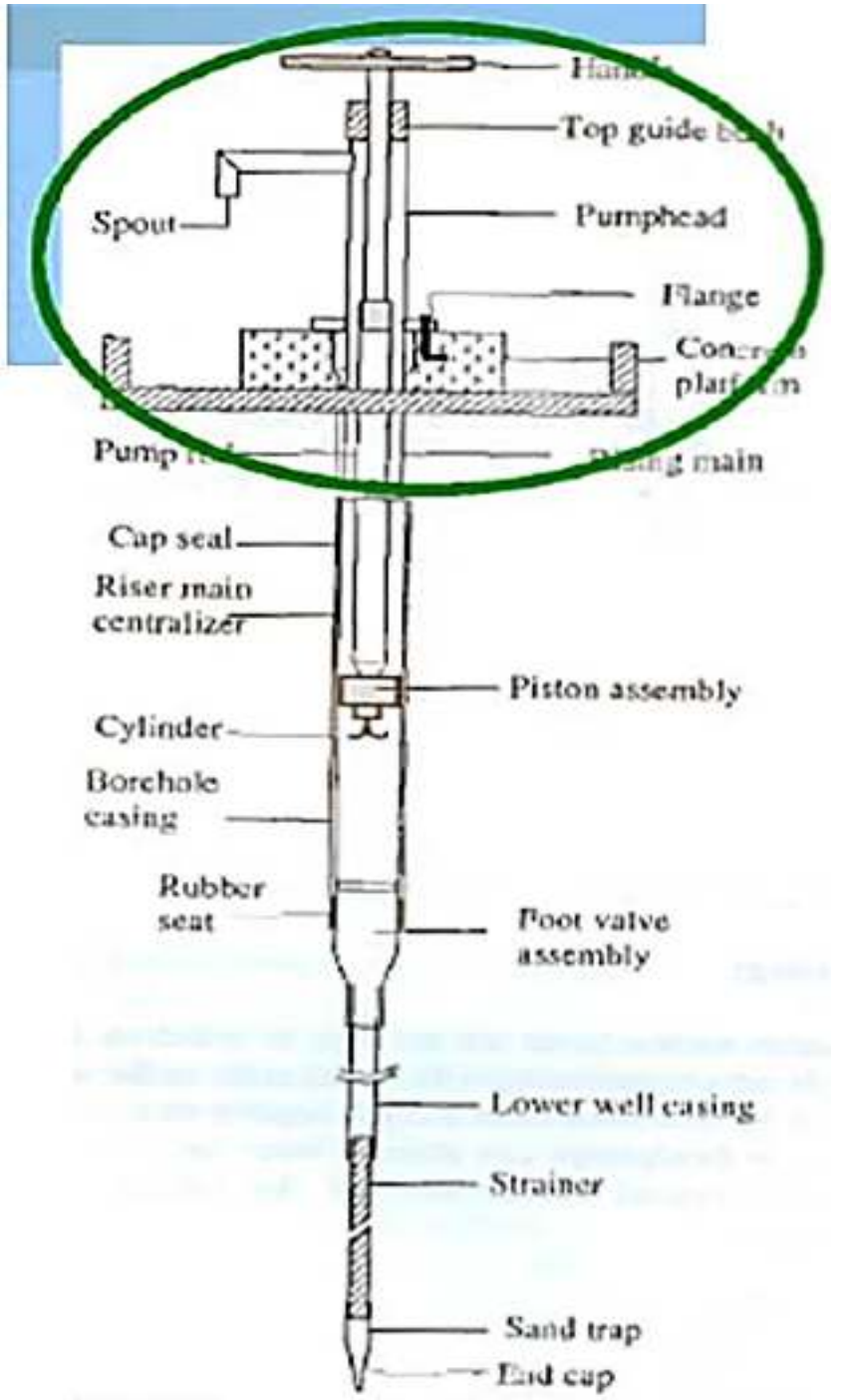
Working principle:

- The term ‘ Direct Action ‘ for Tara hand pump refers to a vertical pumping action using a ‘ T ‘ bar handle connected to a buoyant PVC pump rod.
- The load is transmitted directly from the user to the pump rod and piston during operation.
- The buoyant pump rod, of a relatively large diameter, displaces water in both the upward and downward stroke and the buoyancy of the pump rod makes pumping operation easy.

Moon Hand pump Tubewell

- Moon hand pump tubewell is a modified Tara HP
- The direct action of Tara HP is uncomfortable.
- The head of Tara HP is replaced by the head of No.6 hand pump to get the advantage of lever action.
- PVC pump rod is replaced by steel rod
- Suitable for lifting water up to 25 m
- Maximum discharge 36 litres /min


Handpump
Platform
Pumprod
Piston assembly
Cylinder pipe
Foot valve assembly
Strainer
Sand trap
End cap

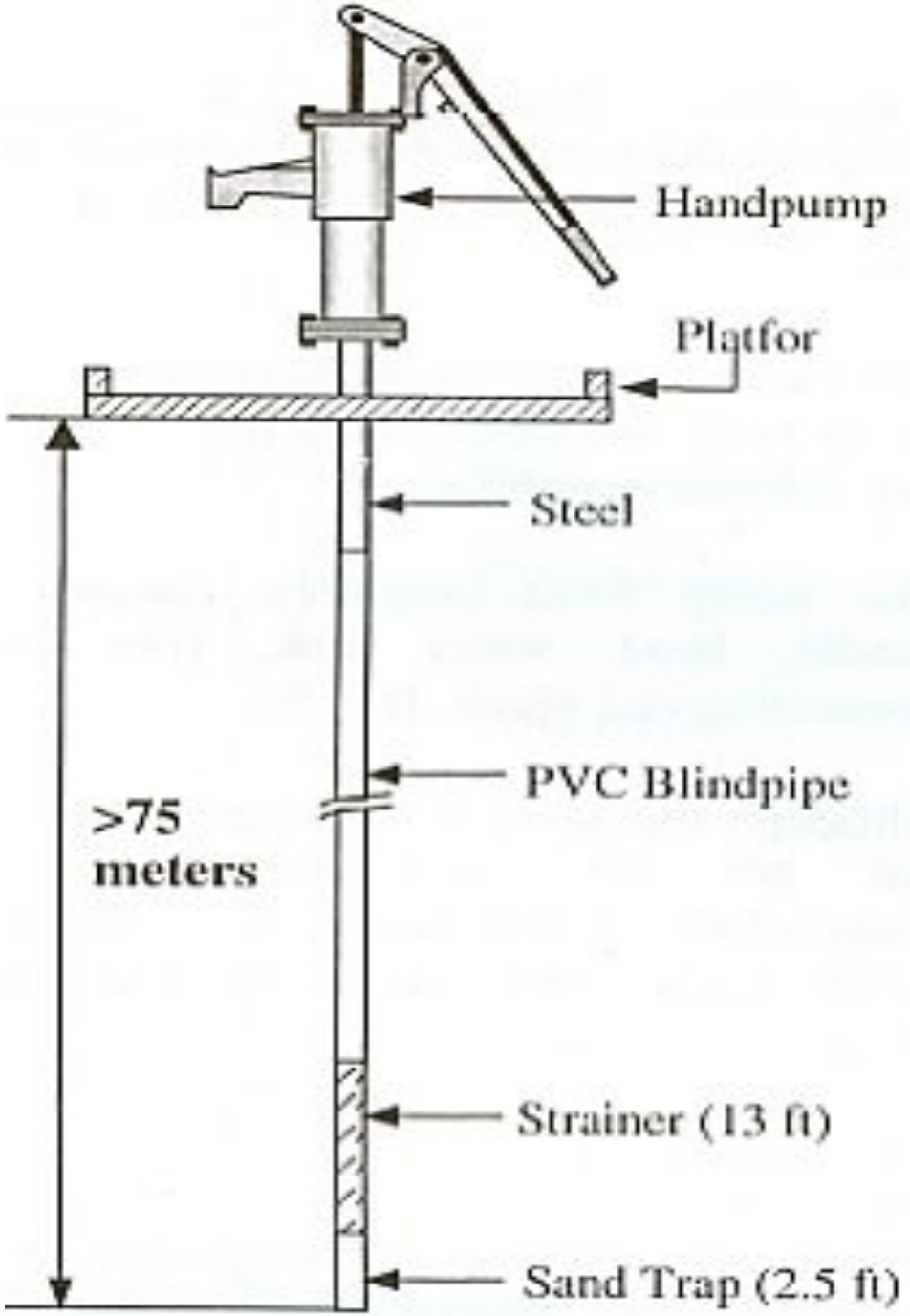

Top guide
Spout
Pumphead
Flange
Cap seal
Riser main centralizer
Piston assembly
Cylinder
Borehole casing
Rubber seat
Foot valve assembly
Lower well casing
Strainer
Sand trap
End cap

Deep Tubewell

- A tubewell penetrating at least one impervious layer
- H >75m
- In coastal belt, it can be as deep as 300m

Components:

- Same as No. 6 hand pump tubewell with the addition of more blind pipes
- Installation cost is high


Handpump
Platfor
Steel
PVC Blindpipe
>75
meters
Strainer (13 ft)
Sand Trap (2.5 ft)

Site Selection Criteria

Dug well:

- At least **10 m** away from latrines, abandoned ditch or marshy land.
- Should not be installed near **pond, canal or river.**
- Should not be installed **under any tree**, near any bush, by the side of road or any disposal site of industries.
- Users **accessibility, Safety factor and comfort** for lifting water.

Site Selection Criteria

Hand Pump Tube well:

- At least **10 m** away from latrines.
- Should be installed at a **place with higher elevation**, which is not usually flooded.
- Should be accessible to **users and caretakers**.

Technology	Inst. Cost (TK.)	Adv.	Disadv.
Dugwell	Low	Low cost	Sanitary protection is difficult
No. 6 Handpump	2000 - 4000	Suitable for shallow WT	May produce high As content
Tara Handpump	13000-15000	Suitable for LWT zone	More force is required
Deep tubewell	50000-70000	Usable in coastal/saline areas	High installation cost

Pumps and Pumping Machinery

Purposes

- Lifting water from source and flow into the mains by gravity
- Boosting water from low service to high service areas
- Transporting water through treatment plant:
  - draining component in settling tanks and filter beds
  - withdraw deposited solids
  - supply water
  - pumping chemical solutions to treatment units
- Lifting water to the overhead water tanks

Types of Pumps

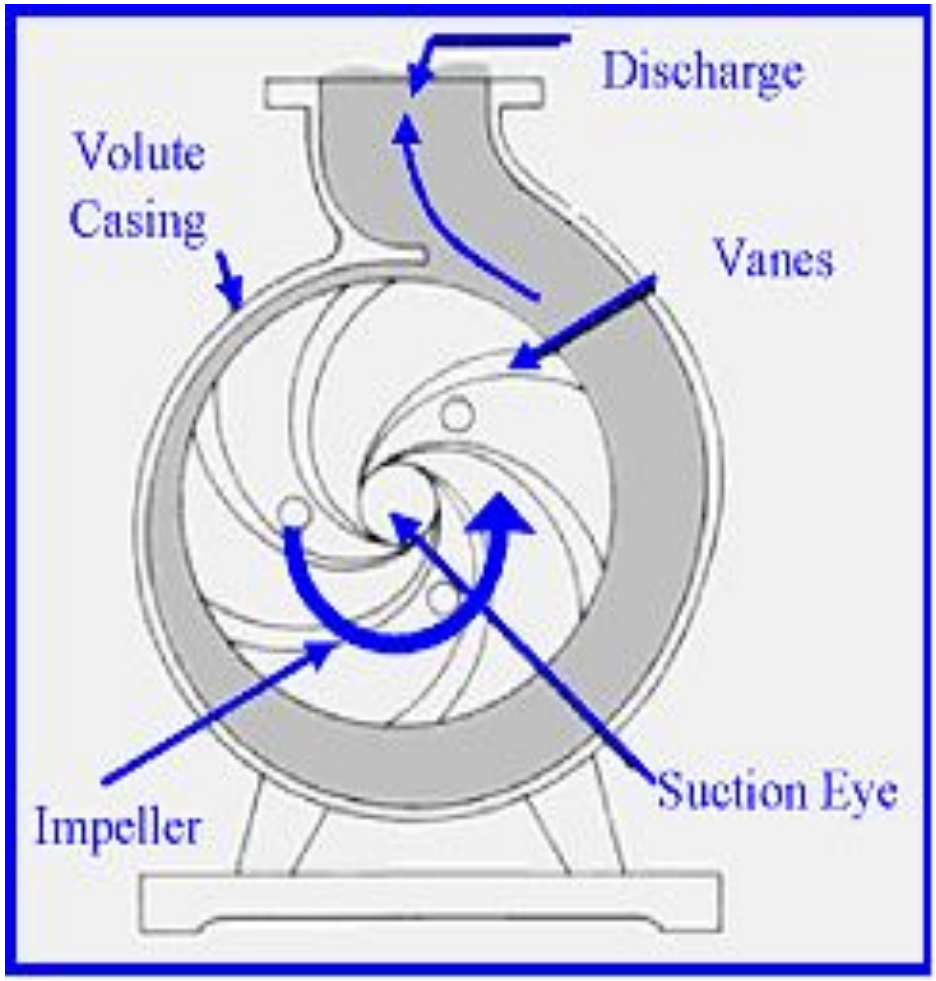
- On the basis of type of service
  - Deep well pump
  - Low lift pump
  - High lift pump
  - Booster pump
  - Fire service pump
  - Stand-by pump
- On the basis of power to drive
  - Steam pump
  - Gasoline pump
  - Diesel pump
  - Electric pump

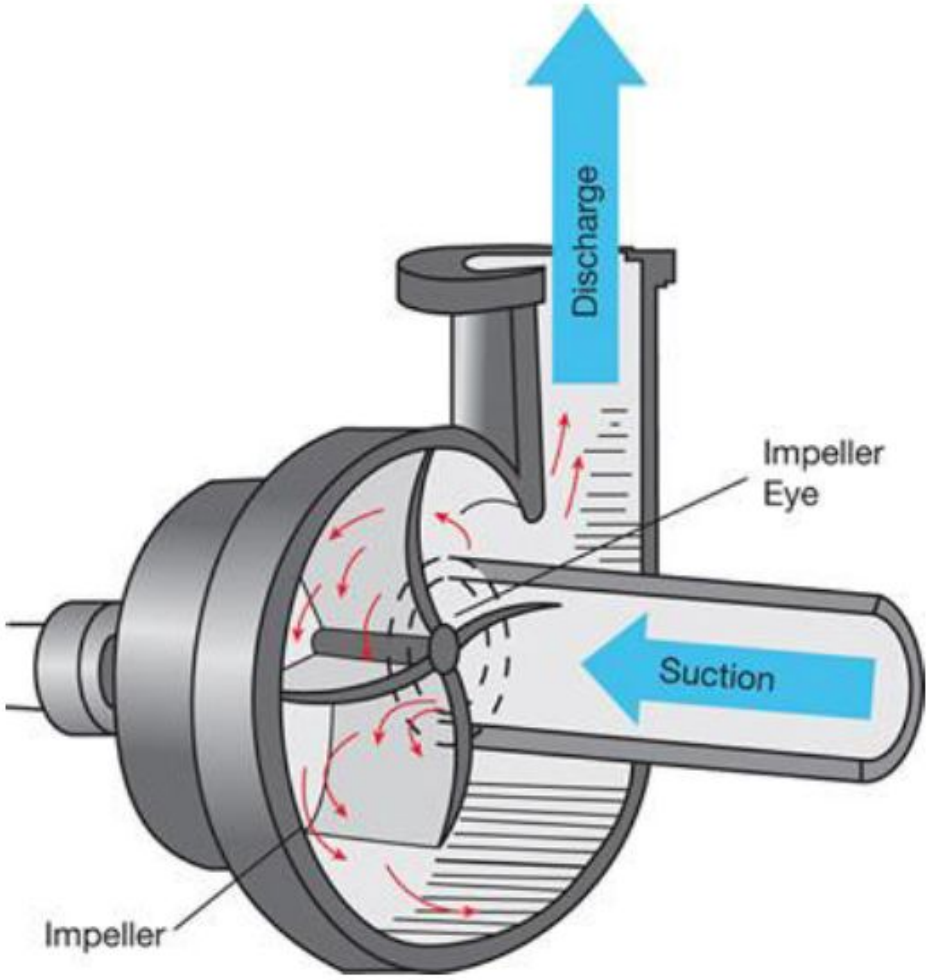
Types of Pumps

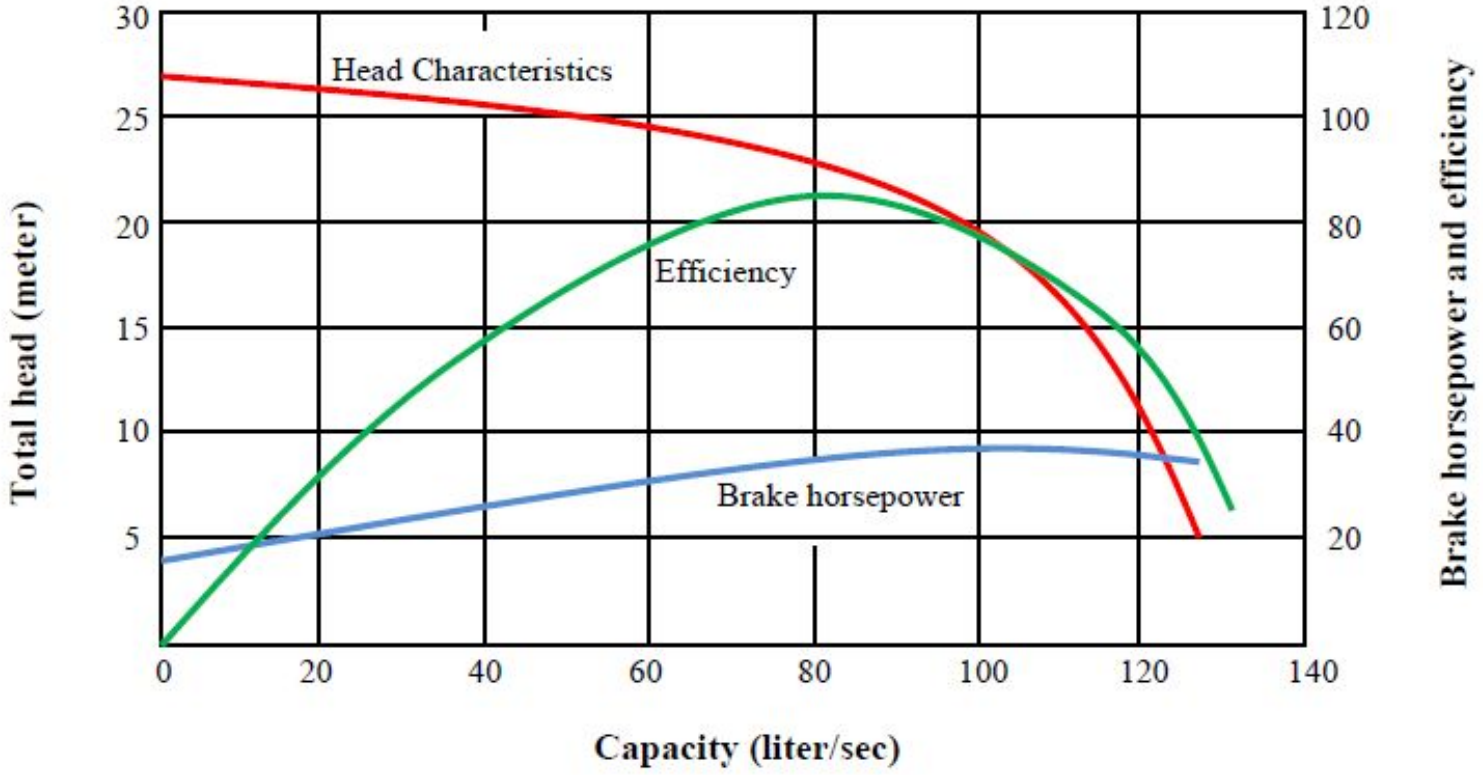
- On the basis of Mechanical principles of operation
  - Displacement pump
  - Centrifugal pump
- On the basis of position of pump shaft
  - Deep well turbine pump
  - Air lift pump
  - Submersible pump

Centrifugal Pump

- Employ the principles of centrifugal force to impart energy to the water.
- Kinetic energy of water is converted into static energy or pressure head.
- Water entering into pump-casing is revolved by a wheel called impeller which discharges water at right angles to the direction of flow.
- High speed normally more than 1,000 rpm in some cases 3,500 rpm are possible.
- Discharge is uniform and power requirements are also uniform.


Discharge
Volute
Casing
Vanes
Impeller
Suction Eye


Discharge
Impeller
Eye
Suction
Impeller



- As the discharge increases, the head decreases. The resulting efficiency is observed to increase from zero where the discharge is zero to a maximum of 82% when the discharge is 86 liter/sec and the head 23 m (and then found to decrease to zero at zero head).
- The BHP curve for a centrifugal pump usually increases over most of the range as the discharge increases, reaching a somewhat higher rate of discharge then that which produce maximum efficiency.

Centrifugal Pump

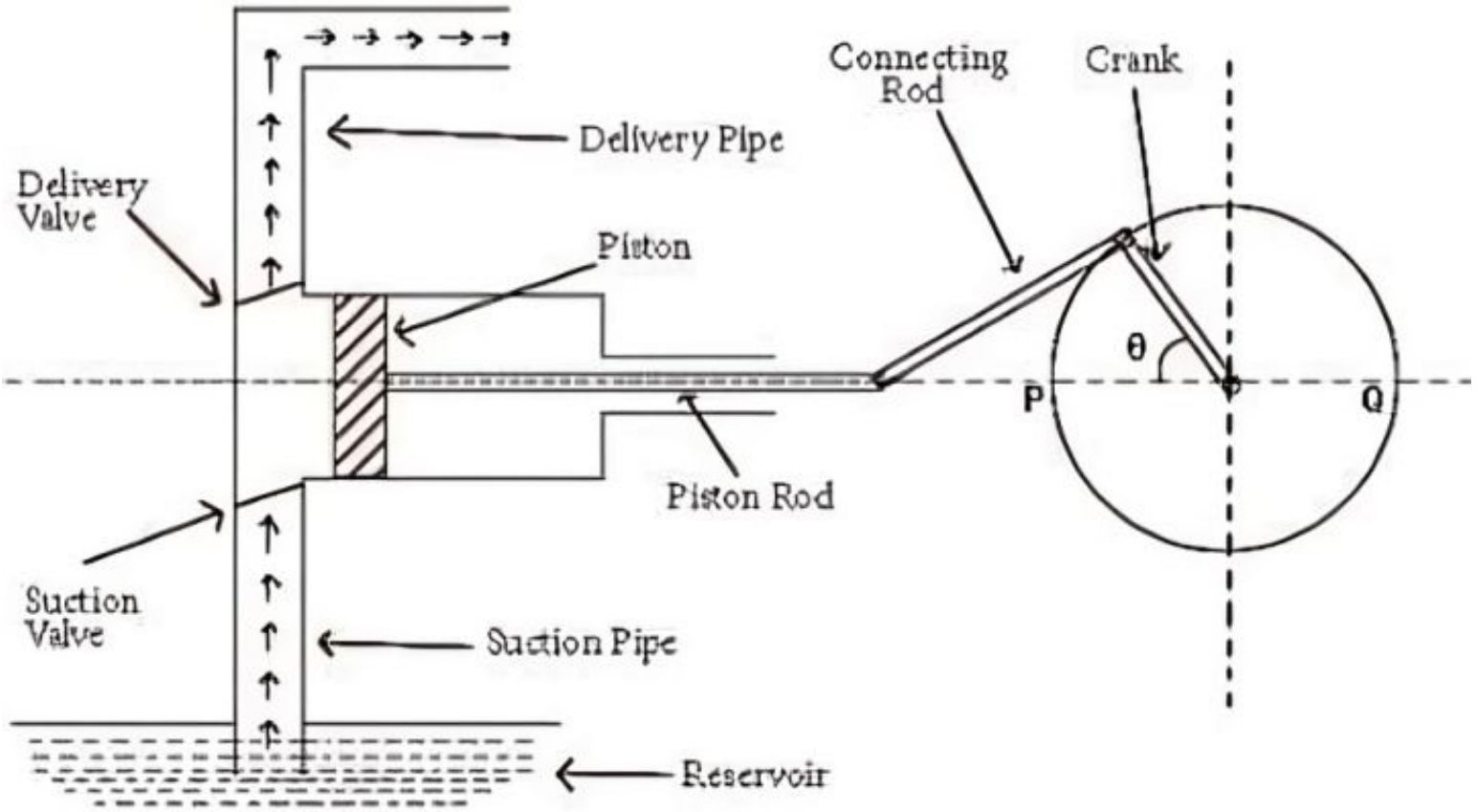
- **Advantages**
  - Requires minimum space for installation as it is compact in design.
  - Can be installed for high speed driving mechanism.
  - Working principle is simple and no valve in the pump, it is reliable and durable.
  - Initial and maintenance cost are comparatively low.
  - Less skilled labor is required for its operation and repair.
  - Can be operated with high speed electric motors, or gas engines and steam turbines.
  - Discharge is steady and non pulsating.
  - Can be used for pumping water containing silt, sand etc.
  - Safe against pressure.

Centrifugal Pump

- **Disadvantages**
  - Will not work, if the chamber is not full of water. Priming should always be done before starting the pump.
  - Will not work if there is any leakage in the suction side.
  - For higher head, efficiency is low.
  - Discharge pipe has to be provided with check valve, to avoid the backflow when the pump suddenly stops due to power failure, with the discharge valve open.
  - Discharge varies with the head of water. When uniform discharge is required at varying heads, the pumps has to be rotated at variable speeds which is neither, practical nor economical.
  - Ordinary suction lift is limited(about 6m or so).

Reciprocating Pump

- Pump consists of a closed cylinder in which a piston moves to and from by a connecting rod.
- Connecting rod is again hinged with a wheel which is rotated by a motor.
- During the suction stroke, the suction valve is opened and delivery valve remains closed and water enters the cylinder.
- During the delivery stroke, the delivery valve is opened and suction valve remains closed and water is forced through the delivery pipe.


Connecting Rod
Crank
Delivery Pipe
Delivery Valve
Piston
θ
P
O
Q
Piston Rod
Suction Valve
Suction Pipe
Reservoir

Components

- **Cylinder** - It is made of cast iron or steel alloy.
- **Piston** - The piston reciprocates inside the cylinder.
- **Connecting Rod** - It connects piston and rotating crank.
- **Suction Pipe** - It connects the source of water and cylinder.
- **Delivery Pipe** - Water sucked by pump is discharged through the delivery pipe.
- **Suction Valve** - It adjusts the flow from the suction pipe into delivery pipe.
- **Delivery Valve** - It admits the flow from the cylinder into the delivery pipe.

Reciprocating Pump

Advantages

- Continuous rate of discharge
- Can deliver water at high pressure
- Can work in wide pressure range
- Precise delivery of required flow rate
- Higher efficiency (10% to 20% greater) compared to centrifugal pumps
- No need for priming

Reciprocating Pump

Disadvantages

- More parts mean high initial cost
- High maintenance cost
- Occupies more space
- Needs skilled supervision during operations
- Low discharging capacity
- High wear in parts

Air Lift Pump

- Consists of a casing pipe in which an educator and an air pipe is introduced.
- Bottom end of the air pipe carries an air diffuser which is introduced into the educator pipe in upward direction.
- Compressed air is forced through the air pipe, a mixture of air and water is formed and rises up in the form of bubbles.

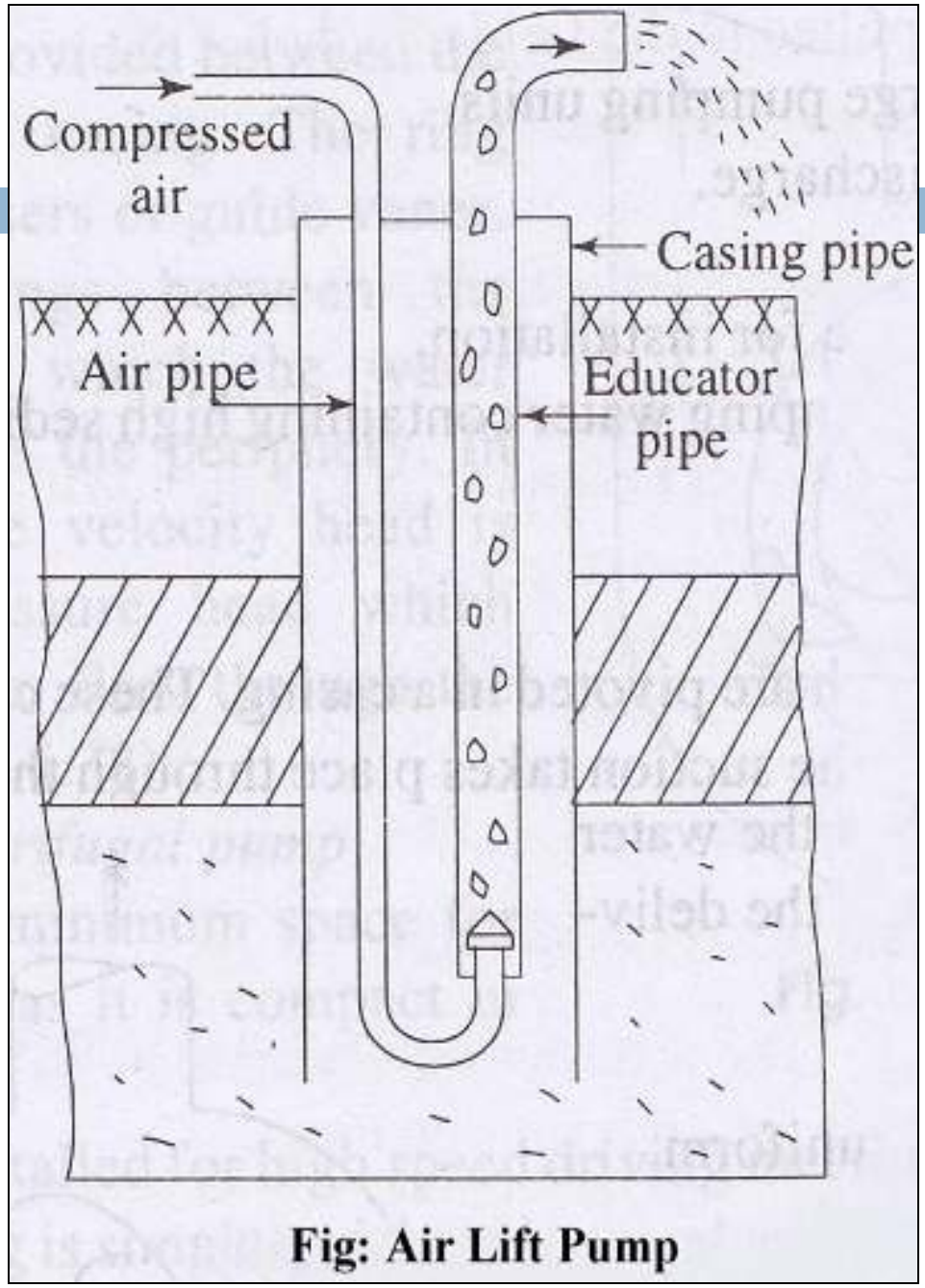


Fig: Air Lift Pump

Air Lift Pump

- Pressure difference forces the water to rise through the educator pipe and finally the water is discharged through the outlet.
- Efficient working of the pump depends on the air pipe's submergence depth.
- Used for pumping water from deep wells for lifting of about 60 – 80m.
- Can be used for high lifts about 150 meters but their efficiency is generally low.

Air Lift Pump

Advantages :

- Inspite of low efficiency, an air lift pump can deliver large amounts of water from small dia wells.
- Not harmed by sedimented water.
- Cheaper, reliable and simple in operation.
- No moving parts which may be in contact with water– used for highly acidic or alkaline water.
- Yield of a well, using such pump, can be increased by using more amount of compressed air.

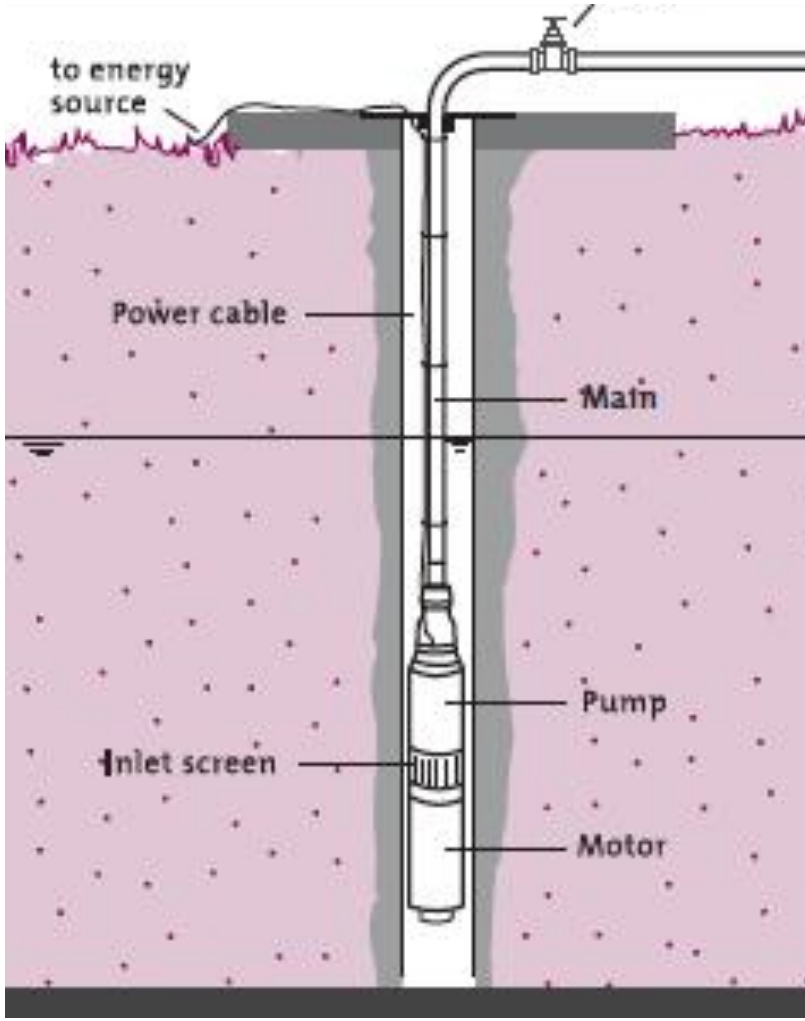
Air Lift Pump

Disadvantages

- Not adopted for raising water much above the ground level, and if this is necessary, a second pump has to be installed.
- Efficiency is low
- Flow obtained is not continuous but is intermittent.
- Less flexible in fulfilling variable demands.
- In order to obtain sufficient value of submergence, the depth of submergence has to be increased and thus the well has to be made deeper than required. This increases the cost.

Submersible Pump

- Driving motor is placed below the pump bowls within the well water level.
- Driving shaft is completely eliminated reducing the bearing friction.
- Electrical parts or the motor bearing are enclosed by a oil filled case with mercury seal.
- Water rises to the surface through a riser pipe on which the assemble is suspended.



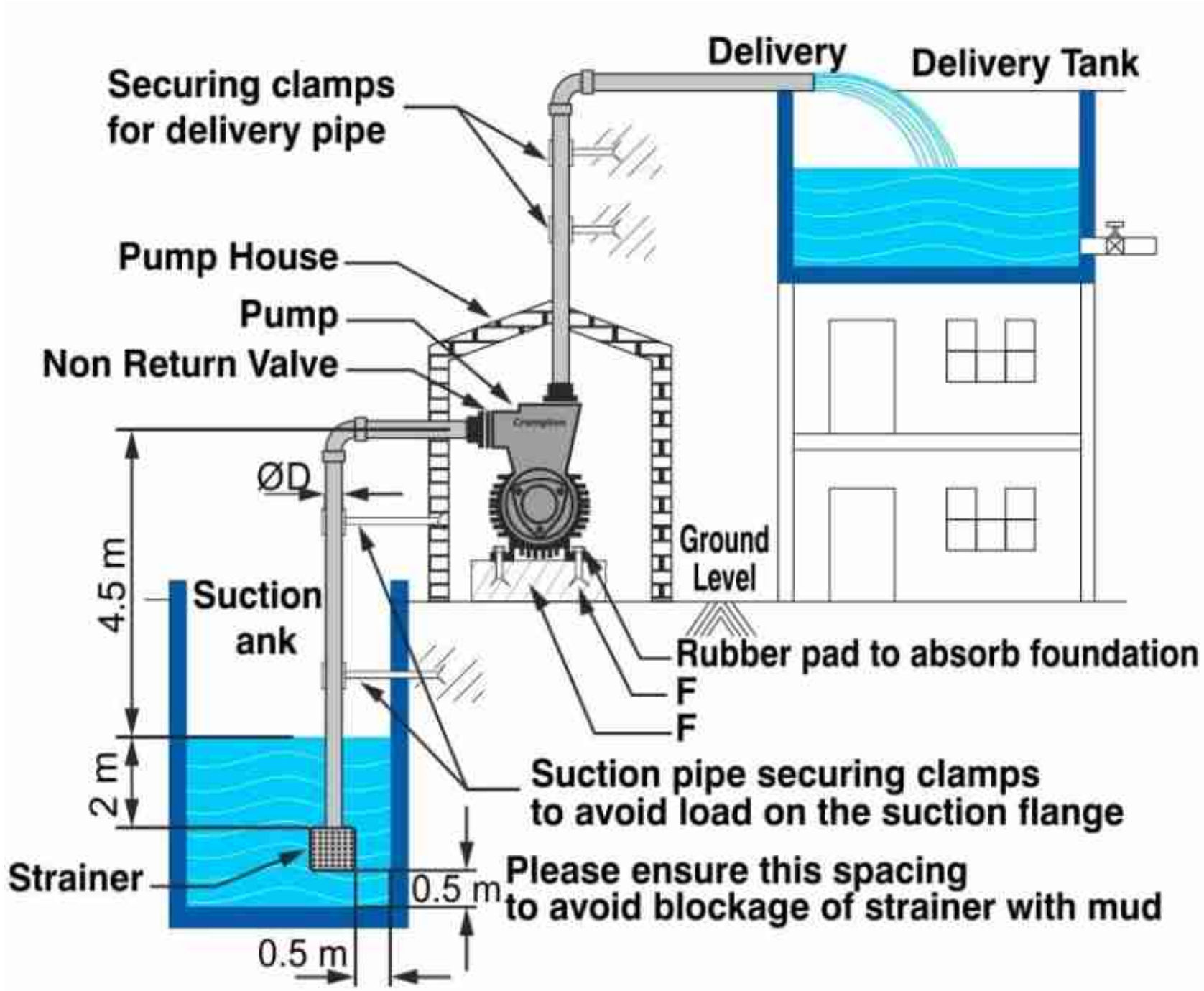
Submersible Pump

Advantage

- Safer than other types of surface pumps
- It produces low or almost no noise
- Submersible pumps are Self-Priming
- Corrosion resist
- Easy to run & are space-saving
- Can run for 15 years smoothly without trouble

Disadvantage

- Seals can become corroded with time
- Must submerge totally before use
- Routine inspections and maintenance are challenging


Delivery
Delivery Tank
Securing clamps
for delivery pipe
Pump House
Pump
Non Return Valve
ØD
4.5 m
Suction
ank
Ground
Level
Rubber pad to absorb foundation
F
F
2 m
Suction pipe securing clamps
to avoid load on the suction flange
Strainer
0.5 m
Please ensure this spacing
to avoid blockage of strainer with mud
0.5 m

General considerations

- **Suction lift:**
  - Due to friction losses, loss of velocity head maximum lift of 32 ft cannot be achieved.
  - Elevation of any pump above the source of water supply should not exceed 22 ft.
  - Suction pipe should be short, straight and ample diameter.
  - Strainer should have clear waterway area 1.5 times the cross sectional area of the suction pipe.
- **Power of pump:**
  - Cost of power to operate the pump is mainly the cost of pumping.
  - Steam engine, gasoline engine, diesel engine and electric motors are commonly used to drive pumps.

General considerations

- **Stand-by or reserve power:**
  - Extra pump units for use in case of breakdown or repairing of regular pumps are necessary.
- **Size of Units:**
  - Pumping station is not operated at full capacity all the time.
  - The complete pump installation should be so designed that some units may be operated of full capacity at all times regardless of the variation in demand.

Power of Pump

- Total lift of pump:

  It is the algebraic sum of (i) **Discharge Lift** or the vertical distance from the centre of the pump to the level where water is to be raised. (ii) **Suction Lift** or the vertical distance from the level of the source of water supply to the centre of the pump.

- The **Horse Power** of pump is determined by work done in raising a particular quantity of water to some height.

  Let, W = Quantity of water (kg)

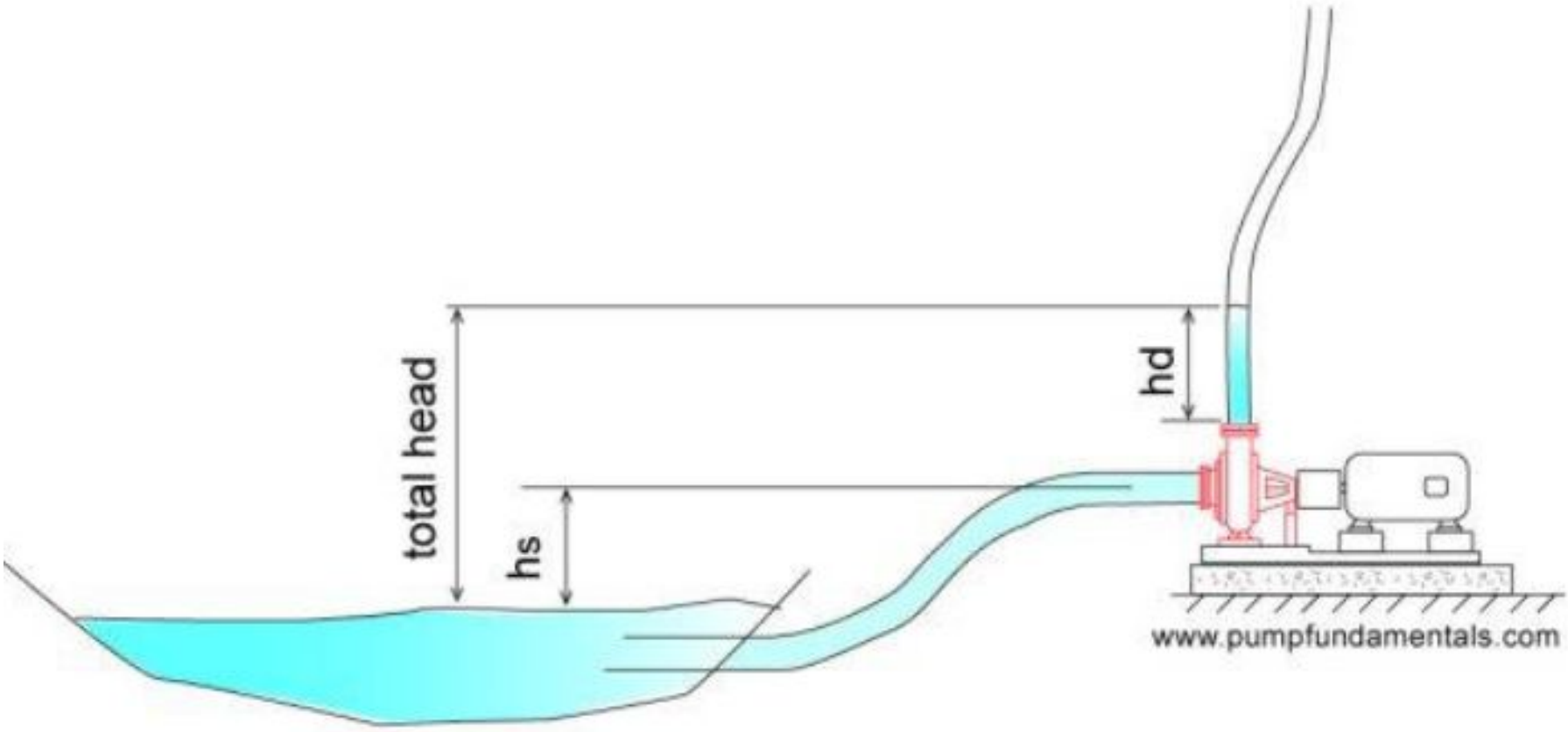
  H = Total head (m)

  Then, work done by pump = $W \times H = \rho \times Q \times H$ $[W = \rho \times Q]$

  Where, ρ = Density of water (1000 kg/m^3)

  Q = Discharge (m^3/s)

Head



Essential Equations

- Pump Head, $h_p = h_s + h_v + h_f = h_s + \frac{v^2}{2g} + h_L$
- h_s = static head including ($h_{suction} + h_{delivery}$)
- h_v = velocity head
- h_L = frictional head loss = $f.\frac{L}{D}.\frac{v^2}{2g}$ (Darcy-Weisbach Equation)
- **P =** $\frac{HQ}{3960}$, theoretical Horse power required to operate the pump (WHP-Water Horse Power)

Essential Equations

- $\mathbf{P = \frac{HQ}{3960}}$, H =total lift or head of the pump,
- $H = h_p$
- Q = volume of water to be pumped in unit time, or discharge, in gpm
- Actual horsepower required to operate the pump depends on the efficiency (E) of the pump
- $\boldsymbol{P' = \frac{P}{E}}$, BHP = Break Horse Power
- $\mathbf{BHP = \frac{WHP}{E}}$

Essential Equations

- Continuity Eqn, Q = AV
- Area, $A = \frac{\pi d^2}{4}$

Pump Design Example

- Ex-01: Design a suitable set of pumping unit to deliver 4,50,000 gph from an intake well of a river bank to the treatment plant. Total Length of rising main from the intake well to the treatment plant is 800 ft and the static head is 60 ft, Design also the cast iron main.
- Assume: velocity of water 12 fps
- Friction factor: 0.0075
- Efficiency: 70%

Solution

- Sol: Q = 450000/60 = 7500 gpm;
- Q = 450000/(60*60*6.24) = 20 cfs
- Cross sectional area = 20/12 = 1.667 sq.ft
- $1.667 = \pi d^2/4$
- d= 1.5 ft= 18 inch
- $H_f = f.\frac{L}{D}.\frac{v^2}{2g} = \frac{2\times0.0075\times800\times12^2}{2\times32.2\times1.5}$ = 36 ft
- $H_v = \frac{v^2}{2g} = \frac{12^2}{2\times32.2}$ =2.24

Solution

- Total Head = hs + hf + hv = 60+ 36+2.24 = 98.24ft
- **P =** $\frac{HQ}{3960} = \frac{98.24 \times 7500}{3960}$ = 188 WHP
- **BHP =** $\frac{WHP}{E} = \frac{188}{0.7}$ **= 268**

PROBLEM 1 : It is required to pump water at the rate of 6,750 gpm from a reservoir whose surface is at an elevation of 180 ft. to a tank whose bottom is at an elevation of 372 ft. The pump is placed at an elevation of 192 ft., the diameter of the suction pipe is 30 inch, the length of the pipe from the pump to the tank is 290 ft. and the estimated size of this pipe is 24 inch. The sum of the minor head losses in the suction and discharge pipe may be taken as 1.5 ft. If the maximum depth of water in the tank is to be 25 ft., what is the required horsepower of a pump for which the overall efficiency is 67 per cent ?

Assume head loss due to friction in 290 ft. + 1.5 ft.

Neglect all other head losses.

Solution :

Elevation of water surface in the tank = 372 + 25 = 397 ft.

Discharge lift or the vertical distance from the centre of the pump to that surface = 397 — 192 = 205 ft.

Suction lift, or the vertical distance from the water surface in the reservoir to the centre of the pump = 192-180 = 12 ft.

Since the pump is above the water surface this lift is positive.

Total head $H = 205 + 12 + 1.5 + 1.5 = 220$ ft.

$$P = \frac{HQ}{3,960} = \frac{220 \times 6,750}{3,960} = 375 \text{ (WHP)}$$

$$P^1 = \frac{375}{0.67} = 560 \text{ (BHP) Ans.}$$

PROBLEM 2 : Design a suitable set of pumping unit to deliver 4,50,000 gph from an intake well of a river bank to the treatment plant. Total length of rising main from the intake well to the treatment plant is 800 ft. and the static head is 60 ft. Design also the cast iron main.

Assume : Velocity of water = 12 fps
friction factor = 0.0075
efficiency = 70%

Solution.

$$Q = 4,50,000 \div 60 = 7,500 \text{ gpm}$$

again $$Q = \frac{4,50,000}{60 \times 60 \times 6.24} = 20 \text{ cfs}$$

Cross-sectional area $= \frac{20}{12} = 1,667$ sq. ft.

$$\frac{\pi d^2}{4} = 1.667 \quad (d = \text{diameter of pipe})$$

$$d = \sqrt{\frac{1.567 \times 4}{\pi}} = 1.5 \text{ ft} = 18 \text{ inch}$$

Frictional head loss, $h_f = \frac{4flv^2}{2gd} = \frac{4 \times 0.0075 \times 800 \times (12)^2}{2 \times 32.2 \times 1.5} = 36$ ft.

Velocity head, $h_v = v^2/2g = (12)^2/2 \times 32.2 = 2.24$ ft.

Total head $H = h_s + h_f + h_v = 60 + 36 + 2.24 = 98.24$ ft.

$$P = \frac{HQ}{3,960} = \frac{98.24 \times 7,500}{3,960} = 188 \text{ (WHP)}$$

$$P^1 = \frac{180}{0.70} = 265 \text{ (BHP) Ans.}$$

PROBLEM 3 : Water is supplied from an impounding reservoir 30 miles away to a service reservoir near the town. A cast iron main is to be designed to supply 425 mgd. Loss of head due to friction in the pipe is estimated to be 300 ft. All other head losses are neglected. What size cast iron pipe would you use ?

Assume $f = 0.0075$

Solution :

$$h_f = \frac{4 \times 0.0075 \times (30 \times 5280) \times v^2}{2 \times 32.2 \times d} = 300$$

$$\frac{v^2}{d} = 4.06 \qquad \therefore \quad v^2 = 4.06 \times d \quad \ldots (1)$$

Again, $Q = 425$ mgd $= 425 \times 1.547 = 787$ cfs [1 mgd $= 1.547$ cfs]

$$Q = av = \frac{\pi d^2}{4} \times v \qquad \therefore \quad v = \frac{4Q}{\pi d^2}$$

$$\therefore \quad v^2 = \frac{16Q^2}{(\pi d)^2}$$

Substituting the value of v^2 from Eq. 2 to Eq. 1.

$$\frac{16Q^2}{\pi^2 d^5} = 4.07$$

$$d^5 = \frac{16 \times (787)^2}{\pi^2 \times 4.07} = 246{,}800$$

$\therefore \quad d = 11.98 \simeq 12$ ft. Ans.

Problem 4 : Design a pumping unit capable of lifting 5 mgd of water from an intake well to the treatment plant against a static head of 60 ft ; length of suction main is 120 ft. and that of rising main is 400 ft. The pump will work in two shifts of eight hours each.

Assume : velocity of flow = 6 fps
friction factor = 0.01
efficiency = 75%

Solution :

Total length of pipe = 120 + 400 = 520 ft.

Discharge, Q = 5mgd = $\frac{5 \times 10^6}{6.24} = 8 \times 10^5$ cuft/day

Since total pumping time is 16 hrs/day.

∴ Pumping capacity = $\frac{8 \times 10^5}{16}$ = 50,000 cuft/hr.

= $\frac{50{,}000}{60 \times 60}$ = 13.9 cfs

$$Q = \frac{\pi d^2}{4} = 13.9$$

$$\therefore \quad d = \sqrt{\frac{4 \times 13.9}{\pi \times 6}} = 1.7 \simeq 21.75 \text{ ft} = 21 \text{ inch}$$

$$h_f = \frac{4 \times 0.01 \times 520 \times 6^2}{2 \times 32.2 \times 1.75} = 6.7 \text{ ft.}$$

$$h_v = \frac{6^2}{2 \times 32.2} = 0.56 \text{ ft.}$$

$$H = h_s + h_f + h_v = 60 + 6.7 + 0.56 = 67.26 \text{ ft.}$$

$$Q = \frac{50,00,000}{16 \times 60} = 5,220 \text{ gpm}$$

$$P = \frac{HQ}{3,960} = \frac{67.26 \times 5,220}{3,960} = 88.5 \text{ (WHP)}$$

$$\therefore P^1 = \frac{P}{E} = \frac{88.5}{0.75} = 118 \text{ (BHP) Ans.}$$

Problem 5 : Design the transmission main and the pumping unit from the following data :

Water supply rate = 40 gpcd
Estimated population = 85,000
Ground R. L. = at the pum house = 102.50 ft.
Treatment plant R. L. = 193.00 ft.
Velocity through pipes = 8 fps
Pumping time = 10 hrs. daily
Total length of pipe = 3,500 ft.
Friction factor = 0.01
Efficiency = 65%

Solution :

Total water required = $40 \times 85{,}000 = 34{,}00{,}000$ gpd

$$= \frac{34{,}00{,}000}{6.24} = 5.45 \times 10^5 \text{ cuft/day}$$

Pumping rate $= \frac{5.45 \times 10^5}{10} = 5.45 \times 10^4$ cu ft/hr

$$= \frac{5.45 \times 10^4}{60 \times 60} = 15.15 \text{ cfs}$$

12.63 cfs.

$$Q = \frac{\pi d^2}{4} \times v = 15.15$$

$$\therefore \quad d = \sqrt{\frac{4 \times 15.15}{\pi \times 8}} = 1.55 \text{ ft.}$$

Use a 21 inch diameter pipe, d = 1.75 ft.

Static head = 193.00 – 102.50 = 90.50

$$\text{Friction head} = \frac{4 \times 0.01 \times 3500 \times 8^2}{2 \times 32.2 \times 1.75} = 80.0 \text{ ft.}$$

$$\text{Velocity head} = \frac{v8^2}{2 \times 32.2} = 1.0 \text{ ft}$$

Total head, H = 90.5 + 80.0 + 1.0 = 171.5 ft

$$\text{Discharge, } Q = \frac{34,00,000}{10 \times 60} = 5,667 \text{ gpm}$$

$$\therefore \quad P = \frac{HQ}{3,960} = \frac{171.5 \times 5667}{3,960} = 246 \text{ (WHP)}$$

$$\therefore \quad P^1 = \frac{P}{E} = \frac{246}{0.65} = 380 \text{ (BHP) Ans.}$$

Practice Problem 1

- Design a suitable set of pumping unit to deliver 450000 gph from an intake well of a river bank to the treatment plant. Total length of rising main from the intake well to the treatment plant is 800 ft and the ~tatic hand is 60 ft. Design also the cast iron main. Assume: Velocity of water = 12 fps; Friction factor = 0.0075; Efficiency = 70%.

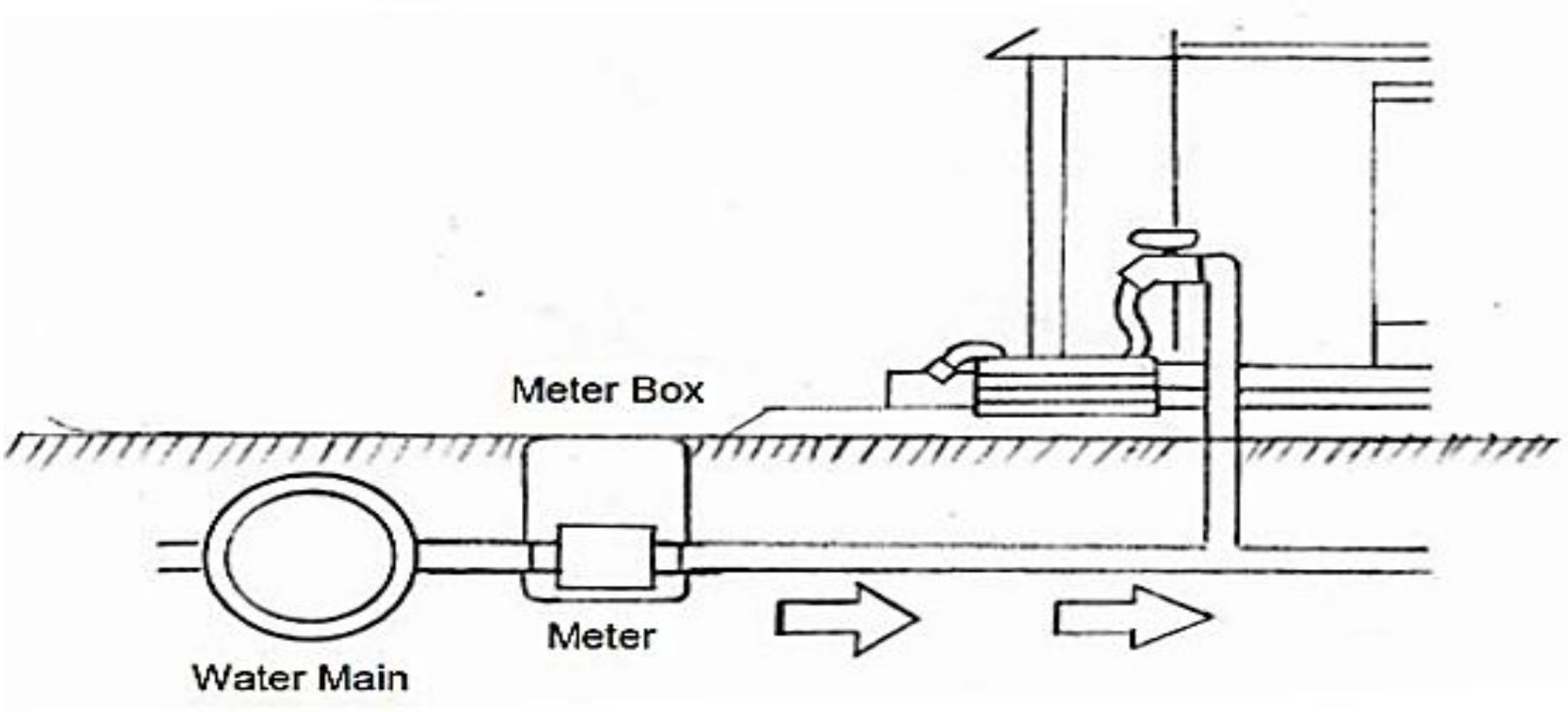
Practice Problem 2

Water supply to a small town with ultimate population of one lakh (1,00,000) supplied with 60 gpcd has to be arranged from a river flowing nearby. Design the economical section of the rising main and the necessary pumping unit from the following data :

Static head	60 ft
Total length of pipe	520 ft.
Coefficient of friction	0.01
Velocity of water in the pipe	6 ft/sec
Pump efficiency	70%

The pumps will work in two shifts of six hours each in a day,

Water Loss



Typical Installation System for Domestic Water Meter

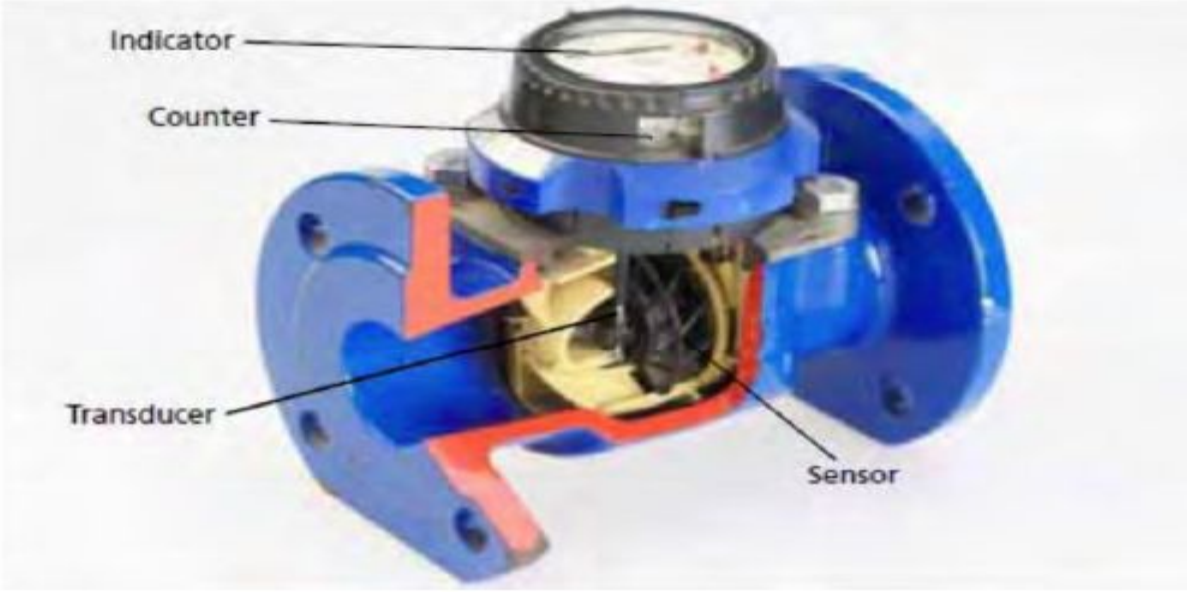
Water Meter

A device that measures the volume of water that passes through it. In most of the world water meters are calibrated in cubic meters (m3) or liters.

Meters installed to measure household consumption are called domestic water meters.

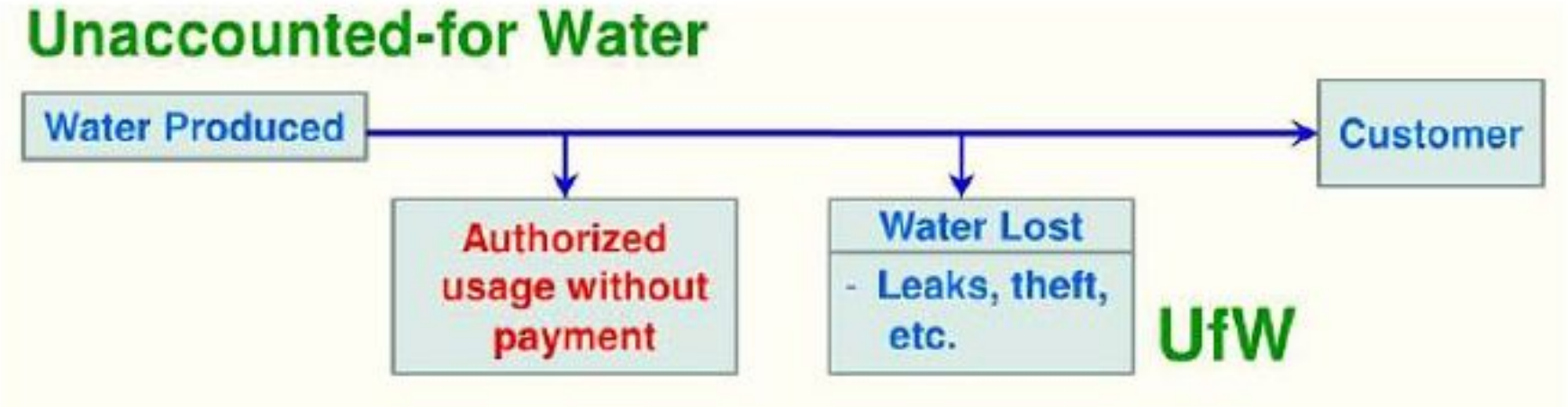
All meters have four basic components

1. Sensor
2. Transducer
3. Calculator
4. Indicator



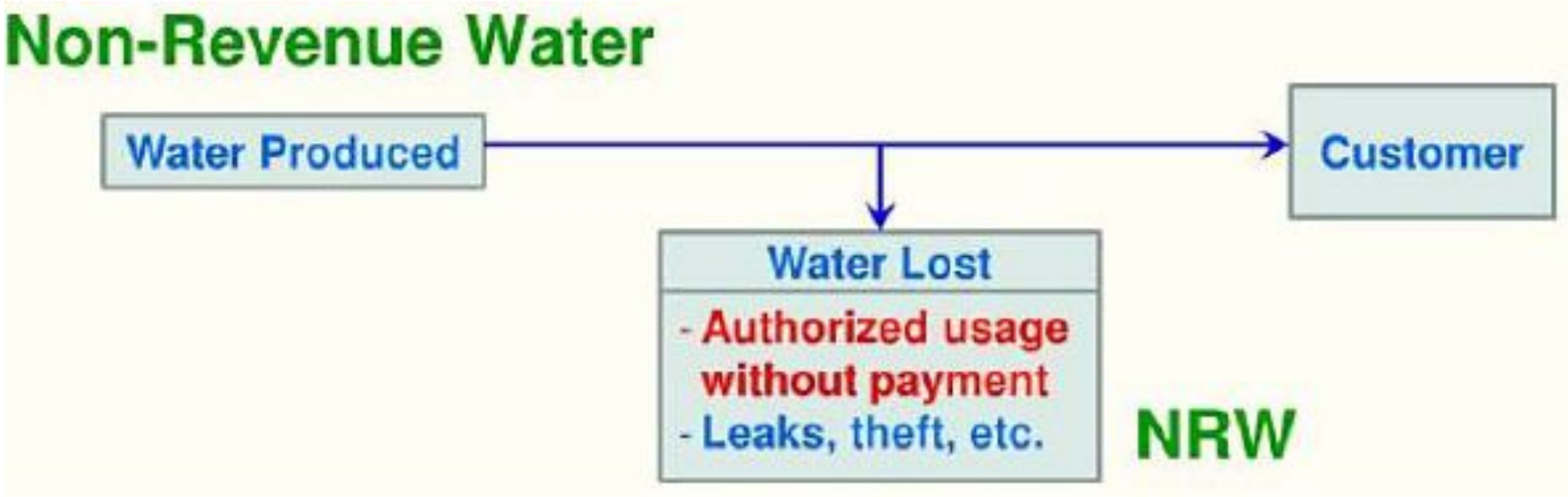
Unaccounted for Water & Non Revenue Water

Unaccounted-for Water (UFW) is the difference between the quantity of water supplied to a city's network and the metered quantity of water used by the customers through leaks, thefts, etc.



Unaccounted for Water & Non Revenue Water

Non revenue water (NRW) produced and lost before it reaches the customer through **leaks, theft, or legal usage** for which no payment is made.



Water Loss	
Physical Loss (Real Loss)	Commercial Loss (Apparent Loss)
Pipe breaks and leaks	Metering errors
Storage overflows	Water theft
House connection leaks	Billing anomalies

Non Revenue Water









APPARENT LOSSES

Apparent losses are the non-physical losses that occur in utility operations due to customer meter inaccuracies, systematic data handling errors in customer billing systems and unauthorized consumption. In other words, this is water that is consumed but is not properly measured, accounted or paid for. These losses cost utilities revenue and distort data on customer consumption patterns.

Apparent Loss

The best ways to **control the apparent losses** is to eliminate:

- customer meter inaccuracies (installation and calibration procedures for large meters, selection of customer meters, consumption profiles, meter sizing, meter installation, meter aging, optimum replacement period, comprehensive and/or targeted replacement programs),
- systematic data handling errors (data capture, data transmission, data processing, meter reading procedures, automatic meter reading)
- unauthorized consumption (overall metering policy will identify unauthorized consumption. Utilities, however, must have autonomy to regulate the illegal connections. Politics is often an obstacle).

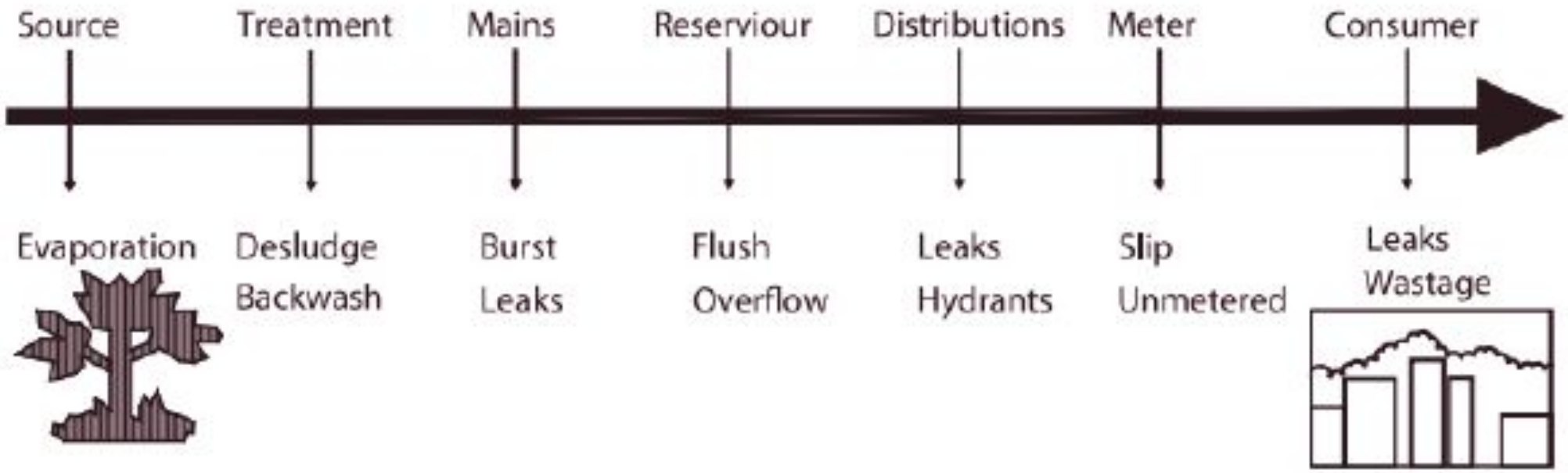
REAL LOSSES

Real losses are the physical losses of water from the distribution system, including leakage and storage overflows. These losses inflate the water utility's production costs and stress water resources since they represent water that is extracted and treated, yet never reaches beneficial use.

Real Loss

- It is impossible to eliminate real losses. Some losses are simply unavoidable and some leakages are undetectable since they are too small or it is not economical to repair them.
- The best ways to **reduce real loss** :
  - rapidly react to leakages (identifying leaks, optimizing pipeline repairs and managing water pressure)
  - avoid storage overflows.

Location of Water Losses



Some Leaks are Easy to Find



Abandoned Service Line

Some Leaks Stay Underground



Subsurface (blind) leak into the sewer

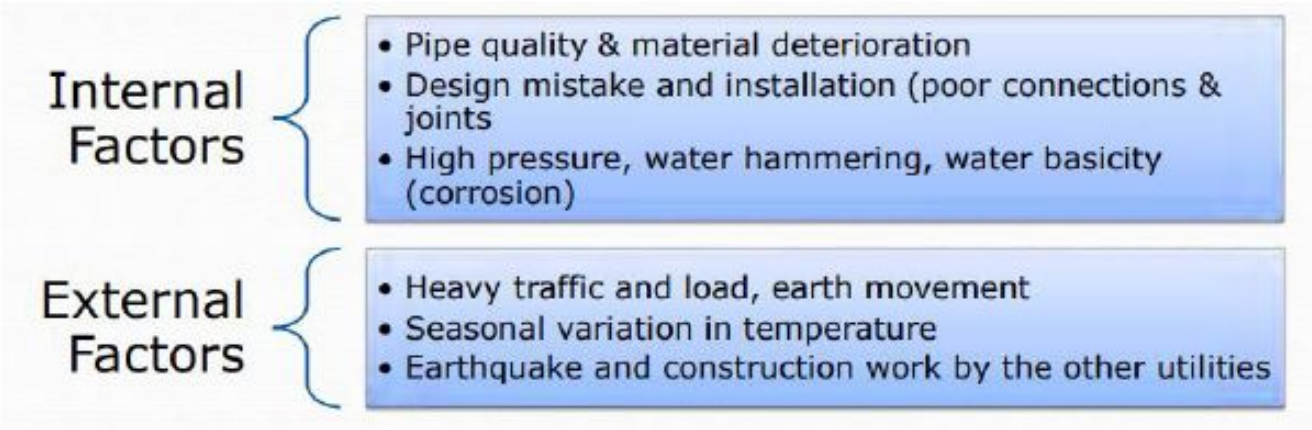


Subsurface (blind) leak formed cavity below the street

Pipe Leakage Detection

- Locating leaks and losses can be accomplished through an examination of billing records, flow monitoring, visual inspection or leak detection equipment (e.g., acoustic, thermal, electromagnetic, tracer).
- **Water audits** compare the amount supplied to the amount consumed using water meters at the supply and householders ends of the distribution network

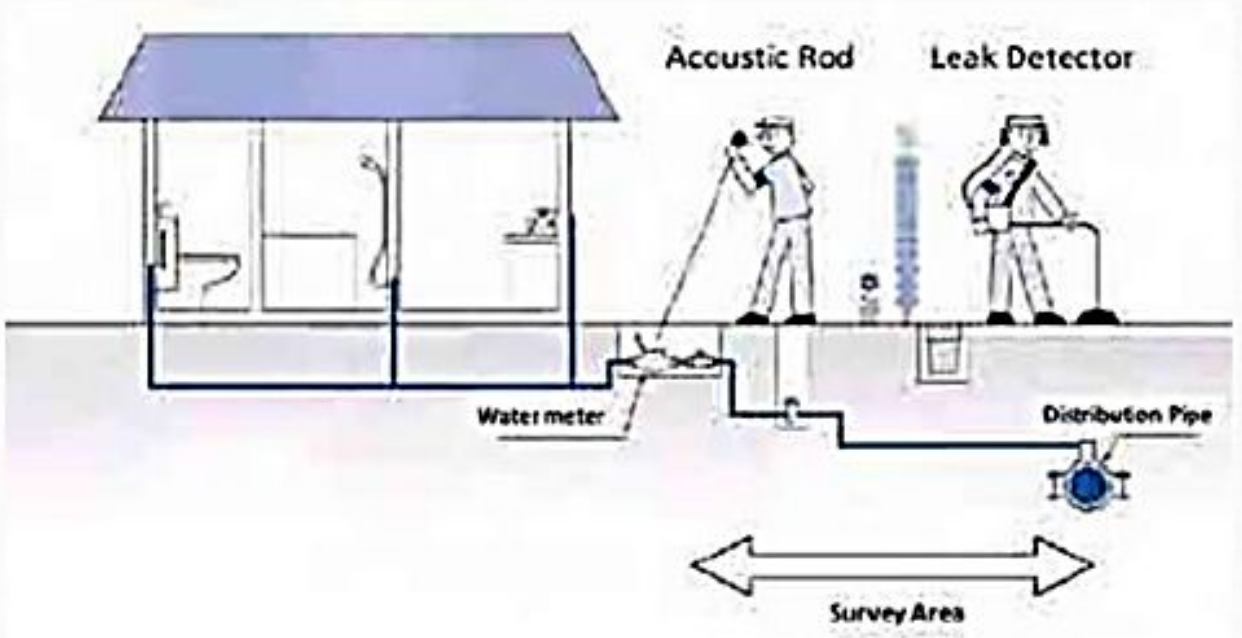
Factors affecting leakage



Pipe Leakage Detection: An Example

Acoustic Rod & Electronic Leak Detector

- Sound is amplified and transmitted to headphones
- As the sound is high exactly above the leak, indication leads to pinpoint exactly.



O&M of Conveyance Systems

Maintain record of pumping head vs. flow: this will provide an indication of pipeline deterioration

Regular inspection:

- illegal or unauthorized connections
- right of way encroachments
- construction activity near pipelines
- slime growth in pipes
- leaks
- damaged structures

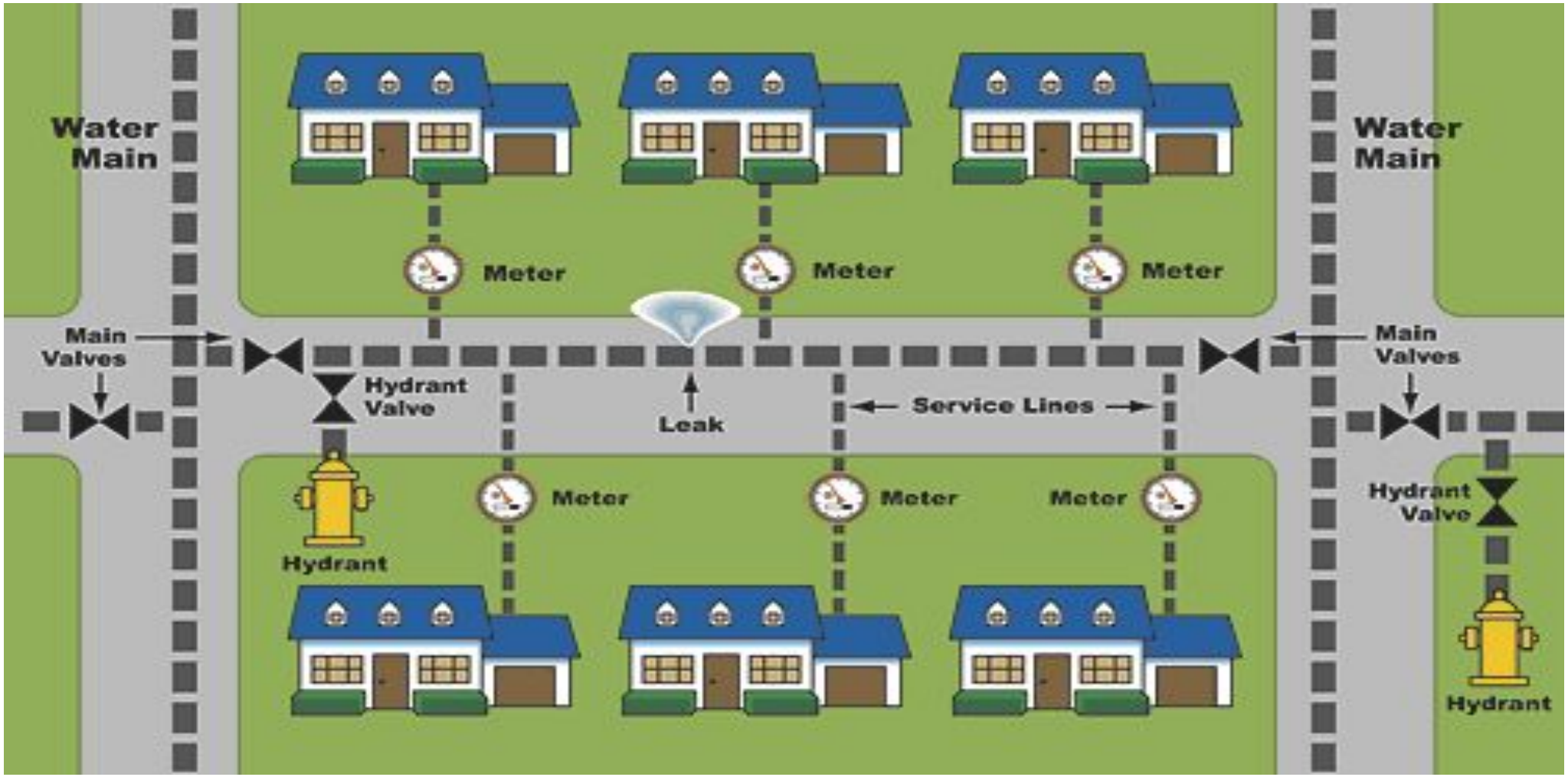
Check operation of air release and vacuum valves Inspect pipe interiors:

- slime accumulation
- deterioration of lining materials

Leak Detection Survey in Water Line

Survey

- “Surveying” is the term applied to listening for water leaks when there is no obvious evidence, like water flowing on the street.
- Every hydrant, valve, and service line is a possible location to hear the sounds of water leaks.
- Since the sounds travel on the pipe walls better than through the soil, always listen at the hydrants, valves, and meters first.
- As you get closer to the leak, the sound gets louder.
- Finally, decide which two of these locations are the loudest. Now you are ready for “Water Leak Pinpointing.”


Water Main
Water Main
Meter
Meter
Meter
Main Valves
Main Valves
Hydrant Valve
Leak
Service Lines
Hydrant Valve
Meter
Meter
Meter
Hydrant
Hydrant



Listening for Leak Sounds at Hydrant

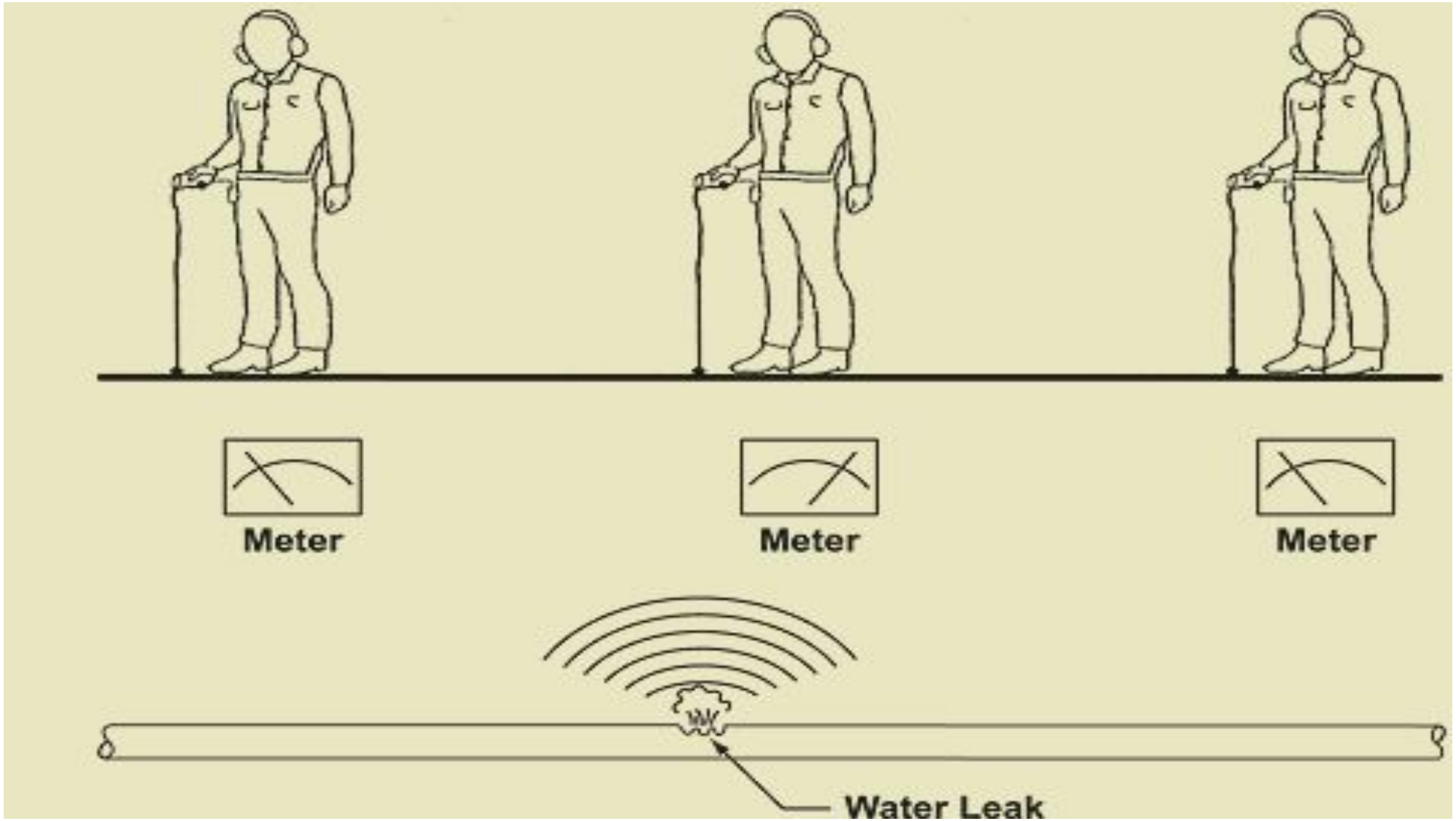


Listening for Leak Sounds at Meter

Pinpointing

- Water Leak Pinpointing” is the term applied to the process of pinpointing the exact leak location.
- For Leak Detection, the exact leak location is usually the spot where the leak sounds are the loudest.
- To find this spot, the listener must carefully mark the location of the water line on the street.
- Usually, the piping between the valve or hydrant with the loudest sound and the valve or hydrant with the second loudest sound is the section of the line that needs to be marked.
- The section must be accurately located and marked on the street in order for the listener to consistently listen directly over the pipe.

Pinpointing



Pinpointing

- The listener moves the ground microphone 3 to 4 feet each time in the direction of the water line, listening, and moving closer to the water leak.
- When the listener is very close to the leak, it may be impossible to decide based upon the user's hearing alone whether the leak is in one spot or in a spot 3 to 4 feet away.
- When this occurs, the listener must study the visible display (meter) to see if the signal is slightly stronger at one location than at another location.



Leak Pinpointing Over a Hydrant Line