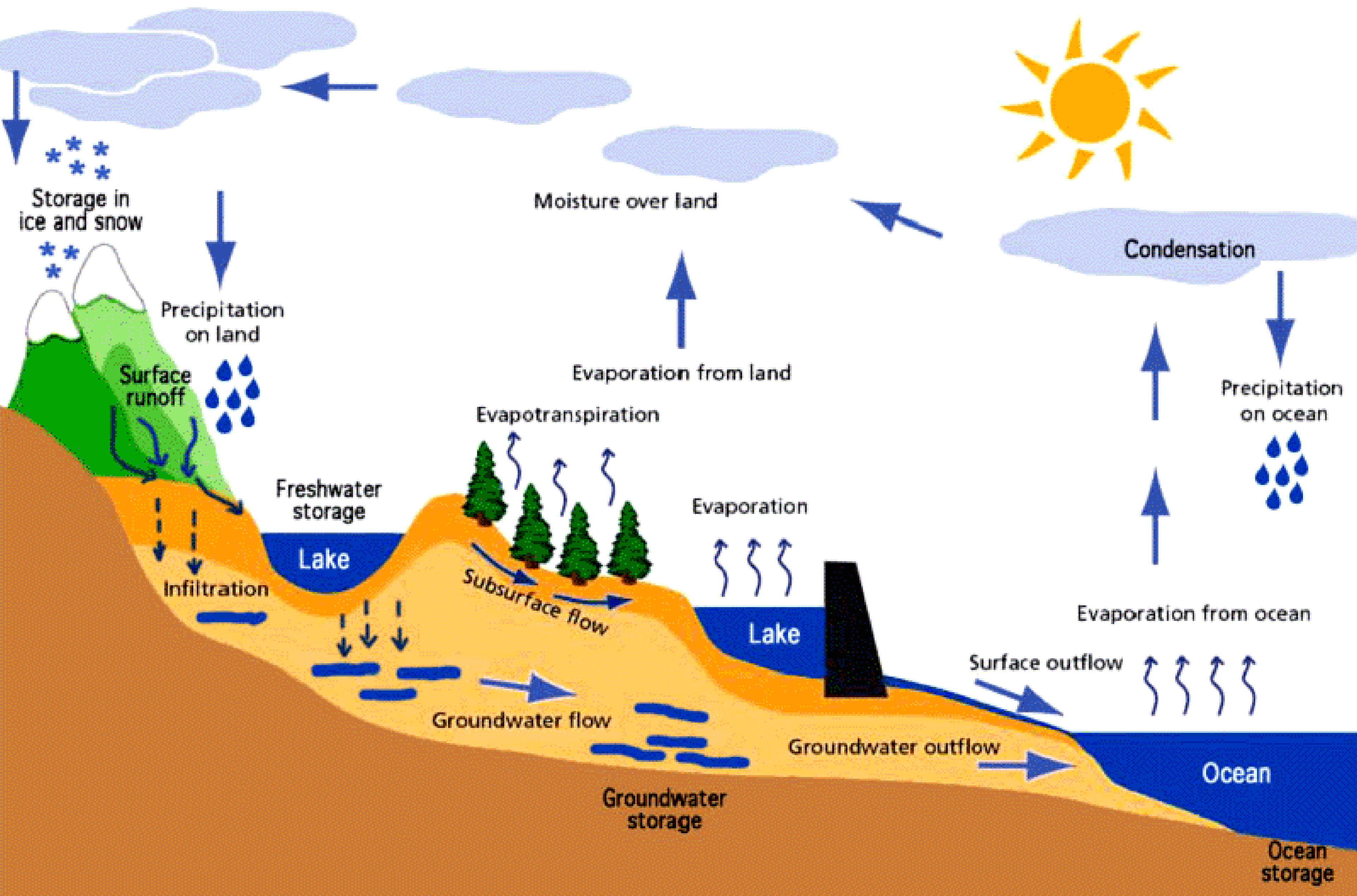
Unit 1

Water Supply Engineering

Introduction

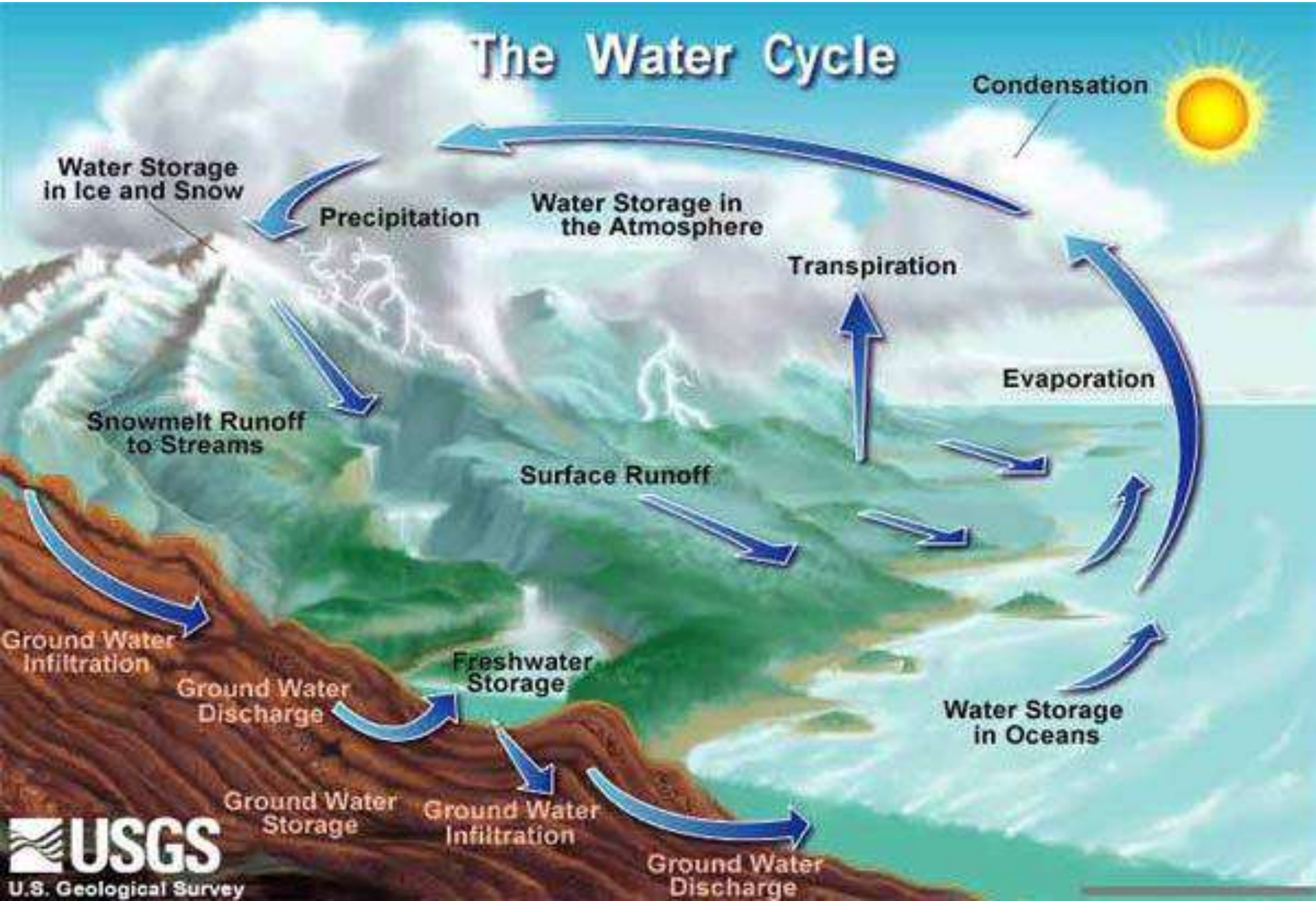
Water Supply Engineering

- Water Supply and Sanitation in India – Poor, Inadequate , Low by International Standards
- Local Government Institutions – Weak in Operation and Maintenance, Lack resources to carry out functions
- Access to improved water sources – 72% (1990) and 88% (2008)
- Urban - 96%; Rural - 84%; Total - 88%



Storage in
ice and snow
Precipitation
on land
Surface
runoff
Moisture over land
Condensation
Evaporation from land
Precipitation
on ocean
Evapotranspiration
Freshwater
storage
Lake
Infiltration
Subsurface flow
Evaporation
Lake
Evaporation from ocean
Surface outflow
Groundwater flow
Groundwater outflow
Ocean
Groundwater
storage
Ocean
storage

Hydrological Cycle

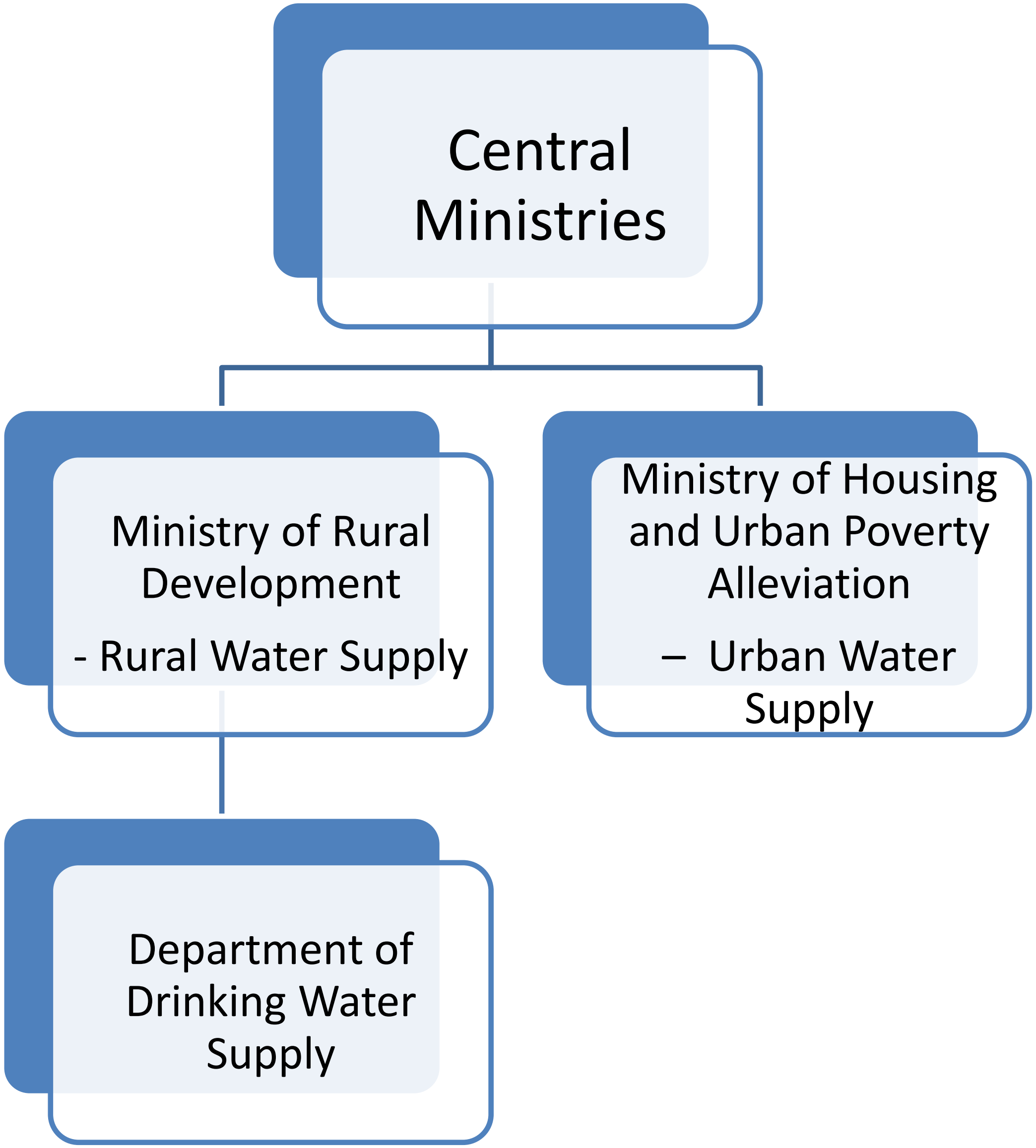


- Average Urban Water Use – 150L/Capita/day
- Annual Investment in Water Supply and Sanitation – US$5/capita
- Indian Norms – Improved water supply exists if at least 40L/capita/day of safe drinking water are provided within distance of 1.6km or 100m elevation difference (to be relaxed as per field conditions). One pump per 250 persons

- 35 cities > 1million population distribute water for few hours
- According to Asian Development Bank (ADB) study in 2007 – average duration of water supply in 20 cities was 4.3hours/day.
- Longest duration of supply – 12hrs/day in Chandigarh and lowest duration of supply - 0.3hrs/day in Rajkot
- According to World Bank – performance indicators not comparable with average International Standards
- No city had continuous supply

- Depleting Groundwater Table and deteriorating Groundwater quality threaten both urban and rural water supply in india
- Surface water – Pollution, scarcity, Conflicts among users (Eg., conflict over Cauvery water among Tamil Nadu and Karnataka)
- Bangalore – Cauvery water pumped since 1974. Cauvery Stage IV (Phase II) project includes supply of 500,000 cubic meter of water per day over a distance of 100km

- Water supply and Sanitation – State Responsibility under Indian constitution
- States may give responsibility to Panchayati Raj Institutions (PRI) in rural areas or municipalities in urban areas, called Urban Local Bodies (ULB)
- At present, states generally plan, design and execute (often operate) through state departments (Public Health Engineering or Rural Development Engineering) or state water boards
- Highly centralized decision making approvals at state affect management of water supply and sanitation services
- Planning Commission Report 2003 – trend to decentralize capital investment to engineering departments at district level and operation and maintenance to district and gram panchayat levels



Only advisory capacity and limited role in funding

- Typically, a state-level agency is in charge of planning and investment, while local government (ULBs) is in charge of operation and maintenance
- Private Sector Participation – limited role on behalf of ULBs.
  - Jamshedpur Utilities and Services Company (JUSCo) – Lease contract for Jharkhand, Management contract in Haldia(West bengal), Mysore (Karnataka) and Contract for reduction of non-revenue water in Bhopal (MP)
  - Veolia (French Water Company) – management contract in 3 cities (Hubli, Belgaum and Gulbarga) in Karnataka in 2005
  - Thames Water
  - Hydrocomp – contract for Latur city (Maharastra)
  - SPML - Bulk water supply project for Bhiwandi (Maharastra) on Build-Operate-Transfer (BOT) basis

Innovative Approaches

- Demand-Driven Approach – *Swajaldhara* – community participation
- Public-Private Partnerships (PPP) to improve continuity of water supply in karnataka
- Micro-credit to women in order to improve access to water

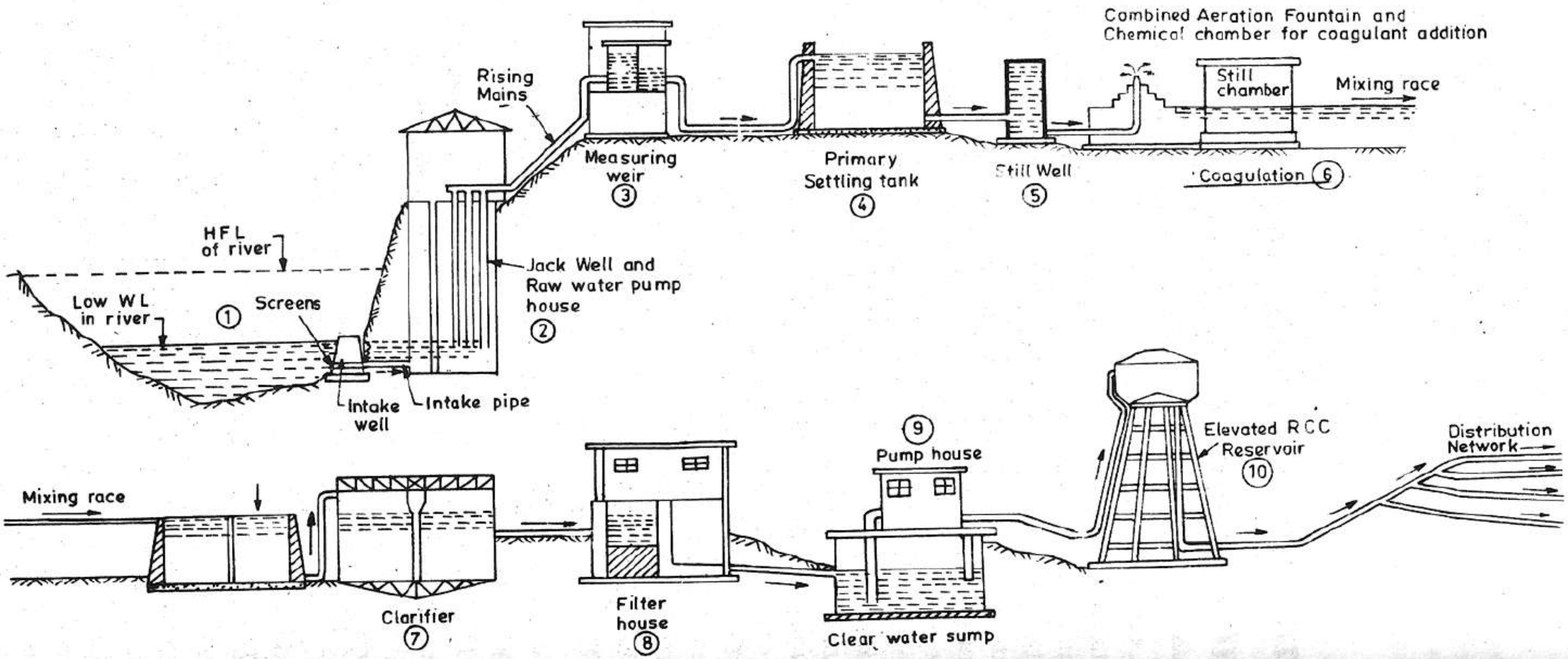
Investment and Financing

- Increased during Ist decade of 21st century
- Central Government grants under Jawaharlal Nehru National Urban Renewal Mission (JNNURM) and loans from Housing and Urban Development Corporation (HUDCO)
- 11th Five Year Plan (2007 – 2012) investments of Rs.127025 crore for urban water supply and sanitation including urban storm water drainage and solid waste management – 55% central govt., 28% state govt., 8% Institutional financing ‘HUDCO’, 8% external agencies and 15% private sector

External Cooperation

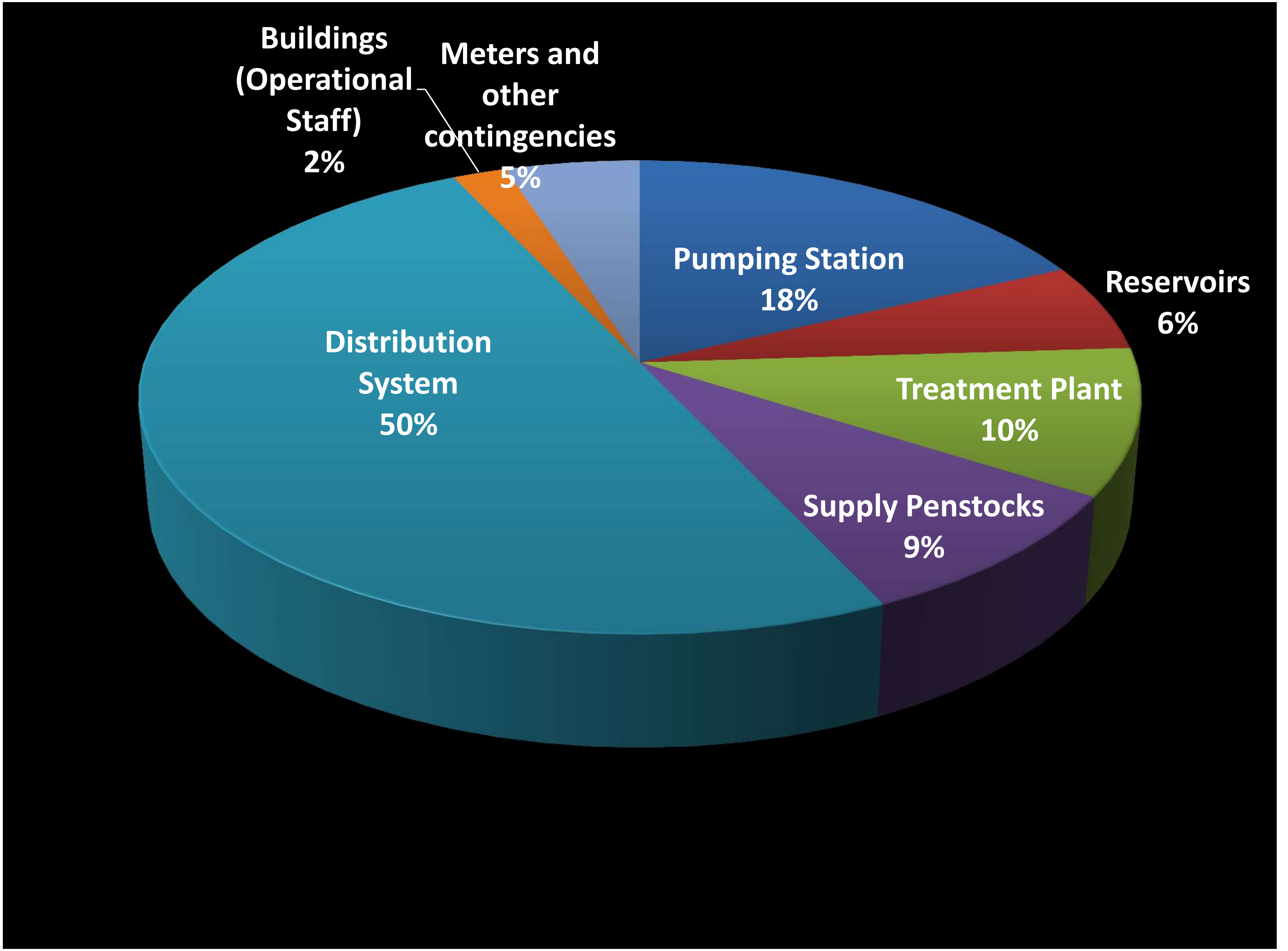
- Japan US$635million – largest donor
  - Projects approved between 2006 and 2009 include Guwahati Water Supply Project (Phase I and II) in Assam
  - Kerala Water Supply Project (Phase II and III)
  - Hogenakkal Water Supply and Fluorosis Mitigation Project (Phase I and II) in Tamil Nadu
  - Goa Water Supply and Sewerage Project
  - Agra Water Supply Project
  - Amritsar Sewerage Project in Punjab
  - Orissa Integrated Sanitation Improvement Project
  - Bangalore Water Supply and Sewerage Project (PhaseII)
- World bank US$130million – financial support in Andhra Pradesh, Karnataka, Tamil Nadu, Uttaranchal and Punjab
- Asian Development Bank
- Germany

General Layout of a Water Supply Scheme using River as a Source of Water



Tentative costs of Components of a water supply scheme

Sl. No	Component Item	Cost of the item expressed as percentage of the total
1.	Pumping Stations	18%
2.	Reservoirs	6%
3.	Treatment Plant	10%
4.	Supply Penstocks	9%
5.	Distribution System	50%
6.	Buildings for housing operational staff, etc.	2%
7.	Meters and other contingencies	5%
	Total	100%


Buildings (Operational Staff) 2%
Meters and other contingencies 5%
Pumping Station 18%
Reservoirs 6%
Treatment Plant 10%
Supply Penstocks 9%
Distribution System 50%

Domestic Tariff (BWSSB)

Consumption Slab Liters	Tariff Rs.	Minimum Rs.
0-8000	6.00	48.00
8001 – 25,000	9.00	201.00
25,001 – 50,000	15.00	676.00
50,001 – 75,000	30.00	1326.00
75,001- 100,000	36.00	2226.00
100,000 and above	36.00	5826.00

Non-domestic tariff (BWSSB)

Consumption Slab Liters	**Tariff Rs.**	**Minimum Rs.**
0- 10000	36.00	360.00
8001 – 25,000	39.00	390.00
25,001 – 50,000	44.00	880.00
50,001 – 75,000	51.00	1002.00
75,001- 100,000	57.00	2280.00
100,000 and above	60.00	

Industrial tariff: Rs.60 per kilo-liter.

Planning Guidelines for Water Supply and Sewerage

Purpose

- Identify service needs in the short, medium and long term in order to deliver defined service standards, social, environmental and financial outcomes
- Evaluate options for delivering the defined outcomes
- Determine the optimal strategy that delivers the defined outcomes at the lowest financial, social and environmental cost
- Communicate the outcomes of the planning process to decision makers through a planning report

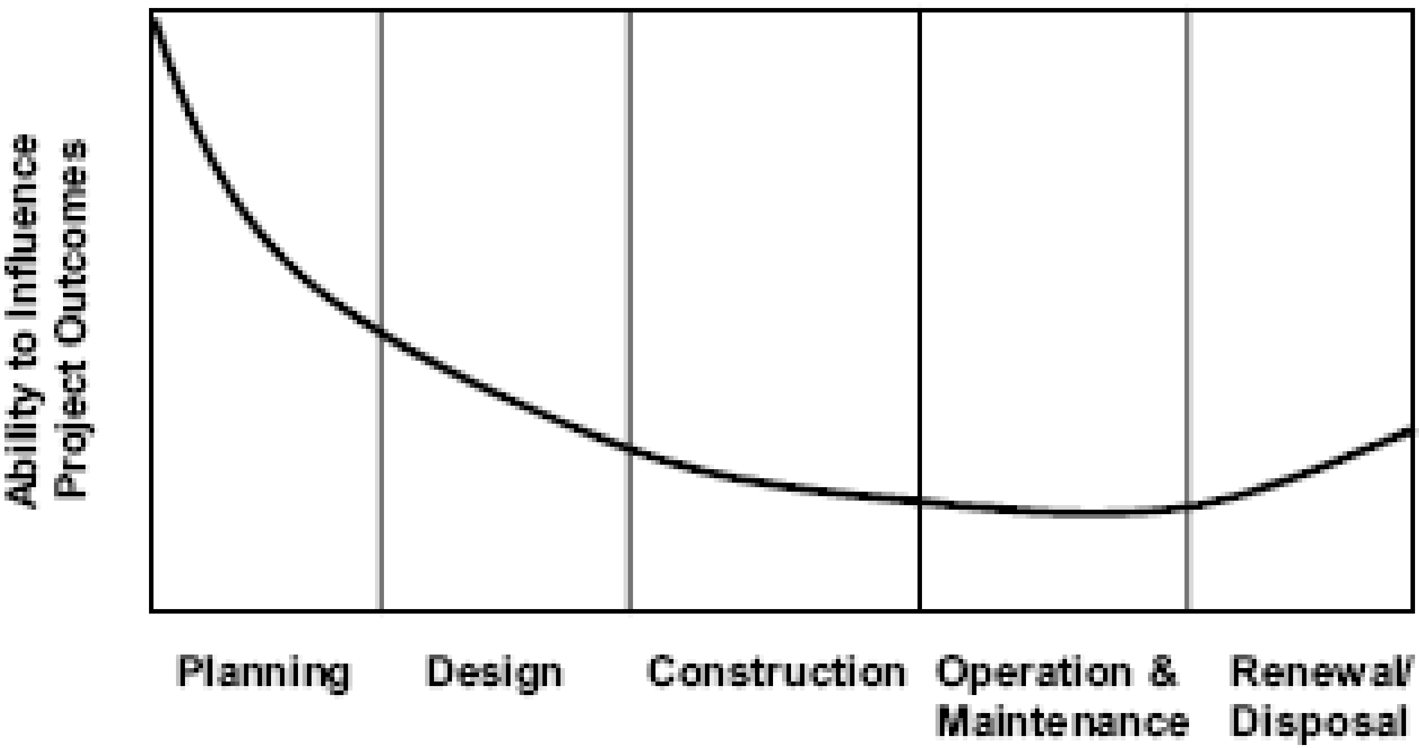
Key Principles

- Include comprehensive and rigorous identification of all options to meet service levels
- Iterative process which attempts to balance service needs with infrastructure, operation and maintenance, financial and environmental options
- Key stakeholders identified and involved in planning stage

Why Planning is Important?

- Planning stage – early stage of an initiative which influences the project outcomes, minimize risk and reduce costs
- Investment in planning results in substantial dividends
- Cost of planning is low (as compared to capital expenditure involved in construction and Operation and Maintenance)

FIGURE 3.1 – Ability to Influence Project Outcomes



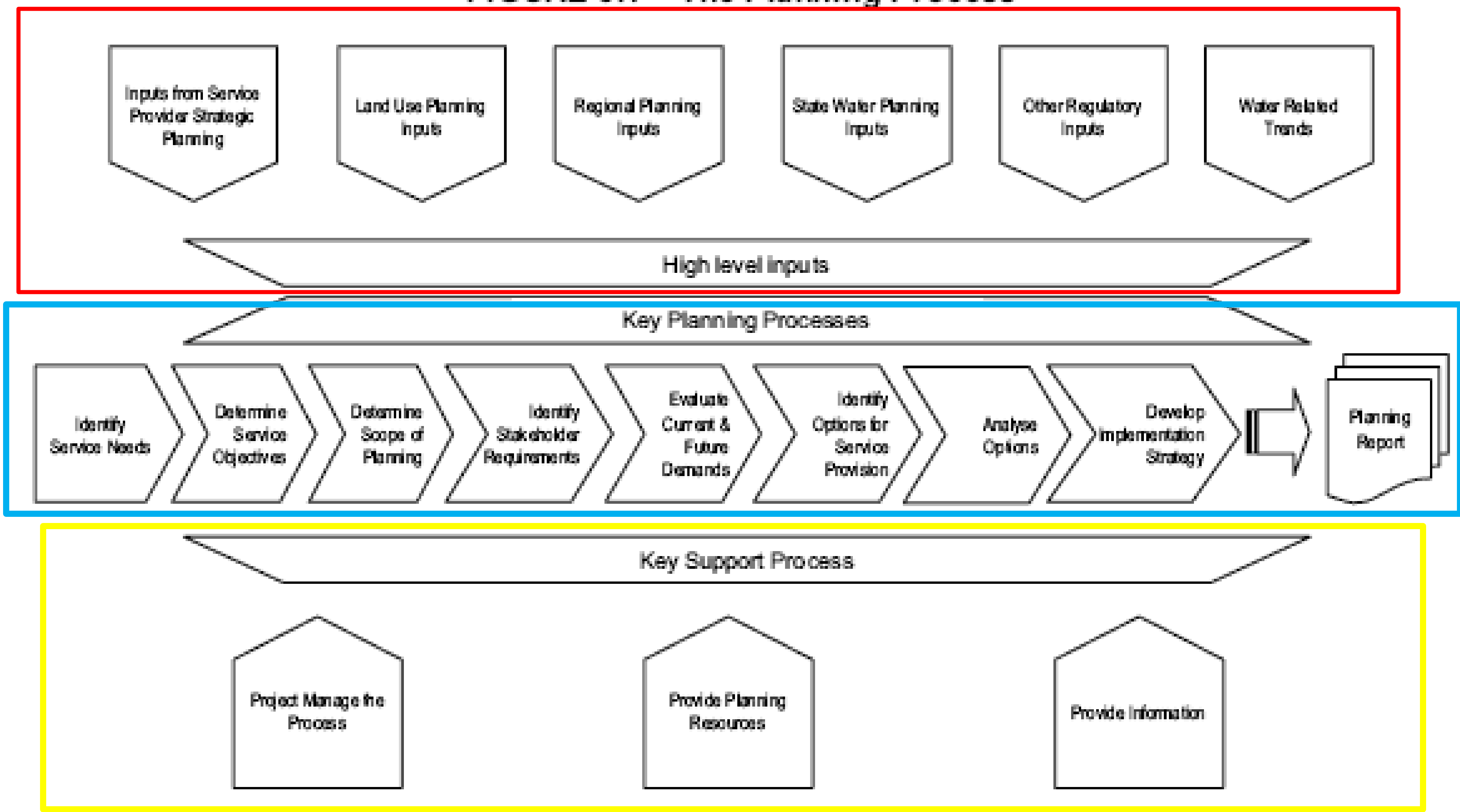
Outcomes from effective planning include:

- Common understanding of the issues, options and outcomes by all stakeholders
- Cost effective Infrastructure investment program
- Achievement of an optimal, financial, social and environmental result
- Lower costs to the customer
- Continued achievement of service standards
- Protection of the natural and built environment
- Minimization of risk
- Appropriate solutions for available skill level

Issues simulated for planning

- Changes in unit demands for services
- Variation in growth projections
- Adverse trends in customer service levels
- Changes in community attitudes
- Changes in technology
- Changes in regulatory requirements or guidelines
- Timeframes for the provision of critical infrastructure to meet service demands

FIGURE 5.1 – The Planning Process



Higher Level Inputs

High Level Input	Typical Source of Information
Service Provider Strategic Planning	Information provides strategic direction for the delivery of water and sewerage services and storm water management. It would address matters such as customer service standards and financial, social and environmental objectives. Information would typically be provided from ➢ Corporate plan ➢ Business plan ➢ Operations plan ➢ Total Strategic Management Plan ➢ Customer Service Standards ➢ Environmental Management Plan - Iterative process.
Land Use Planning	➢ Strategic Land Use Plan ➢ Priority Infrastructure Plan ➢ Integrated Catchment Management Plan

Regional Planning	➢ Regional and Sub Regional Planning Strategy Plans and Studies ➢ Regional and Sub Regional Infrastructure Planning Studies
State Water Planning	➢ Water Resource Plan (WRP) ➢ Resource Operations Plan ➢ Resources Operations Licence (ROL) ➢ Regional Water Supply Strategies
Other Regulatory Inputs	➢ Water Act ➢ Environmental Protection Act
Water Related Trends	Issues covered : ➢ Climate Change ➢ Status of the Environment and Future Scenarios ➢ Planning Trends (e.g. Integrated Water Management) ➢ Trends in Technology ➢ Regulatory Trends ➢ Trends in community perception ➢ Trends in customer needs

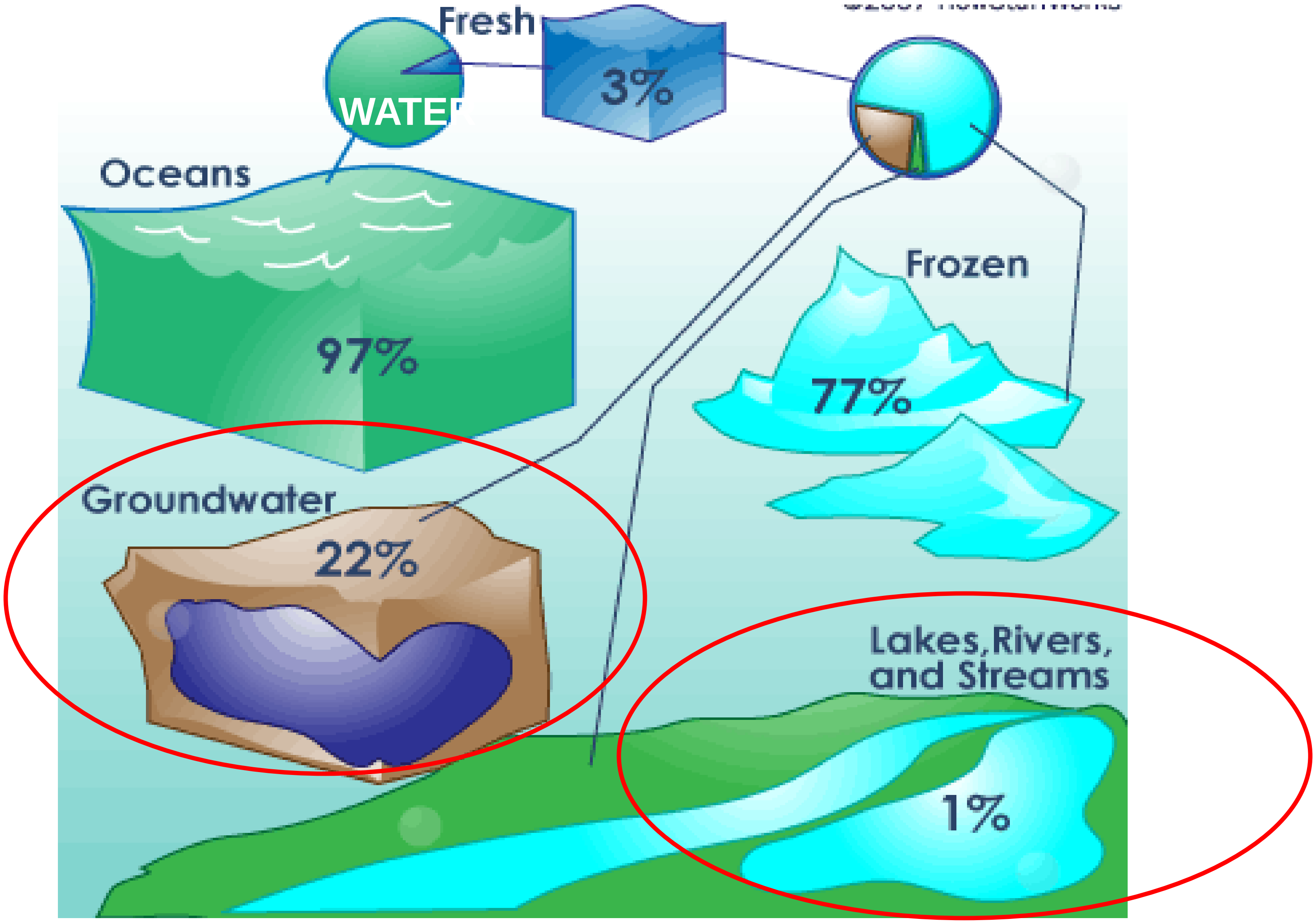
Key Elements

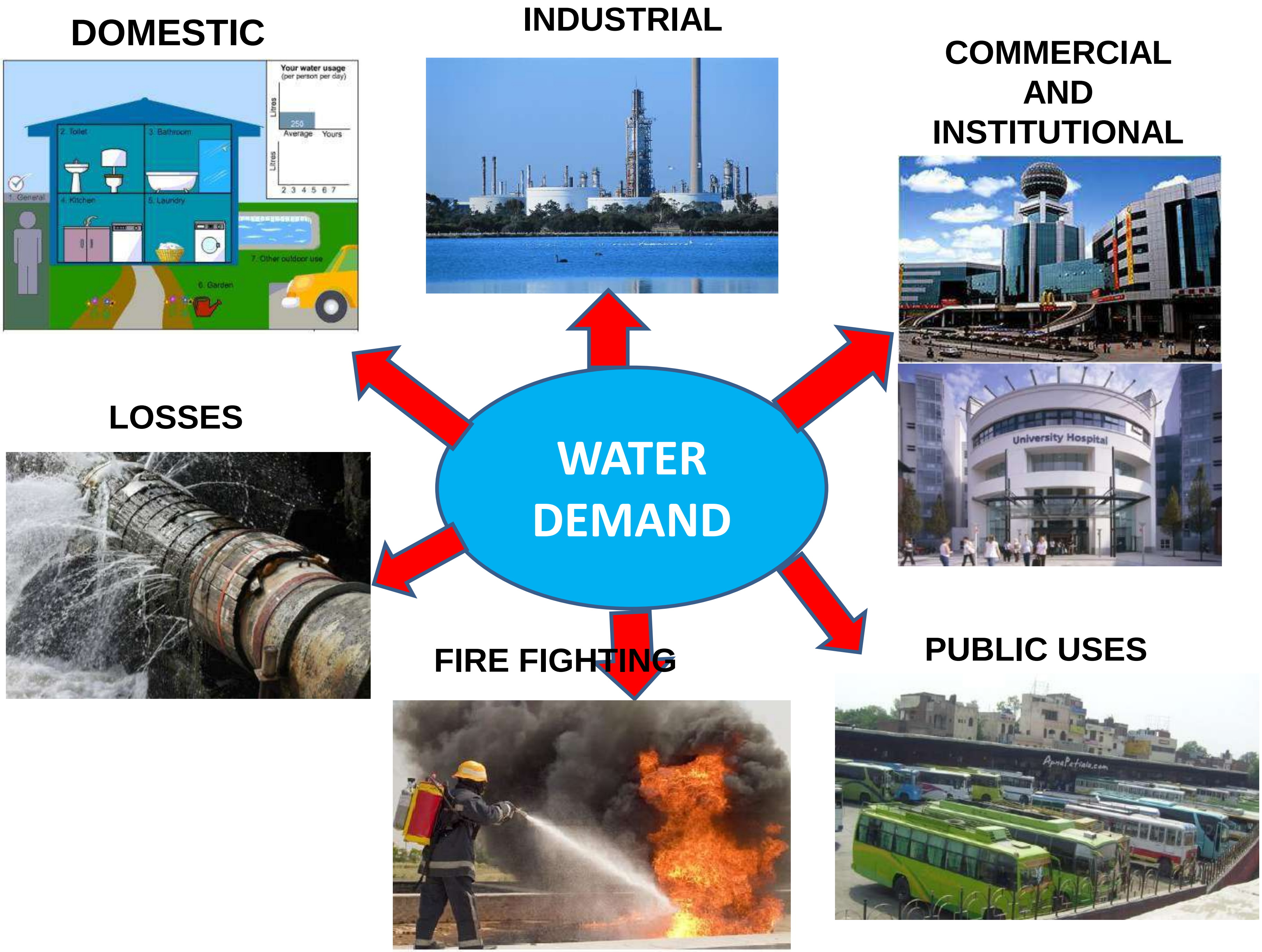
- Identify Service Need
- Determine Service Objectives
- Determine Scope of Planning
- Identify Stakeholder Requirements
- Evaluate Current and Future Demands
- Identify Options for Service Provision
- Undertake Options Analysis
- Develop Implementation Strategy
- Outputs from the planning process

Key Support Processes

- Project Management
- Planning Information
- Planning Resources

DISTRIBUTION OF WATER ON EARTH




DOMESTIC
Your water usage
(per person per day)
Litres
250
Average
Yours
2. Toilet
3. Bathroom
1. General
4. Kitchen
5. Laundry
7. Other outdoor use
6. Garden
INDUSTRIAL
COMMERCIAL
AND
INSTITUTIONAL
University Hospital
LOSSES
WATER
DEMAND
FIRE FIGHTING
PUBLIC USES

Minimum Domestic Water Consumption (Annual Average) for Indian Towns and Cities

Sl.No.	Use	Consumption	
		(For Flushing Systems as per IS:1172 - 1993	**(LIG and Weaker Sections)**
1.	Drinking	5	5
2.	Cooking	5	5
3.	Bathing	75	55
4.	Washing of Clothes	25	20
5.	Washing of Utensils	15	10
7.	Washing and Cleaning of Houses and Residences	15	10
8.	Lawn watering and Gardening	15	-
9.	Flushing of Water Closets, etc.	45	30
	Total	**200**	**135**

Industrial Need

Sl.No.	Industry	Unit of Production	Water Requirements in Kilolitres per unit
1.	Automobile	Vehicle	40
2.	Fertilizer	Tonne	80-200
3.	Leather	100kg(tonne)	4
4.	Paper	Tonne	200-400
5.	Steel	Tonne	200-250
6.	Sugar	Tonne(cane crushed)	1-2
7.	Textile	100kg (goods)	8 - 14

Water for Institutional Needs

Sl.No.	Institution	Water Requirement (litres per head per day)
1.	Hospitals (including Laundry) (a) No. of beds > 100 (b) No. of beds < 100	 450 (per bed) 340 (per bed)
2.	Hotels	180 (per bed)
3.	Hostels	135
4.	Boarding Schools/Colleges	135
5.	Restaurants	70 (per seat)
6.	Airports and Sea Ports	70
7.	Day Schools/Colleges	45
8.	Offices	45
9.	Cinemas, Concert Halls and Theatres	15

Water Consumption for Various Purposes

Sl.No	Types of Consumption	Normal Range (litres/capita/day)	Average	%
1.	Domestic Consumption	65-300	160	35
2.	Industrial and Commercial Demand	45-450	135	30
3.	Public Uses including Fire Demand	20-90	45	10
4.	Losses and Waste	45-150	62	25

Breakup of Per Capita Demand for an Average Indian City

Sl.No.	Use	Demand, Lpcd
1.	Domestic	200
2.	Industrial	50
3.	Commercial	20
4.	Public use	10
5.	Wastes and Thefts etc.	55
	Total	335

Fire Demand

- Fire hydrants of 15-20cm diameter, normally provided on all street corners and at suitable intermediate points.
- Minimum water pressure available at fire hydrants should be of the order of 100 to 200 kN/m^2 (0.1 to 0.2 N/mm^2).
- For a fire of moderate nature, three jet streams are simultaneously thrown from each hydrant; one on the burning property and one each on adjacent property on either side of the burning property. The discharge of each stream should be about 1100 litres/minute.
- For Indian conditions, a provision of 1 litre per head per day will be sufficient for fire fighting

Fire Fighting Demand

- Empirical Formulae

Sl.No.	Authority	Formulae (P in thousand)	Q for 1 lakh Population
1.	Kuchling's Formula	Q (Litres/min.) = $3182\sqrt{P}$	31820
2.	Freeman's Formula	Q (Litres/min.) = $1136\ (\frac{P}{5} + 10)$	34080
3.	National Board of Underwriters Formula	$Q = 4637\sqrt{P}\left(1 - 0.01\sqrt{P}\right)$	41760
4.	Buston's Formula	$Q = 5663\sqrt{P}$	56630

P = Population in thousands

$$Q = \frac{4360T^{0.275}}{(t+12)^{0.757}} litres/min$$

$$t = duration\ of\ fire\ in\ mins$$

$$T = period\ of\ occurance\ of\ fire\ in\ years$$

Recommended minimum values for the above formula are:

t= 30mins and T=1year

Terms

- Design Period – It is the number of years for which the system or component is to be adequate
- Design Population – The number of persons to be served
- Design area – area to be served by the system or component for the residential, commercial and industrial districts and public areas
- Design Flows – rates of consumption for the residential, commercial, industrial districts and public areas of the city

Design Periods for Project Components

Sl.No.	Component	Design Period (Years)
1.	Storage by Dams	50
2.	Infiltration Works	30
3.	Pump Sets (i) All Prime Movers except electric motors (ii) (ii) Electric Motors and Pumps	 30 15
4.	Water Treatment Units	15
5.	Pipe connections to the several treatment units and other small appurtenances	30
6.	Raw water and clear water conveying mains	30
7.	Clear water reservoirs at the head works, balancing tanks and service reservoirs (over head or ground level)	15
8.	Distribution system	30

Per Capita Demand

- Let the total annual volume of water required for a population of ‘x’ (in terms of litres (or) KL (or) .... } = V
- Annual average water consumption by ‘x’ population (L/day) } = V/365
- Annual average water consumption per person per day (L/day/person) } = V/(365 * x)

Per Capita Demand

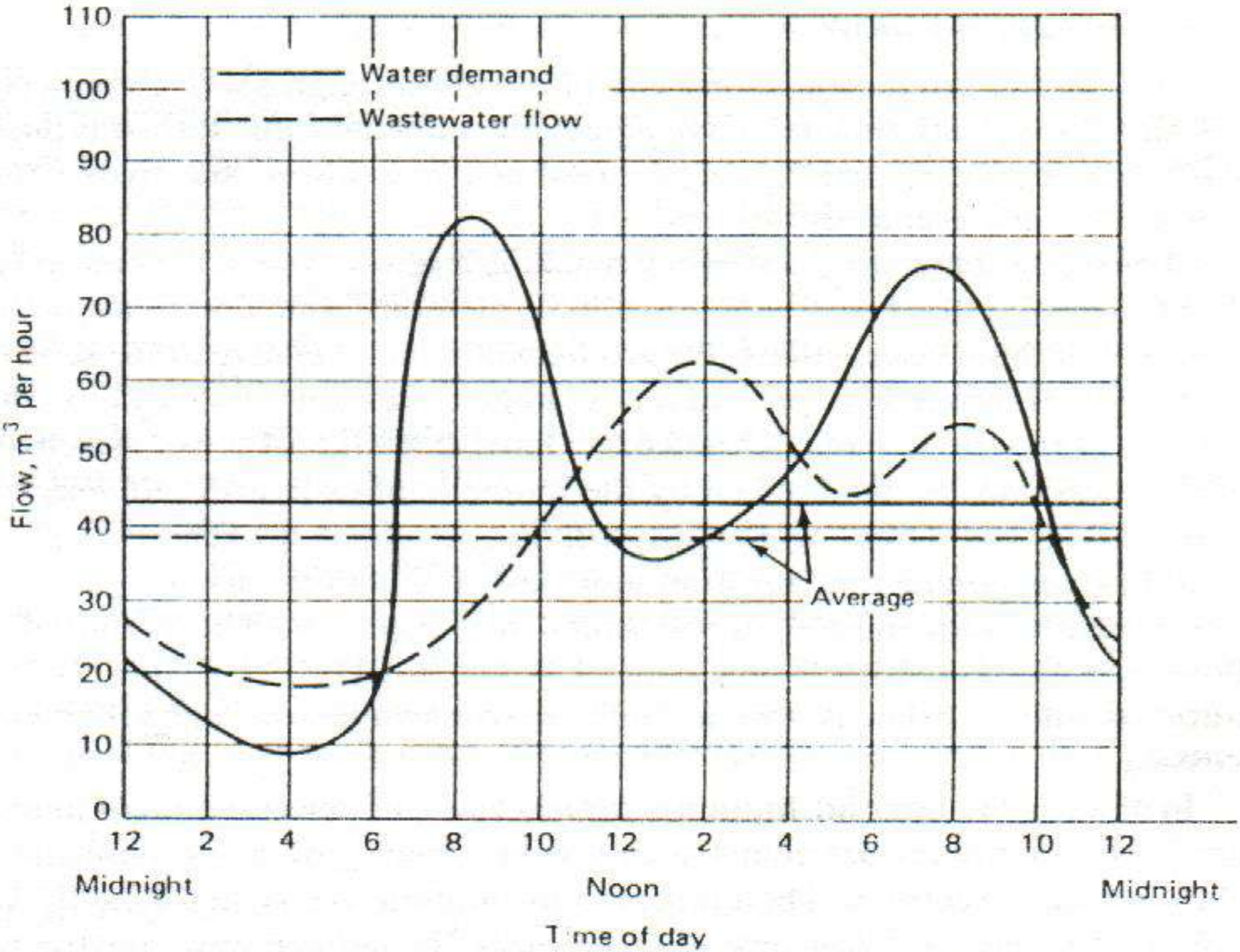
Factors affecting Per Capita Demand

- Size of the city
- Presence of Industries
- Climatic Conditions
- Habits of people and their economic status
- Quality of water
- Pressure in the distribution system
- Efficiency of water works administration
- Cost of water
- Policy of metering and charging method

Fluctuations in Rate of Demand

- Variations in Water Consumption occur throughout the day, week and season of the year
- The average annual water consumption is the total water consumption for the year divided by the number of days per year and the population of the city
- There will be a variation in water demand throughout the day, week and the month. The variations area a characteristic of each city and they must be determined by studying water consumption or water pumpage records for the city begin investigated

Average Daily Per Capita Demand = Quantity Required in 12 Months/(365 x Population)



Water demand
Wastewater flow
Average
Flow, m^3 per hour
110
100
90
80
70
60
50
40
30
20
10
0
12
2
4
6
8
10
12
2
4
6
8
10
12
Midnight
Noon
Midnight
T me of day

Maximum daily flow. The maximum flow rate that occurs over a 24-hour period based on annual operating data. The maximum daily flow rate is important particularly in the design of facilities involving retention time such as equalization basins and chlorine-contact tanks.

Maximum hourly flow. The peak sustained hourly flow rate occurring a 24-hour period based on annual operating data. Data on peak hourly flows are needed for the design of flow meters, pumping, grit chambers, sedimentation tanks.

Minimum daily flow. The minimum daily flow rate that occurs over a 24-hour period based on annual operating data. Minimum flow rates are important in the sizing of conduits where solid deposition might occur at low flow rates.

Minimum hourly flow. Data on the minimum hourly flow rate are needed to determine possible process effects. At some treatment facilities, such as those using trickling filters, recirculation of effluent is required to sustain the process.

- Maximum daily demand = 1.8 x average daily demand
- Maximum hourly demand of maximum day i.e.

Peak demand = 1.5 x avg. hourly demand

= 1.5 x Maximum daily demand/24

= 1.5 x (1.8 x avg.daily demand)/24

= 2.7 x average daily demand/24

= 2.7 x annual average hourly demand

$$p = 180t^{-0.10}$$

Where p = percentage of annual average consumption for time t in days
t = Time in days from 1/24 to 365 days

t = 1 day (for daily variations)
$p = 180 \times (1)^{-0.10} = 180$

$$\frac{Max.\ daily\ demand}{Averagedailydemand} = 180\%$$

When t = 7 days (for weekly vaiorations)
$P=180(7)^{-0.10} = 148\%$

$$\frac{Max.\ weekly\ demand}{Average\ weekly\ demand} = 148\%$$

When t = 30 days (for monthly variations)

$p = 180\ (30)^{-0.10}$

$$\frac{Max.\ monthly\ demand}{Average\ monthly\ demand} = 128\%$$

- Seasonal Variation: Demand peaks during summer. Fire Breakouts are generally more in summer
- Daily Variation: depends on the activity. People draw more water on sundays and festival days, thus increasing demand on these days
- Hourly variations

Population Forecasting Methods

- Arithmetic Increase Method
- Geometric Increase Method
- Incremental Increase Method
- Decreasing Rate of Growth Method
- Graphical Comparison with similar cities
- Ratio Method
- Logistic Curve Method

Arithmetic Increase Method

- Population is assumed to increase at a constant rate. This is the most simple method of population forecast. In this method, the increase in population from decade to decade is assumed constant. The method is used for short- term estimates (1 – 5 yr).

Mathematically,

$$\frac{dP}{dt} = K$$

Where dP/dt is the rate of change of population and K is a constant.

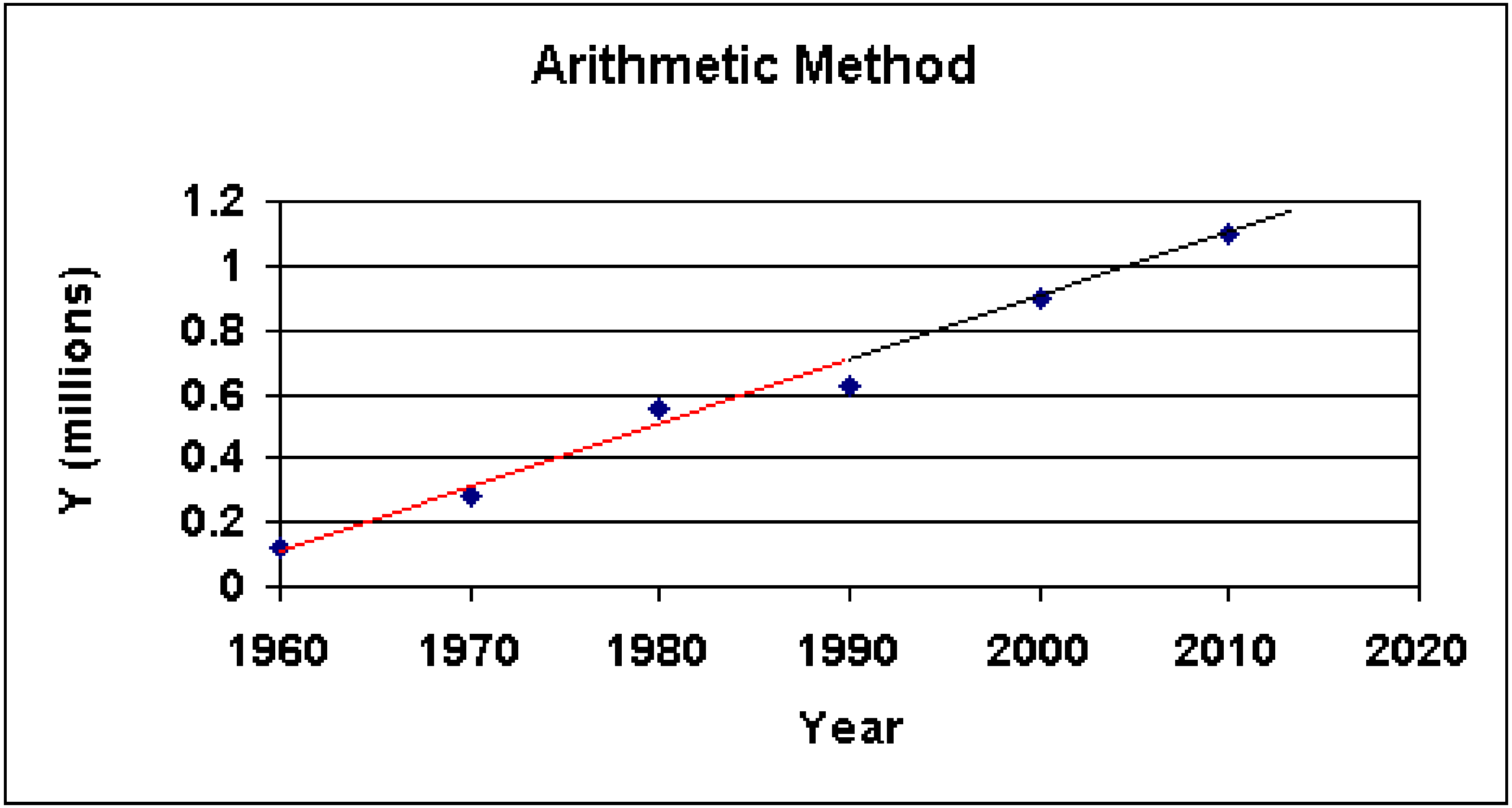
The future population is given by

$$P_n = P + nI$$

Where Pn = future population at the end of n decades

P = present population

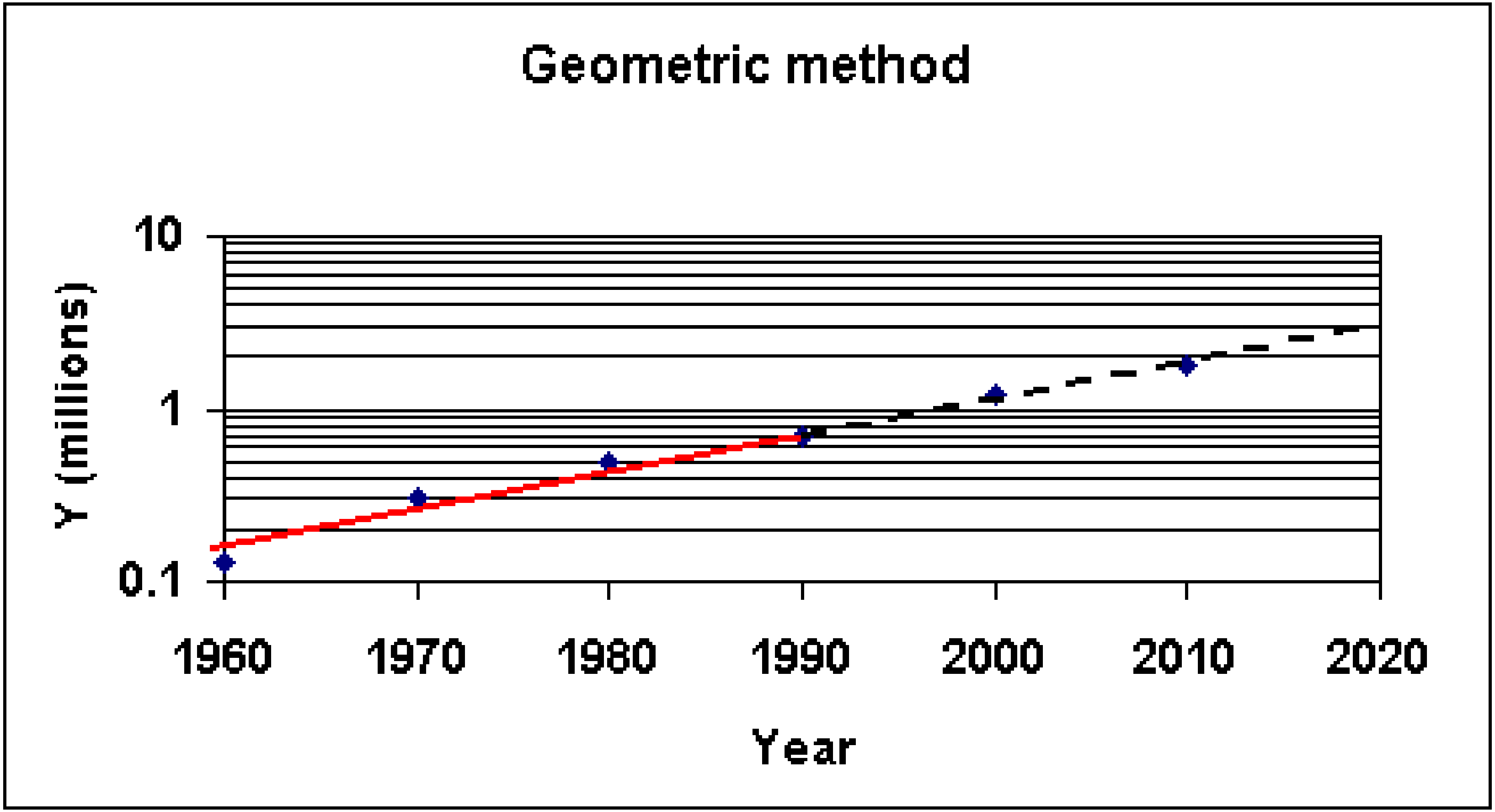
I = average increment for a decade



Geometrical Increase Method

- Population is assumed to increase in proportion to the number present. i.e., the percentage increase in population from decade to decade is constant. If Ig is the average percentage increase per decade, or rg is the increase per decade expressed as ratio, the population Pn after n decades is given by

$$P_n = P\left(1 + \frac{i_g}{100}\right)^n = P\left(1 + r_g\right)^n$$



Geometric method
10
1
0.1
Y (millions)
1960
1970
1980
1990
2000
2010
2020
Year

Incremental Increase Method

- This method combines both the arithmetic average method and the geometrical average method. Growth rate is assumed to be progressively increasing or decreasing, depending upon whether the average of the incremental increase in the past is positive or negative. The population for a future decade is worked out by adding the mean arithmetic increase to the last known population as in the arithmetic increase method, and to this is added the average of incremental increases, once for first decade, twice for second and so on.

The future population at the end of n decades is given by

$$P_n = P + nI + \frac{n(n+1)}{2}r$$

Where
P = present population
I = average increase per decade
r = average incremental increase
n = number of decades

Decreased Rate of Growth Method

- It is found that the rate of increase of population never remains constant, but varies. In this method, the average decrease in the percentage increase is worked out, and is then subtracted from the latest percentage increase to get the percentage increase of next decade.

Decreased Rate of Growth Method

City has some limiting saturation population and that rate of growth is a function of population deficit. Hence, as the city expands, smaller will be the rate of growth from year to year. The Saturation population must be calculated to obtain the design population.

$$\frac{dP}{dt} = K_d * (S - P)$$

$$K_d = \left(\frac{-\ln[(S - P_2)/(S - P_1)]}{t_2 - t_1} \right)$$

$$P = P_1 + \left\{ (S - P_1) * \left(1 - e^{-K_d(t - t_1)} \right) \right\}$$

Where, K_d = Decreasing rate of growth constant

S = Saturation Population

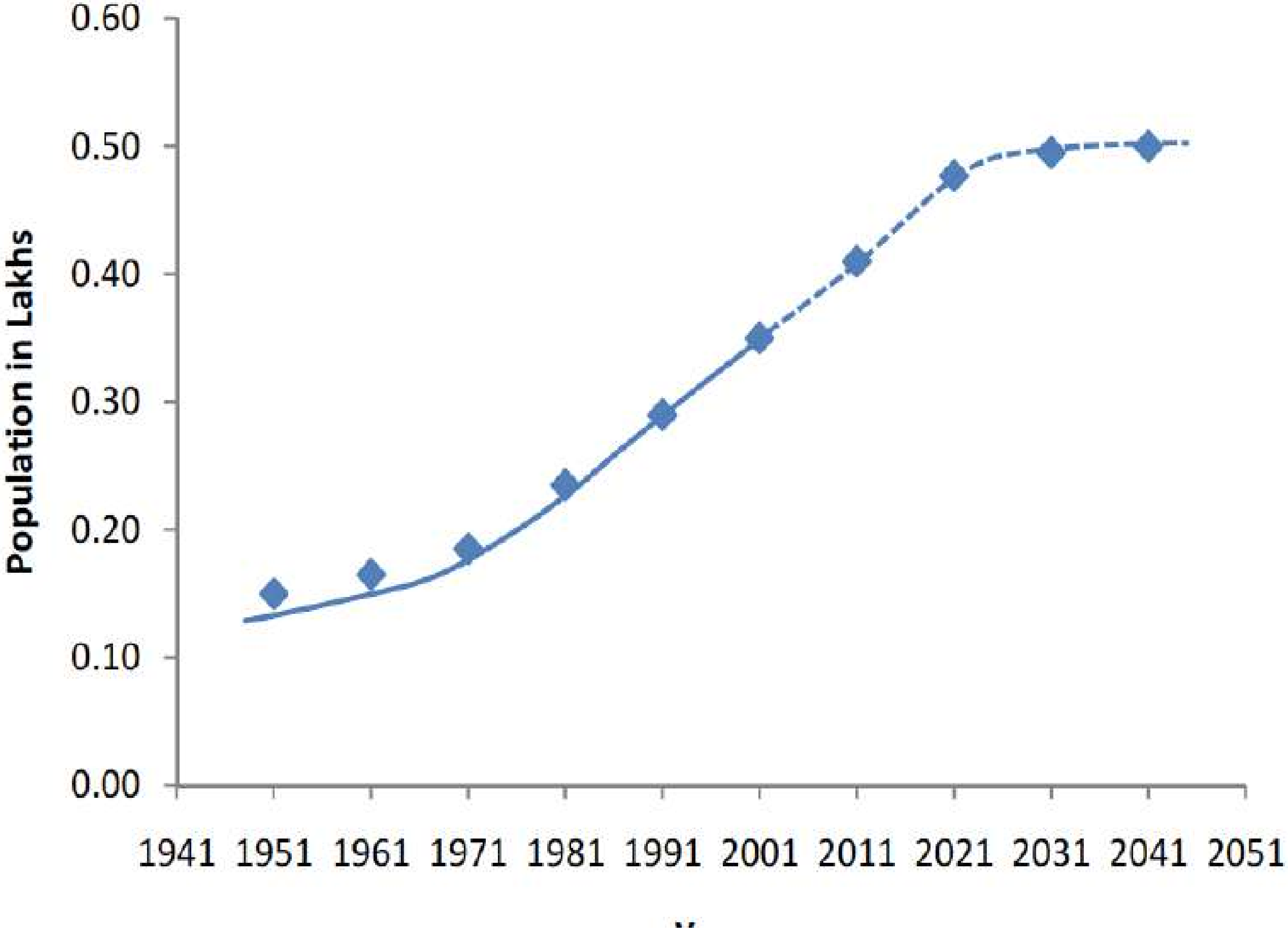
P = Population

P_1 = Population at last census

t = Time

5. Graphical Increase Method

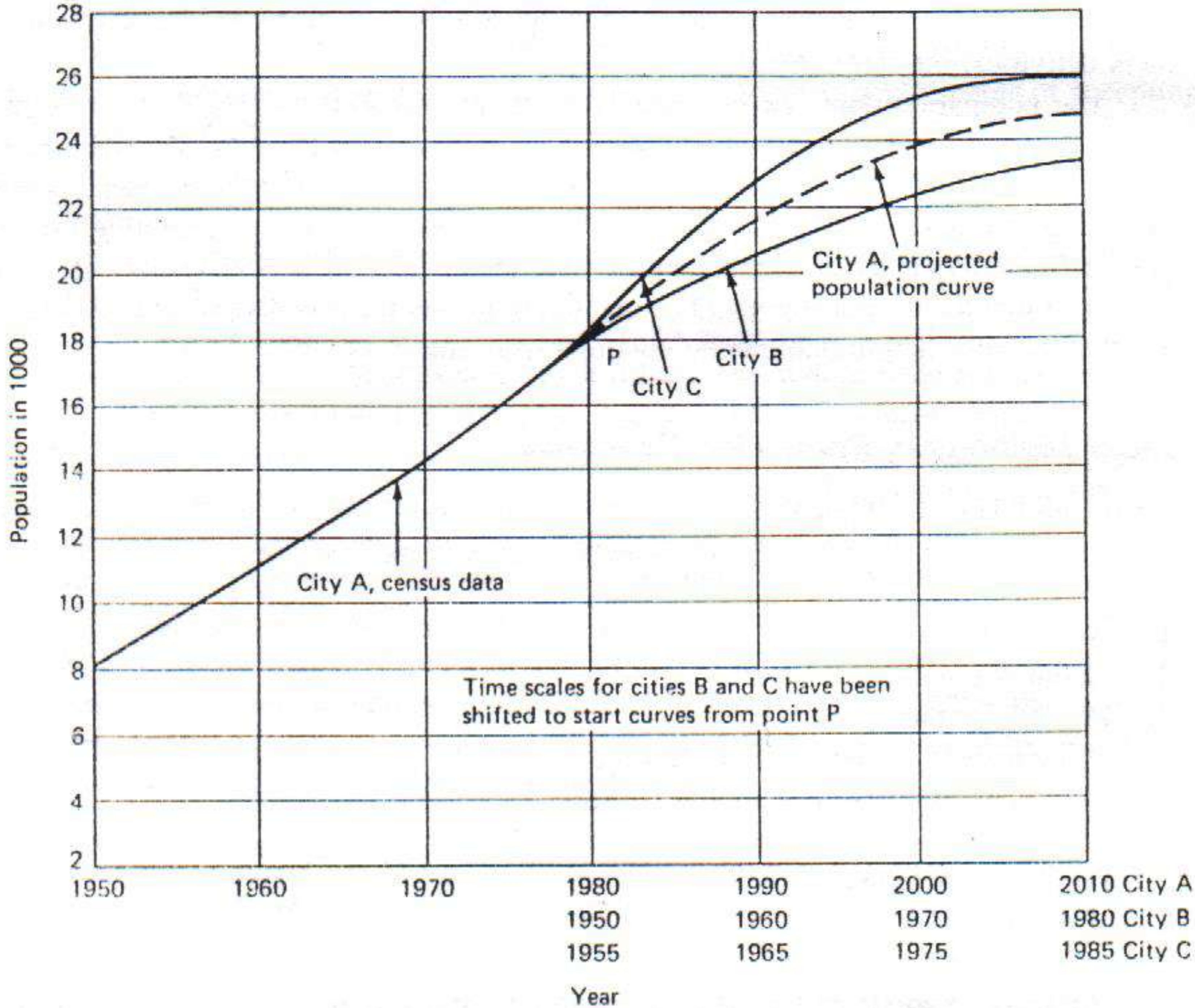
In this method, the populations of last few decades are correctly plotted to a suitable scale on graph. The population curve is smoothly extended for getting future population. This extension should be done carefully and it requires proper experience and judgment. The best way of applying this method is to extend the curve by comparing with population curve of some other similar cities having the similar growth condition.



0.60
0.50
0.40
0.30
0.20
0.10
0.00
Population in Lakhs
1941
1951
1961
1971
1981
1991
2001
2011
2021
2031
2041
2051

Comparative Graphical Method

- In this method, the cities having conditions and characteristics similar to the city whose future population is to be estimated are selected. It is then assumed that the city under consideration will develop, as the selected similar cities have developed in the past.



28
26
24
22
20
18
16
14
12
10
8
6
4
2
Population in 1000
City A, projected
population curve
P
City C
City B
City A, census data
Time scales for cities B and C have been
shifted to start curves from point P
1950 1960 1970 1980 1990 2000 2010 City A
1950 1960 1970 1980 City B
1955 1965 1975 1985 City C
Year

7. Master Plan Method

The big and metropolitan cities are generally not developed in haphazard manner, but are planned and regulated by local bodies according to a master plan. The master plan is prepared for the next 25 to 30 years for the city. According to the master plan, the city is divided into various zones such as residential, commercial and industrial. The population densities are fixed for various zones in the master plan. From this population density, total water demand and wastewater generation for that zone can be worked out. Hence, by this method it is very easy to precisely determine the design population. This method is also called the **Zoning Method**

Ratio Method

- In this method, the local population and the country's population for the last four to five decades is obtained from the census records. The ratios of the local population to national population are then worked out for these decades. A graph is then plotted between time and these ratios, and extended up to the design period to extrapolate the ratio corresponding to future design year. This ratio is then multiplied by the expected national population at the end of the design period, so as to obtain the required city's future population.

Drawbacks: 1. Depends on accuracy of national population estimate

2. Does not consider the abnormal or special conditons which can lead to population shifts from one city to another

The population growth of a small town or area is related to big towns or big areas. The increase in population of big cities bear a direct relationship to the whole state or country. In this method, the local to national (or state) population ratio is determined in the previous two to four decades. Depending on the conditions and other influencing factors, even changing ratio may be adopted. These ratios may be used in predicting future population growth. This approach considers the regional and national factors affecting population growth. This method is suitable only for those areas whose population growth in the past is fairly consistent with that of state or nation.

8. Ratio and Correlation Method (Continued)

$$\frac{P_2}{P_{2R}} = \frac{P_1}{P_{1R}} = K_R$$

P_2 = Projected population
P_{2R} = Projected population in the larger region
P_1 = Population at last census for the projected region
P_{1R} = Population at last census for the projected region in the larger region
K_R = ratio or correlation constant

9. Growth Composition Analysis Method

The change in population of a city is due to three reasons: (a) birth, (b) death, and (c) migration from villages and other towns. The population forecast may be made by proper analysis of these three factors. The difference between birth rate and death rate gives the natural in crease in population. Hence,

$$P_n = P + \text{Natural Increase} + \text{Migration}$$

The estimated natural expression is given by the following expression:

$$\text{Natural Increase} = T*(I_B*P - I_D*P)$$

T = Design (forecast period)

P = Present population

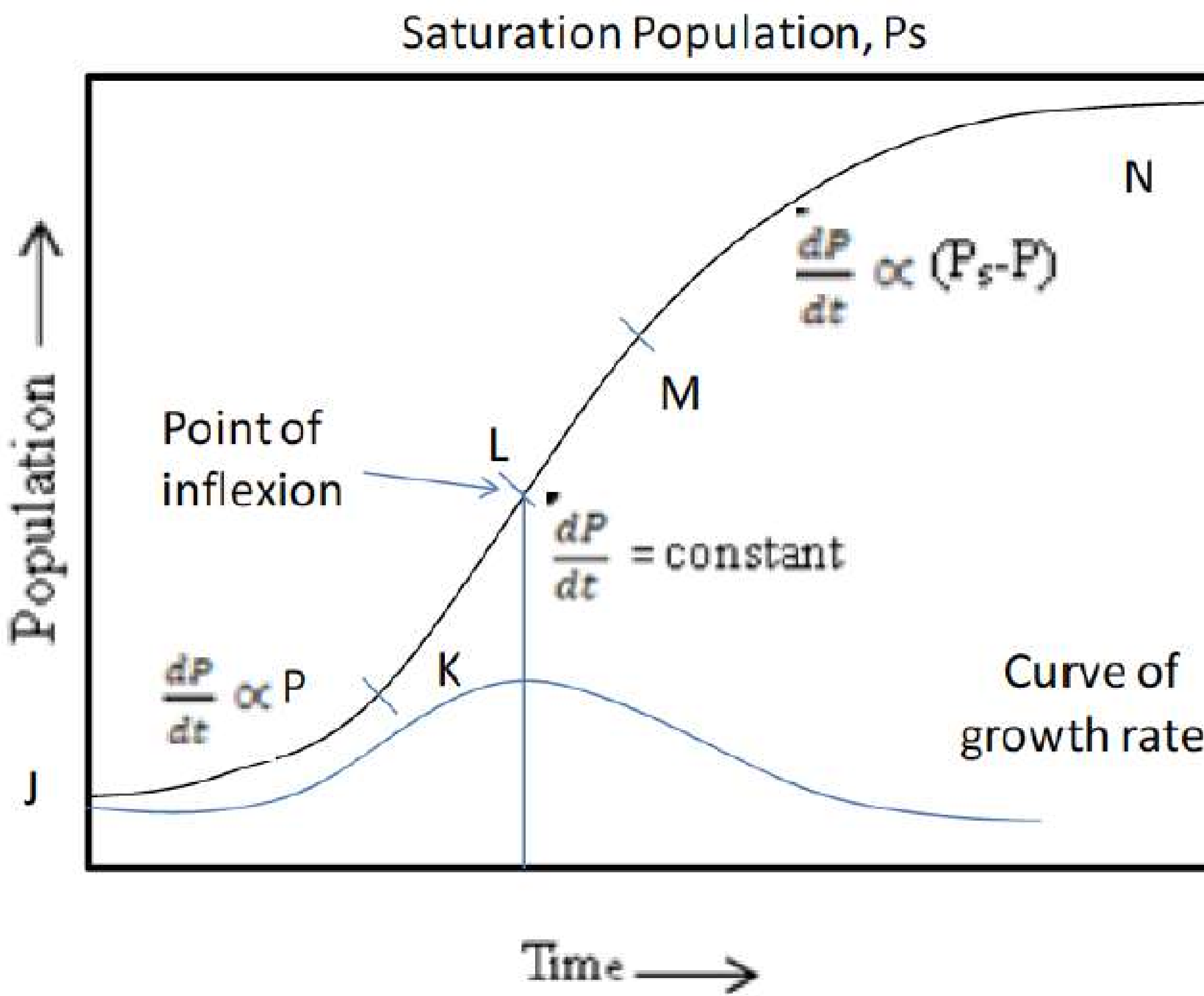
I_B = Average birth rate per year

I_D = Average death rate per year

Logistic Curve Method

- The three factors responsible for changes in population are:

(i) Births (ii) Deaths and (iii) Migrations. Logistic curve method is based on the hypothesis that when these varying influences do not produce extraordinary changes, the population would probably follow the growth curve characteristics of living things within limited space and with limited economic opportunity. The curve is S-shaped and is known as logistic curve.


Saturation Population, Ps
N
$\frac{dP}{dt} \propto (P_s - P)$
M
Point of inflexion
L
$\frac{dP}{dt}$ = constant
$\frac{dP}{dt} \propto P$
K
Curve of growth rate
J
Population
Time

In figure, the curve shows an early growth JK at an increasing rate i.e. geometric growth or log growth, $\frac{dP}{dt} \propto P$, the transitional middle curve KM follows arithmetic increase i.e. $\frac{dP}{dt}$ = constant and later growth MN the rate of change of population is proportional to difference between saturation population and existing population, i.e. $\frac{dP}{dt} \propto (P_s - P)$. Verhaulst has put forward a mathematical solution for this logistic curve JN which can be represented by an autocatalytic first order equation, given by

$$\log_e \left(\frac{Ps-P}{P}\right) - \log_e \left(\frac{Ps-P0}{P0}\right) = -K.P_s.t$$

P = Population at any time t from J

P_s = Saturation population

P_0 = Population of the city at start point J

K= Constant

T= Years

From the above equation we get

$$\log_e\left(\frac{Ps-P}{P}\right)\left(\frac{P0}{Ps-P0}\right) = -K.P_s.t$$

After solving we get,

$$P = \frac{P_S}{1+\frac{P_S-P_O}{P_O}\log_e^{-1}(-K.P_S.t)}$$

Substituting $\frac{Ps-P0}{P0} = m$ (a constant)

and $-K.P_s = n$ (another constant)

we get $P = \frac{P_S}{1+m\log_e^{-1}(n.t)}$

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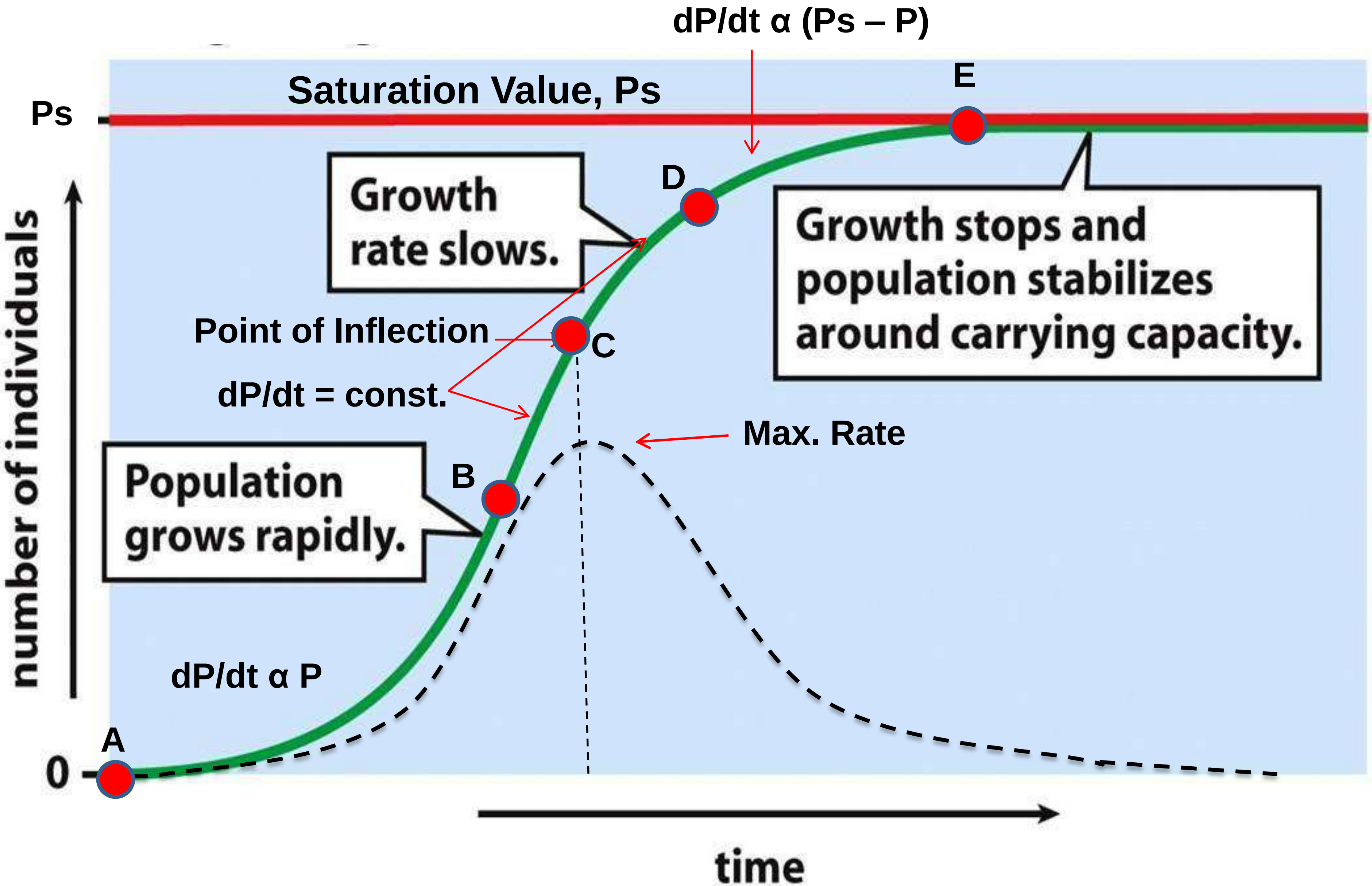
we get $\mathrm{P} = \frac{P_S}{1+m\log_e^{-1}(n.t)}$

This is the required equation of the logistic curve, which will be used for predicting population. McLean further suggested that if only three pairs of characteristic values P_0, P_1, P_2 at times $t = t_0 = 0$, t_1 and $t_2 = 2t_1$ extending over the past record are chosen, the saturation population P_s and constant m and n can be estimated by the following equation, as follows:

$$P_s = \frac{2P_0P_1P_2 - P_1^2(P_0 + P_2)}{P_0P_2 - P_1^2}$$

$$m = \frac{Ps - P0}{P0}$$

$$n = \frac{2.3}{t_1}\log_{10}\left(\frac{P_0(P_S - P_1)}{P_1(P_S - P_0)}\right)$$



dP/dt α (Ps – P)
Saturation Value, Ps
E
Ps
D
Growth rate slows.
Growth stops and population stabilizes around carrying capacity.
Point of Inflection
C
dP/dt = const.
Max. Rate
B
Population grows rapidly.
number of individuals
dP/dt α P
A
0
time

$$P = \frac{P_s}{1 + e^{a+b\Delta t}}$$

$$P_s = \frac{2P_0P_1P_2 - P_1^2(P_0 + P_2)}{P_0P_1 - P_1^2}$$

$$a = ln\left(\frac{P_s - P_0}{P_0}\right)$$

$$b = \frac{1}{n} ln \frac{P_0(P_s - P_1)}{P_1(P_s - P_0)}$$

P = population for a future year

Ps = Saturation Population

a,b = data constants

Δt = future time period, years

P0 = Population recorded during time t0

P1 = Population recorded during time t1

P2 = Population recorded at time t2

The number of years recorded between t0 and t1 and t1 and t2 is designated as n.

The logistic method is based on the fact that populations will grow until they reach a saturation population that is established by the limit of economic opportunity. All populations, without regard to size, tend to grow according to the s-shaped curve or logistic curve. The curve starts with a low rate of growth, followed by a high rate, and then by a progressively lower rate until the saturation population is reached

Example: The following is the population data of a city available from past census records. Determine the population of the city in 2011 by (a) arithmetical increase method (b) geometrical increase method © incremental increase method and (d) decreased rate of growth method

Year	1931	1941	1951	1961	1971	1981	1991
Population (P)	12000	16500	26800	41500	57500	68000	74100

Year	Population	Increment per decade	% increment per decade	Incremental Increase
1931	12000			
		4500	37.5	
1941	16500			+5800
		10300	62.42	
1951	26800			+4400
		14700	54.85	
1961	41500			+1300
		16000	38.55	
1971	57500			-5500
		10500	18.26	
1981	68000			-4400
		6100	8.97	
1991	74100			
	Total	62100	220.55	+1600
	Average	62100/6 = 10350	220.55/6 = 36.76	1600/5 = 320

Solution:

Arithmetic Average Method

$$P_n = P + nI$$

$$P_{2011} = 74100 + (2) * (10350) = 94800$$

Geometric Increase Method

$$P_n = P\left(1 + \frac{I_g}{100}\right)^n$$

Ig by Arithmetic Average

$$I_g = \frac{37.5 + 62.42 + 54.85 + 38.55 + 18.26 + 8.97}{6} = 36.76$$

$$I_g = 36.76; P_{2011} = 74100\left(1 + \frac{36.76}{100}\right)^2 = 138591$$

Ig by Geometric Average

$$I_g = (37.5 * 62.42 * 54.85 * 38.55 * 18.26 * 8.97)^{\frac{1}{6}} = 30.5357$$

$$I_g = 30.5357; P_{2011} = 74100\left(1 + \frac{30.5357}{100}\right)^2 = 126263$$

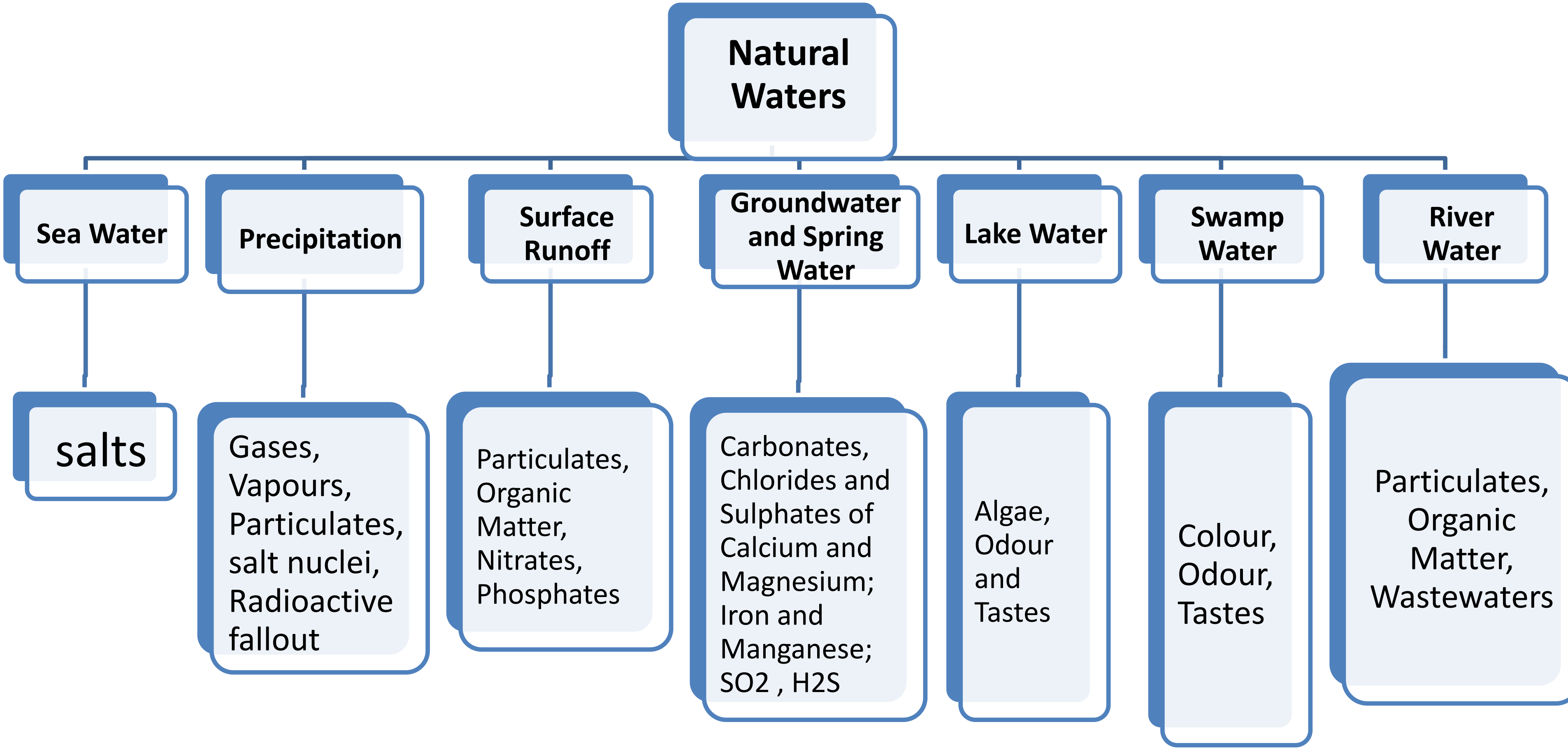
Incremental Increase Method

$$P_n = P + nI + \frac{n(n+1)}{2}r$$

$$P_{2011} = 74100 + (2 * 10350) + \frac{2(2+1)}{2} * 320 = 95760$$

Water System Losses

- Leakage and Overflow from service reservoirs
- Leakage from Main and Service Pipe Connections
- Leakage and Losses on Consumer’s Premises when they get un-metered household supplies
- Under-registration of supply meters
- Large Leakage or wastage from public taps
- Losses in supply lines
  - Defective pipe joints
  - Cracked pipes
  - loose valves and fittings


Natural Waters
Sea Water
Precipitation
Surface Runoff
Groundwater and Spring Water
Lake Water
Swamp Water
River Water
salts
Gases, Vapours, Particulates, salt nuclei, Radioactive fallout
Particulates, Organic Matter, Nitrates, Phosphates
Carbonates, Chlorides and Sulphates of Calcium and Magnesium; Iron and Manganese; SO2 , H2S
Algae, Odour and Tastes
Colour, Odour, Tastes
Particulates, Organic Matter, Wastewaters

Surface Water Sources	Ground Water Sources
Streams, Rivers, Lakes, Impounded Reservoirs	Pumped Wells or Flowing Artesian Wells
Users – Medium to Large sized Cities	Users – small to medium sized cities
Moderate to high Coliform Counts, High total bacterial counts, moderate to high turbidity, variable colour, Taste, low to moderate dissolved solids, variable DO and CO_2	Low turbidity, Colour, low Coliform Counts, low DO, moderate to high DS and CO_2
Need more flexibility in treatment	Higher quality and Uniform throughout the year
	Only Disinfection is required
	Easy to treat
	Disadvantages – Have high DS, Calcium, Magnesium, Iron, Manganese, Sulfate and Chloride contents. Removal of DS, sulfates and chlorides is difficult and expensive since distillation or ion exchange is required.

Forecasting of Population

Introduction

Design of water supply and sanitation scheme is based on the projected population of a particular city, estimated for the design period. Any underestimated value will make system inadequate for the purpose intended; similarly overestimated value will make it costly. Change in the population of the city over the years occurs, and the system should be designed taking into account of the population at the end of the design period.

Factors affecting changes in population are:

- increase due to births
- decrease due to deaths
- increase/ decrease due to migration
- increase due to annexation.

Additional Factors affecting changes in population are:

- Economic factors (like new development of industries)
- Development programs (projects of national importance)

Introduction

Additional Factors affecting changes in population are (continued):

- Social facilities (like educational, medical, recreational and other social facilities)
- Communication links (proper communication links to big cities and also to villages for agricultural products)
- Tourism (like tourist facilities, religious places or historical buildings)
- Community life (general standards of living, social norms and customs)
- Unforseen circumstances (like natural calamity)

The present and past population record for the city can be obtained from the census population records. After collecting these population figures, the population at the end of design period is predicted using various methods as suitable for that city considering the growth pattern followed by the city.

1. Arithmetical Increase Method

This method is suitable for large and old city with considerable development. If it is used for small, average or comparatively new cities, it will give low result than actual value. In this method the average increase in population per decade is calculated from the past census reports. This increase is added to the present population to find out the population of the next decade. Thus, it is assumed that the population is increasing at constant rate.

Hence, $dP/dt = C$ i.e. rate of change of population with respect to time is constant.

Therefore, Population after n^{th} decade will be $\mathbf{P_n = P + n.C}$

Where, P_n is the population after n decade and P is present population.

Example:1

Predict the population for the year 2021, 2031, and 2041 from the following population data.

Year	1961	1971	1981	1991	2001	2011
Population	8,58,545	10,15,672	12,01,553	16,91,538	20,77,820	25,85,862

Solution:

Year	Population	Increment
1961	858545	-
1971	1015672	157127
1981	1201553	185881
1991	1691538	489985
2001	2077820	386282
2011	2585862	508042

Average Increment over the years = 345463.

Population in year 2021 is, $P_{2021} = 2585862 + 345463 \times 1 = \underline{2931325}$

Similarly,

Population in year 2031 is, $P_{2031} = 2585862 + 345463 \times 2 = \underline{3276788}$

Population in year 2041 is, $P_{2041} = 2585862 + 345463 \times 3 = \underline{3622251}$

2. Geometrical Increase Method

In this method the percentage increase in population from decade to decade is assumed to remain constant. Geometric mean increase is used to find out the future increment in population. Since this method gives higher values and hence should be applied for a new industrial town at the beginning of development for only few decades. The population at the end of n^{th} decade 'P_n' can be estimated as:

$$P_n = P\,(1 + I_G/100)^n$$

Where, I_G = geometric mean (%)

P = Present population

N = no. of decades.

Example : 2

Considering data given in example 1 predict the population for the year 2021, 2031, and 2041 using geometrical progression method.

Solution:

Year	Population	Increment	Geometrical Rate of growth
1961	858545	-	
1971	1015672	157127	(157127/858545) = 0.18
1981	1201553	185881	(185881/1015672) = 0.18
1991	1691538	489985	(489985/1201553) = 0.40
2001	2077820	386282	(386282/1691538) = 0.23
2011	2585862	508042	(508042/2077820) = 0.24

Geometric mean $I_G = (0.18 \times 0.18 \times 0.40 \times 0.23 \times 0.24)^{1/4}$

$= 0.235$ i.e., 23.5%

Population in year 2021 is,

$P_{2021} = 2585862 \times (1+ 0.235)^1 = \underline{3193540}$

Similarly for year 2031 and 2041 can be calculated by,

$P_{2031} = 2585862 \times (1+ 0.235)^2 = \underline{3944021}$

$P_{2041} = 2585862 \times (1+ 0.235)^3 = \underline{4870866}$

3. Incremental Increase Method

This method is modification of arithmetical increase method and it is suitable for an average size town under normal condition where the growth rate is found to be in increasing order.

While adopting this method the increase in increment is considered for calculating future population. The incremental increase is determined for each decade from the past population and the average value is added to the present population along with the average rate of increase.

Hence, population after n^{th} decade is

$$P_n = P + n.X + \{n\,(n+1)/2\}.Y$$

Where, P_n = Population after n^{th} decade

X = Average increase

Y = Incremental increase

Example : 3

Considering data given in example 1 predict the population for the year 2021, 2031, and 2041 using incremental increase method.

Solution:

Year	Population	Increase (X)	Incremental increase (Y)
1961	858545	-	-
1971	1015672	157127	-
1981	1201553	185881	+28754
1991	1691538	489985	+304104
2001	2077820	386282	-103703
2011	2585862	508042	+121760
	Total	1727317	350915
	Average	345463	87729

Population in year 2021 is,

$P_{2021} = 2585862 + (345463 \times 1) + \{(1\ (1+1))/2\} \times 87729 = \underline{3019054}$

Population in year 2031 is,

$P_{2031} = 2585862 + (345463 \times 2) + \{((2\ (2+1)/2)\} \times 87729 = \underline{3539975}$

Population in year 2041 is,

$P_{2041} = 2585862 + (345463 \times 3) + \{((3\ (3+1)/2)\} \times 87729 = \underline{4148625}$

4. Decreasing Rate of Growth Method

City has some limiting saturation population and that rate of growth is a function of population deficit. Hence, as the city expands, smaller will be the rate of growth from year to year. The Saturation population must be calculated to obtain the design population.

$$\frac{dP}{dt} = K_d * (S - P)$$

$$K_d = \left(\frac{-\ln[(S - P_2)/(S - P_1)}{t_2 - t_1} \right)$$

$$P = P_1 + \left\{ (S - P_1) * \left(1 - e^{-K_d (t - t_1)} \right) \right\}$$

Where, K_d = Decreasing rate of growth constant

S = Saturation Population

P = Population

P_1 = Population at last census

t = Time

Example : 4

Census analysis conducted on a certain town in 1990 reported a population of 110,500. The same town reported a population of 118,200 in 2000. The Saturation population is assumed to be 250,000. Calculate the population of the town in 2020.

Solution:

$$K_d = \left(\frac{-\ln[(S - P_2)/(S - P_1)}{t_2 - t_1} \right)$$

$$K_d = \left(\frac{-\ln[(250000 - 118200)/(250000 - 110500)}{t_{2000} - t_{1990}} \right)$$

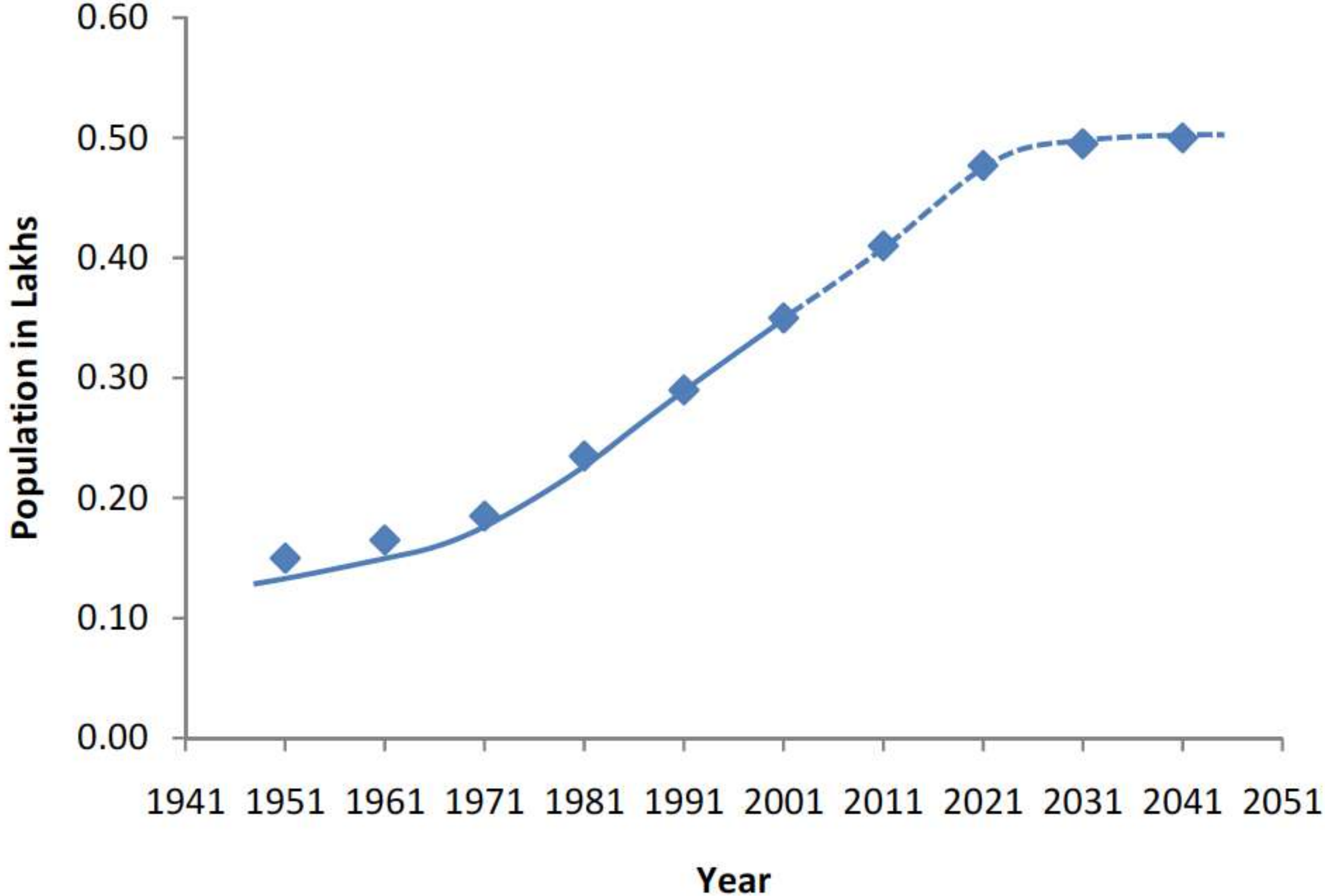
$$K_d = \left(\frac{-\ln(.9448)}{10} \right) = 0.00568$$

$$P = 110500 + \left\{ (250000 - 110500) * \left(1 - e^{-0.00568(2020-1990)}\right) \right\}$$

P_{2020} = <u>132356</u>

5. Graphical Increase Method

In this method, the populations of last few decades are correctly plotted to a suitable scale on graph. The population curve is smoothly extended for getting future population. This extension should be done carefully and it requires proper experience and judgment. The best way of applying this method is to extend the curve by comparing with population curve of some other similar cities having the similar growth condition.


0.60
0.50
0.40
0.30
0.20
0.10
0.00
Population in Lakhs
1941
1951
1961
1971
1981
1991
2001
2011
2021
2031
2041
2051
Year

6. Comparative Graphical Method

In this method, the census populations of cities already developed under similar conditions are plotted. The curve of the past population of the city under consideration is plotted on the same graph. The curve is extended carefully by comparing with the population curve of similar cities having similar conditions of growth. The advantage of this method is that the future population can be predicted from present population even in absence of past census reports.

Example : 5

Let the population of a new city X be given for decades 1970, 1980, 1990 and 2000 were 32000, 38000, 43000 and 50,000 respectively. The cities A, B, C and D were developed in similar conditions of the city X in the years 2010 and 2020. The population of cities A,B, C and D of different decades were given below

(a) City A was 50,000; 62,000; 72,000 and 87,000 in 1960, 1972, 1980 and 1990 respectively.

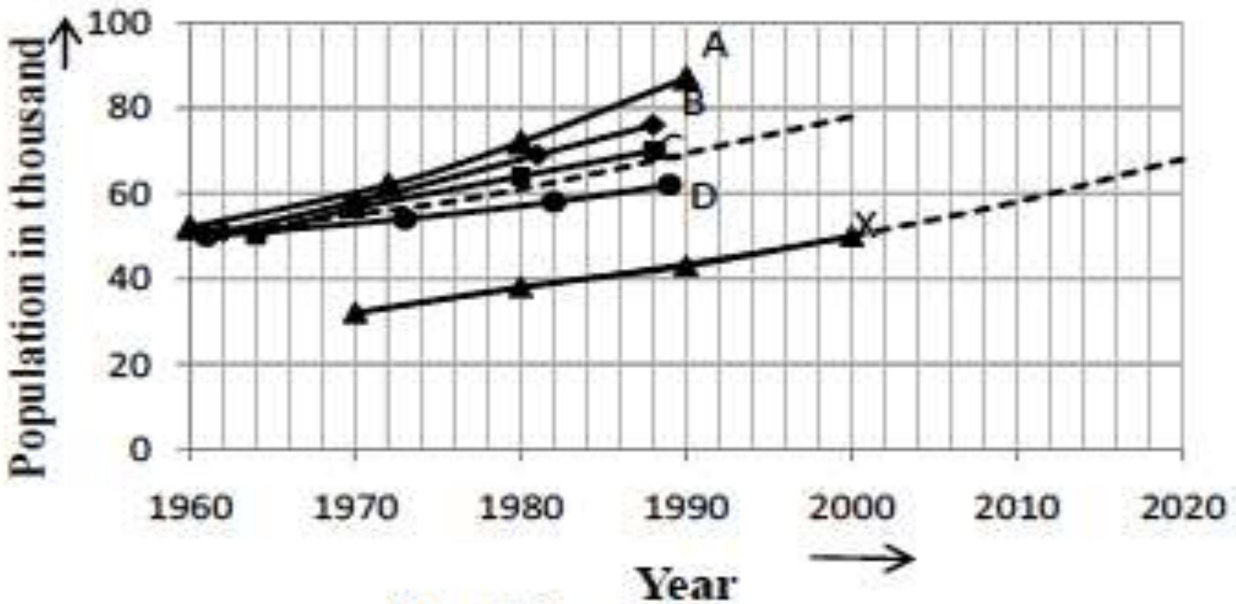
(b) City B was 50,000; 58,000; 69,000 and 76,000 in 1962,1970,1981 and 1988 respectively

(c) City C was 50,000; 56,500; 64,000 and 70,000 in 1964, 1970, 1980 and 1988 respectively

(d) City D was 50,000; 54,000; 58,000 and 62,000 in 1961, 1973, 1982 and 1989 respectively.

Solution:

Population curves for the cities A, B, C, D and X were plotted. Then an average mean curve is plotted as a dotted line as shown in the figure. The population curve X is extended beyond 50,000 matching with the dotted mean curve. From the curve the populations obtained for city X are 58,000 and 68,000 in year 2010 and 2020 respectively



Population curve

7. Master Plan Method

The big and metropolitan cities are generally not developed in haphazard manner, but are planned and regulated by local bodies according to a master plan. The master plan is prepared for the next 25 to 30 years for the city. According to the master plan, the city is divided into various zones such as residential, commercial and industrial. The population densities are fixed for various zones in the master plan. From this population density, total water demand and wastewater generation for that zone can be worked out. Hence, by this method it is very easy to precisely determine the design population. This method is also called the **Zoning Method**

8. Ratio and Correlation Method

The population growth of a small town or area is related to big towns or big areas. The increase in population of big cities bear a direct relationship to the whole state or country. In this method, the local to national (or state) population ratio is determined in the previous two to four decades. Depending on the conditions and other influencing factors, even changing ratio may be adopted. These ratios may be used in predicting future population growth. This approach considers the regional and national factors affecting population growth. This method is suitable only for those areas whose population growth in the past is fairly consistent with that of state or nation.

8. Ratio and Correlation Method (Continued)

$$\frac{P_2}{P_{2R}} = \frac{P_1}{P_{1R}} = K_R$$

P_2 = Projected population
P_{2R} = Projected population in the larger region
P_1 = Population at last census for the projected region
P_{1R} = Population at last census for the projected region in the larger region
K_R = ratio or correlation constant

9. Growth Composition Analysis Method

The change in population of a city is due to three reasons: (a) birth, (b) death, and (c) migration from villages and other towns. The population forecast may be made by proper analysis of these three factors. The difference between birth rate and death rate gives the natural in crease in population. Hence,

$$P_n = P + \text{Natural Increase} + \text{Migration}$$

The estimated natural expression is given by the following expression:

$$\text{Natural Increase} = T*(I_B*P - I_D*P)$$

T = Design (forecast period)

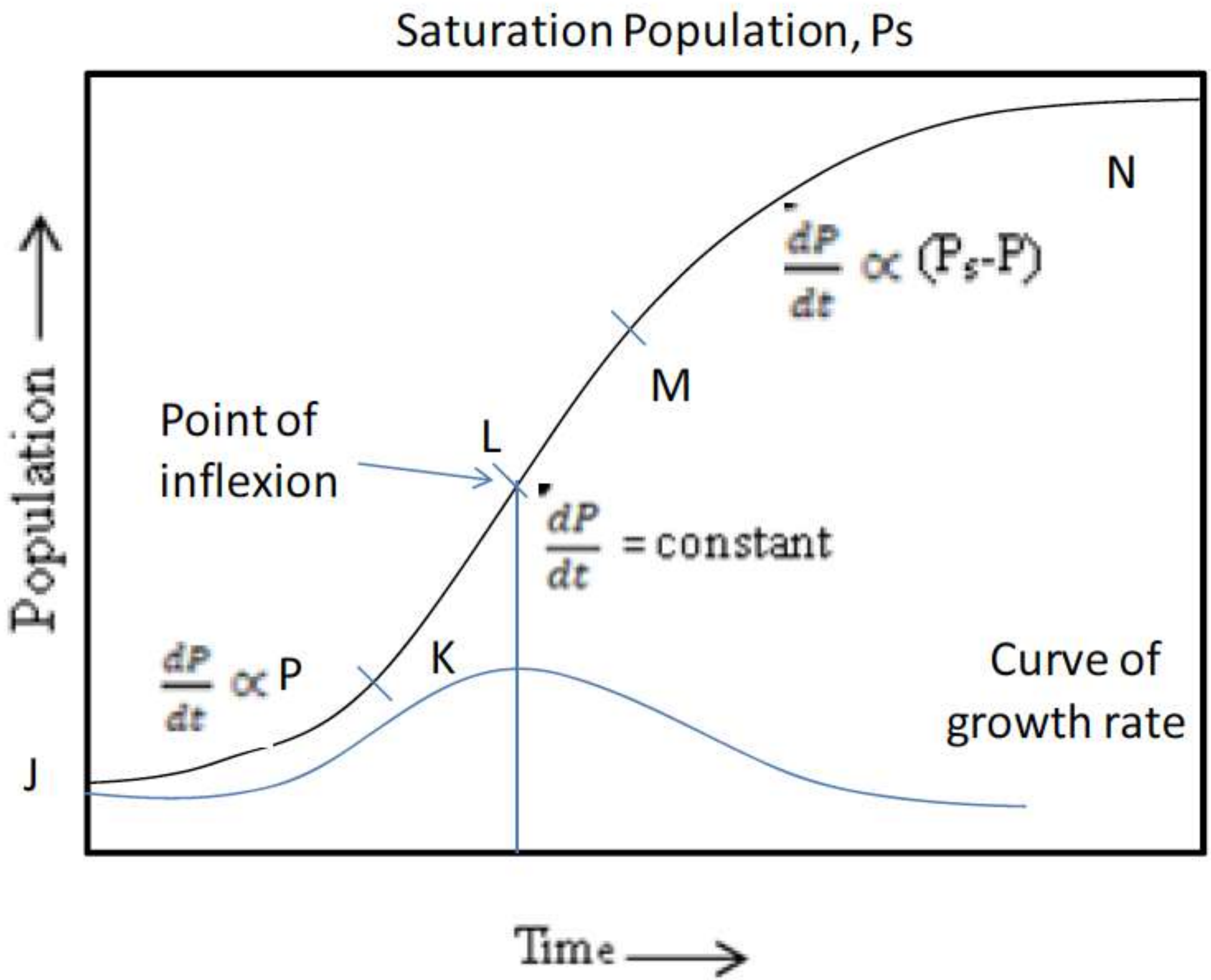
P = Present population

I_B = Average birth rate per year

I_D = Average death rate per year

10. Logistic Curve Method

This method is used when the growth rate of population due to births, deaths and migrations takes place under normal situation and it is not subjected to any extraordinary changes like epidemic, war, earth quake or any natural disaster etc. the population follow the growth curve characteristics of living things within limited space and economic opportunity. If the population of a city is plotted with respect to time, the curve so obtained under normal condition is look like S-shaped curve and is known as logistic curve.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Curve of
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$$\log_e \left(\frac{Ps-P}{P}\right) - \log_e \left(\frac{Ps-P0}{P0}\right) = -K.P_s.t$$

P = Population at any time t from J

P_s = Saturation population

P_0 = Population of the city at start point J

K= Constant

T= Years

From the above equation we get

$$\log_e\left(\frac{Ps-P}{P}\right)\left(\frac{P0}{Ps-P0}\right) = -K.P_s.t$$

After solving we get,

$$P = \frac{P_S}{1+\frac{P_S-P_o}{P_o}\log_e^{-1}(-K.P_S.t)}$$

Substituting $\frac{Ps-P0}{P0} = m$ (a constant)

and $-K.P_s = n$ (another constant)

we get $P = \frac{P_S}{1+m\log_e^{-1}(n.t)}$

This is the required equation of the logistic curve, which will be used for predicting population. McLean further suggested that if only three pairs of characteristic values P_0, P_1, P_2 at times $t = t_0 = 0$, t_1 and $t_2 = 2t_1$ extending over the past record are chosen, the saturation population P_s and constant m and n can be estimated by the following equation, as follows:

$$P_s = \frac{2P_0P_1P_2 - P_1^2(P_0 + P_2)}{P_0P_2 - P_1^2}$$

$$m = \frac{Ps - P0}{P0}$$

$$n = \frac{2.3}{t_1} \log_{10}\left(\frac{P_0(P_S - P_1)}{P_1(P_S - P_0)}\right)$$

Example: 5

The population of a city in three consecutive years i.e. 1991, 2001 and 2011 is 80,000; 250,000 and 480,000, respectively. Determine (a) The saturation population, (b) The equation of logistic curve, (c) The expected population in 2021.

Solution

It is given that

$P_0 = 80{,}000 \qquad t_0 = 0$

$P_1 = 250{,}000 \qquad t_1 = 10$ years

$P_2 = 480{,}000 \qquad t_2 = 20$ years

The saturation population can be calculated by using equation

$$P_s = \frac{2P_0P_1P_2 - P_1^2(P_0 + P_2)}{P_0P_2 - P_1^2}$$

$$= \frac{2 \times 80{,}000 \times 2{,}50{,}000 \times 4{,}80{,}000 - 2{,}50{,}000 \times 2{,}50{,}000 \times (80{,}000 + 4{,}80{,}000)}{80{,}000 \times 4{,}80{,}000 - 2{,}50{,}000 \times 2{,}50{,}000}$$

$$= 655{,}602$$

We have $\quad m = \dfrac{Ps - P0}{P0} = \dfrac{655{,}602 - 80{,}000}{80{,}000} = 7.195$

$$n = \frac{2.3}{t_1} \log_{10} \frac{P_0(P_S - P_1)}{P_1(P_S - P_0)}$$

$$= \frac{2.3}{} \log_{10} \left[\frac{80{,}000(655{,}602 - 2{,}50{,}000)}{250{,}000(655{,}602 - 80{,}000)}\right]$$

$$= -0.1488$$

Population in 2021

$$P = \frac{P_S}{1 + m\log_e^{-1}(n.t)}$$

$$\frac{6{,}55{,}602}{1 + 7.195 \times \log_e^{-1}(-0.1488 \times 30)}$$

$$= \frac{6{,}55{,}602}{1 + 7.195 \times 0.0117} = 605{,}436$$

Unit- 1
Part C: Development of Groundwater

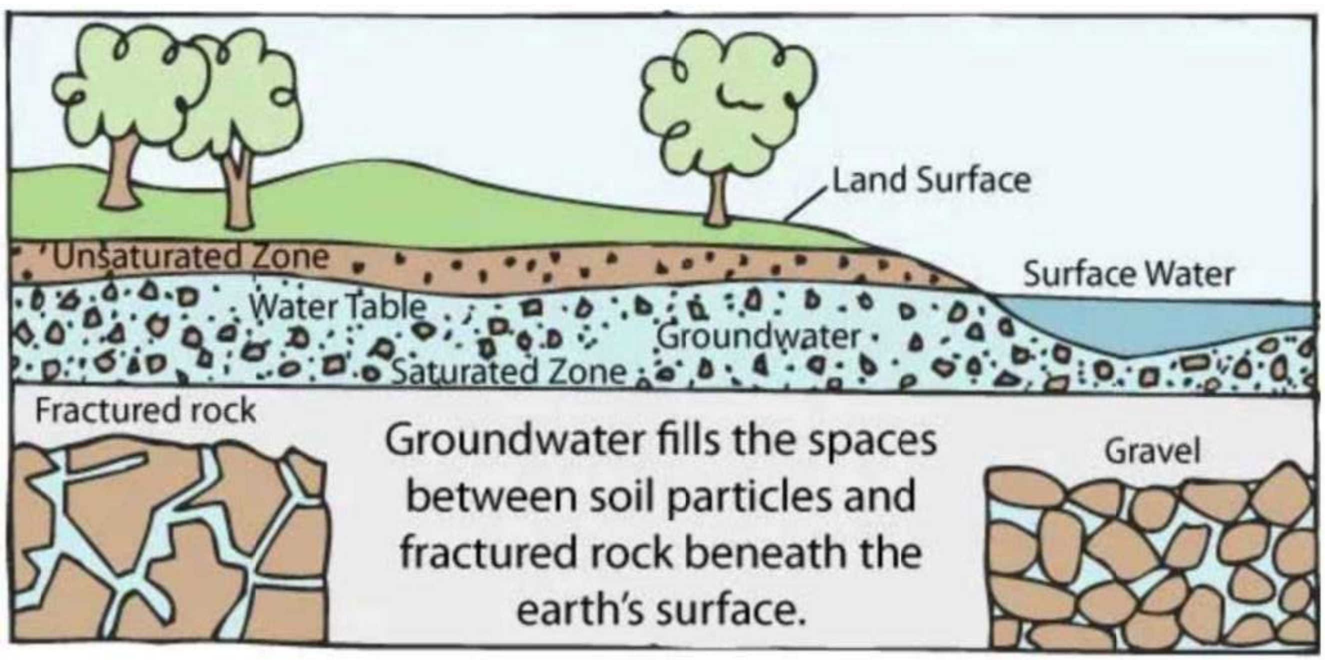
Which one is correct?

(a) Groundwater

(b) Ground water

What is groundwater?

- Water found underground in the cracks and spaces in soil, sand and rock.
- It is stored in and moves slowly through geologic formations of soil, sand and rocks called aquifers.



Source: https://www.groundwater.org/get-informed/basics/whatis.html

Hydrologic cycle

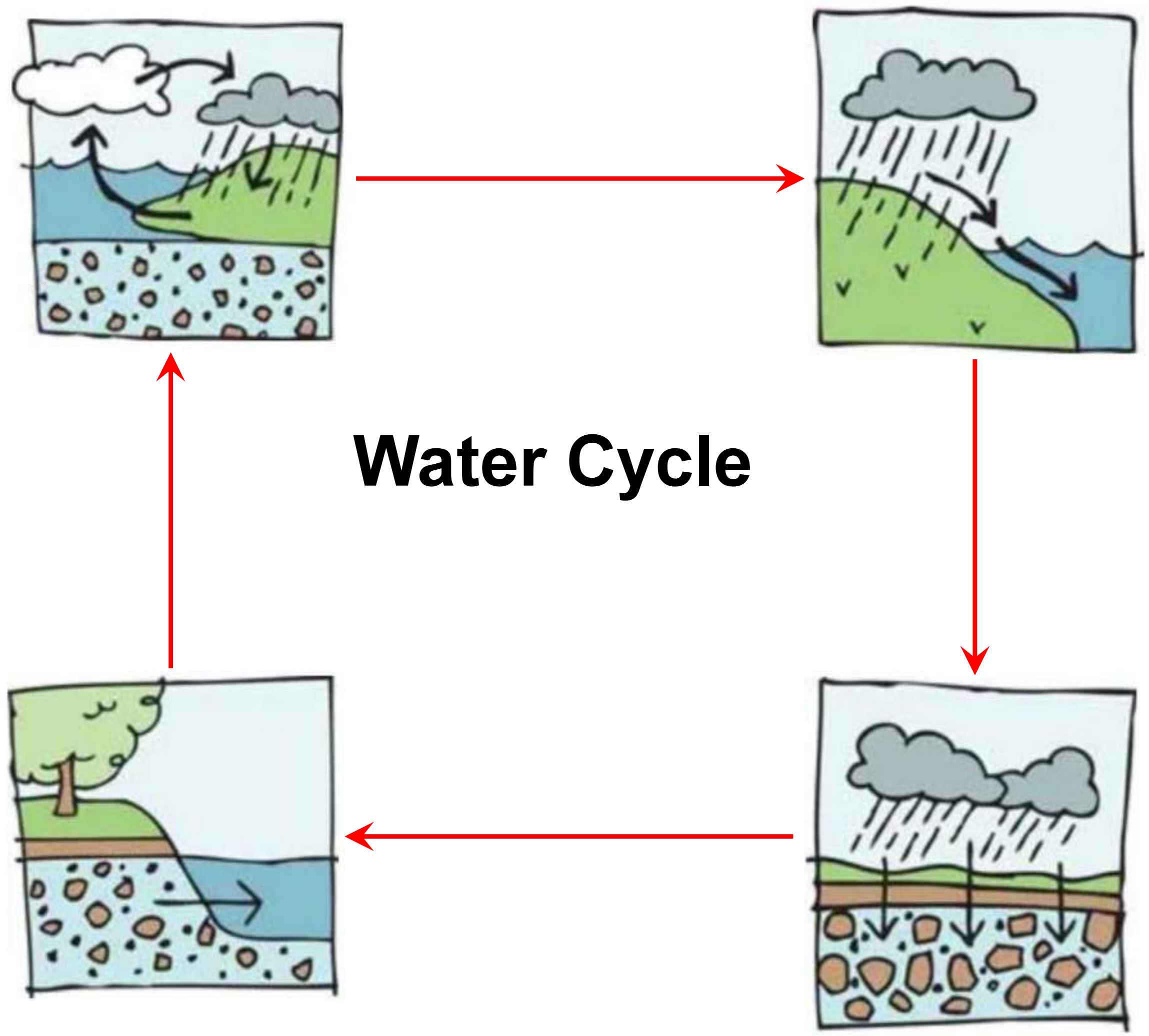
Question (Homework)?
Calculate the concentration of Cl^- in groundwater? Given:

(a) Total chloride present in HBTU artificial pond was 20 mg/L
(b) 40% was lost during evaporation
(c) Everything precipitated, but only 30% of run-off was percolated to the groundwater

Assume, no other system exists in the world

- 1.Evaporation
- 2.Condensation

- Precipitation
- Run-off

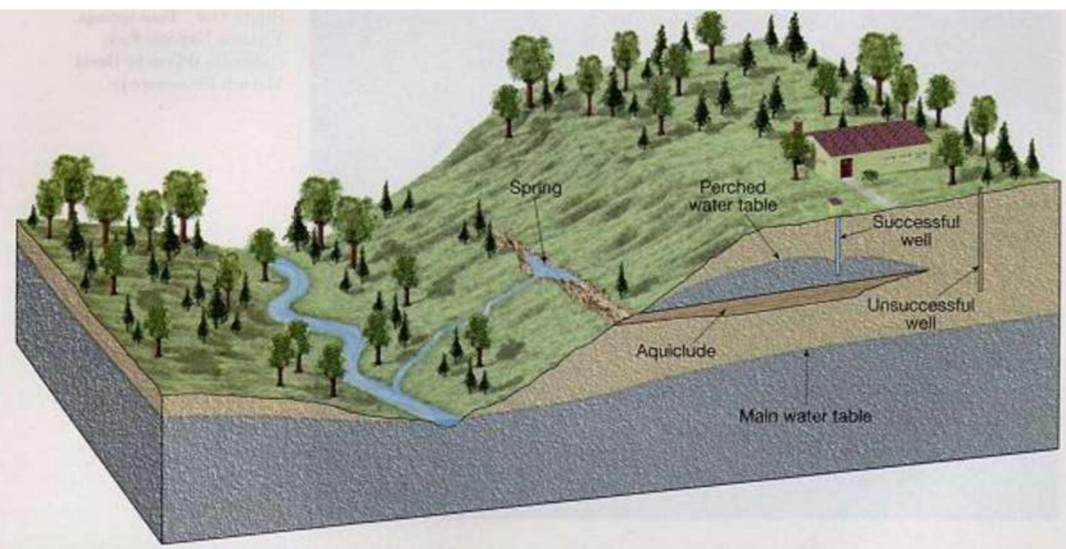


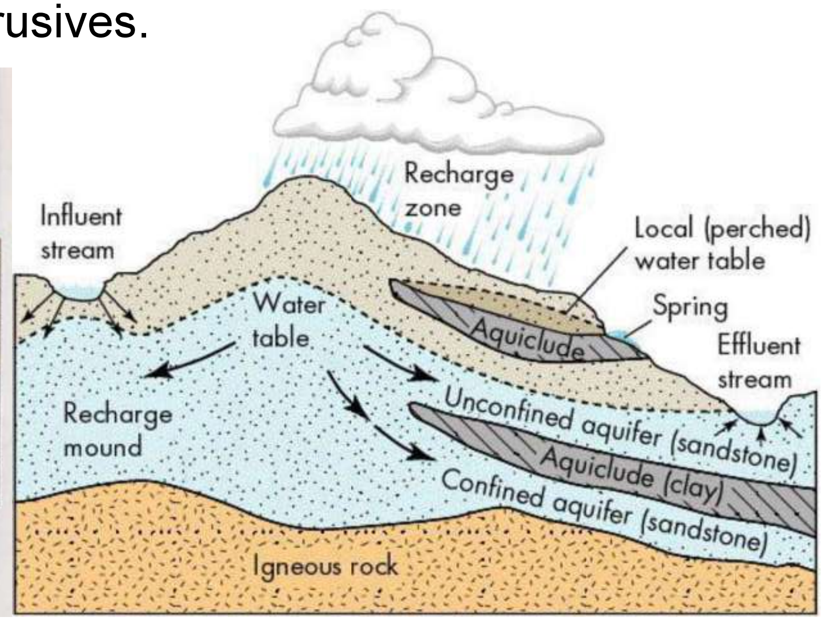
- Discharge (after several years
- Recharge
- Groundwater flow

Groundwater Glossary

Follow this link for details: https://www.groundwater.org/get-informed/basics/glossary.html

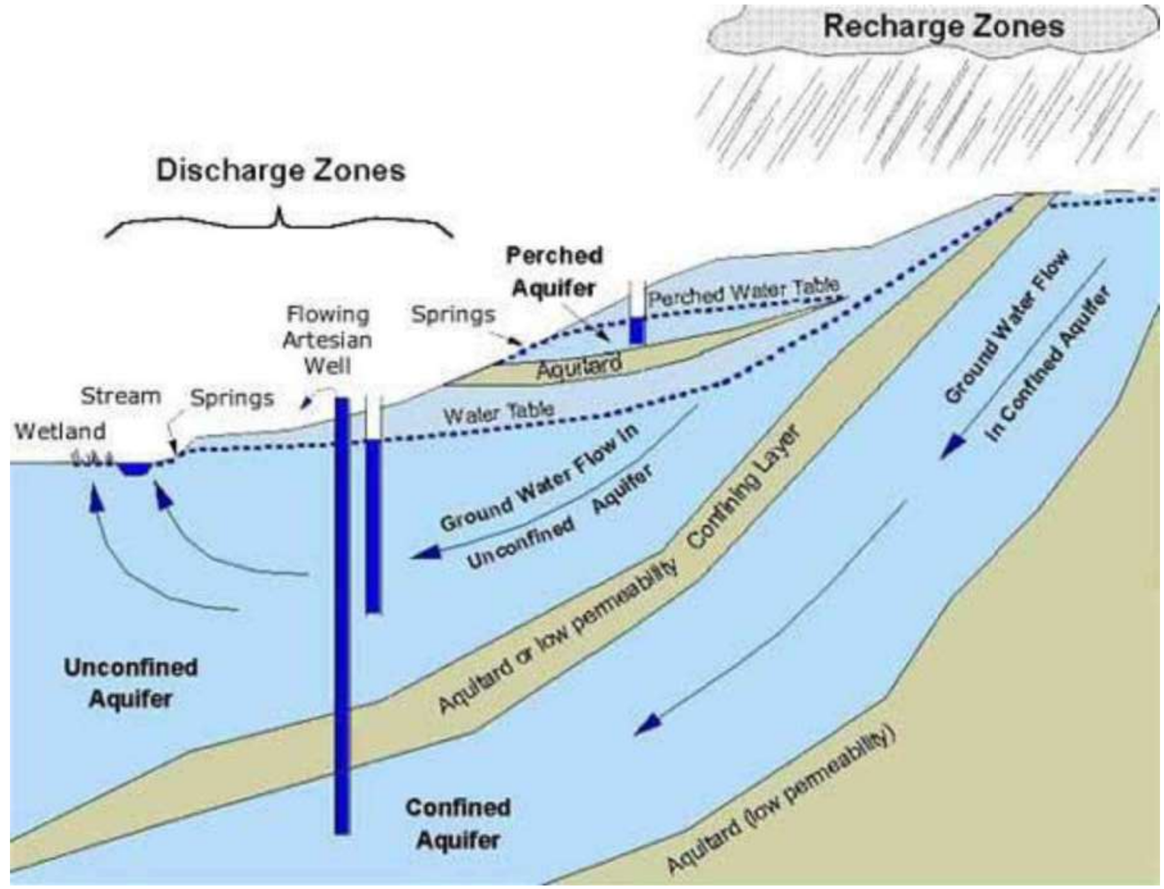
- An **aquifer** is a formation that allows water to be **accessible** at a **usable rate**. Aquifers are permeable layers such as sand, gravel, and fractured rock.
- An **aquiclude** is an impermeable layer of rock or soil which therefore acts to stop the flow of groundwater. Aquicludes are normally located in a layer above or below and aquifer, such as clay.
- An **aquitard** is a bed of low permeability adjacent to an aquifer; may serve as a storage unit for groundwater, although it does not yield water readily, such as mudstone.
- An **aquifuge** is a geologic formation which has no interconnected openings and cannot hold or transmit water such as unfractured igneous intrusives.





- **Confined aquifers** have non-permeable layers, above and below the aquifer zone, referred to as **aquitards** or **aquicludes**. These layers restrict water movement. Clay soils, shales, and non-fractured, weakly porous igneous and metamorphic rocks are examples of aquitards.

- Sometimes a lens of non-permeable material will be found within more permeable material. Water percolating through the unsaturated zone will be intercepted by this layer and will accumulate on top of the lens. This water is a **perched aquifer**.



- **Unconfined aquifer** has no confining layers that retard vertical water movement.

- **Artesian aquifers** are confined under hydraulic pressure, resulting in free-flowing water, either from a spring or from a well.

Disposal, Reuse and Recycling

Due to the addition of impurities during beneficial use, water is transformed to wastewater.

This wastewater may be discharged to aquatic or terrestrial environments provided the relevant discharge standards are attained through wastewater treatment. This is known as wastewater disposal.

Alternatively, the wastewater may be used for certain other beneficial purpose, provided adequate treatment is given to the wastewater to conform to the water quality standards for that beneficial use. This procedure of using water for multiple beneficial uses is known as reuse.

Alternatively, the wastewater may be used for the same beneficial purpose as before, provided adequate treatment is given to the wastewater such that it again conforms to the standards for the original beneficial use. This procedure for using water for the same beneficial use is known as recycling.

Natural Contaminants in Surface Water and Ground Water Samples

The concentration of inorganic particulate matter, i.e., sand, silt and clay is high in surface water samples. Surface water may also contain dissolved natural organic matter (NOM)

Concentration of dissolved contaminants, i.e., anions (e.g., chloride, sulfate, nitrate, bicarbonate, fluoride, etc.) and cations (e.g., sodium, calcium, magnesium, iron, arsenic, etc.) are high in ground water samples.

Origin of the Contaminants

Eroded soil is carried by surface runoff into natural water bodies resulting in high sand, silt and clay concentration in surface water. Surface runoff over decaying vegetation contributes to dissolved NOM

Passage of water through rock formations containing various minerals result in leaching of cations and anions into ground water samples.

Anthropogenic Impacts

Fecal contamination of surface water results in the addition of organic matter (responsible for color, odor etc.) and bacteria/viruses. Surface runoff may add nitrates, pesticides etc,. To surface water.

Dissolved contaminants such as nitrates, pesticides, other synthetic organic compounds, cations/anions, fecal organic matter etc. are added to ground water (only the top aquifer) due to anthropogenic impacts.

Main Contaminants in Surface Water

Natural Origin
- **Sand, Silt and Clay**
- **Natural Organic Matter (NOM)**

Anthropogenic Origin
- **Fecal organic matter**
- **Bacteria, viruses**

Main Contaminants in Ground Water

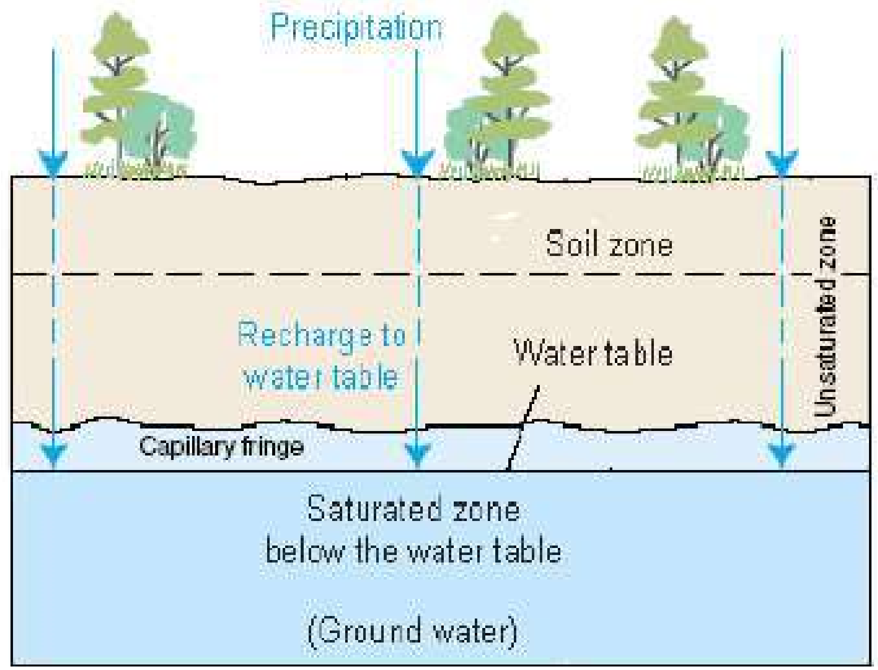
Natural Origin
- **Dissolved Cations and Anions**

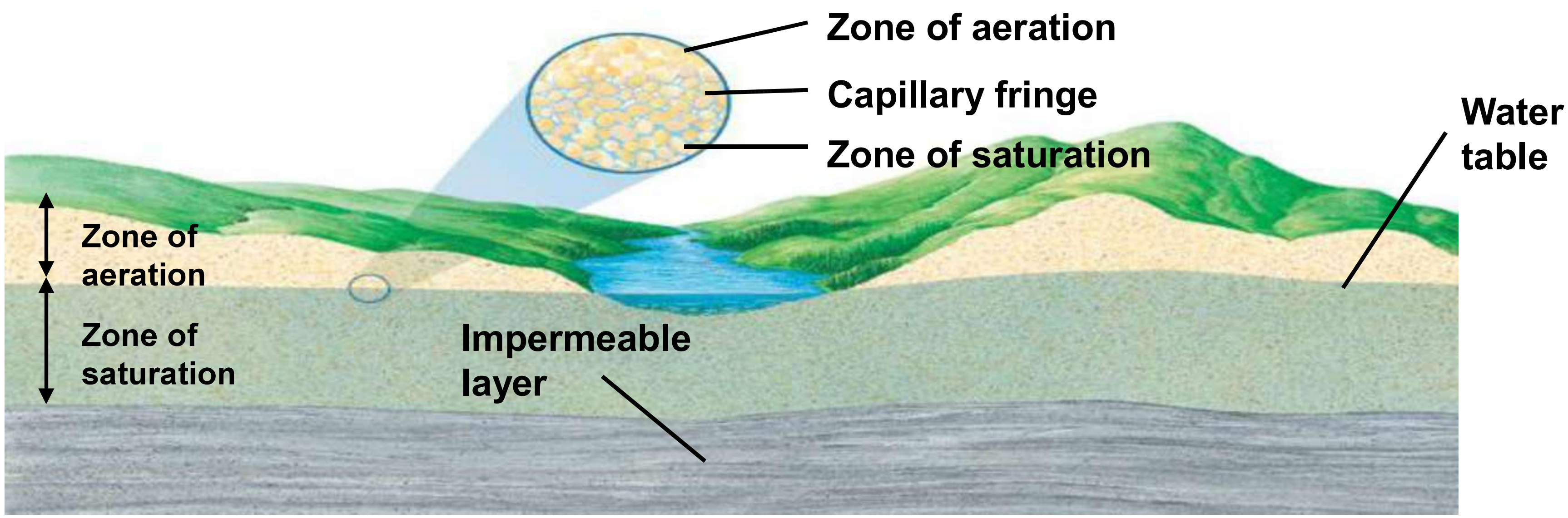
Anthropogenic Origin (only top aquifer)
- **Agricultural pollutants**
- **Other synthetic organic pollutants**
- **Nitrates, Ammonia (from fecal pollution)**
- **Bacteria, viruses**

Vertical Distribution of Subsurface Water

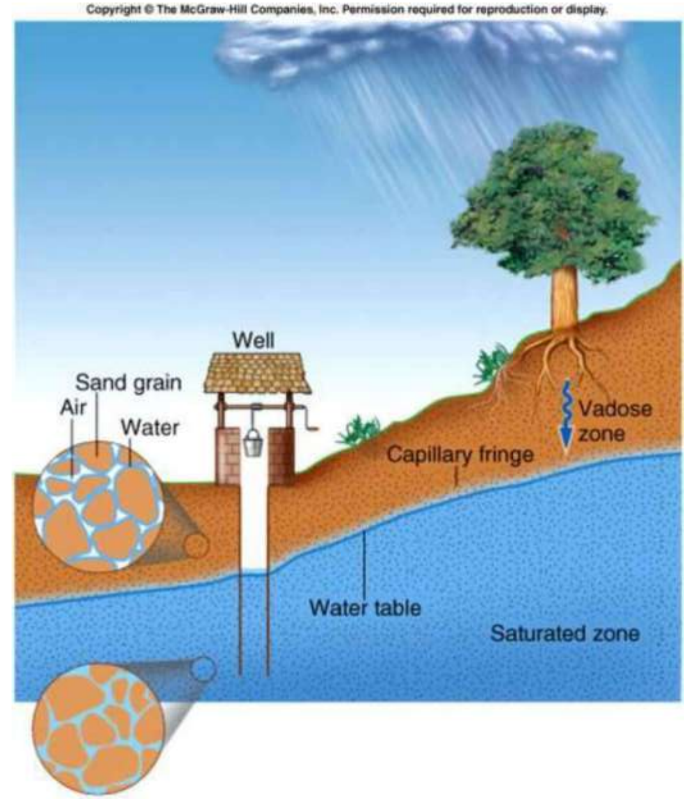
- Belt of Soil Moisture- water held by molecular attraction on soil particles in the near surface zone
- Capillary Fringe
  - Extends upward from the water table
  - Groundwater is feld by surface tension in tiny passages between grains of soil or sediment.

- Zone of Aeration
  - Area above the water table
  - Includes capillary fringe and the belt of soil moisture
  - Water cannot be pumped by wells



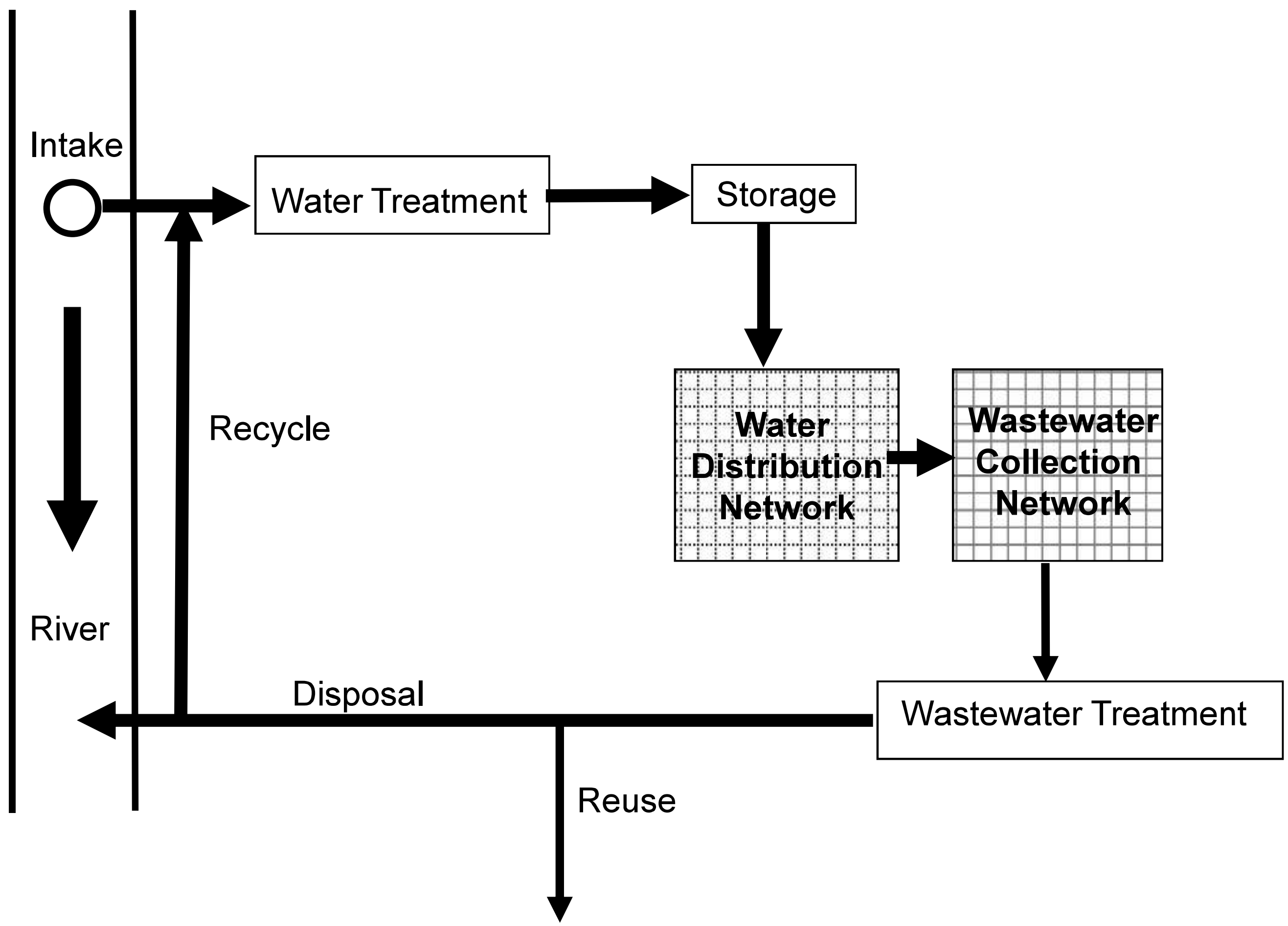


- Zone of Saturation
  - Water not held as soil moisture percolates downward
  - Water reaches a zone where all of the open spaces in sediment and rock are completely filled with water.
  - Water within the pores is called Groundwater
  - Water table the upper limit of the zone of saturation



A

Urban Water Cycle



Classification of Microorganisms

All microorganisms needs three things to survive,
1) Energy source,
2) Carbon / food source
3) Terminal electron acceptor

Aerobic microorganisms use ***oxygen*** as the terminal electron acceptor
Anaerobic microorganisms use chemicals ***other than oxygen*** as terminal electron acceptor

Heterotrophic microorganisms use *organic carbon* as energy source. Hence they need organic carbon to survive. They also use *organic carbon* as food source.

Chemo-autotrophic microorganisms use *chemical compounds other than organic carbon* as energy source. They do not need reduced carbon to survive. They use *inorganic carbon* as food source.

Photo-autotrophic microorganisms use light (photons) as energy source and *inorganic carbon* as food source.

Nitrosomonas / Nitrobactor:

Energy source:	Ammonia / Nitrite
Food Source:	Inorganic Carbon
Electron acceptor:	Oxygen

Aerobic, chemo-autotrophic microorganisms

References

All pictures used in this presentation were taken from the following:

Carlson, Diane H., David McGeary and Charles C. Plummer. *Physical Geology: Updated Eighth Edition*. New York City, McGraw-Hill Higher Education, 2001.

Ground Water

- ground water: the water that lies beneath the ground surface, filling the pore space between grains in bodies of sediment and clastic sedimentary rock, and filling cracks and crevices in all types of rock
- ground water is a major economic resource, particularly in the dry areas of India
- source of ground water is rain and snow that falls to the ground a portion of which percolates down into the ground to become ground water

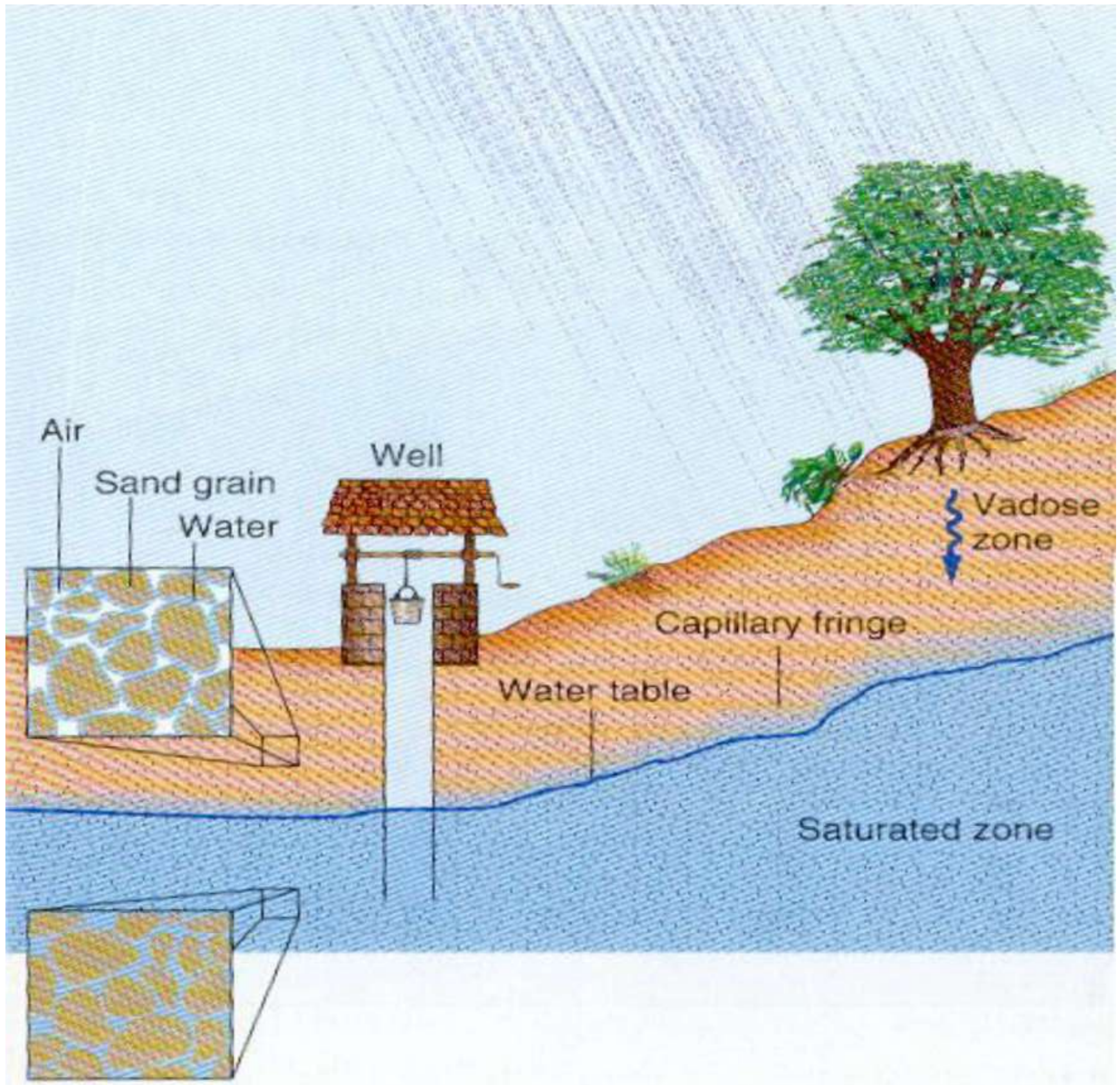
Porosity and Permeability

- porosity: the percentage of rock or sediment that consists of voids or openings
- permeability: the capacity of a rock to transmit a fluid such as water or petroleum through pores and fractures
- porous: a rock that holds much water
- permeable: a rock that allows water to flow easily through it
- impermeable: a rock that does not allow water to flow through it easily

The Water Table

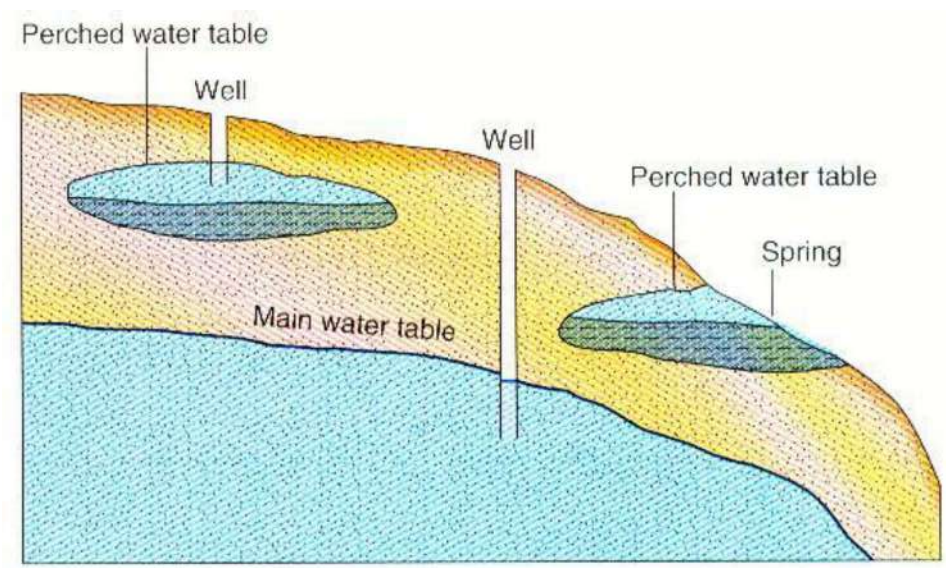
- saturated zone: the subsurface zone in which all rock openings are filled with water
- water table: the upper surface of the zone of saturation
- vadose zone: a subsurface zone in which rock openings are generally unsaturated and filled partly with air and partly with water; above the saturated zone
- capillary fringe: a transition zone with higher moisture content at the base of the vadose zone just above the water table

The Water Table (cont.)



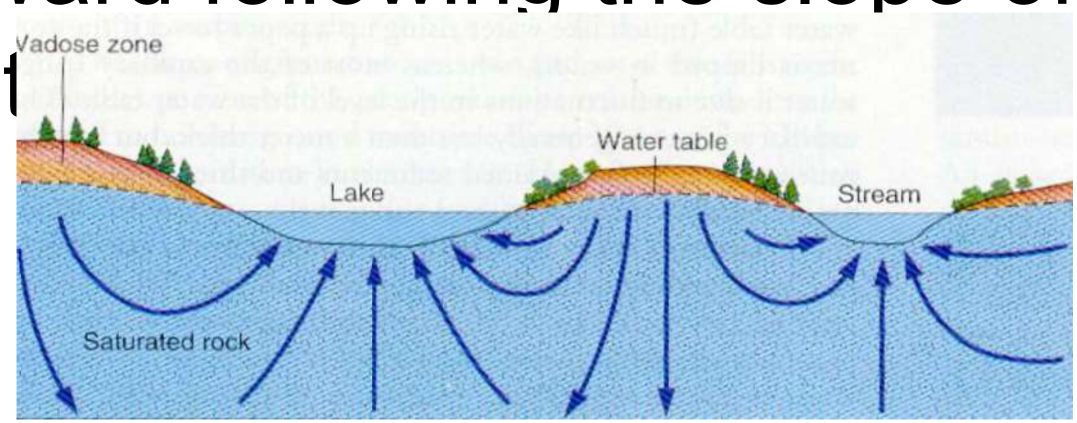
The Water Table (cont.)

- perched water table: the top of a body of ground water separated from the main water table beneath it by a zone that is not saturated



The Movement of Ground Water

- most ground water moves relatively slowly through rock underground
- because it moves in response to differences in water pressure and elevation, water within the upper part of the saturated zone tends to move downward following the slope of the water t



Movement of ground water beneath a sloping water table in uniformly permeable rock. Near the surface the ground water tends to flow parallel to the sloping water table

Movement of Ground Water (cont.)

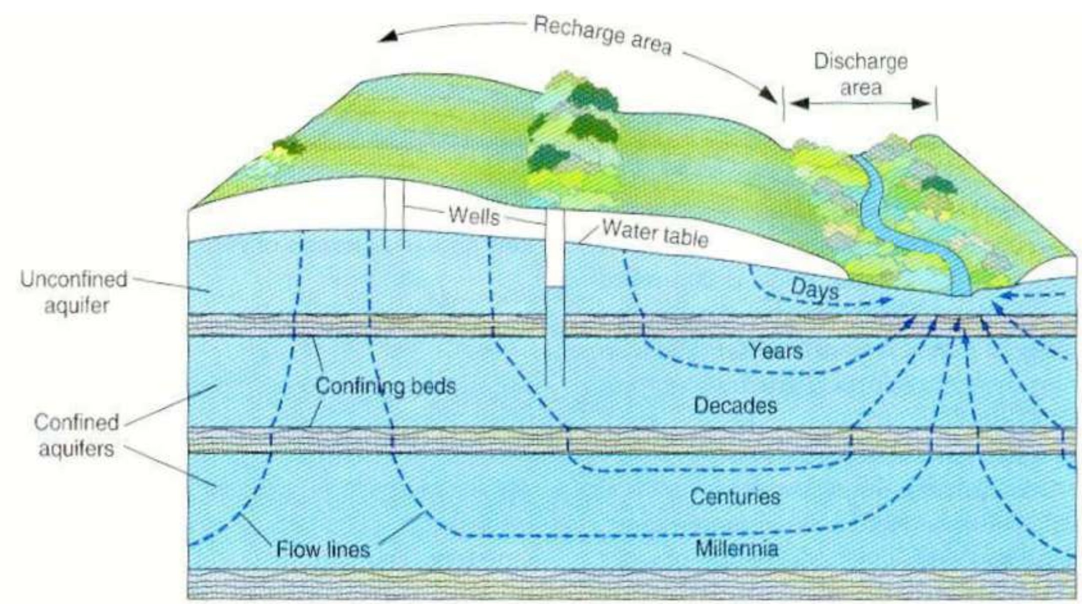
- factors affecting the flow of ground water:
  - the slope of the water table - the steeper the water table, the faster ground water moves
  - permeability - if rock pores are small and poorly connected, water moves slowly; when openings are large and well connected, the flow of water is more rapid

Aquifers

- aquifer: a body of saturated rock or sediment through which water can move easily
- good aquifers include sandstone, conglomerate, well-joined limestone, bodies of sand and gravel, and some fragmental or fractured volcanic rocks such as columnar basalt
- aquitards: when the porosity of a rock is 1% or less and therefore retards the flow of ground water

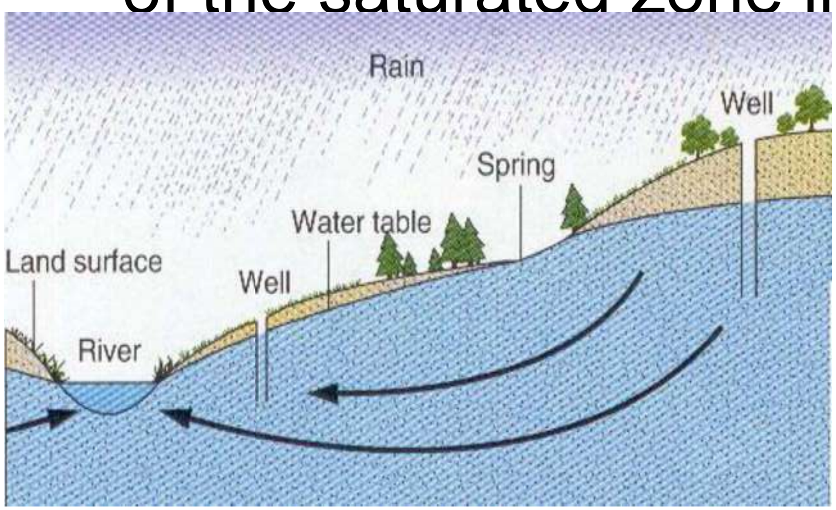
Aquifers (cont.)

- unconfined aquifer: a partially filed aquifer exposed to the land surface and marked by a rising and falling water table
- confined aquifer (artesian aquifer): an aquifer completely filled with pressurized water and separated from the land surface by a relatively impermeable confining bed, such as shale

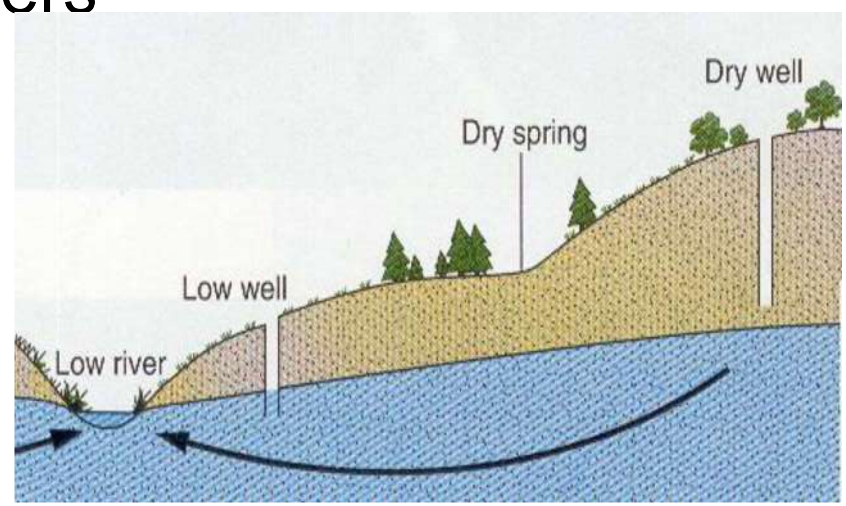


Wells

- well: a deep hole, generally cylindrical, that is dug of drilled into the ground to penetrate an aquifer within the saturated zone
- recharge: the addition of new water to the saturated zone
- the water table in an unconfined aquifer rises in wet seasons and falls in dry seasons as water drains out of the saturated zone into rivers



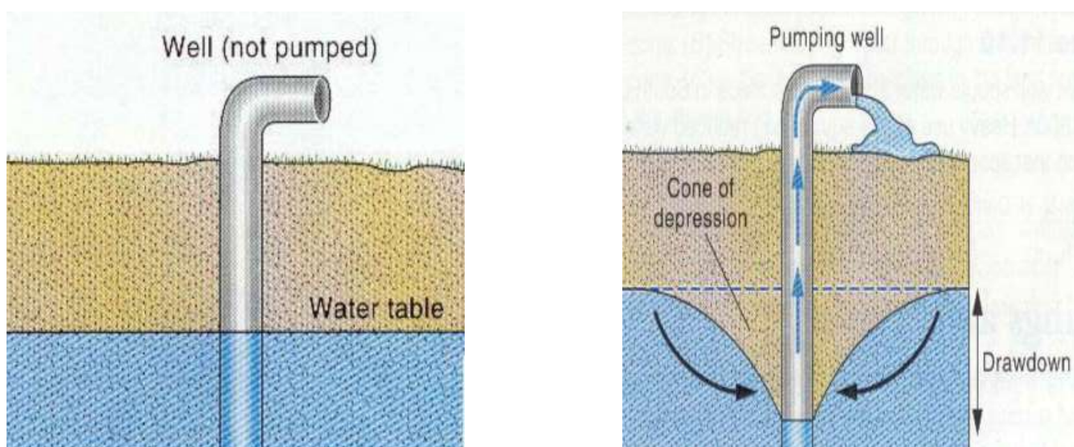
Wet season: water table and rivers are high; springs and wells flow readily



Dry season: water table and rivers are low; some springs and wells dry up

Wells (cont.)

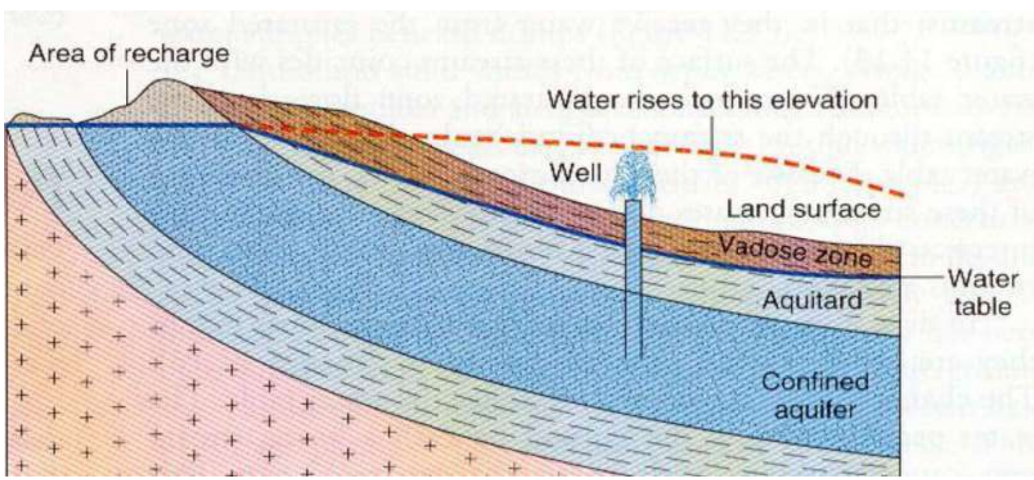
- cone of depression: a depression of the water table formed around a well when water is pumped out; it is shaped like an inverted cone
- drawdown: the lowering of the water table near a pumped well

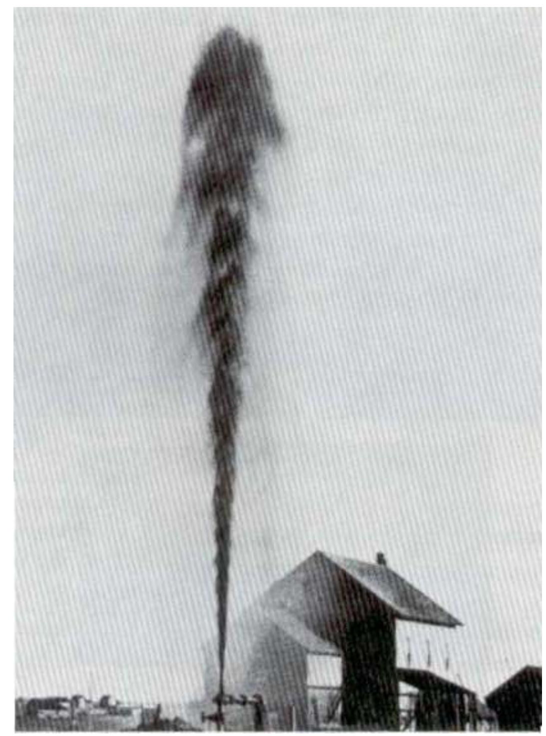


Pumping well lowers the water table into a cone of depression

Wells (cont.)

- artesian well: a well in which water rises above the aquifer

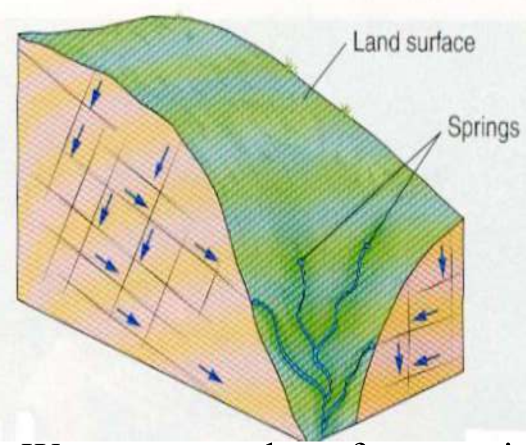




Artesian well spouts water above land surface in South Dakota, early 1900s. Heave use of this aquifer has reduced water pressure so much that spouts do not occur today

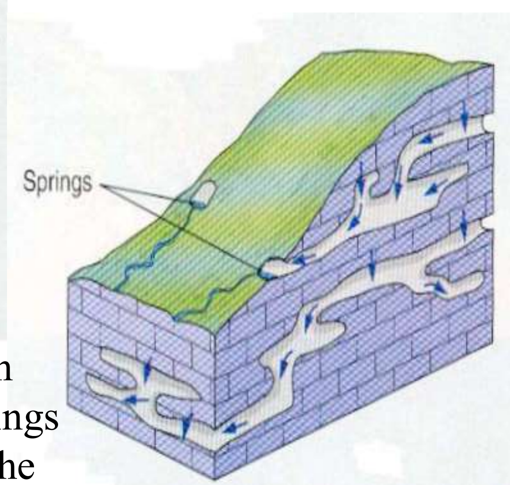
Springs and Streams

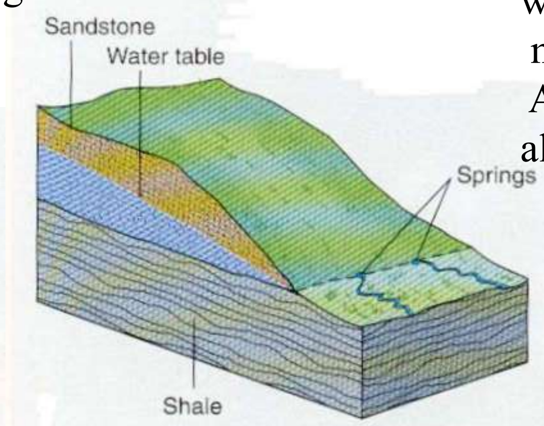
- spring: a place where water flows naturally from rock onto the land surface
- some springs discharge where the water table intersects the land surface, but they also occur where water flows out from caverns or along fractures, faults, or rock contacts that come to the surface



Water moves along fractures in crystalline rock and forms springs where the fractures intersect the land surface

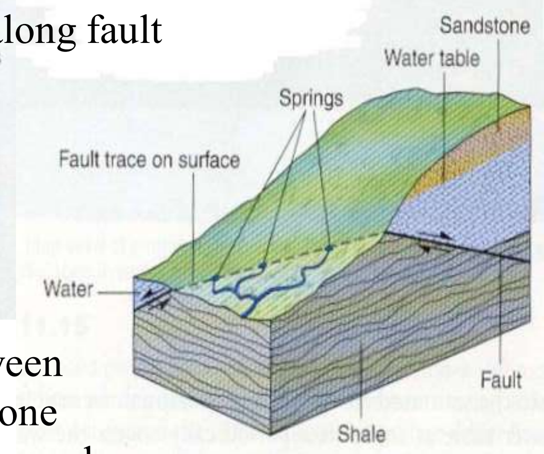
Water enters caves along joints in limestone and exits as springs at the mouths of caves





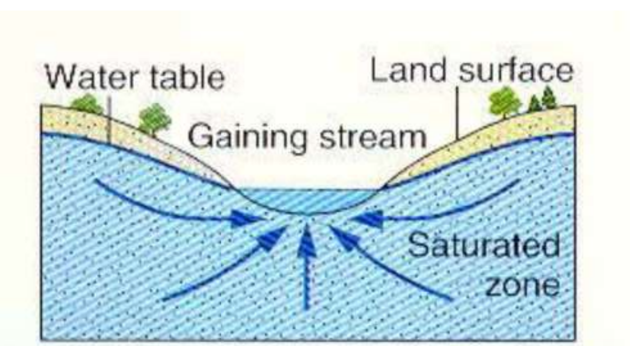
Springs form at the contact between a permeable rock such as sandstone and an underlying less permeable rock such as shale

Springs can form along faults when permeable rock has been moved against less permeable roc Arrows show relative motion along fault

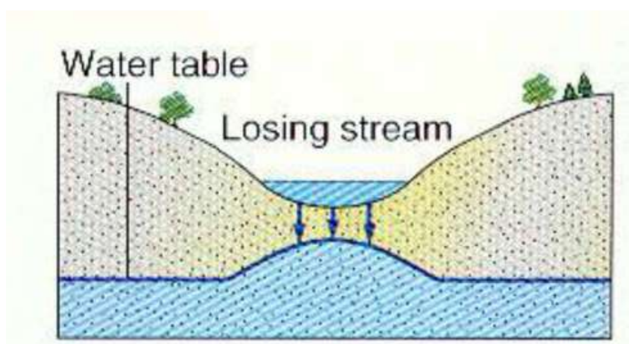


Springs and Streams (cont.)

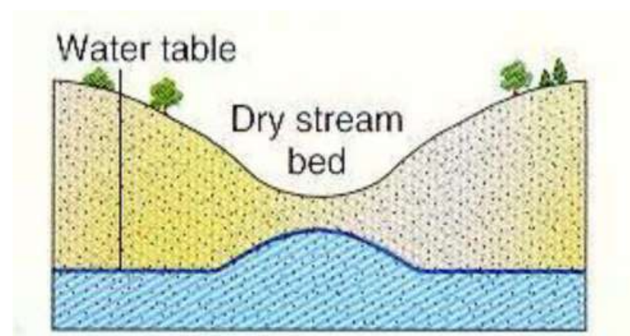
- gaining stream: a stream that receives water from the zone of saturation
- losing stream: a stream that looses water to the zone of saturation



Stream gaining water from saturated zone



Stream losing water through stream bed to saturated zone



Water table can be close to the land surface beneath a dry stream bed

Pollution of Ground Water

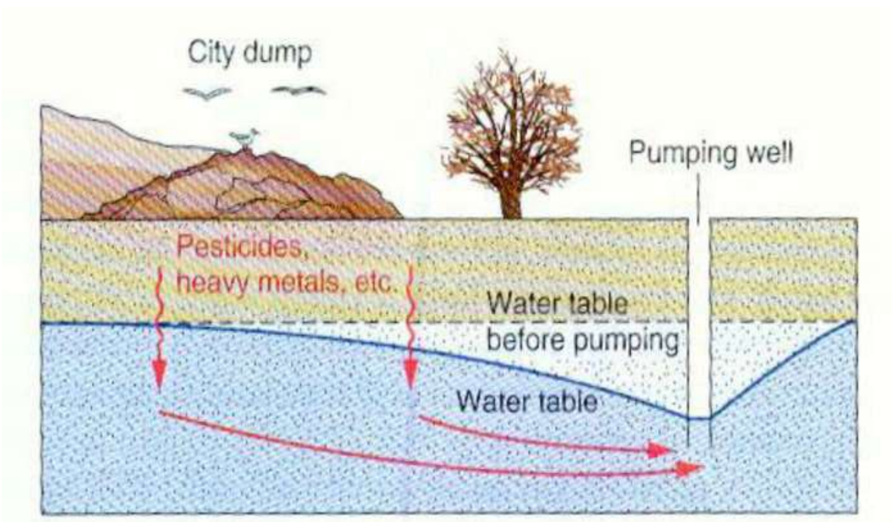
- pesticides, herbicides, fertilizers: chemicals that are applied to agricultural crops that can find their way into ground water when rain or irrigation water leaches the poisons downward into the soil
- rain can also leach pollutants from city dumps into ground-water supplies
- Heavy metals such as mercury, lead, chromium, copper, and cadmium, together with household chemicals and poisons, can all be concentrated in ground-water supplies beneath dumps

Pollution of Ground Water (cont.)

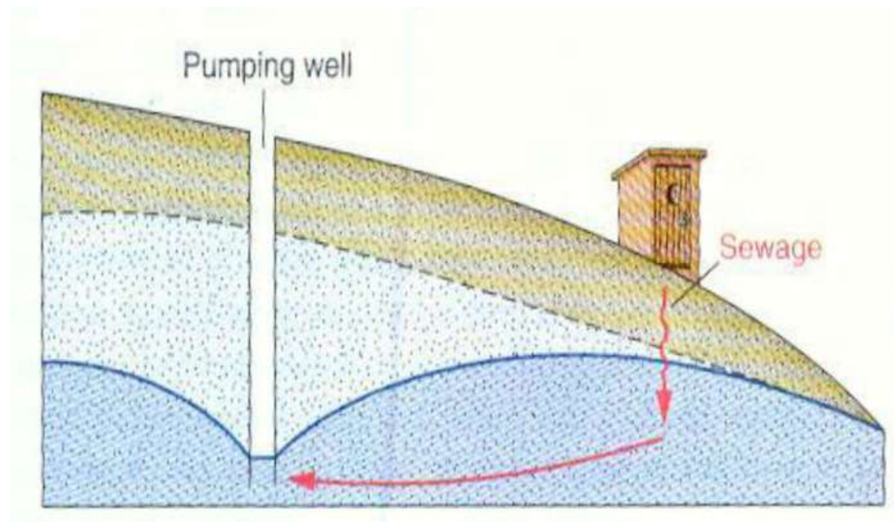
- liquid and solid wastes from septic tanks, sewage plants, and animal feedlots and slaughterhouses may contain bacteria, viruses, and parasites that can contaminate ground water
- acid mine drainage from coal and metal mines can contaminate both surface and ground water
- radioactive waste can cause the pollution of ground water due to the shallow burial of low-level solid and liquid radioactive wastes from the nuclear power industry

Pollution of Ground Water (cont.)

- pumping wells can cause or aggravate ground-water pollution



Water table steepens near a dump, increasing the velocity of ground-water flow and drawing pollutants into a well



Water-table slope is reversed by pumping, changing direction of the ground-water flow, and polluting the well

Balancing Withdrawal and Recharge

- a local supply of groundwater will last indefinitely if it is withdrawn for use at a rate equal to or less than the rate of recharge to the aquifer
- if ground water is withdrawn faster than it is being recharged, however, the supply is being reduced and will one day be gone

Balancing Withdrawal and Recharge

- heavy use of ground water can result in:
  - a regional water table dropping
  - deepening of a well which means more electricity is needed to pump the water to the surface
  - the ground surface settling because the water no longer supports the rock and sediment

Subsidence of the land surface caused by the extraction of ground water, near Mendota, San Joaquin Valley, CA. Signs on the pole indicate the positions of the land surface in 1925, 1955, and 1977. The land sank 30 feet in 52 years.

Balancing Withdrawal and Recharge (cont.)

- to avoid the problems of falling water tables, subsidence, and compaction, many towns use artificial recharge to increase recharge; natural floodwaters or treated industrial or domestic wastewaters are stored in infiltration ponds in the surface to increase the rate of water percolation into the ground

Effects of Ground-Water Action

- caves (or caverns): naturally formed underground chamber
- most caves develop when slightly acidic ground water dissolves limestone along joints and bedding planes, opening up cavern systems as calcite is carried away in solution
- most caves probably are formed by ground water circulating below the water table

$$H_2O + CO_2 + CaCO_3 \Leftrightarrow Ca^{++} + 2HCO_3^-$$

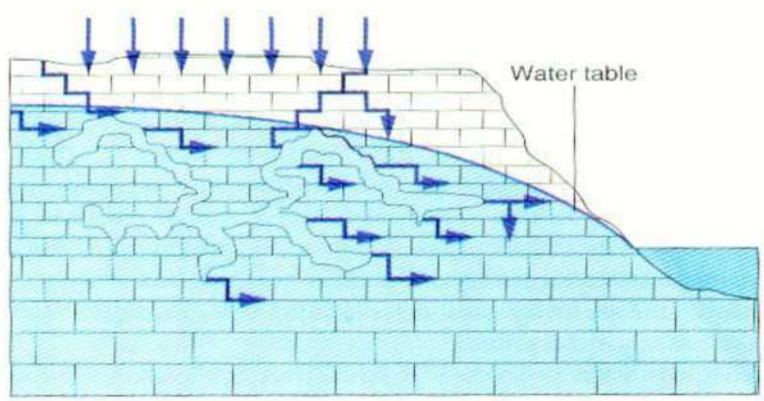
water	carbon dioxide	calcite in limestone	calcium ion	bicarbonate ion

→ development of caves (solution)

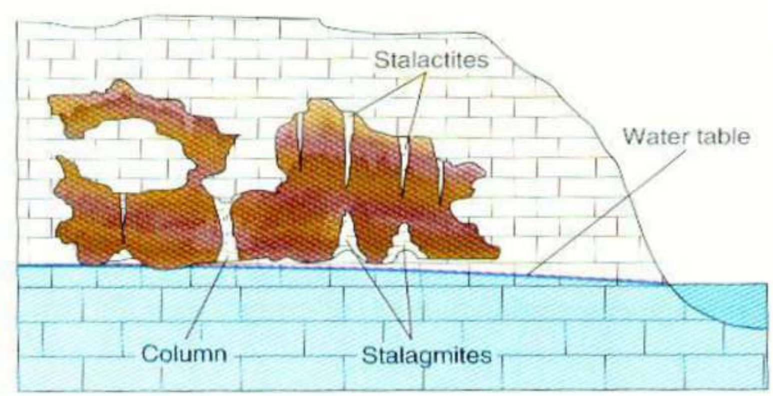
← development of flowstone and dripstone (precipitation)

Effects of Ground-Water Action (cont.)

- stalactites: icicle-like pendants of dripstone hanging from cave ceilings, generally slender and are commonly aligned along cracks in the ceiling, which act as conduits for ground water
- stalagmites: cone-shaped masses of drip-stone formed on cave floors, generally ctite



Water moves along fractures and bedding planes in limestone, dissolving the limestone to form caves below the water table



Falling water table allows cave system, now greatly enlarged, to fill with air. Calcite precipitation forms stalactites, stalagmites, and columns above the water table

Effects of Ground-Water Action (cont.)

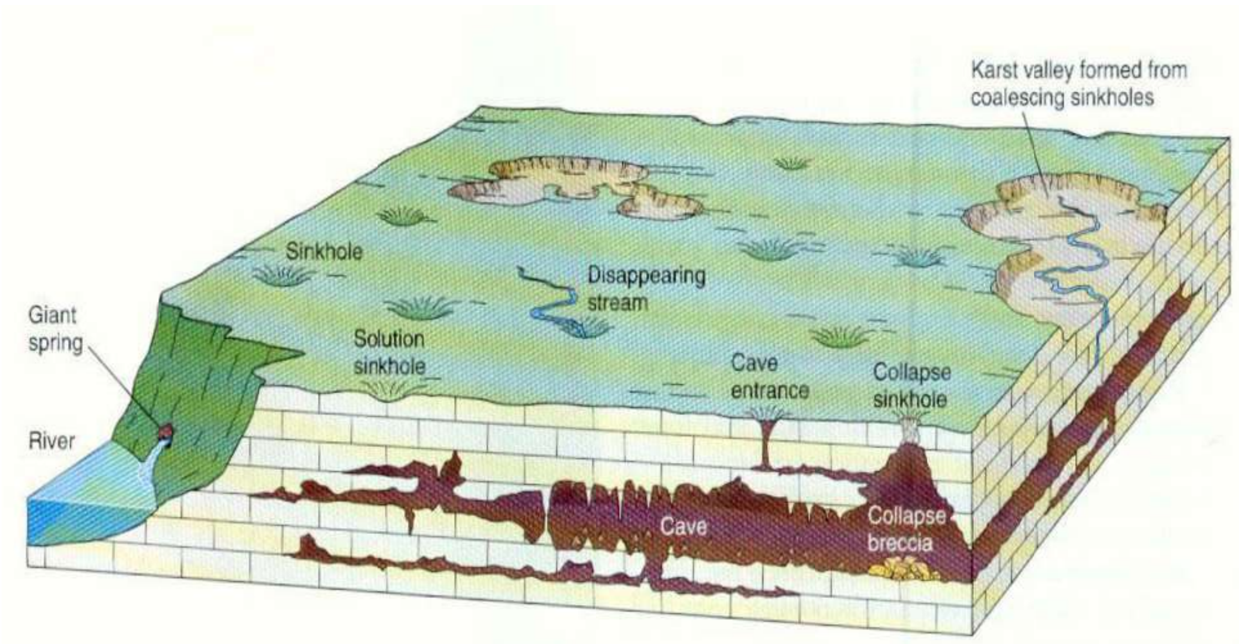
- sinkholes: closed depressions found on land surfaces underlain by limestone; they form either by the collapse of a cave roof or by solution as descending water enlarges a crack in limestone

A collapse sinkhole that formed suddenly in Winter Park, Florida, in 1981

Trees grow in a sinkhole formed in limestone near Mammoth Cave, Kentucky

Effects of Ground-Water Action (cont.)

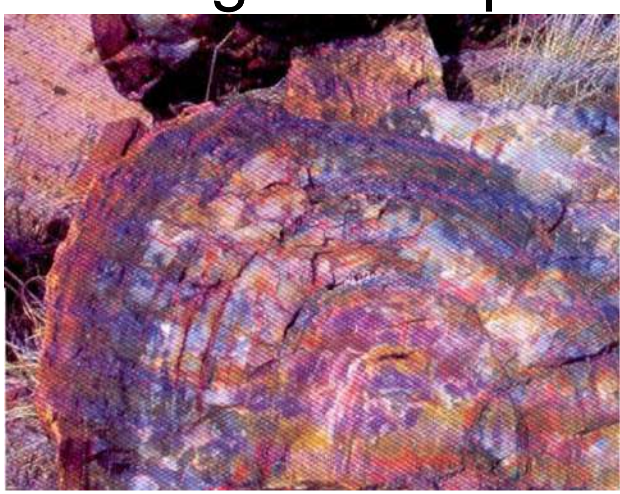
- karst topography: an area with many sinkholes and with cave systems beneath the land surface



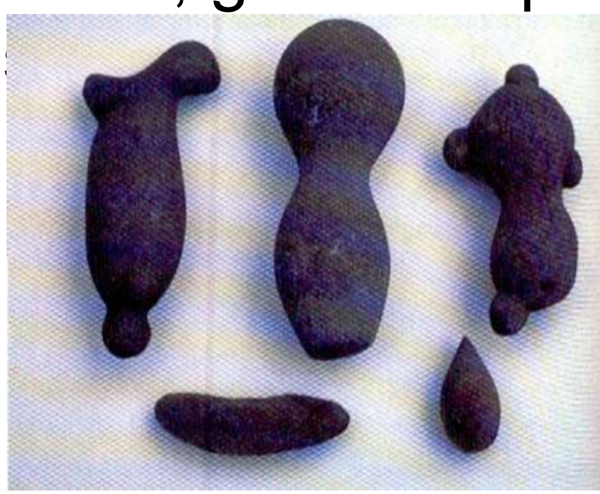
Karst topography is marked by underground caves and numerous surface sinkholes. A major river may cross the region, but small surface streams generally disappear down sinkholes

Effects of Ground-Water Action (cont.)

- petrified wood: develops when porous buried wood is either filled in or replaced by inorganic silica carried in by ground water
- concentration: a hard, round mass that develops when a considerable amount of cementing material precipitates locally in a rock, often around an organic nucleus
- geodes: partly hollow, globe-shaped bodies found in ...ne... ...er r...



Petrified log



Concretions that have weathered out of shale

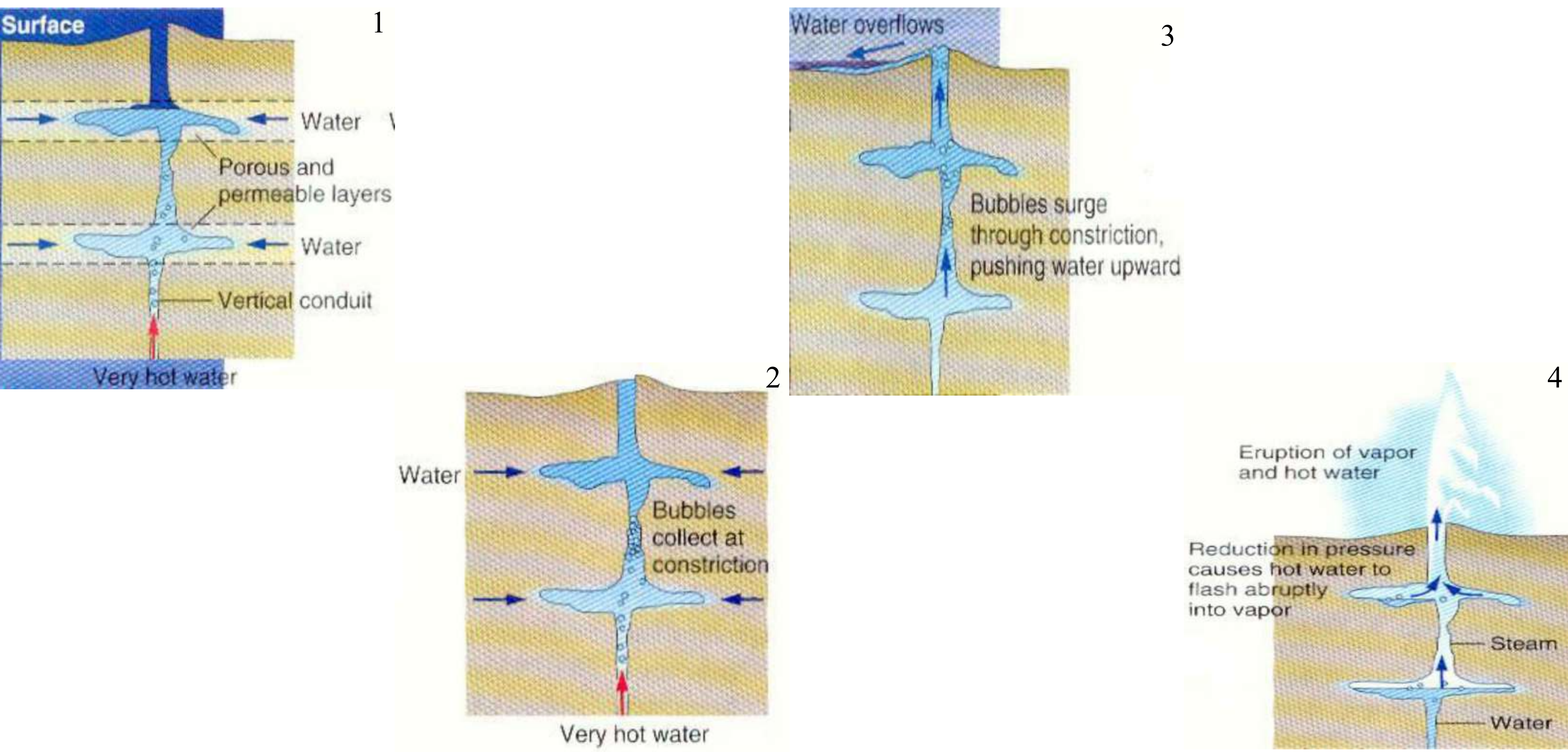
Geodes

Hot Water Underground

- hot springs: springs in which the water is warmer than human body temperature
- water can gain heat in two ways while underground:
  - ground water may circulate near a magma chamber or a body of cooling igneous rock
  - ground water may circulate unusually deep in the earth

Hot Water Underground

- geyser: a type of hot spring that periodically erupts hot water and stream; the water is generally near boiling (100°C)



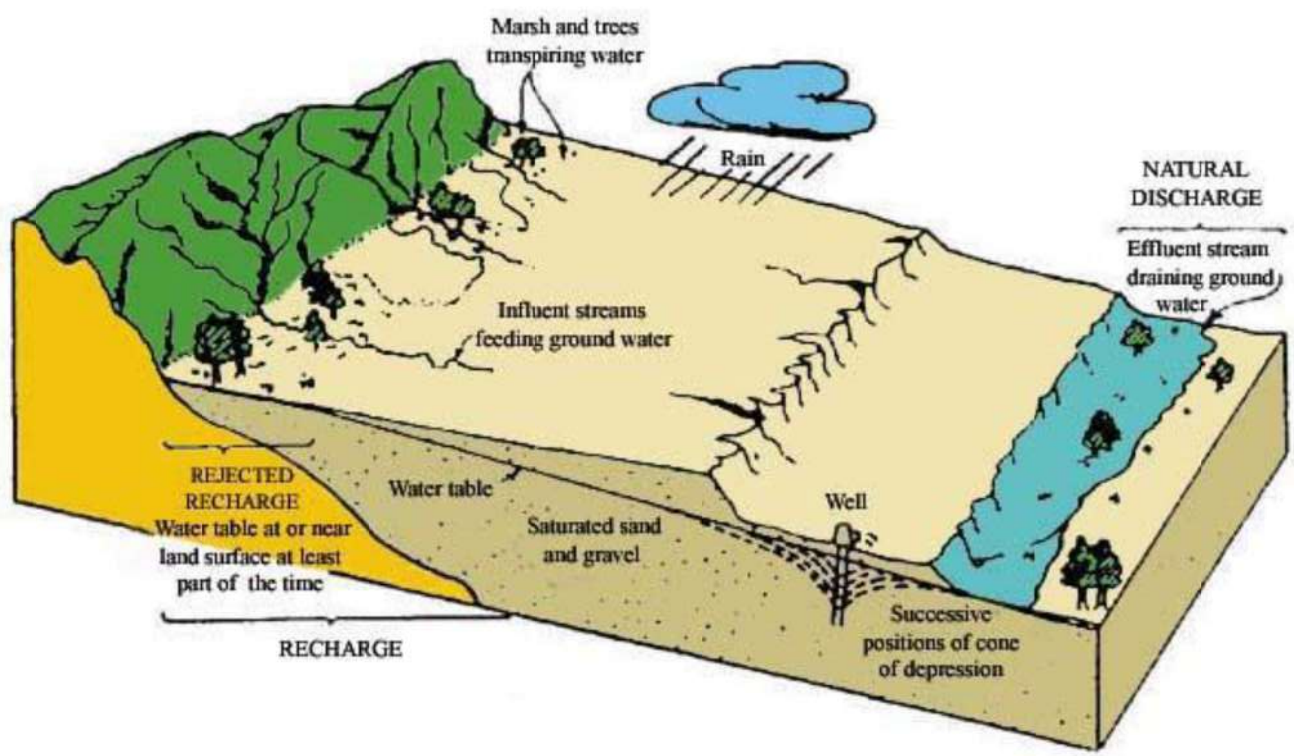
Geothermal Energy

- Electricity can be generated by harnessing naturally occurring stream and hot water in areas that are exceptionally hot underground (geothermal areas);
- nonelectric uses of geothermal energy include space heating, as well as paper manufacturing, ore processing, and food preparation

Groundwater Recharge and Discharge Zone

Groundwater recharge or **deep drainage** or **deep percolation** is a hydrologic process where water moves downward from surface water to groundwater. This process usually occurs in the vadose zone below plant roots and is often expressed as a flux to the water table surface. Recharge occurs both naturally (through the water cycle) and through anthropogenic processes (i.e., "artificial groundwater recharge"), where rainwater and or reclaimed water is routed to the subsurface.

Groundwater discharge usua refers to the water leaving aquifers in the soil, sometim the term is also used to reference water moving through an aquifer. In either case, the unit of measuremen of groundwater flow that is typically used is cubic meter per second (m3/s).



Hydrogeological Properties

POROSITY = Φ or n (units - fraction or %)

= fraction of **void space** (empty space) in soil or rock.

Represents the path water molecules can follow in the subsurface

Primary porosity - intergranular

Secondary porosity - fractures, faults, cavities, etc.

Porosity = volume of pore space relative to the total volume (rock and/or sediment + pore space). **Primary porosity** (% pore space) is the initial void space present (intergranular) when the rock formed. **Secondary porosity** (% added by openings) develops later. It is the result of fracturing, faulting, or dissolution. Grain shape and cementation also affect porosity.

PERMEABILITY is the capability of a rock to allow the passage of fluids. Permeability is dependent on the size of pore spaces and to what degree the pore spaces are connected. Grain shape, grain packing, and cementation affect permeability.

SPECIFIC YIELD (S_y) is the ratio of the volume of water drained from a rock (due to gravity) to the total rock volume. Grain size has a definite effect on specific yield. Smaller grains have larger surface area/volume ratio, which means more surface tension. Fine-grained sediment will have a lower S_y than coarse-grained sediment.

SPECIFIC RETENTION (S_r) is the ratio of the volume of water a rock can retain (in spite of gravity) to the total volume of rock.

Specific yield plus specific retention equals porosity (often designated with the Greek letter phi):

$$Sr + Sy = \Phi$$

Movement of groundwater depends on rock and sediment properties and the groundwater's flow potential. Porosity, permeability, specific yield and specific retention are important **components of hydraulic conductivity**.

HYDRAULIC CONDUCTIVITY = K (or P)

units = length/time (m/day)

Ability of a particular material to allow water to pass through it

The definition of hydraulic conductivity (denoted "K" or "P" in hydrology formulas) is the rate at which water moves through material. Internal friction and the various paths water takes are factors affecting hydraulic conductivity. Hydraulic conductivity is generally expressed in meters per day.

Storage Coefficient
The volume of water released from storage in a confined aquifer per unit surface area per unit decrease in the hydraulic head. The storage coefficient is the product of the specific storage and the aquifer thickness.

The **specific storage** is the amount of water that a portion of an aquifer releases from storage, per unit mass or volume of aquifer, per unit change in hydraulic head, while remaining fully saturated.

Transmissivity

The transmissivity of an aquifer is a measure of the quantity of water that the aquifer can transmit horizontally and should not be confused with transmittance, a measure used in optics. An aquifer is a layer of rock or unconsolidated sediments that can yield water to a spring or well. Transmissivity is typically used to determine the water that an aquifer can deliver to a pumping well. It can be calculated directly from the aquifer's average horizontal permeability and thickness.

$T = K B$

T: transmissivity (L2/T or m2/d)
K: hydraulic conductivity (L/T)
B: saturated thickness of the aquifer (L or m)

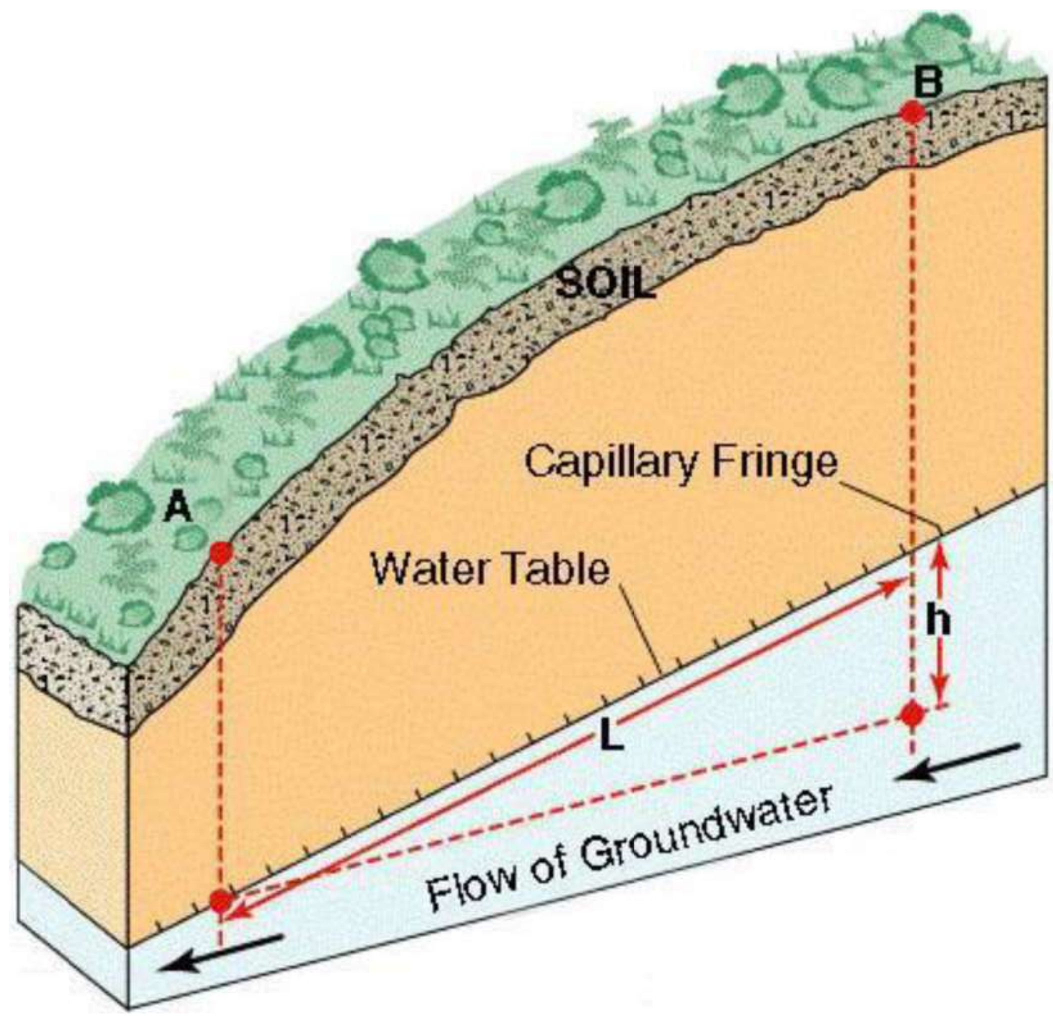
Groundwater Movement -- General Concepts

The **water table** is actually a sloping surface.

Slope (gradient) is determined by the difference in water table elevation **(h)** over a specified distance **(L)**.

Direction of flow is downslope.

Flow rate depends on the gradient and the properties of the aquifer.



Groundwater Movement

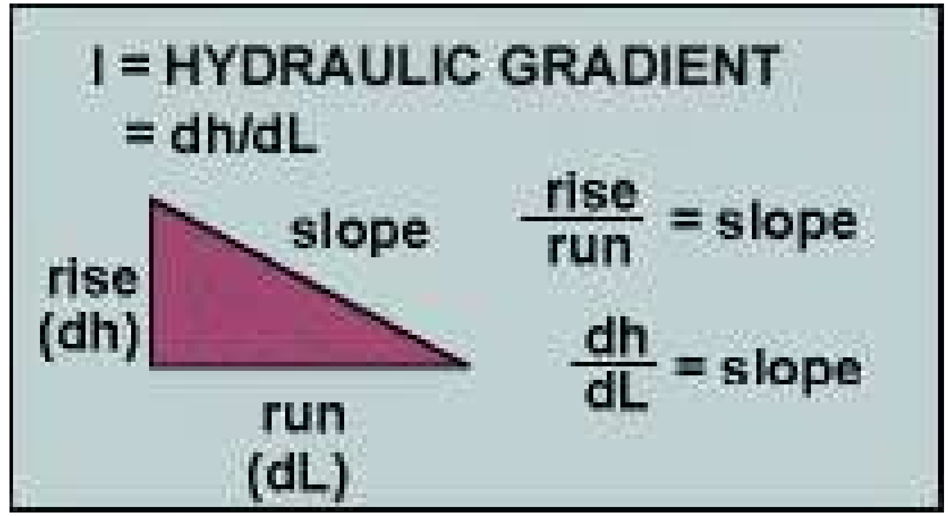
HYDRAULIC HEAD/ FLUID POTENTIAL = h (length units)

- Measure of energy potential (essentially is a measure of elevational/gravitational potential energy)
- The driving force for groundwater flow
- Water flows from high to low fluid potential or head (even if this means it may go "uphill"!)
- Hydraulic head is used to determine the hydraulic gradient

Hydraulic head = the driving force that moves groundwater. The hydraulic head combines **fluid pressure and gradient**, and can be though of as the standing elevation that water will rise to in a well allowed to come to equilibrium with the subsurface. Groundwater always moves from an area of higher hydraulic head to an area of lower hydraulic head. Therefore, groundwater not only flows downward, it can also flow laterally or upward.

General Concepts

- **Hydraulic gradient** for an unconfined aquifer = approximately the slope of the water table.

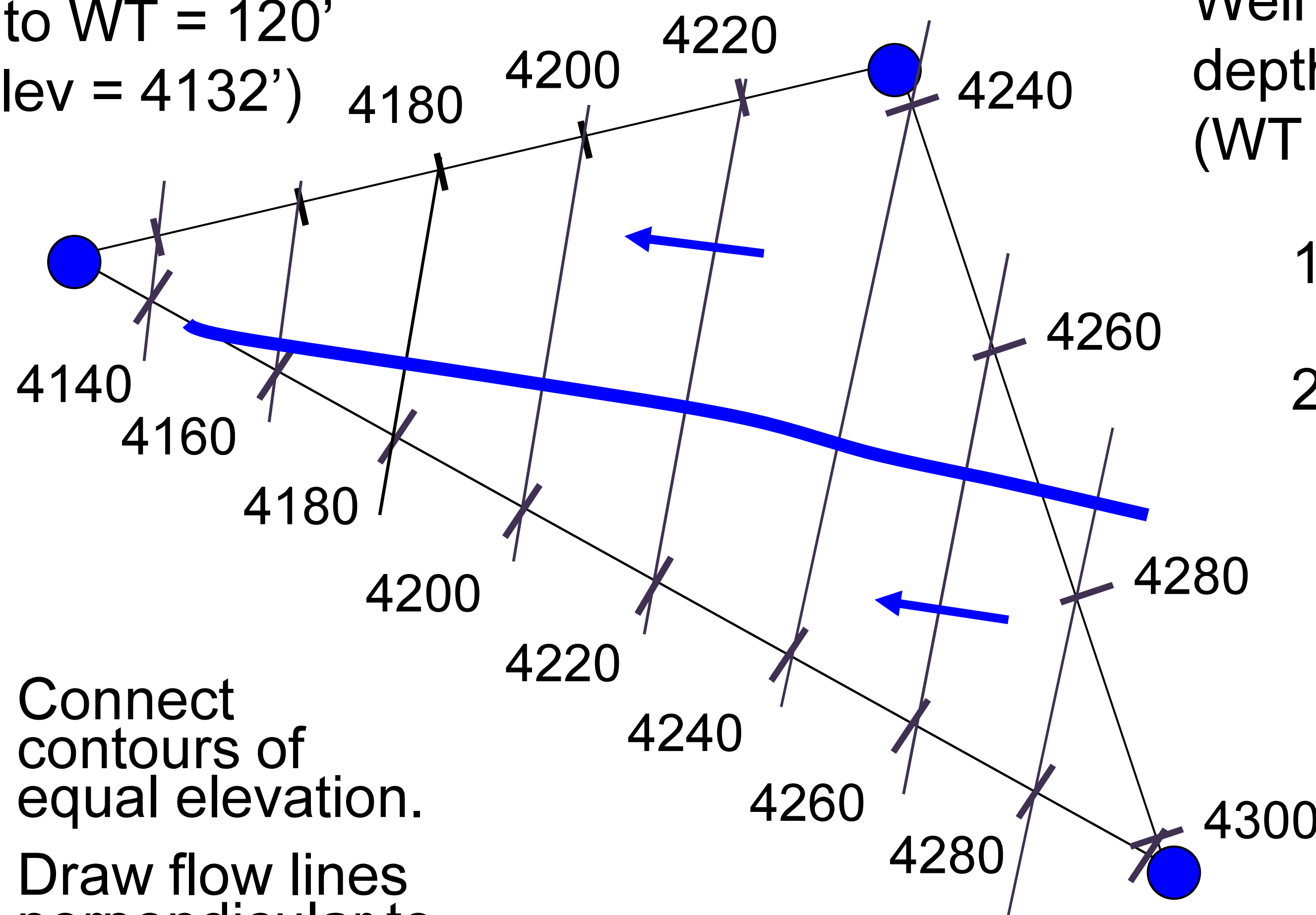


- **Porosity** = fraction (or %) of void space in rock or soil.
- **Permeability** = Similar to hydraulic conductivity; a measure of an earth material to transmit fluid, but only in terms of material properties, not fluid properties.
- **Hydraulic conductivity** = ability of material to allow water to move through it, expressed in terms of m/day (distance/time). It is a function of the size and shape of particles, and the size, shape, and connectivity of pore spaces.

Determine flow direction from well data

Well #1 4252’ elev
depth to WT = 120’
(WT elev = 4132’)

Well #2 4315’ elev
depth to WT = 78’
(WT elev = 4237’)

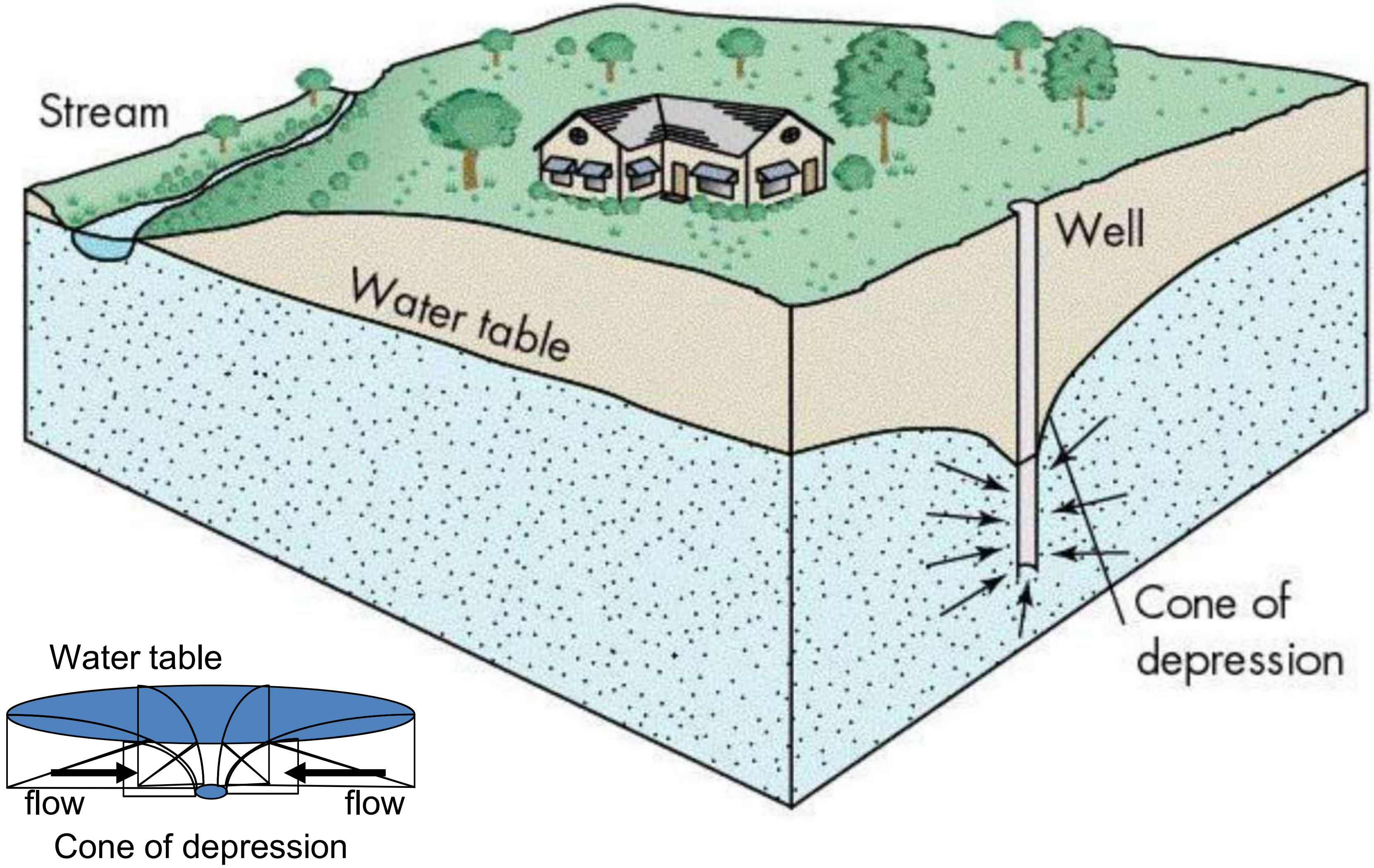


Well #3 4397’ elev
depth to WT = 95’
(WT elev = 4302’)

N

1. Calculate WT elevations.
2. Interpolate contour intervals.
3. Connect contours of equal elevation.
4. Draw flow lines perpendicular to contours.

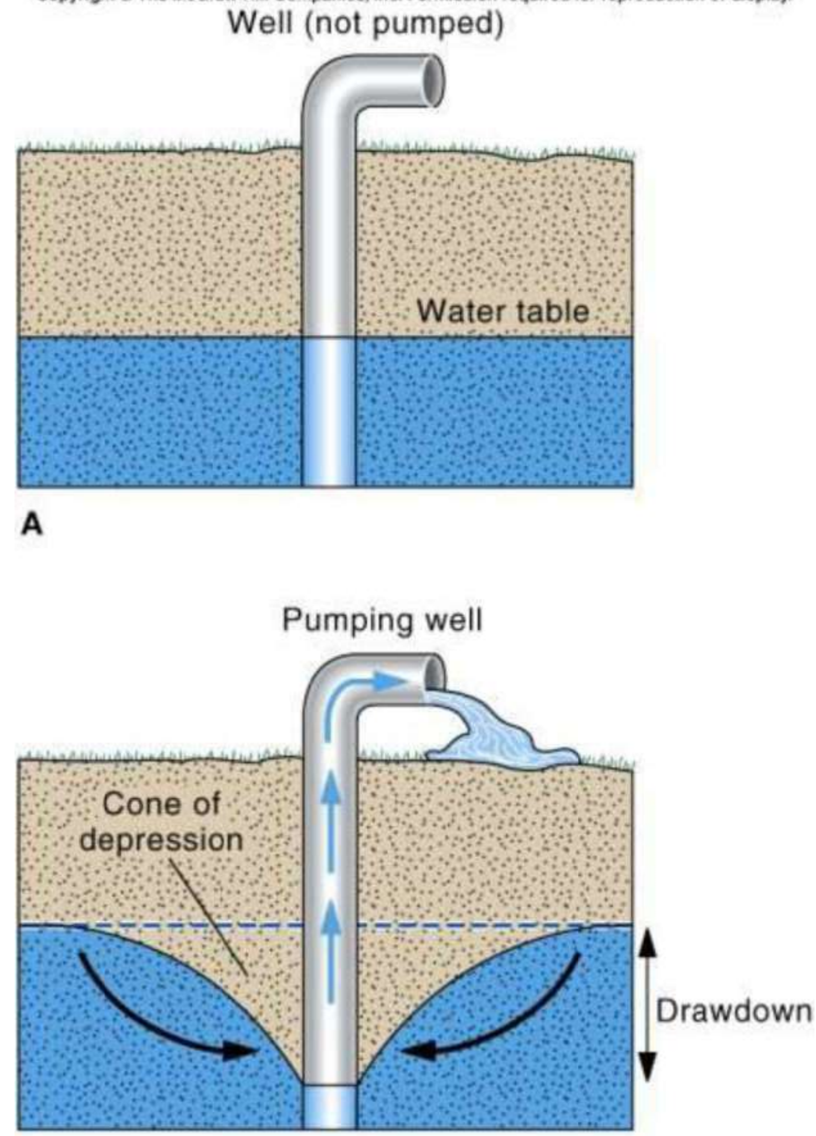
Cone of Depression



Pumping water from a well causes a **cone of depression** to form in the water table at the well site.

Drawdown: depression of a piezometric surface (including water table) due to pumping. Since pumping water out means lifting it, this is important.

Cone of depression is lowering of piezometric surface due to pumping around a well. Much more depressed near the well and less depressed further away. For a given amount of water withdrawal, the shape (width vs. depth) depends on hydraulic conductivity, storativity, and layer thickness. Other things being equal, a higher-permeability aquifer will have a broader, shallower cone of depression. A higher-storativity aquifer will also have a broad, shallow cone of depression. A thicker aquifer has a broader, shallower cone of depression. (This is part of why pump tests are hard to interpret.)



A

B

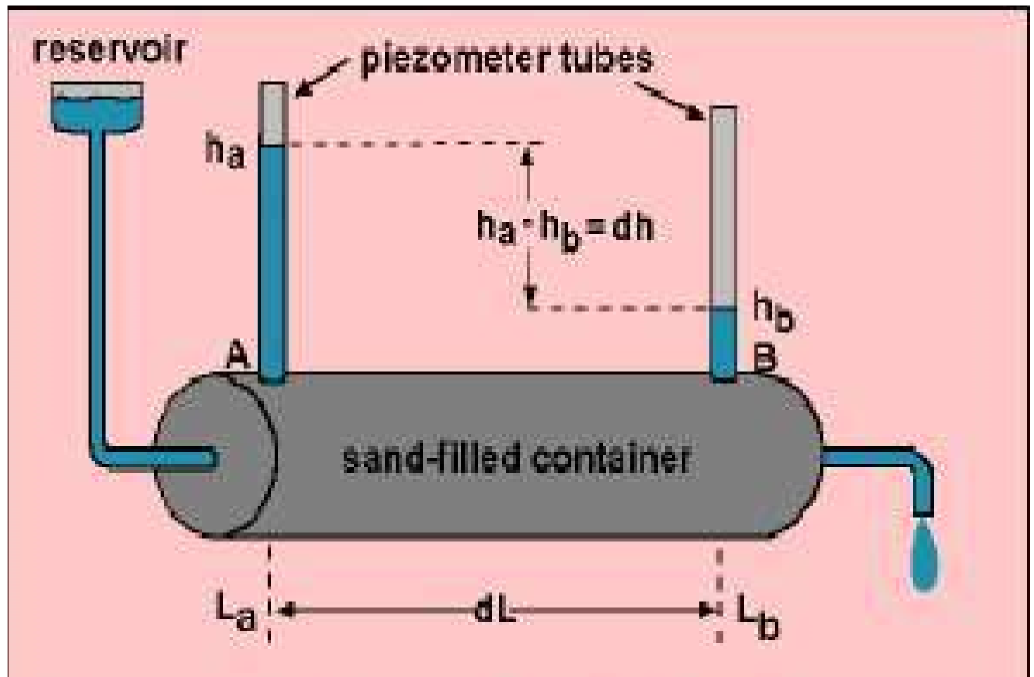
Groundwater Movement -- Darcy's Law

Q = KIA -- Henry Darcy, 1856, studied water flowing through porous material. His equation describes groundwater flow.

Darcy's experiment:

- Water is applied under pressure through end A, flows through the pipe, and discharges at end B.
- Water pressure is measured using **piezometer tubes**

Hydraulic head = dh (change in height between A and B)
Flow length = dL (distance between the two tubes)
Hydraulic gradient (I) = dh / dL



Horizontal pipe demonstrating Darcy's experiment

Groundwater Movement -- Darcy’s Law

The **velocity of groundwater** is based on hydraulic conductivity (K), as well as the hydraulic head (I).

The equation to describe the relations between subsurface materials and the movement of water through them is

$$Q = KIA$$

Q = Discharge = volumetric flow rate, volume of water flowing through an aquifer per unit time (m^3/day)

A = Area through which the groundwater is flowing, cross-sectional area of flow (aquifer width x thickness, in m^2)

Rearrange the equation to **Q/A = KI**, known as the flux (**v**), which is an **apparent velocity**

Actual groundwater velocity is higher than that determined by Darcy’s Law.

Groundwater Movement -- Darcy's Law

FLUX given by **v = Q/A = KI** is the **IDEAL velocity** of groundwater; it assumes that water molecules can flow in a straight line through the subsurface.

NOTE: Flux doesn't account for the water molecules actually following a tortuous path in and out of the pore spaces. They travel quite a bit farther and faster in reality than the flux would indicate.

DARCY FLUX given by **vx = Q/An = KI/n (m/sec)** is the **ACTUAL velocity** of groundwater, which DOES account for tortuosity of flow paths by including porosity (n) in the calculation. Darcy velocity is higher than ideal velocity.

Darcy's Law is used extensively in groundwater studies. It can help answer important questions such as the direction a pollution plume is moving in an aquifer, and how fast it is traveling.

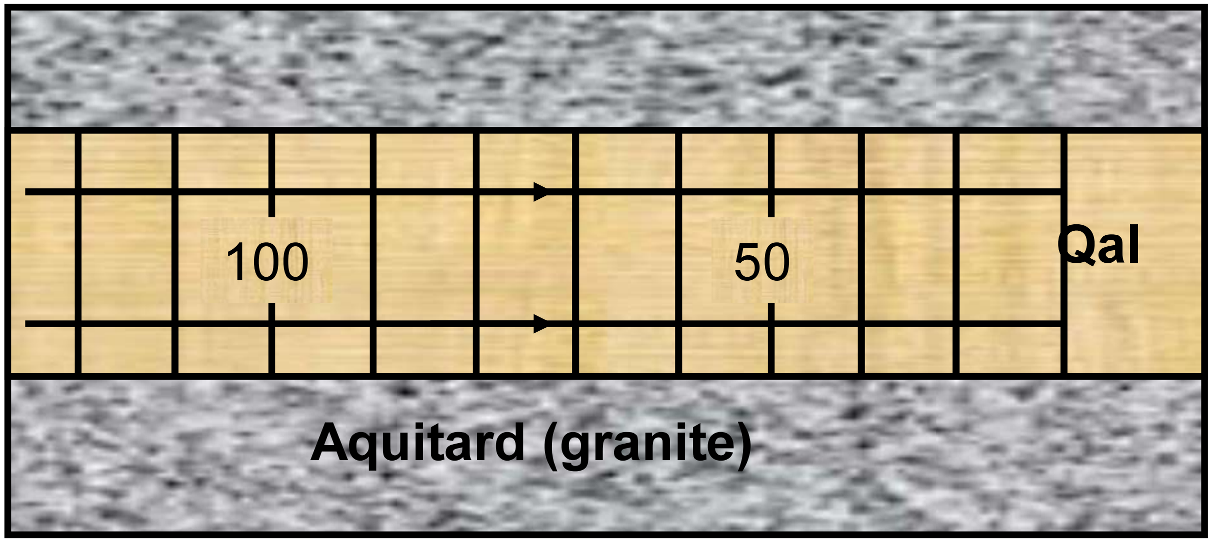
Groundwater Flow Nets

Water table **contour lines** are similar to topographic lines on a map. They essentially represent "elevations" in the subsurface. These elevations are the hydraulic head mentioned above.

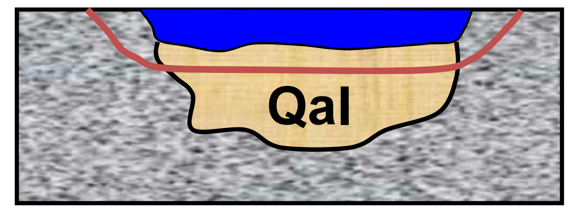
Water table contour lines can be used to determine the **direction groundwater will flow** in a given region. Many wells are drilled and hydraulic head is measured in each one. Water table contours (called **equipotential lines**) are constructed to join areas of equal head. Groundwater flow lines, which represent the paths of groundwater downslope, are drawn **perpendicular** to the contour lines.

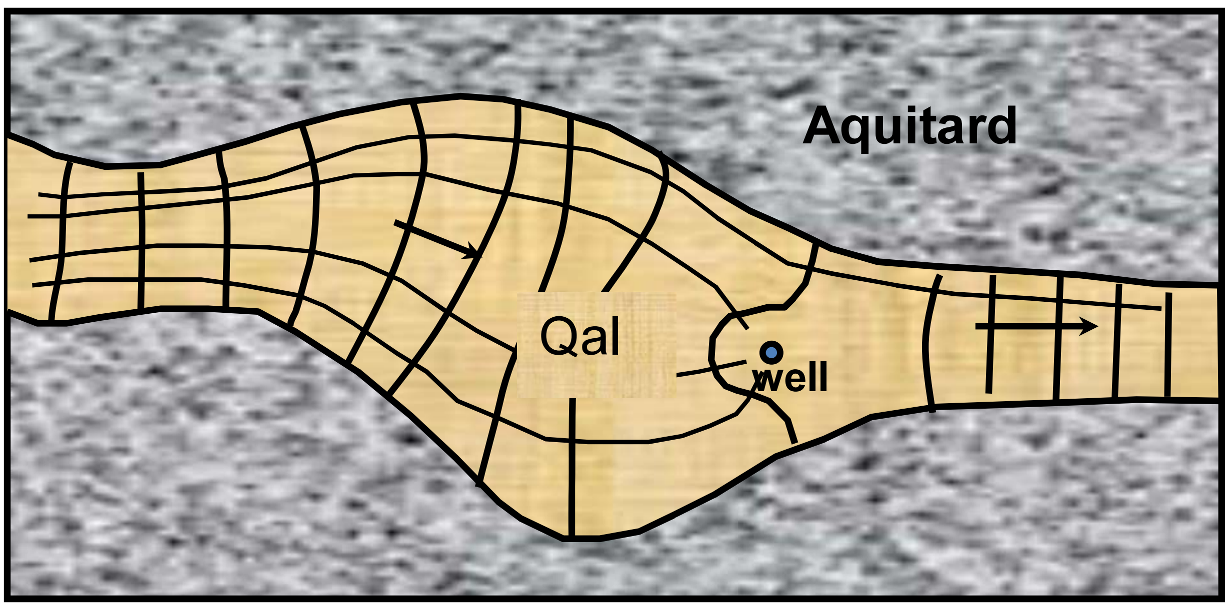
A map of groundwater contour lines with groundwater flow lines is called a **flow net**.

Remember: groundwater always moves from an area of higher hydraulic head to an area of lower hydraulic head, and perpendicular to equipotential lines.



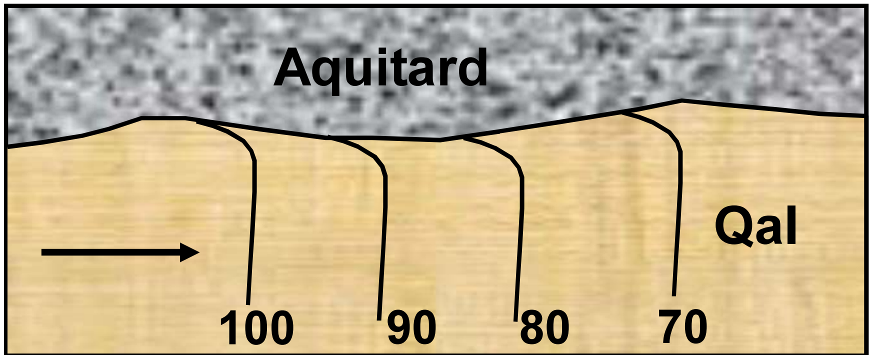
A simple flow net
Cross-profile view



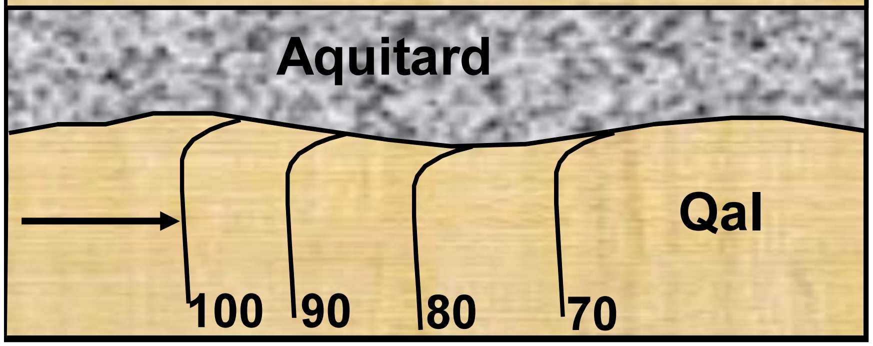


- Effect of a producing well
- Notice the approximate diameter of the cone of depression

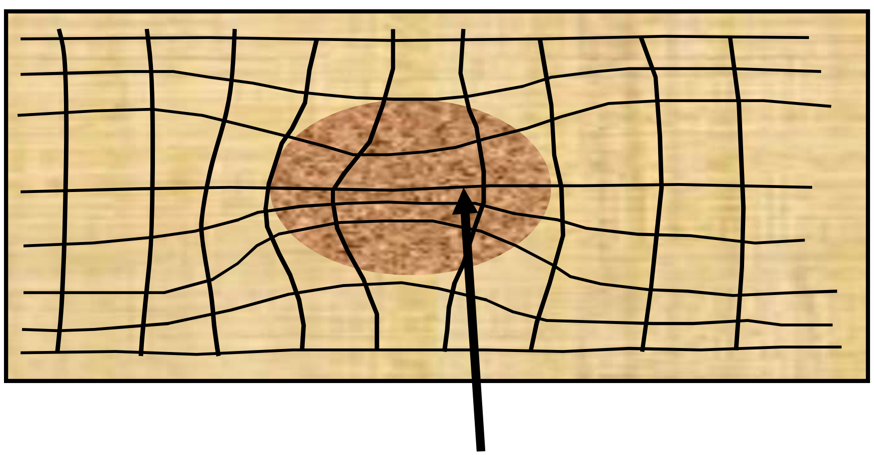
Water table contours



Water is flowing from Qal to granite



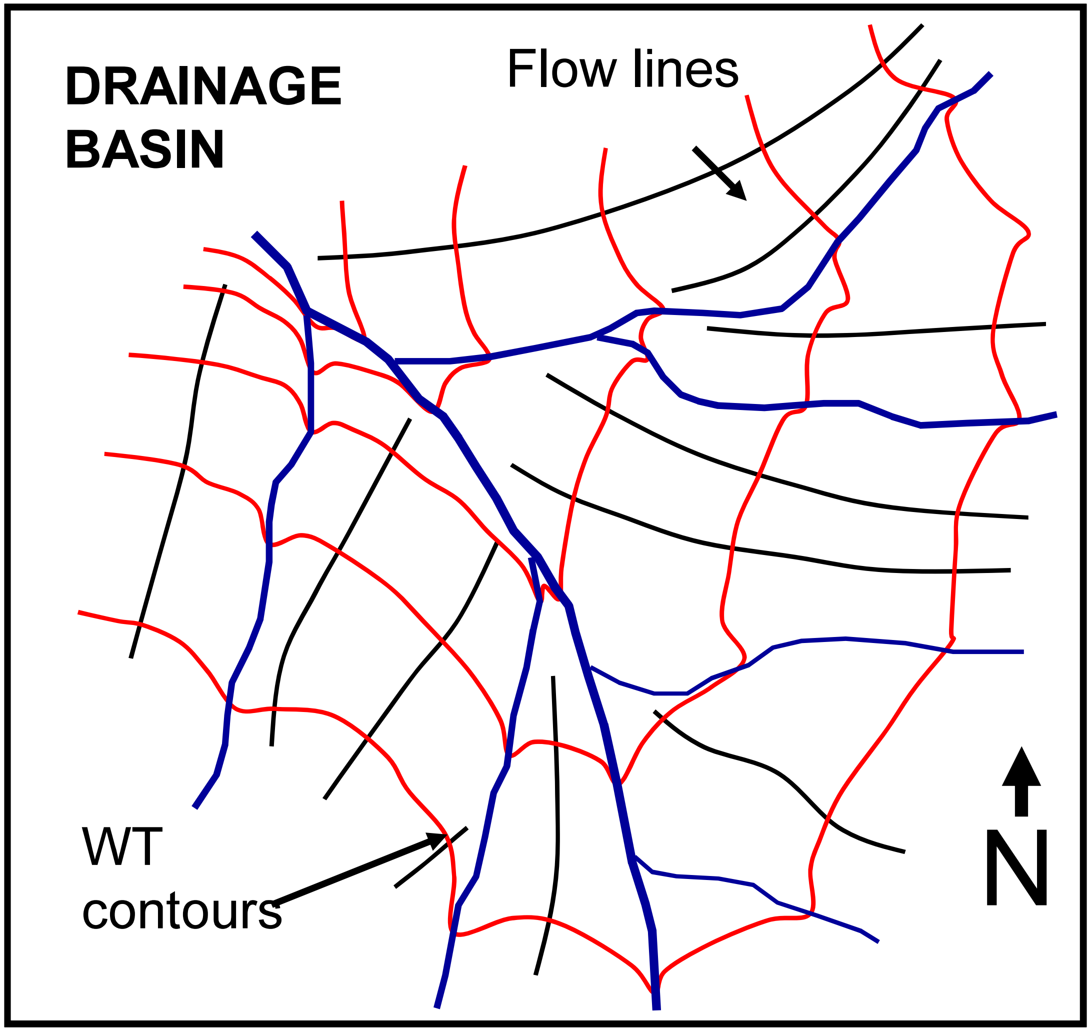
Water is flowing from granite to Qal



Distorted contours may occur due to anisotropic conditions (changes in aquifer properties).

Area of high permeability (high conductivity)

Groundwater Flow Nets

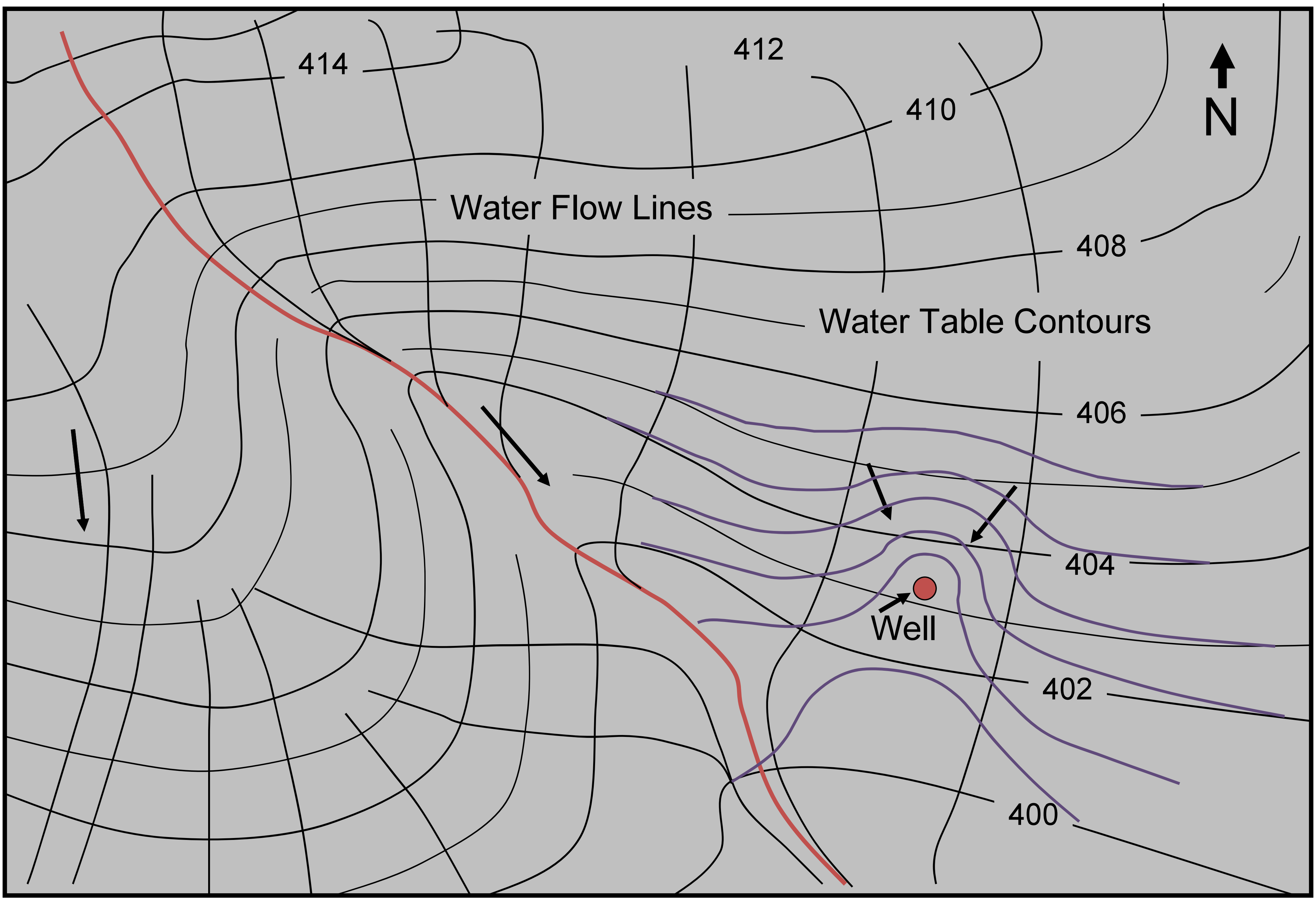


Water table contours in drainage basins roughly follow the surface topography, but depend greatly on the properties of rock and soil that compose the aquifer:

- Variations in mineralogy and texture
- Fractures and cavities
- Impervious layers
- Climate

Drainage basins are often used to collect clean, unpolluted water for domestic consumption.

Groundwater Flow Net



Chapter

Water Quality Parameters

Nayla Hassan Omer

Abstract

Since the industrial revolution in the late eighteenth century, the world has discovered new sources of pollution nearly every day. So, air and water can potentially become polluted everywhere. Little is known about changes in pollution rates. The increase in water-related diseases provides a real assessment of the degree of pollution in the environment. This chapter summarizes water quality parameters from an ecological perspective not only for humans but also for other living things. According to its quality, water can be classified into four types. Those four water quality types are discussed through an extensive review of their important common attributes including physical, chemical, and biological parameters. These water quality parameters are reviewed in terms of definition, sources, impacts, effects, and measuring methods.

Keywords: water quality, physical parameters, chemical parameters, biological parameters, radioactive substances, toxic substances, indicator organisms

1. Introduction

Water is the second most important need for life to exist after air. As a result, water quality has been described extensively in the scientific literature. The most popular definition of water quality is "it is the physical, chemical, and biological characteristics of water" [1, 2]. Water quality is a measure of the condition of water relative to the requirements of one or more biotic species and/or to any human need or purpose [3, 4].

2. Classification of water

Based on its source, water can be divided into ground water and surface water [5]. Both types of water can be exposed to contamination risks from agricultural, industrial, and domestic activities, which may include many types of pollutants such as heavy metals, pesticides, fertilizers, hazardous chemicals, and oils [6].

Water quality can be classified into four types—potable water, palatable water, contaminated (polluted) water, and infected water [7]. The most common scientific definitions of these types of water quality are as follows:

1. *Potable water:* It is safe to drink, pleasant to taste, and usable for domestic purposes [1, 7].

2. *Palatable water:* It is esthetically pleasing; it considers the presence of chemicals that do not cause a threat to human health [7].

3. *Contaminated (polluted) water:* It is that water containing unwanted physical, chemical, biological, or radiological substances, and it is unfit for drinking or domestic use [7].

4. *Infected water:* It is contaminated with pathogenic organism [7].

3. Parameters of water quality

There are three types of water quality parameters physical, chemical, and biological [8, 9]. They are summarized in **Table 1**.

3.1 Physical parameters of water quality

3.1.1 Turbidity

Turbidity is the cloudiness of water [10]. It is a measure of the ability of light to pass through water. It is caused by suspended material such as clay, silt, organic material, plankton, and other particulate materials in water [2].

No.	Types of water quality parameters		
	Physical parameters	**Chemical parameters**	**Biological parameters**
1	Turbidity	pH	Bacteria
2	Temperature	Acidity	Algae
3	Color	Alkalinity	Viruses
4	Taste and odor	Chloride	Protozoa
5	Solids	Chlorine residual	
6	Electrical conductivity (EC)	Sulfate	
7		Nitrogen	
8		Fluoride	
9		Iron and manganese	
10		Copper and zinc	
11		Hardness	
12		Dissolved oxygen	
13		Biochemical oxygen demand (BOD)	
14		Chemical oxygen demand (COD)	
15		Toxic inorganic substances	
16		Toxic organic substances	
17		Radioactive substances	

Table 1.
Parameters of water quality.

Turbidity in drinking water is esthetically unacceptable, which makes the water look unappetizing. The impact of turbidity can be summarized in the following points:

1. It can increase the cost of water treatment for various uses [11].

2. The particulates can provide hiding places for harmful microorganisms and thereby shield them from the disinfection process [12].

3. Suspended materials can clog or damage fish gills, decreasing its resistance to diseases, reducing its growth rates, affecting egg and larval maturing, and affecting the efficiency of fish catching method [13, 14].

4. Suspended particles provide adsorption media for heavy metals such as mercury, chromium, lead, cadmium, and many hazardous organic pollutants such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and many pesticides [15].

5. The amount of available food is reduced [15] because higher turbidity raises water temperatures in light of the fact that suspended particles absorb more sun heat. Consequently, the concentration of the dissolved oxygen (DO) can be decreased since warm water carries less dissolved oxygen than cold water.

Turbidity is measured by an instrument called nephelometric turbidimeter, which expresses turbidity in terms of NTU or TU. A TU is equivalent to 1 mg/L of silica in suspension [10].

Turbidity more than 5 NTU can be visible to the average person while turbidity in muddy water, it exceeds 100 NTU [10]. Groundwater normally has very low turbidity because of the natural filtration that occurs as the water penetrates through the soil [9, 16].

3.1.2 Temperature

Palatability, viscosity, solubility, odors, and chemical reactions are influenced by temperature [10]. Thereby, the sedimentation and chlorination processes and biological oxygen demand (BOD) are temperature dependent [11]. It also affects the biosorption process of the dissolved heavy metals in water [17, 18]. Most people find water at temperatures of 10–15°C most palatable [10, 19].

3.1.3 Color

Materials decayed from organic matter, namely, vegetation and inorganic matter such as soil, stones, and rocks impart color to water, which is objectionable for esthetic reasons, not for health reasons [10, 20].

Color is measured by comparing the water sample with standard color solutions or colored glass disks [10]. One color unit is equivalent to the color produced by a 1 mg/L solution of platinum (potassium chloroplatinate (K_2PtCl_6)) [10].

The color of a water sample can be reported as follows:

- *Apparent color* is the entire water sample color and consists of both dissolved and suspended components color [10].

- *True color* is measured after filtering the water sample to remove all suspended material [19].

Color is graded on scale of 0 (clear) to 70 color units. Pure water is colorless, which is equivalent to 0 color units [10].

3.1.4 Taste and odor

Taste and odor in water can be caused by foreign matter such as organic materials, inorganic compounds, or dissolved gasses [19]. These materials may come from natural, domestic, or agricultural sources [21].

The numerical value of odor or taste is determined quantitatively by measuring a volume of sample A and diluting it with a volume of sample B of an odor-free distilled water so that the odor of the resulting mixture is just detectable at a total mixture volume of 200 ml [19, 22]. The unit of odor or taste is expressed in terms of a threshold number as follows:

$$\text{TON or TTN} = (A + B)/A \tag{1}$$

where TON is the threshold odor number and TTN is the threshold taste number.

3.1.5 Solids

Solids occur in water either in solution or in suspension [22]. These two types of solids can be identified by using a glass fiber filter that the water sample passes through [22]. By definition, the suspended solids are retained on the top of the filter and the dissolved solids pass through the filter with the water [10].

If the filtered portion of the water sample is placed in a small dish and then evaporated, the solids as a residue. This material is usually called total dissolved solids or TDS [10].

$$\text{Total solid (TS)} = \text{Total dissolved solid (TDS)} + \text{Total suspended solid (TSS)} \tag{2}$$

Water can be classified by the amount of TDS per liter as follows:

- freshwater: <1500 mg/L TDS;
- brackish water: 1500–5000 mg/L TDS;
- saline water: >5000 mg/L TDS.

The residue of TSS and TDS after heating to dryness for a defined period of time and at a specific temperature is defined as fixed solids. Volatile solids are those solids lost on ignition (heating to 550°C) [10].

These measures are helpful to the operators of the wastewater treatment plant because they roughly approximate the amount of organic matter existing in the total solids of wastewater, activated sludge, and industrial wastes [1, 22]. **Figure 1** describes the interrelationship of solids found in water [22]. They are calculated as follows [10]:

- Total solids:

$$\text{Total solids (mg/L)} = [(\text{TSA}-\text{TSB})] \times 1000/\text{sample (mL)} \tag{3}$$

where TSA = weight of dried residue + dish in milligrams and TSB = weight of dish in milligrams.

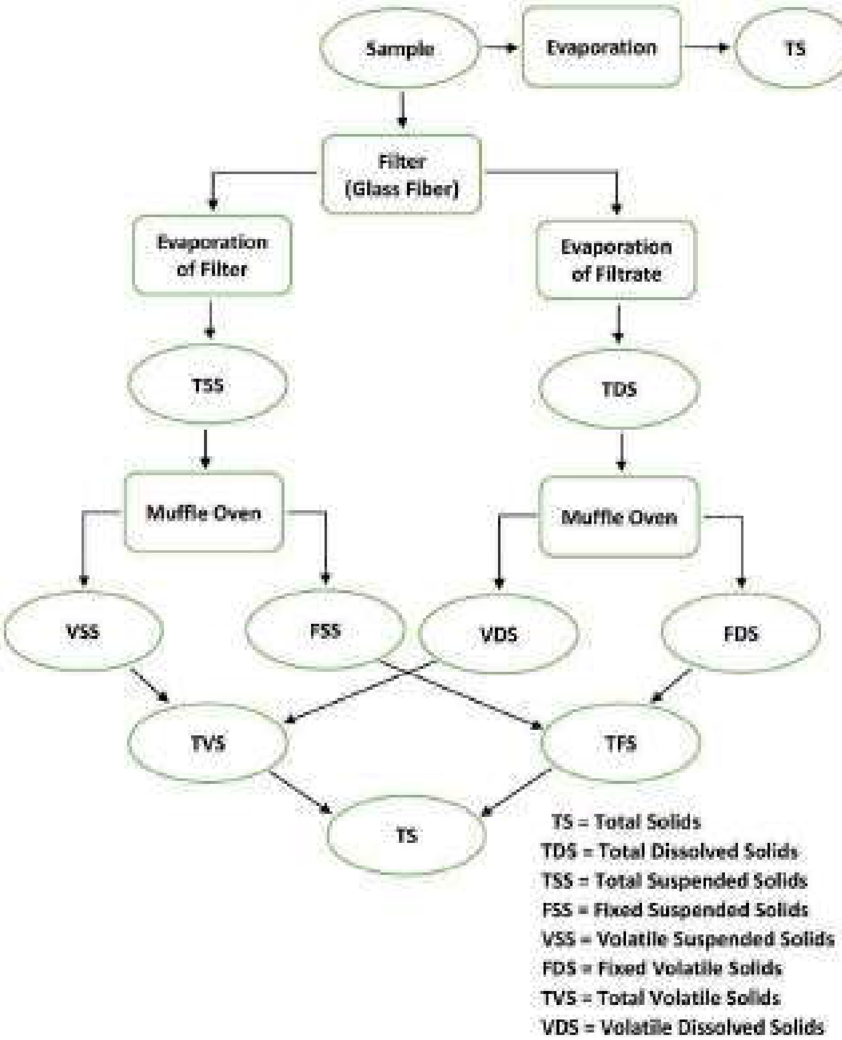


Figure 1.
Interrelationship of solids found in water [22].

- Total dissolved solids:

$$\text{Total dissolved solids (mg/L)} = [(\text{TDSA} - \text{TDSB})] \times 1000/\text{sample (mL)} \quad (4)$$

where TDSA = weight of dried residue + dish in milligrams and TDSB = weight of dish in milligrams.

- Total suspended solids:

$$\text{Total suspended solids (mg/L)} = [(\text{TSSA} - \text{TSSB})] \times 1000/\text{sample (mL)} \quad (5)$$

where TSSA = weight of dish and filter paper + dried residue and TSSB = weight of dish and filter paper in milligram.

- Fixed and volatile suspended solids:

$$\text{Volatile suspended solids (mg/L)} = [(\text{VSSA} - \text{VSSB})] \times 1000/\text{sample (mL)} \quad (6)$$

where VSSA = weight of residue + dish and filter before ignition, mg and VSSB = weight of residue + dish and filter after ignition, mg.

3.1.6 Electrical conductivity (EC)

The electrical conductivity (EC) of water is a measure of the ability of a solution to carry or conduct an electrical current [22]. Since the electrical current is carried by ions in solution, the conductivity increases as the concentration [10] of ions increases. Therefore, it is one of the main parameters used to determine the suitability of water for irrigation and firefighting.

Units of its measurement are as follows:

- U.S. units = micromhos/cm
- S.I. units = milliSiemens/m (mS/m) or dS/m (deciSiemens/m)

where (mS/m) = 10 umho/cm (1000 μS/cm = 1 dS/m).

Pure water is not a good conductor of electricity [2, 10]. Typical conductivity of water is as follows:

- Ultra-pure water: 5.5×10^{-6} S/m;
- Drinking water: 0.005–0.05 S/m;
- Seawater: 5 S/m.

The electrical conductivity can be used to estimate the TDS value of water as follows [10, 22]:

$$\text{TDS (mg/L)} \cong \text{EC (dS/m or umho/cm)} \times (0.55\text{–}0.7) \qquad (7)$$

TDS can be used to estimate the ionic strength of water in the applications of groundwater recharging by treated wastewater [22]. The normal method of measurement is electrometric method [10].

3.2 Chemical parameters of water quality

3.2.1 pH

pH is one of the most important parameters of water quality. It is defined as the negative logarithm of the hydrogen ion concentration [9, 12]. It is a dimensionless number indicating the strength of an acidic or a basic solution [23]. Actually, pH of water is a measure of how acidic/basic water is [19, 20]. Acidic water contains extra hydrogen ions (H^+) and basic water contains extra hydroxyl (OH^-) ions [2].

As shown in **Figure 2**, pH ranges from 0 to 14, with 7 being neutral. pH of less than 7 indicates acidity, whereas a pH of greater than 7 indicates a base solution [2, 24]. Pure water is neutral, with a pH close to 7.0 at 25°C. Normal rainfall has a pH of approximately 5.6 (slightly acidic) owing to atmospheric carbon dioxide gas [10]. Safe ranges of pH for drinking water are from 6.5 to 8.5 for domestic use and living organisms need [24].

A change of 1 unit on a pH scale represents a 10-fold change in the pH [10], so that water with pH of 7 is 10 times more acidic than water with a pH of 8, and water with a pH of 5 is 100 times more acidic than water with a pH of 7. There are two methods available for the determination of pH: electrometric and colorimetric methods [10].

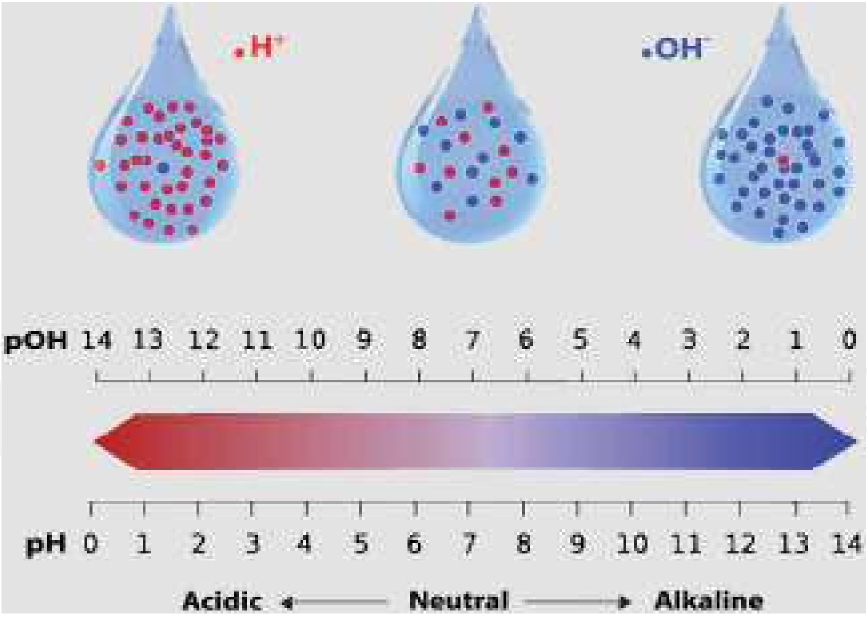


Figure 2.
pH of water.

Excessively high and low pHs can be detrimental for the use of water. A high pH makes the taste bitter and decreases the effectiveness of the chlorine disinfection, thereby causing the need for additional chlorine [21]. The amount of oxygen in water increases as pH rises. Low-pH water will corrode or dissolve metals and other substances [10].

Pollution can modify the pH of water, which can damage animals and plants that live in the water [10].

The effects of pH on animals and plants can be summarized as follows:

- Most aquatic animals and plants have adapted to life in water with a specific pH and may suffer from even a slight change [15].

- Even moderately acidic water (low pH) can decrease the number of hatched fish eggs, irritate fish and aquatic insect gills, and damage membranes [14].

- Water with very low or high pH is fatal. A pH below 4 or above 10 will kill most fish, and very few animals can endure water with a pH below 3 or above 11 [15].

- Amphibians are extremely endangered by low pH because their skin is very sensitive to contaminants [15]. Some scientists believe that the current decrease in amphibian population throughout the globe may be due to low pH levels induced by acid rain.

The effects of pH on other chemicals in water can be summarized as follows:

- Heavy metals such as cadmium, lead, and chromium dissolve more easily in highly acidic water (lower pH). This is important because many heavy metals become much more toxic when dissolved in water [21].

- A change in the pH can change the forms of some chemicals in the water. Therefore, it may affect aquatic plants and animals [21]. For instance, ammonia is relatively harmless to fish in neutral or acidic water. However, as the water becomes more alkaline (the pH increases), ammonia becomes progressively more poisonous to these same organisms.

3.2.2 Acidity

Acidity is the measure of acids in a solution. The acidity of water is its quantitative capacity to neutralize a strong base to a selected pH level [10]. Acidity in water is usually due to carbon dioxide, mineral acids, and hydrolyzed salts such as ferric and aluminum sulfates [10]. Acids can influence many processes such as corrosion, chemical reactions and biological activities [10].

Carbon dioxide from the atmosphere or from the respiration of aquatic organisms causes acidity when dissolved in water by forming carbonic acid (H_2CO_3). The level of acidity is determined by titration with standard sodium hydroxide (0.02 N) using phenolphthalein as an indicator [10, 20].

3.2.3 Alkalinity

The alkalinity of water is its acid-neutralizing capacity comprised of the total of all titratable bases [10]. The measurement of alkalinity of water is necessary to determine the amount of lime and soda needed for water softening (e.g., for corrosion control in conditioning the boiler feed water) [22]. Alkalinity of water is mainly caused by the presence of hydroxide ions (OH^-), bicarbonate ions (HCO^{3-}), and carbonate ions (CO_3^{2-}), or a mixture of two of these ions in water. As stated in the following equation, the possibility of OH^- and HCO_3^- ions together are not possible because they react together to produce CO_3^{2-} ions:

$$OH^- + HCO_3^- \rightarrow CO_3^{2-} + H_2O \qquad (8)$$

Alkalinity is determined by titration with a standard acid solution (H_2SO_4 of 0.02 N) using selective indicators (methyl orange or phenolphthalein).

The high levels of either acidity or alkalinity in water may be an indication of industrial or chemical pollution. Alkalinity or acidity can also occur from natural sources such as volcanoes. The acidity and alkalinity in natural waters provide a buffering action that protects fish and other aquatic organisms from sudden changes in pH. For instance, if an acidic chemical has somehow contaminated a lake that had natural alkalinity, a neutralization reaction occurs between the acid and alkaline substances; the pH of the lake water remains unchanged. For the protection of aquatic life, the buffering capacity should be at least 20 mg/L as calcium carbonate.

3.2.4 Chloride

Chloride occurs naturally in groundwater, streams, and lakes, but the presence of relatively high chloride concentration in freshwater (about 250 mg/L or more) may indicate wastewater pollution [7]. Chlorides may enter surface water from several sources including chloride-containing rock, agricultural runoff, and wastewater.

Chloride ions Cl^- in drinking water do not cause any harmful effects on public health, but high concentrations can cause an unpleasant salty taste for most people. Chlorides are not usually harmful to people; however, the sodium part of table salt has been connected to kidney and heart diseases [25]. Small amounts of chlorides are essential for ordinary cell functions in animal and plant life.

Sodium chloride may impart a salty taste at 250 mg/L; however, magnesium or calcium chloride are generally not detected by taste until reaching levels of

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1000 mg/L [10]. Standards for public drinking water require chloride levels that do not exceed 250 mg/L. There are many methods to measure the chloride concentration in water, but the normal one is the titration method by silver nitrate [10].

3.2.5 Chlorine residual

Chlorine (Cl_2) does not occur naturally in water but is added to water and wastewater for disinfection [10]. While chlorine itself is a toxic gas, in dilute aqueous solution, it is not harmful to human health. In drinking water, a residual of about 0.2 mg/L is optimal. The residual concentration which is maintained in the water distribution system ensures good sanitary quality of water [11].

Chlorine can react with organics in water forming toxic compounds called trihalomethanes or THMs, which are carcinogens such as chloroform $CHCl_3$ [11, 22]. Chlorine residual is normally measured by a color comparator test kit or spectrophotometer [10].

3.2.6 Sulfate

Sulfate ions (SO_4^{2-}) occur in natural water and in wastewater. The high concentration of sulfate in natural water is usually caused by leaching of natural deposits of sodium sulfate (Glauber's salt) or magnesium sulfate (Epson salt) [11, 26]. If high concentrations are consumed in drinking water, there may be objectionable tastes or unwanted laxative effects [26], but there is no significant danger to public health.

3.2.7 Nitrogen

There are four forms of nitrogen in water and wastewater: organic nitrogen, ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen [10]. If water is contaminated with sewage, most of the nitrogen is in the forms of organic and ammonia, which are transformed by microbes to form nitrites and nitrates [22]. Nitrogen in the nitrate form is a basic nutrient to the growth of plants and can be a growth-limiting nutrient factor [10].

A high concentration of nitrate in surface water can stimulate the rapid growth of the algae which degrades the water quality [22]. Nitrates can enter the groundwater from chemical fertilizers used in the agricultural areas [22]. Excessive nitrate concentration (more than 10 mg/L) in drinking water causes an immediate and severe health threat to infants [19]. The nitrate ions react with blood hemoglobin, thereby reducing the blood's ability to hold oxygen which leads to a disease called blue baby or methemoglobinemia [10, 19].

3.2.8 Fluoride

A moderate amount of fluoride ions (F^-) in drinking water contributes to good dental health [10, 19]. About 1.0 mg/L is effective in preventing tooth decay, particularly in children [10].

Excessive amounts of fluoride cause discolored teeth, a condition known as dental fluorosis [11, 19, 26]. The maximum allowable levels of fluoride in public water supplies depend on local climate [26]. In the warmer regions of the country, the maximum allowable concentration of fluoride for potable water is 1.4 mg/L; in colder climates, up to 2.4 mg/L is allowed.

There are four methods to determine ion fluoride in water; the selection of the used method depends on the type of water sample [10].

3.2.9 Iron and manganese

Although iron (Fe) and manganese (Mn) do not cause health problems, they impart a noticeable bitter taste to drinking water even at very low concentration [10, 11].

These metals usually occur in groundwater in solution as ferrous (Fe^{2+}) and manganous (Mn^{2+}) ions. When these ions are exposed to air, they form the insoluble ferric (Fe^{3+}) and manganic (Mn^{3+}) forms making the water turbid and unacceptable to most people [10].

These ions can also cause black or brown stains on laundry and plumbing fixtures [7]. They are measured by many instrumental methods such as atomic absorption spectrometry, flame atomic absorption spectrometry, cold vapor atomic absorption spectrometry, electrothermal atomic absorption spectrometry, and inductively coupled plasma (ICP) [10].

3.2.10 Copper and zinc

Copper (Cu) and zinc (Zn) are nontoxic if found in small concentrations [10]. Actually, they are both essential and beneficial for human health and growth of plants and animals [25]. They can cause undesirable tastes in drinking water. At high concentrations, zinc imparts a milky appearance to the water [10]. They are measured by the same methods used for iron and manganese measurements [10].

3.2.11 Hardness

Hardness is a term used to express the properties of highly mineralized waters [10]. The dissolved minerals in water cause problems such as scale deposits in hot water pipes and difficulty in producing lather with soap [11].

Calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions cause the greatest portion of hardness in naturally occurring waters [9]. They enter water mainly from contact with soil and rock, particularly limestone deposits [10, 27].

These ions are present as bicarbonates, sulfates, and sometimes as chlorides and nitrates [10, 26]. Generally, groundwater is harder than surface water. There are two types of hardness:

- *Temporary hardness* which is due to carbonates and bicarbonates can be removed by boiling, and

- *Permanent hardness* which is remaining after boiling is caused mainly by sulfates and chlorides [10, 21, 22]

Water with more than 300 mg/L of hardness is generally considered to be hard, and more than 150 mg/L of hardness is noticed by most people, and water with less than 75 mg/L is considered to be soft.

From health viewpoint, hardness up to 500 mg/L is safe, but more than that may cause a laxative effect [10]. Hardness is normally determined by titration with ethylene diamine tetra acidic acid or (EDTA) and Eriochrome Black and Blue indicators. It is usually expressed in terms of mg/L of $CaCO_3$ [10, 19].

$$\text{Total hardness mg/L as } CaCO_3 = \text{calcium hardness mg/L as } CaCO_3 + \text{magnesium hardness mg/L as } CaCO_3 \quad (9)$$

An accepted water classification according to its hardness is as in **Table 2** [19].

3.2.12 Dissolved oxygen

Dissolved oxygen (DO) is considered to be one of the most important parameters of water quality in streams, rivers, and lakes. It is a key test of water pollution [10]. The higher the concentration of dissolved oxygen, the better the water quality.

Oxygen is slightly soluble in water and very sensitive to temperature. For example, the saturation concentration at 20°C is about 9 mg/L and at 0°C is 14.6 mg/L [22].

The actual amount of dissolved oxygen varies depending on pressure, temperature, and salinity of the water. Dissolved oxygen has no direct effect on public health, but drinking water with very little or no oxygen tastes unpalatable to some people.

There are three main methods used for measuring dissolved oxygen concentrations: the colorimetric method—quick and inexpensive, the Winkler titration method—traditional method, and the electrometric method [10].

3.2.13 Biochemical oxygen demand (BOD)

Bacteria and other microorganisms use organic substances for food. As they metabolize organic material, they consume oxygen [10, 22]. The organics are broken down into simpler compounds, such as CO_2 and H_2O, and the microbes use the energy released for growth and reproduction [22].

When this process occurs in water, the oxygen consumed is the DO in the water. If oxygen is not continuously replaced by natural or artificial means in the water, the DO concentration will reduce as the microbes decompose the organic materials. This need for oxygen is called the biochemical oxygen demand (BOD). The more organic material there is in the water, the higher the BOD used by the microbes will be. BOD is used as a measure of the power of sewage; strong sewage has a high BOD and weak sewage has low BOD [22].

The complete decomposition of organic material by microorganisms takes time, usually 20 d or more under ordinary circumstances [22]. The quantity of oxygen used in a specified volume of water to fully decompose or stabilize all biodegradable organic substances is called the ultimate BOD or BOD_L.

BOD is a function of time. At time = 0, no oxygen will have been consumed and the BOD = 0. As each day goes by, oxygen is used by the microbes and the BOD increases. Ultimately, the BOD_L is reached and the organic materials are completely decomposed.

Water classification	Total hardness concentration as mg/L as $CaCO_3$
Soft water	<50 mg/L as $CaCO_3$
Moderately hard	50–150 mg/L as $CaCO_3$
Hard water	150–300 mg/L as $CaCO_3$
Very hard	>300 mg/L as $CaCO_3$

Table 2.
Classification of water according to its hardness.

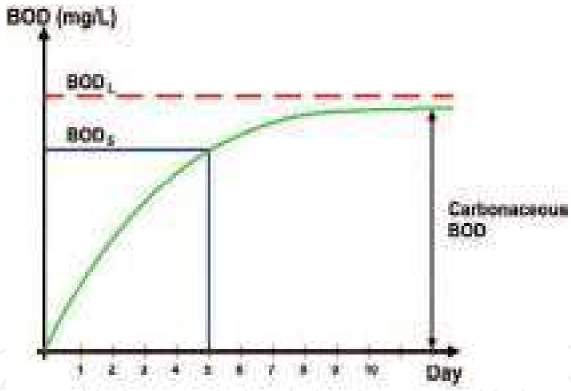

Figure 3.
BOD curve [22].

A graph of the BOD versus time is illustrated as in **Figure 3**. This is called the BOD curve, which can be expressed mathematically by the following equation:

$$BOD_t = BOD_L \times \left(1 - 10^{-kt}\right) \tag{10}$$

where BOD_t = BOD at any time t, mg/L; BOD_L = ultimate BOD, mg/L; k = a constant representing the rate of the BOD reaction; t = time, d.

The value of the constant rate k depends on the temperature, the type of organic materials, and the type of microbes exerting the BOD [22].

3.2.14 Chemical oxygen demand (COD)

The chemical oxygen demand (COD) is a parameter that measures all organics: the biodegradable and the non-biodegradable substances [22]. It is a chemical test using strong oxidizing chemicals (potassium dichromate), sulfuric acid, and heat, and the result can be available in just 2 h [10]. COD values are always higher than BOD values for the same sample [22].

3.2.15 Toxic inorganic substances

A wide variety of inorganic toxic substances may be found in water in very small or trace amounts. Even in trace amounts, they can be a danger to public health [11]. Some toxic substances occur from natural sources but many others occur due to industrial activities and/or improper management of hazardous waste [22]. They can be divided into two groups:

- *Metallic compounds:* This group includes some heavy metals that are toxic, namely, cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), silver (Ag), arsenic (As), barium (Ba), thallium (Tl), and selenium (Se) [22, 28]. They have a wide range of dangerous effects that differ from one metal to another. They may be acute fatal poisons such as (As) and (Cr^{6+}) or may produce chronic diseases such as (Cd, Hg, Pb, and Tl) [21, 29–32]. The heavy metals concentration can be determined by atomic absorption photometers, spectrophotometer, or inductively coupled plasma (ICP) for very low concentration [10].

- *Nonmetallic compounds:* This group includes nitrates (NO_3^-) and cyanides (CN^-), nitrate has been discussed with the nitrogen in the previous section. Regarding cyanide, as Mackenzie stated [11] it causes oxygen deprivation by binding the hemoglobin sites and prevents the red blood cell from carrying the oxygen [11]. This causes a blue skin color syndrome, which is called cyanosis [33]. It also causes chronic effects on the central nervous system and thyroid [33]. Cyanide is normally measured by colorimetric, titrimetric, or electrometric methods [10].

3.2.16 Toxic organic substances

There are more than 100 compounds in water that have been listed in the literature as toxic organic compounds [11, 22]. They will not be found naturally in water; they are usually man-made pollutants. These compounds include insecticides, pesticides, solvents, detergents, and disinfectants [11, 21, 22]. They are measured by highly sophisticated instrumental methods, namely, gas chromatographic (GC), high-performance liquid chromatographic (HPLC), and mass spectrophotometric [10].

3.2.17 Radioactive substances

Potential sources of radioactive substances in water include wastes from nuclear power plants, industries, or medical research using radioactive chemicals and mining of uranium ores or other radioactive materials [11, 21]. When radioactive substances decay, they release beta, alpha, and gamma radiation [34]. Exposure of humans and other living things to radiation can cause genetic and somatic damage to the living tissues [34, 35].

Radon gas is of a great health concern because it occurs naturally in groundwater and is a highly volatile gas, which can be inhaled during the showering process [35]. For drinking water, there are established standards commonly used for alpha particles, beta particles, photons emitters, radium-226 and -228, and uranium [34, 35].

The unit of radioactivity used in water quality applications is the picocurie per liter (pCi/L); 1 pCi is equivalent to about two atoms disintegrating per minute. There are many sophisticated instrumental methods to measure it [35].

3.3 Biological parameters of water quality

One of the most helpful indicators of water quality may be the presence or lack of living organisms [10, 15]. Biologists can survey fish and insect life of natural waters and assess the water quality on the basis of a computed species diversity index (SDI) [15, 19, 36, 37]; hence, a water body with a large number of well-balanced species is regarded as a healthy system [17]. Some organisms can be used as an indication for the existence of pollutants based on their known tolerance for a specified pollutant [17].

Microorganisms exist everywhere in nature [38]. Human bodies maintain a normal population of microbes in the intestinal tract; a big portion of which is made up of coliform bacteria [38]. Although there are millions of microbes per milliliter in wastewater, most of them are harmless [37]. It is only harmful when wastewater contains wastes from people infected with diseases that the presence of harmful microorganisms in wastewater is likely to occur [38].

3.3.1 Bacteria

Bacteria are considered to be single-celled plants because of their cell structure and the way they ingest food [10, 37]. Bacteria occur in three basic cell shapes: rod-shaped or bacillus, sphere-shaped or coccus, and spiral-shaped or spirellus [19]. In less than 30 min, a single bacterial cell can mature and divide into two new cells [39].

Under favorable conditions of food supply, temperature, and pH, bacteria can reproduce so rapidly that a bacterial culture may contain 20 million cells per milliliter after just 1 day [22, 37]. This rapid growth of visible colonies of bacteria on a suitable nutrient medium makes it possible to detect and count the number of bacteria in water [39].

There are several distinctions among the various species of bacteria. One distinction depends on how they metabolize their food [38]. Bacteria that require oxygen for their metabolism are called aerobic bacteria, while those live only in an oxygen-free environment are called anaerobic bacteria. Some species called facultative bacteria can live in either the absence or the presence of oxygen [37–39].

At low temperatures, bacteria grow and reproduce slowly. As the temperature increases, the rate of growth and reproduction doubles in every additional 10°C (up to the optimum temperature for the species) [38]. The majority of the species of bacteria having an optimal temperature of about 35°C [39].

A lot of dangerous waterborne diseases are caused by bacteria, namely, typhoid and paratyphoid fever, leptospirosis, tularemia, shigellosis, and cholera [19]. Sometimes, the absence of good sanitary practices results in gastroenteritis outbreaks of one or more of those diseases [19].

3.3.2 Algae

Algae are microscopic plants, which contain photosynthetic pigments, such as chlorophyll [37, 39]. They are autotrophic organisms and support themselves by converting inorganic materials into organic matter by using energy from the sun, during this process they take in carbon dioxide and give off oxygen [38, 39]. They are also important for wastewater treatment in stabilization ponds [22]. Algae are primarily nuisance organisms in the water supply because of the taste and odor problems they create [2, 16]. Certain species of algae cause serious environmental and public health problems; for example, blue-green algae can kill cattle and other domestic animals if the animals drink water containing those species [37, 39].

3.3.3 Viruses

Viruses are the smallest biological structures known to contain all genetic information necessary for their own reproduction [19]. They can only be seen by a powerful electronic microscope [39]. Viruses are parasites that need a host to live [39]. They can pass through filters that do not permit the passage of bacteria [37]. Waterborne viral pathogens are known to cause infectious hepatitis and poliomyelitis [19, 25, 37]. Most of the waterborne viruses can be deactivated by the disinfection process conducted in the water treatment plant [19].

3.3.4 Protozoa

Protozoa are single-celled microscopic animal [19], consume solid organic particles, bacteria, and algae for food, and they are in turn ingested as food by higher level multicellular animals [37]. Aquatic protozoa are floating freely in water and sometimes called zooplankton [37]. They form cysts that are difficult to inactivate by disinfection [19].

3.3.5 Indicator organisms

A very important biological indicator of water and pollution is the group of bacteria called coliforms [20]. Pathogenic coliforms always exist in the intestinal system of humans, and millions are excreted with body wastes [37]. Consequently, water that has been recently contaminated with sewage will always contain coliforms [19].

A particular species of coliforms found in domestic sewage is *Escherichia coli* or *E. coli* [22]. Even if the water is only slightly polluted, they are very likely to be found. There are roughly 3 million of *E. coli* bacteria in 100 mL volume of untreated sewage [10]. Coliform bacteria are aggressive organisms and survive in the water longer than most pathogens. There are normally two methods to test the coliform bacteria—the membrane filter method and multiple-tube fermentation method [10, 37]. Since the test of coliform bacteria is very important for public health, the first method will be described in details in the coming section.

3.3.5.1 Testing for coliforms: membrane filter method

A measured volume of sample is filtered through a special membrane filter by applying a partial vacuum [10, 39].

The filter, a flat paper-like disk, has uniform microscopic pores small enough to retain the bacteria on its surface while allowing the water to pass through. The filter paper is then placed in a sterile container called a petri dish, which contains a special culture medium that the bacteria use as a food source [39].

Then, the petri dish is usually placed in an incubator, which keeps the temperature at 35°C, for 24 h. After incubation, colonies of coliform bacteria each containing millions of organisms will be visible [10]. The coliform concentration is obtained by counting the number of colonies on the filter; each colony counted represents only one coliform in the original sample [10, 39].

Coliform concentrations are expressed in terms of the number of organisms per 100 mL of water as follows:

$$\text{coliforms per 100 mL} = \text{number of colonies} \times 100/\text{mL of sample} \tag{11}$$

4. Water quality requirements

Water quality requirements differ depending on the proposed used of water [19]. As reported by Tchobanoglous et al. [19], "water unsuitable for one use may be quite satisfactory for another and water may be considered acceptable for a particular use if water of better quality is not available."

Water quality requirements should be agreed with the water quality standards, which are put down by the governmental agency and represent the legislation requirements. In general, there are three types of standards: in-stream, potable water, and wastewater effluent [19], each type has its own criteria by using the same methods of measurement. The World Health Organization (WHO) has established minimum standards for drinking water that all countries are recommended to meet [25].

5. Conclusion

The physical, chemical, and biological parameters of water quality are reviewed in terms of definition, sources, impacts, effects, and measuring methods. The classification of water according to its quality is also covered with a specific definition for each type.

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Water Borne Diseases

- Diseases caused by pathogenic organisms carried by water containing fecal or sewage contamination
- Water-borne diseases can be grouped under:
  - Bacterial Disease
  - Viral Disease
  - Protozoal Disease
  - Helminthic (worm) Disease (*Schistosomiasis* and *Swimmers itch*); *Schistosomiasis is caused due to trematode worms(flukes) that inhibit the veins of bladder or large intestines and discharge eggs into the urine or feces*

TABLE 6-5 Potential waterborne disease–causing organisms

Organism	Major Disease	Primary Source
Bacteria		
Salmonella typhi	Typhoid fever	Human feces
Salmonella paratyphi	Paratyphoid fever	Human feces
Other *Salmonella* sp.	Gastroenteritis (salmonellosis)	Human/animal feces
Shigella	Bacillary dysentery	Human feces
Vibrio cholera	Cholera	Human feces, coastal water
Pathogenic *Escherichia coli*	Gastroenteritis	Human/animal feces
Yersinia enterocolitica	Gastroenteritis	Human/animal feces
Campylobacter jejuni	Gastroenteritis	Human/animal feces
Legionella pneumophila	Legionnaires' disease, Pontiac fever	Warm water
Mycobacterium avium intracellulare	Pulmonary disease	Human/animal feces, soil, water
Pseudomonas aeruginosa	Dermatitis	Natural waters
Aeromonas hydrophila	Gastroenteritis	Natural waters
Helicobacter pylori	Peptic ulcers	Saliva, human feces?
Cyanobacteria	Gastroenteritis, liver damage, nervous system damage	Natural waters
Enteric Viruses		
Poliovirus	Poliomyelitis	Human feces
Coxsackievirus	Upper respiratory disease	Human feces
Echovirus	Upper respiratory disease	Human feces
Rotavirus	Gastroenteritis	Human feces
Norwalk virus and other caliciviruses	Gastroenteritis	Human feces

Table continued next page

TABLE 6-5 Potential waterborne disease-causing organisms (Continued)

Organism	Major Disease	Primary Source
Hepatitis A virus	Infectious hepatitis	Human feces
Hepatitis E virus	Hepatitis	Human feces
Astrovirus	Gastroenteritis	Human feces
Enteric adenoviruses	Gastroenteritis	Human feces
Protozoa and other organisms		
Giardia lamblia	giardiasis (gastroenteritis)	Human and animal feces
Cryptosporidium parvum	Cryptosporidiosis (gastroenteritis)	Human and animal feces
Entamoeba histolytica	Amoebic dysentery	Human feces
Cyclospora cayatanensis	Gastroenteritis	Human feces
Microspora	Gastroenteritis	Human feces
Acanthamoeba	Eye infection	Soil and water
Toxoplasma gondii	Flulike symptoms	Cats
Naegleria fowleri	Primary amoebic meningoencephalitis	Soil and water
Fungi	Respiratory allergies	Air, water?

Source: Water Quality and Treatment, 5th ed., *1999, AWWA.*

भारतीय मानक

पीने का पानी — विशिष्टि

(दूसरा पुनरीक्षण)

Indian Standard

DRINKING WATER — SPECIFICATION

(Second Revision)

ICS 13.060.20

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

May 2012 **Price Group 6**

AMENDMENT NO. 1 JUNE 2015
TO
IS 10500 : 2012 DRINKING WATER — SPECIFICATION

(Second Revision)

[*Page* 2, *Table* 2, *Sl No.* xii), *col* 3] — Substitute '1.0' *for* '0.3'.

[*Page* 3, *Table* 3, *Sl No.* x) , *col* 4] — Substitute 'No relaxation' *for* '0.05'.

(FAD 14)

Publication Unit, BIS, New Delhi, India

Drinking Water Sectional Committee, FAD 25

FOREWORD

This Indian Standard (Second Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Drinking Water Sectional Committee had been approved by the Food and Agriculture Division Council.

This standard was originally published in 1983. A report prepared by the World Health Organization in cooperation with the World Bank showed that in 1975, some 1 230 million people were without safe water supplies. These appalling facts were central to the United Nations decision to declare an International Drinking Water Supply and Sanitation decade, beginning in 1981. Further, the VI Five-Year Plan of India had made a special provision for availability of safe drinking water for the masses. Therefore, the standard was formulated with the objective of assessing the quality of water resources, and to check the effectiveness of water treatment and supply by the concerned authorities.

The first revision was undertaken to take into account the up-to-date information available about the nature and effect of various contaminants as also the new techniques for identifying and determining their concentration. Based on experience gained additional requirements for alkalinity; aluminium and boron were incorporated and the permissible limits for dissolved solids, nitrate and pesticides residues modified.

As per the eleventh five year plan document of India (2007-12), there are about 2.17 lakh quality affected habitations in the country with more than half affected with excess iron, followed by fluoride, salinity, nitrate and arsenic in that order. Further, approximately, 10 million cases of diarrhoea, more than 7.2 lakh typhoid cases and 1.5 lakh viral hepatitis cases occur every year a majority of which are contributed by unclean water supply and poor sanitation. The eleventh five year plan document of India (2007-2012) recognizes dealing with the issue of water quality as a major challenge and aims at addressing water quality problems in all quality affected habitations with emphasis on community participation and awareness campaigns as well as on top most priority to water quality surveillance and monitoring by setting up of water quality testing laboratories strengthened with qualified manpower, equipments and chemicals.

The second revision was undertaken to upgrade the requirements of the standard and align with the internationally available specifications on drinking water. In this revision assistance has been derived from the following:

a) EU Directives relating to the quality of water intended for human consumption (80/778/EEC) and Council Directive 98/83/EC.

b) USEPA standard — National Primary Drinking Water Standard. EPA 816-F-02-013 dated July, 2002.

c) WHO Guidelines for Drinking Water Quality. 3rd Edition Vol. 1 Recommendations, 2008.

d) Manual on Water Supply and Treatment, third edition — revised and updated May 1999, Ministry of Urban Development, New Delhi.

This standard specifies the acceptable limits and the permissible limits in the absence of alternate source. It is recommended that the acceptable limit is to be implemented as values in excess of those mentioned under 'Acceptable' render the water not suitable. Such a value may, however, be tolerated in the absence of an alternative source. However, if the value exceeds the limits indicated under 'permissible limit in the absence of alternate source' in col 4 of Tables 1 to 4, the sources will have to be rejected.

Pesticide residues limits and test methods given in Table 5 are based on consumption pattern, persistence and available manufacturing data. The limits have been specified based on WHO guidelines, wherever available. In cases where WHO guidelines are not available, the standards available from other countries have been examined and incorporated, taking in view the Indian conditions.

In this revision, additional requirements for ammonia, chloramines, barium, molybdenum, silver, sulphide, nickel, polychlorinated biphenyls and trihalomethanes have been incorporated while the requirements for colour, turbidity, total hardness, free residual chlorine, iron, magnesium, mineral oil, boron, cadmium, total arsenic, lead, polynuclear aromatic hydrocarbons, pesticides and bacteriological requirements have been modified.

In this revision, requirement and test method for virological examination have been included. Further, requirements and test methods for cryptosporidium and giardia have also been specified.

Routine surveillance of drinking water supplies should be carried out by the relevant authorities to understand the risk of specific pathogens and to define proper control procedures. The WHO Guidelines for Drinking Water Quality, 3rd Edition, Vol. 1 may be referred for specific recommendations on using a water safety approach incorporating risk identification. Precautions/Care should be taken to prevent contamination of drinking water from chlorine resistant parasites such as cryptosporidium species and giardia.

Indian Standard

DRINKING WATER — SPECIFICATION

(Second Revision)

1 SCOPE

This standard prescribes the requirements and the methods of sampling and test for drinking water.

2 REFERENCES

The standards listed in Annex A contain provisions which through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated in Annex A.

3 TERMINOLOGY

For the purpose of this standard the following definition shall apply.

3.1 Drinking Water — Drinking water is water intended for human consumption for drinking and cooking purposes from any source. It includes water (treated or untreated) supplied by any means for human consumption.

4 REQUIREMENTS

Drinking water shall comply with the requirements given in Tables 1 to 4. The analysis of pesticide residues given in Table 3 shall be conducted by a recognized laboratory using internationally established test method meeting the residue limits as given in Table 5.

Drinking water shall also comply with bacteriological requirements (*see* **4.1**), virological requirements (*see* **4.2**) and biological requirements (*see* **4.3**).

4.1 Bacteriological Requirements

4.1.1 *Water in Distribution System*

Ideally, all samples taken from the distribution system including consumers' premises, should be free from coliform organisms and the following bacteriological quality of drinking water collected in the distribution system, as given in Table 6 is, therefore specified when tested in accordance with IS 1622.

4.2 Virological Requirements

4.2.1 Ideally, all samples taken from the distribution

Table 1 Organoleptic and Physical Parameters
(*Foreword* and *Clause* 4)

Sl No.	Characteristic	Requirement (Acceptable Limit)	Permissible Limit in the Absence of Alternate Source	Method of Test, Ref to Part of IS 3025	Remarks
(1)	(2)	(3)	(4)	(5)	(6)
i)	Colour, Hazen units, *Max*	5	15	Part 4	Extended to 15 only, if toxic substances are not suspected in absence of alternate sources
ii)	Odour	Agreeable	Agreeable	Part 5	a) Test cold and when heated b) Test at several dilutions
iii)	*p*H value	6.5-8.5	No relaxation	Part 11	—
iv)	Taste	Agreeable	Agreeable	Parts 7 and 8	Test to be conducted only after safety has been established
v)	Turbidity, NTU, *Max*	1	5	Part 10	—
vi)	Total dissolved solids, mg/l, *Max*	500	2 000	Part 16	—

NOTE — It is recommended that the acceptable limit is to be implemented. Values in excess of those mentioned under 'acceptable' render the water not suitable, but still may be tolerated in the absence of an alternative source but up to the limits indicated under 'permissible limit in the absence of alternate source' in col 4, above which the sources will have to be rejected.

Table 2 General Parameters Concerning Substances Undesirable in Excessive Amounts
(*Foreword* and *Clause* 4)

Sl No.	Characteristic	Requirement (Acceptable Limit)	Permissible Limit in the Absence of Alternate Source	Method of Test, Ref to	Remarks
(1)	(2)	(3)	(4)	(5)	(6)
i)	Aluminium (as Al), mg/l, *Max*	0.03	0.2	IS 3025 (Part 55)	—
ii)	Ammonia (as total ammonia-N), mg/l, *Max*	0.5	No relaxation	IS 3025 (Part 34)	—
iii)	Anionic detergents (as MBAS) mg/l, *Max*	0.2	1.0	Annex K of IS 13428	—
iv)	Barium (as Ba), mg/l, *Max*	0.7	No relaxation	Annex F of IS 13428* or IS 15302	—
v)	Boron (as B), mg/l, *Max*	0.5	1.0	IS 3025 (Part 57)	—
vi)	Calcium (as Ca), mg/l, *Max*	75	200	IS 3025 (Part 40)	—
vii)	Chloramines (as Cl_2), mg/l, *Max*	4.0	No relaxation	IS 3025 (Part 26)* or APHA 4500-Cl G	—
viii)	Chloride (as Cl), mg/l, *Max*	250	1 000	IS 3025 (Part 32)	—
ix)	Copper (as Cu), mg/l, *Max*	0.05	1.5	IS 3025 (Part 42)	—
x)	Fluoride (as F) mg/l, *Max*	1.0	1.5	IS 3025 (Part 60)	—
xi)	Free residual chlorine, mg/l, *Min*	0.2	1	IS 3025 (Part 26)	To be applicable only when water is chlorinated. Tested at consumer end. When protection against viral infection is required, it should be minimum 0.5 mg/l
xii)	Iron (as Fe), mg/l, *Max*	0.3	No relaxation	IS 3025 (Part 53)	Total concentration of manganese (as Mn) and iron (as Fe) shall not exceed 0.3 mg/l
xiii)	Magnesium (as Mg), mg/l, *Max*	30	100	IS 3025 (Part 46)	—
xiv)	Manganese (as Mn), mg/l, *Max*	0.1	0.3	IS 3025 (Part 59)	Total concentration of manganese (as Mn) and iron (as Fe) shall not exceed 0.3 mg/l
xv)	Mineral oil, mg/l, *Max*	0.5	No relaxation	Clause **6** of IS 3025 (Part 39) Infrared partition method	—
xvi)	Nitrate (as NO_3), mg/l, *Max*	45	No relaxation	IS 3025 (Part 34)	—
xvii)	Phenolic compounds (as C_6H_5OH), mg/l, *Max*	0.001	0.002	IS 3025 (Part 43)	—
xviii)	Selenium (as Se), mg/l, *Max*	0.01	No relaxation	IS 3025 (Part 56) or IS 15303*	—
xix)	Silver (as Ag), mg/l, *Max*	0.1	No relaxation	Annex J of IS 13428	—
xx)	Sulphate (as SO_4) mg/l, *Max*	200	400	IS 3025 (Part 24)	May be extended to 400 provided that Magnesium does not exceed 30
xxi)	Sulphide (as H_2S), mg/l, *Max*	0.05	No relaxation	IS 3025 (Part 29)	—
xxii)	Total alkalinity as calcium carbonate, mg/l, *Max*	200	600	IS 3025 (Part 23)	—
xxiii)	Total hardness (as $CaCO_3$), mg/l, *Max*	200	600	IS 3025 (Part 21)	—
xxiv)	Zinc (as Zn), mg/l, *Max*	5	15	IS 3025 (Part 49)	—

NOTES

1 In case of dispute, the method indicated by '*' shall be the referee method.

2 It is recommended that the acceptable limit is to be implemented. Values in excess of those mentioned under 'acceptable' render the water not suitable, but still may be tolerated in the absence of an alternative source but up to the limits indicated under 'permissible limit in the absence of alternate source' in col 4, above which the sources will have to be rejected.

Table 3 Parameters Concerning Toxic Substances
(*Foreword* and *Clause* 4)

Sl No.	Characteristic	Requirement (Acceptable Limit)	Permissible Limit in the Absence of Alternate Source	Method of Test, Ref to	Remarks
(1)	(2)	(3)	(4)	(5)	(6)
i)	Cadmium (as Cd), mg/l, *Max*	0.003	No relaxation	IS 3025 (Part 41)	—
ii)	Cyanide (as CN), mg/l, *Max*	0.05	No relaxation	IS 3025 (Part 27)	—
iii)	Lead (as Pb), mg/l, *Max*	0.01	No relaxation	IS 3025 (Part 47)	—
iv)	Mercury (as Hg), mg/l, *Max*	0.001	No relaxation	IS 3025 (Part 48)/ Mercury analyser	—
v)	Molybdenum (as Mo), mg/l, *Max*	0.07	No relaxation	IS 3025 (Part 2)	—
vi)	Nickel (as Ni), mg/l, *Max*	0.02	No relaxation	IS 3025 (Part 54)	—
vii)	Pesticides, μg/l, *Max*	See Table 5	No relaxation	See Table 5	—
viii)	Polychlorinated biphenyls, mg/l, *Max*	0.000 5	No relaxation	ASTM 5175*	— or APHA 6630
ix)	Polynuclear aromatic hydro-carbons (as PAH), mg/l, *Max*	0.000 1	No relaxation	APHA 6440	—
x)	Total arsenic (as As), mg/l, *Max*	0.01	0.05	IS 3025 (Part 37)	—
xi)	Total chromium (as Cr), mg/l, *Max*	0.05	No relaxation	IS 3025 (Part 52)	—
xii)	Trihalomethanes:				
	a) Bromoform, mg/l, *Max*	0.1	No relaxation	ASTM D 3973-85* or APHA 6232	—
	b) Dibromochloromethane, mg/l, *Max*	0.1	No relaxation	ASTM D 3973-85* or APHA 6232	—
	c) Bromodichloromethane, mg/l, *Max*	0.06	No relaxation	ASTM D 3973-85* or APHA 6232	—
	d) Chloroform, mg/l, *Max*	0.2	No relaxation	ASTM D 3973-85* or APHA 6232	—

NOTES

1 In case of dispute, the method indicated by '*' shall be the referee method.

2 It is recommended that the acceptable limit is to be implemented. Values in excess of those mentioned under 'acceptable' render the water not suitable, but still may be tolerated in the absence of an alternative source but up to the limits indicated under 'permissible limit in the absence of alternate source' in col 4, above which the sources will have to be rejected.

Table 4 Parameters Concerning Radioactive Substances
(*Foreword* and *Clause* 4)

Sl No.	Characteristic	Requirement (Acceptable Limit)	Permissible Limit in the Absence of Alternate Source	Method of Test, Ref to Part of IS 14194	Remarks
(1)	(2)	(3)	(4)	(5)	(6)
i)	Radioactive materials:				
	a) Alpha emitters Bq/l, *Max*	0.1	No relaxation	Part 2	—
	b) Beta emitters Bq/l, *Max*	1.0	No relaxation	Part 1	—

NOTE — It is recommended that the acceptable limit is to be implemented. Values in excess of those mentioned under 'acceptable' render the water not suitable, but still may be tolerated in the absence of an alternative source but up to the limits indicated under 'permissible limit in the absence of alternate source' in col 4, above which the sources will have to be rejected.

Table 5 Pesticide Residues Limits and Test Method
(*Foreword* and *Table* 3)

Sl No.	Pesticide	Limit µg/l	Method of Test, Ref to	
			USEPA	AOAC/ ISO
(1)	(2)	(3)	(4)	(5)
i)	Alachlor	20	525.2, 507	—
ii)	Atrazine	2	525.2, 8141 A	—
iii)	Aldrin/ Dieldrin	0.03	508	—
iv)	Alpha HCH	0.01	508	—
v)	Beta HCH	0.04	508	—
vi)	Butachlor	125	525.2, 8141 A	—
vii)	Chlorpyriphos	30	525.2, 8141 A	—
viii)	Delta HCH	0.04	508	—
ix)	2,4- Dichlorophenoxyacetic acid	30	515.1	—
x)	DDT (*o, p* and *p, p* – Isomers of DDT, DDE and DDD)	1	508	AOAC 990.06
xi)	Endosulfan (alpha, beta, and sulphate)	0.4	508	AOAC 990.06
xii)	Ethion	3	1657 A	—
xiii)	Gamma — HCH (Lindane)	2	508	AOAC 990.06
xiv)	Isoproturon	9	532	—
xv)	Malathion	190	8141 A	—
xvi)	Methyl parathion	0.3	8141 A	ISO 10695
xvii)	Monocrotophos	1	8141 A	—
xviii)	Phorate	2	8141 A	—

NOTE — Test methods are for guidance and reference for testing laboratory. In case of two methods, USEPA method shall be the reference method.

Table 6 Bacteriological Quality of Drinking Water[1)]
(*Clause* 4.1.1)

Sl No.	Organisms	Requirements
(1)	(2)	(3)
i)	*All water intended for drinking*:	
	a) *E. coli* or thermotolerant coliform bacteria[2), 3)]	Shall not be detectable in any 100 ml sample
ii)	*Treated water entering the distribution system*:	
	a) *E. coli* or thermotolerant coliform bacteria[2)]	Shall not be detectable in any 100 ml sample
	b) Total coliform bacteria	Shall not be detectable in any 100 ml sample
iii)	*Treated water in the distribution system*:	
	a) *E. coli* or thermotolerant coliform bacteria	Shall not be detectable in any 100 ml sample
	b) Total coliform bacteria	Shall not be detectable in any 100 ml sample

[1)]Immediate investigative action shall be taken if either *E.coli* or total coliform bacteria are detected. The minimum action in the case of total coliform bacteria is repeat sampling; if these bacteria are detected in the repeat sample, the cause shall be determined by immediate further investigation.

[2)]Although, *E. coli* is the more precise indicator of faecal pollution, the count of thermotolerant coliform bacteria is an acceptable alternative. If necessary, proper confirmatory tests shall be carried out. Total coliform bacteria are not acceptable indicators of the sanitary quality of rural water supplies, particularly in tropical areas where many bacteria of no sanitary significance occur in almost all untreated supplies.

[3)]It is recognized that, in the great majority of rural water supplies in developing countries, faecal contamination is widespread. Under these conditions, the national surveillance agency should set medium-term targets for progressive improvement of water supplies.

system including consumers' premises, should be free from virus.

4.2.2 None of the generally accepted sewage treatment methods yield virus-free effluent. Although a number of investigators have found activated sludge treatment to be superior to trickling filters from this point of view, it seems possible that chemical precipitation methods will prove to be the most effective.

4.2.3 Virus can be isolated from raw water and from springs, enterovirus, reovirus, and adenovirus have been found in water, the first named being the most resistant to chlorination. If enterovirus are absent from chlorinated water, it can be assumed that the water is safe to drink. Some uncertainty still remains about the virus of infectious hepatitis, since it has not so far been isolated but in view of the morphology and resistance of enterovirus it is likely that, if they have been inactivated hepatitis virus will have been inactivated also.

4.2.4 An exponential relationship exists between the rate of virus inactivation and the redox potential. A redox potential of 650 mV (measured between platinum and calomel electrodes) will cause almost instantaneous inactivation of even high concentrations of virus. Such a potential can be obtained with even a low concentration of free chlorine, but only with an extremely high concentration of combined chlorine. This oxidative inactivation may be achieved with a number of other oxidants also, for example, iodine, ozone and potassium permanganate, but the effect of the oxidants will always be counteracted, if reducing components, which are mainly organic, are present. As a consequence, the sensitivity of virus towards disinfectants will depend on the *milieu* just as much as on the particular disinfectant used.

4.2.5 Viruses are generally resistant to disinfectants as well as get protected on account of presence of particulate and organic matter in water. Because the difference between the resistance of coliform organisms and of virus to disinfection by oxidants increases with increasing concentration of reducing components, for example, organic matter, it cannot be assumed that the absence of available coliform organisms implies freedom from active virus under circumstances where a free chlorine residual cannot be maintained. Sedimentation and slow sand filtration in themselves may contribute to the removal of virus from water.

4.2.6 In practice, >0.5 mg/l of free chlorine for 1 h is sufficient to inactivate virus, even in water that was originally polluted provided the water is free from particulates and organic matter.

4.2.7 MS2 phage are indicator of viral contamination in drinking water. MS2 phage shall be absent in 1 litre of water when tested in accordance with USEPA method 1602. If MS2 phage are detected in the drinking water, virological examination shall be done by the Polymerase Chain Reaction (PCR) method for virological examination as given in Annex B. USEPA method in Manual of Method for Virology Chapter 16, June 2001 shall be the alternate method. If viruses are detected, the cause shall be determined by immediate further investigation.

4.3 Biological Requirements

4.3.1 Ideally, all samples taken including consumers premises should be free from biological organisms. Biological examination is of value in determining the causes of objectionable tastes and odours in water and controlling remedial treatments, in helping to interpret the results of various chemical analysis, and in explaining the causes of clogging in distribution pipes and filters. In some instances, it may be of use in demonstrating that water from one source has been mixed with that from another.

4.3.2 The biological qualities of water are of greater importance when the supply has not undergone the conventional flocculation and filtration processes, since increased growth of methane-utilizing bacteria on biological slimes in pipes may then be expected, and the development of bryozoal growths such as *Plumatella* may cause operational difficulties.

4.3.3 Some of the animalcules found in water mains may be free-living in the water, but others such as *Dreissena* and *Asellus* are more or less firmly attached to the inside of the mains. Although these animalcules are not themselves pathogenic, they may harbour pathogenic organisms or virus in their intestines, thus protecting these pathogens from destruction by chlorine.

4.3.4 Chlorination, at the dosages normally employed in waterworks, is ineffective against certain parasites, including amoebic cysts; they can be excluded only by effective filtration or by higher chlorine doses than can be tolerated without subsequent dechlorination. *Amoebiasis* can be conveyed by water completely free from enteric bacteria; microscopic examination after concentration is, therefore, the only safe method of identification.

4.3.5 Strict precautions against back-syphonage and cross-connections are required, if amoebic cysts are found in a distribution system containing tested water.

4.3.6 The *cercariae of schistosomiasis* can be detected by similar microscopic examination, but there is, in any case, no evidence to suggest that this disease is normally spread through piped water supplies.

4.3.7 The cyclops vector of the embryos of *Dracunculus medinensis* which causes dracontiasis or Guinea-worm disease can be found in open wells in a number of tropical areas. They are identifiable by microscopic examination. Such well supplies are frequently used untreated, but the parasite can be relatively easily excluded by simple physical improvements in the form of curbs, drainage, and apron surrounds and other measures which prevent physical contact with the water source.

4.3.8 Cryptosporidium shall be absent in 10 liter of water when tested in accordance with USEPA method 1622 or USEPA method 1623* or ISO 15553 : 2006.

4.3.9 Giardia shall be absent in 10 liter of water when tested in accordance with USEPA method 1623* or ISO 15553 : 2006.

4.3.10 The drinking water shall be free from microscopic organisms such as algae, zooplanktons, flagellates, parasites and toxin producing organisms. An illustrative (and not exhaustive) list is given in Annex C for guidance.

NOTE — In case of dispute, the method indicated by '*' in **4.3.8** and **4.3.9** shall be referee method.

5 SAMPLING

Representative samples of water shall be drawn as prescribed in IS 1622 and IS 3025 (Part 1).

ANNEX A

(*Clause* 2)

LIST OF REFERRED INDIAN STANDARDS

IS No.	*Title*
1622 : 1981	Methods of sampling and microbiological examination of water (*first revision*)
3025	Methods of sampling and test (physical and chemical) for water and waste water:
(Part 1) : 1987	Sampling (*first revision*)
(Part 2) : 2002	Determination of 33 elements by inductively coupled plasma atomic emission spectroscopy
(Part 4) : 1983	Colour (*first revision*)
(Part 5) : 1983	Odour (*first revision*)
(Part 7) : 1984	Taste threshold (*first revision*)
(Part 8) : 1984	Tasting rate (*first revision*)
(Part 10) : 1984	Turbidity (*first revision*)
(Part 11) : 1983	*p*H value (*first revision*)
(Part 16) : 1984	Filterable residue (total dissolved solids) (*first revision*)
(Part 21) : 1983	Total hardness (*first revision*)
(Part 23) : 1983	Alkalinity (*first revision*)
(Part 24) : 1986	Sulphates (*first revision*)
(Part 26) : 1986	Chlorine residual (*first revision*)
(Part 27) : 1986	Cyanide (*first revision*)
(Part 29) : 1986	Sulphide (*first revision*)
(Part 32) : 1988	Chloride (*first revision*)
(Part 34) : 1988	Nitrogen (*first revision*)
(Part 37) : 1988	Arsenic (*first revision*)
(Part 39) : 1989	Oil and grease
(Part 40) : 1991	Calcium
(Part 41) : 1992	Cadmium (*first revision*)
(Part 42) : 1992	Copper (*first revision*)
(Part 43) : 1992	Phenols (*first revision*)
(Part 46) : 1994	Magnesium
(Part 47) : 1994	Lead
(Part 48) : 1994	Mercury
(Part 49) : 1994	Zinc
(Part 52) : 2003	Chromium
(Part 53) : 2003	Iron
(Part 54) : 2003	Nickel
(Part 55) : 2003	Aluminium
(Part 56) : 2003	Selenium
(Part 57) : 2005	Boron
(Part 59) : 2006	Manganese
(Part 60) : 2008	Fluoride
13428 : 2003	Packaged natural mineral water — Specification (*first revision*)
14194	Radionuclides in environmental samples — Method of estimation:
(Part 1) : 1994	Gross beta activity measurement
(Part 2) : 1994	Gross alpha activity measurement
15302 : 2002	Determination of aluminium and barium in water by direct nitrous oxide-acetylene flame atomic absorption spectrometry
15303 : 2002	Determination of antimony, iron and selenium in water by electrothermal atomic absorption spectrometry

ANNEX B

(*Clause* 4.2.7)

POLYMERASE CHAIN REACTION (PCR) METHOD

B-1 GENERAL

The method involves the concentration of viruses from 100 litre of drinking water to 1 ml by membrane filter technique. The concentrate is subjected to amplification using polymerase chain reaction (PCR) and primers based on highly conserved regions of viral genomes. This method can detect as low as 10 genome copies. Stringent precautions are needed to avoid contamination with amplified DNA products leading to false positive reactions. Detection of hepatitis A virus (HAV) RNA and enterovirus (EV) RNA is considered as an indication of presence of viruses in water. Steps involved include concentration of water, RNA extraction, complementary DNA (cDNA) synthesis and PCR.

B-2 CONCENTRATION OF DRINKING WATER

B-2.1 Apparatus

B-2.1.1 *Pressure Pump*

B-2.1.2 *Membrane Filter Assembly with 144 mm Diameter with Tripod Stand*

B-2.1.3 *Pressure Vessel (50 litre capacity) with Pressure Gauge*

B-2.1.4 *Inter-connecting Pressure Tubes*

B-2.2 Reagents

Autoclaved double distilled water shall be used for the preparation of reagents/buffers in this study.

B-2.2.1 *Aluminium Chloride*

B-2.2.2 *HCl/NaOH Urea (Extra Pure)*

B-2.2.3 *Disodium Hydrogen Phosphate* ($Na_2HPO_4.2H_2O$) — 0.2 M, filter sterilized.

B-2.2.4 *Sodium Dihydrogen Phosphate* ($NaH_2PO_4.2H_2O$) — 0.2 M, filter sterilized.

B-2.2.5 *Citric Acid* — 0.1 M, filter sterilized.

B-2.2.6 *L-Arginine* — 0.5 M, filter sterilized.

B-2.2.7 *Urea-Arginine Phosphate Buffer* (*U-APB*) — Mix 4.5 g of urea with 2 ml of 0.2 M NaH_2PO_4 and 2 ml of 0.5 M L - Arginine and make up the volume to 50 ml with sterile distilled water. The *p*H of the eluent shall be 9.0.

B-2.2.8 *Magnesium Chloride* ($MgCl_2$) — 1 M.

B-2.2.9 *McII Vaines Buffer* (*p*H *5.0*) — Mix 9.7 ml of 0.1 M citric acid with 10.3 ml of 0.2 M $Na_2HPO_4.2H_2O$ under sterile conditions.

B-2.3 Procedure

Filter 100 litre of drinking water sample through membrane filter assembly using either positively charged membrane of 144 mm diameter or 0.22 micron diameter pore size nitrocellulose membrane. For positively charged membrane the test water *p*H need not be adjusted. But for the 0.22 micron nitrocellulose membrane adjust the *p*H to 3.5 after adding the aluminium chloride as a coagulant to a final concentration of 0.000 5 M.

At lower *p*H pass the water through the membrane. The flow rate shall be 40 litre/h approximately. After the completion of the filtration, elute the adsorbed particles using 100 ml of urea-arginine phosphate buffer (U-APB). Precipitate the suspended particles using 1 ml of magnesium chloride (1 M). Dissolve the resultant precipitate centrifuged out of the sample in 800-1.0 ml of McII vaines buffer. The processed sample can be stored at refrigerator until required.

B-3 RNA EXTRACTION

B-3.1 Apparatus

B-3.1.1 *Cooling Centrifuge*

B-3.1.2 *Deep Freezer (–20°C)*

B-3.1.3 *Vortex Mixer*

B-3.1.4 *Pipette Man*

B-3.2 Reagents

B-3.2.1 *Cetyl Trimethyl Ammonium Bromide (CTAB) Buffer*

CTAB	:	1 percent
Sodium Dodecyl Sulphate (SDS)	:	1 percent
EDTA	:	20 mM
Sodium Chloride	:	1 M

B-3.2.2 *Phenol, Chloroform and Isoamylalcohol in the ratio of 25:24:1 (PCI)*

B-3.2.3 *Ethanol*

B-3.2.4 *TE Buffer* (*p*H *8.0*)

Tris base	:	1 M
EDTA	:	0.5 M

B-3.2.5 *Sodium Acetate* — 3 M.

B-3.3 Procedure

Treat 300 µl of concentrated water sample with equal volume of CTAB and 1/10th volume of PCI. Vortex and centrifuge at 5 000 × g for 30 min at 4°C. Add 1/10th volume of 3 M sodium acetate and double the volume of cold ethanol to the aqueous layer. Keep the mixture at either at –20°C for overnight or in liquid nitrogen for 2-5 min. Centrifuge at 10 000 × g, for 30 min at 4°C. Discard the supernatant and air dry the pellet and dissolve it in 20 µl TE buffer.

B-4 COMPLEMENTARY DNA (c DNA) SYNTHESIS

B-4.1 Apparatus

B-4.1.1 *PCR Machine*

B-4.1.2 *Deep Freezer (–20°C)*

B-4.2 Reagents

B-4.2.1 *cDNA Synthesis Kit*

B-4.3 Procedure

Suspend the extracted RNA in 20 µl of cDNA reaction mixture, which consists of 4 µl of 5X reverse transcriptase reaction buffer [250 mM TRIS–HCl (*p*H 8.5), 40 mM KCl, 150 mM $MgCl_2$, 5 mM dithiothreitol (DTT)], 0.5 µl of 10 mM deoxynucleotide phosphate (dNTP), 2 µl of hexa nucleotide mixture, 1 µl of 25 U of Maloney Murine Leukaemia Virus (M-MuLV) reverse transcriptase, 0.5 µl of 20 U of human placental RNase inhibitor. Heat the reaction mixture to 95°C for 5 min and rapidly chill on ice, this is followed by the addition of 1 µl (25 U/µl) of M-MuLV reverse transcriptase. Incubate the reaction mixture as given by the manufacturer of the kit and quickly chill the reaction tube on ice.

B-5 PCR AMPLIFICATION

B-5.1 Apparatus

B-5.1.1 *PCR Machine*

B-5.1.2 *Deep Freezer (–20°C)*

B-5.1.3 *Micropippette*

B-5.2 Reagents

B-5.2.1 *Primers for EV and HAV*

EV sense primer, 5’ — TCC TCC GGC CCC TGA ATG CG — 3’
antisense primer, 5’ — ATT GTC ACC ATA AGC AGC CA — 3’

HAV sense primer, 5’ — GTTTT GCTCC TCTTT ATCAT GCTAT G-3’
antisense primer, 5’ — GGAAA TGTCT CAGGT ACTTT CTTTG-3’

B-5.2.2 *PCR Master Mix*

B-5.2.3 *Mineral Oil*

B-5.3 Procedure

B-5.3.1 *PCR Amplification for Hepatitis A Virus (HAV)*

In 5 µl of cDNA, add 95 µl of a PCR Master Mix (10 mM TRIS–HCl (*p*H 8.3), 50 mM KCl, 2.5 mM $MgCl_2$, 0.01 percent gelatin (1× PCR buffer), 200 µM of each dNTP, 1.5 U of *Thermus aquaticus* polymerase). Add 25 pico moles of sense and antisense oligonucleotide primers of HAV and overlay with mineral oil. Appropriate positive and negative controls shall be included with each run. Set the following reaction at thermo cycler:

Denaturation at 94°C for 2 min

Denaturation for	1.0 min	at 94°C	35 cycles
Annealing for	1.0 min	at 57°C	
Extension for	1.3 min	at 72°C	

Final extension at 72°C for 7 min.

B-5.3.2 *PCR Amplification for Enterovirus (EV)*

In 5 µl of cDNA, add 95 µl of a PCR Master Mix (10 mM TRIS–HCl (*p*H 8.3), 50 mM KCl, 2.5 mM $MgCl_2$, 0.01 percent gelatin (1X PCR buffer), 200 µM of each dNTP, 1.5 U of *Thermus aquaticus* polymerase). Add 25 pico moles of sense and antisense oligonucleotide primers of EV and overlay with mineral oil. Appropriate positive and negative controls shall be included with each run. Set the following reaction at thermo cycler:

Denaturation at 94°C for 2 min

Denaturation for	1.0 min	at 94°C	35 cycles
Annealing for	1.0 min	at 42°C	
Extension for	2.0 min	at 72°C	

Final extension at 72°C for 7 min.

B-6 AGAROSE GEL ELECTROPHORESIS

B-6.1 Apparatus

B-6.1.1 *Micropippette*

B-6.1.2 *Electrophoresis Apparatus*

B-6.1.3 *Gel Documentation System*

B-6.2 Reagents

B-6.2.1 *Running Buffer* — 50X TAE buffer

Tris base/Tris buffer : 121.00 g

Glacial acetic acid	:	28.55 ml
0.5 M EDTA	:	50 .00 ml
Distilled water (autoclaved)	:	300.45 ml

Make the final volume upto 1 000 ml with deionised distilled water, sterilize and store at 4°C. The final concentration for the preparation of agarose gel and to run the gel shall be 1X.

B-6.2.2 *Tracking Dye* — 6X bromophenol blue.

B-6.2.3 *Ethidium Bromide* — 0.5 µg/ml.

B-6.3 Procedure

Run the PCR amplified product of EV and HAV on 1.5 percent agarose gel using 1X TAE buffer. Load 10 µl of amplified product after mixing it with 1 µl 10X loading dye. Run the molecular weight marker along with the samples. Run the electrophoresis at 100 V for 30 min. Stain the gel with ethidium bromide (0.5 µl/ml) for 20 min. Wash it with distilled water and view under UV transilluminator and photograph the gel to analyse the band pattern. EV gives the band as 155 base pair and the HAV gives band as 225 base pair.

ANNEX C

(*Clause* 4.3.10)

ILLUSTRATIVE LIST OF MICROSCOPIC ORGANISMS PRESENT IN WATER

Sl No.	*Classification of Microscopic Organism*	*Group and Name of the Organism*	*Habitat*	*Effect of the Organisms and Significance*
(1)	(2)	(3)	(4)	(5)
i)	Algae	a) Chlorophyceae:		
		1) *Species of* Coelastrum, Gomphospherium, Micractinium, Mougeotia, Oocystis, Euastrum, Scenedesmus, Actinastrum, Gonium, Eudorina Pandorina, Pediastrum, Zygnema, Chlamydomonas, Careteria, Chlorella, Chroococcus, Spirogyra, Tetraedron, Chlorogonium, Stigeoclonium	Polluted water, impounded sources	Impart colouration
		2) *Species of* Pandorina, Volvox, Gomphospherium, Staurastrum, Hydrodictyon, Nitella	Polluted waters	Produce taste and odour
		3) *Species of* Rhizoclonium, Cladothrix, Ankistrodesmus, Ulothrix, Micrasterias, Chromulina	Clean water	Indicate clean condition
		4) *Species of* Chlorella, Tribonema, Clostrium, Spirogyra, Palmella	Polluted waters, impounded sources	Clog filters and create impounded difficulties
		b) Cyanophyceae:		
		1) *Species of* Anacystis and Cylindrospermum	Polluted waters	Cause water bloom and impart colour
		2) *Species of* Anabena, Phormidium, Lyngbya, Arthrospira, Oscillatona	Polluted waters	Impart colour
		3) *Species of* Anabena, Anacystis, Aphanizomenon	Polluted waters, impounded sources	Produce taste and odour
		4) *Species of* Anacystis, Anabena, Coelospherium, Cleotrichina, Aphanizomenon	Polluted waters	Toxin producing
		5) *Species of* Anacystis, Rivularia, Oscillatoria, Anabena	Polluted waters	Clog filters

Sl No.	*Classification of Microscopic Organism*	*Group and Name of the Organism*	*Habitat*	*Effect of the Organisms and Significance*
(1)	(2)	(3)	(4)	(5)
		6) *Species of* Rivularia	Calcareous waters and also rocks	Bores rocks and calcareous strata and causes matted growth
		7) *Species of* Agmenellum, Microcoleus, Lemanea	Clean waters	Indicators of purification
		c) Diatoms (Bacillareophyceae):		
		1) *Species of* Fragillaria, Stephanodiscus, Stauroneis	—	Cause discoloration
		2) *Species of* Asterionella, Tabellaria	Hill streams high altitude, torrential and temperate waters	Taste and odour producing clog filters
		3) *Species of* Synedra and Fragillavia	Polluted waters	Taste and odour producing
		4) *Species of* Nitzchia, Gomphonema	Moderately polluted waters	Cause discoloration
		5) *Species of* Cymbela, Synedra, Melosira, Navicula, Cyclotella, Fragillaria, Diatoma, Pleurogsigma	Rivers and streams impounded sources	Clog filters and cause operational difficulties
		6) *Species of* Pinmularia, Surinella, Cyclotella, Meridion, Cocconeis	Clean waters	Indicators of purification
		d) Xanthophyceae:		
		Species of Botryococcus	Hill streams, high altitude and temperate waters	Produces coloration
	ii) Zooplankton	a) Protozoa:		
		1) Amoeba, Giardia Lamblia Arcella, Difflugia, Actinophrys	Polluted waters	Pollution indicators
		2) Endamoeba, Histolytica	Sewage and activated sludge	Parasitic and pathogenic
		b) Ciliates:		
		Paramoecium, Vorticella, Carchesium, Stentor, Colpidium, Coleps, Euplotes, Colopoda, Bodo	Highly polluted waters, sewage and activated sludge	Bacteria eaters
		c) Crustacea:		
		1) Bosmina, Daphnia	Stagnant polluted waters	Indicators of pollution
		2) Cyclops	Step wells in tropical climate	Carrier host of guinea worm
	iii) Rotifers	a) Rotifers:		
		Anurea, Rotaria, Philodina	Polluted and Algae laden waters	Feed on algae
		b) Flagellates:		
		1) Ceratium, Glenodinium, Peridinium Dinobryon	Rocky strata, iron bearing and acidic waters	Impart colour and fishy taste
		2) Euglena, Phacus	Polluted waters	Impart colour

Sl No.	*Classification of Microscopic Organism*	*Group and Name of the Organism*	*Habitat*	*Effect of the Organisms and Significance*
(1)	(2)	(3)	(4)	(5)
iv)	Miscellaneous Organisms	a) Sponges, Hydra	Fresh water	Clog filters and affect purification systems
		b) Tubifex, Eristalls, Chironomids	Highly polluted waters, sewage and activated sludge and bottom deposits	Clog filters and render water unaesthetic
		c) Plumatella	Polluted waters	Produces biological slimes and causes filter operational difficulties
		c) Dreissena, Asellus	Polluted waters	Harbour pathogenic organisms

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WATER QUALITY STANDARDS

Water Quality

Indian Standard for

Drinking Water - Specification

IS 10500 : 1991

Technical Terms

- BIS (Bureau of Indian Standards)
- Desirable limits
- Permissible limit
- PPM
- NTU
- Hazen Units

Colour, Hazen Units	
IS 10500-1991	Desirable : 5 Hz. , Permissible : 25 Hz.
Risks or effects	Visible tint, acceptance decreases
Sources	Tannins, Iron, Copper, Manganese Natural deposits
Treatment	Filtration, Distillation, Reverse osmosis, Ozonisation

Odour	
IS 10500-1991	Unobjectionable
Risks or effects	Rotten egg, Musty, Chemical
Sources	Chlorine, Hydrogen sulfide, Organic matter, Septic contamination, Methane gas
Treatment	Activated carbon, Air stripping, oxidation, Filtration

pH	
IS 10500-1991	Desirable :6.5 – 8.5, Permissible :No relaxation
Risks or effects	Low pH - corrosion, metallic taste High pH – bitter/soda taste, deposits
Sources	Natural
Treatment	Increase pH by soda ash Decrease pH with white vinegar / citric acid

Total Dissolved Solids (TDS)	
IS 10500-1991	Desirable : 500 mg/l , Permissible : 2000 mg/l
Risks or effects	Hardness, scaly deposits, sediment, cloudy colored water, staining, salty or bitter taste, corrosion of pipes and fittings
Sources	Livestock waste, septic system Landfills, nature of soil Hazardous waste landfills Dissolved minerals, iron and manganese
Treatment	Reverse Osmosis, Distillation, deionization by ion exchange

Hardness	
IS 10500-1991	Desirable :300 mg/l , Permissible : 600 mg/l
Risks or effects	Scale in utensils and hot water system, soap scums
Sources	Dissolved calcium and magnesium from soil and aquifer minerals containing limestone or dolomite
Treatment	Water Softener Ion Exchanger , Reverse Osmosis

Alkalinity	
IS 10500-1991	Desirable : 200 mg/l , Permissible : 600 mg/lit
Risks or effects	Low Alkalinity (i.e. high acidity) causes deterioration of plumbing and increases the chance for many heavy metals in water are present in pipes, solder or plumbing fixtures.
Sources	Pipes, landfills Hazardous waste landfills
Treatment	Neutralizing agent

Iron, Fe	
IS 10500-1991	Desirable : 0.3 mg/l , Permissible : 1.0 mg/l
Risks or effects	Brackish color, rusty sediment, bitter or metallic taste, brown-green stains, iron bacteria, discolored beverages
Sources	Leaching of cast iron pipes in water distribution systems Natural
Treatment	Oxidizing Filter , Green-sand Mechanical Filter

Manganese, Mn	
IS 10500-1991	Desirable : 0.1 mg/l , Permissible : 0.3 mg/l
Risks or effects	Brownish color, black stains on laundry and fixtures at .2 mg/l, bitter taste, altered taste of water-mixed beverages
Sources	Landfills Deposits in rock and soil
Treatment	Ion Exchange , Chlorination, Oxidizing Filter , Green-sand Mechanical Filter

Sulphate, SO_4	
IS 10500-1991	Desirable : 200 mg/l, Permissible : 400 mg/l
Risks or effects	Bitter, medicinal taste, scaly deposits, corrosion, laxative effects, "rotten-egg" odor from hydrogen sulfide gas formation
Sources	Animal sewage, septic system, sewage By-product of coal mining, industrial waste Natural deposits or salt
Sulphate Treatment	Ion Exchange , Distillation , Reverse Osmosis

Nitrate, NO_{3-}	
IS 10500-1991	Desirable : 45 mg/l, Permissible : 100 mg/lit
Risks or effects	Methemoglobinemia or blue baby disease in infants
Sources	Livestock facilities, septic systems, manure lagoons, fertilizers Household waste water, fertilizers Fertilizers Natural Deposits
Treatment	Ion Exchange, Distillation, Reverse Osmosis

Chloride, Cl	
IS 10500-1991	Desirable : 250 mg/l , Permissible : 1000 mg/l
Risks or effects	High blood pressure, salty taste, corroded pipes, fixtures and appliances, blackening and pitting of stainless steel
Sources	Fertilizers Industrial wastes Minerals, seawater
Treatment	Reverse Osmosis , Distillation, Activated Carbon

Fluoride, F	
IS 10500-1991	Desirable : 1.0 mg/l, Permissible : 1.5 mg/l
Risks or effects	Brownish discoloration of teeth, bone damage
Sources	Industrial waste Geological
Treatment	Activated Alumina, Distillation, Reverse Osmosis, Ion Exchange

Arsenic, As	
IS:10500-1991	Desirable: 0.05 mg/l Permissible: No relaxation
Risks or effects	Weight loss; Depression; Lack of energy; Skin and nervous system toxicity
Sources	Previously used in pesticides (orchards) Improper waste disposal or product storage of glass or electronics, Mining Rocks
Treatment	Activated Alumina Filtration, Reverse Osmosis, Distillation, Chemical Precipitation, Ion exchange, lime softening

Chromium, Cr	
IS 10500-1991	Desirable : 0.05 mg/l, Permissible : No relaxation
Risks or effects	Skin irritation, skin and nasal ulcers, lung tumors, gastrointestinal effects, damage to the nervous system and circulatory system, accumulates in the spleen, bones, kidney and liver
Sources	Septic systems Industrial discharge, mining sites Geological
Treatment	Ion Exchange, Reverse Osmosis, Distillation

Copper, Cu	
IS 10500-1991	Desirable : 0.05 mg/l, Permissible : 1.5 mg/l
Risks or effects	Anemia, digestive disturbances, liver and kidney damage, gastrointestinal irritations, bitter or metallic taste; Blue-green stains on plumbing fixtures
Sources	Leaching from copper water pipes and tubing, algae treatment Industrial and mining waste, wood preservatives Natural deposits
Treatment	Ion Exchange, Reverse Osmosis, Distillation

Cyanide	
IS 10500-1991	Desirable : 0.05 mg/l, Permissible : No relaxation
Risks or effects	Thyroid, nervous system damage
Sources	Fertilizer Electronics, steel, plastics mining
Treatment	Ion Exchange, Reverse Osmosis, Chlorination

Lead, Pb	
IS 10500-1991	Desirable : 0.05 mg/l, Permissible : No relaxation
Risks or effects	Reduces mental capacity (mental retardation), interference with kidney and neurological functions, hearing loss, blood disorders, hypertension, death at high levels
Sources	Paint, diesel fuel combustion Pipes and solder, discarded batteries, paint, leaded gasoline Natural deposits
Treatment	Ion Exchange, Activated Carbon , Reverse Osmosis, Distillation

Mercury, Hg	
IS 10500-1991	Desirable : 0.001 mg/l, Permissible : No relaxation
Risks or effects	Loss of vision and hearing, intellectual deterioration, kidney and nervous system disorders, death at high levels
Sources	Fungicides Batteries, fungicides Mining, electrical equipment, plant, paper and vinyl chloride Natural deposits
Treatment	Reverse Osmosis, Distillation

Zinc, Zn	
IS 10500-1991	Desirable :5 mg/l, Permissible : 15 mg/l
Risks or effects	Metallic taste
Sources	Leaching of galvanized pipes and fittings, paints, dyes Natural deposits
Treatment	Ion Exchange Water Softeners, Reverse Osmosis, Distillation

Total Coliform Bacteria	
IS 10500-1991	95% of samples should not contain coliform in 100 ml 10 coliform / 100ml
Risks or effects	Gastrointestinal illness
Sources	Livestock facilities, septic systems, manure lagoons Household waste water Naturally occurring
Treatment	Chlorination , Ultraviolet, Distillation, Iodination

E.coliform Bacteria	
IS 10500-1991	Nil / 100ml
Risks or effects	Gastrointestinal illness
Sources	Livestock facilities, septic systems, manure lagoons Household waste water Naturally occurring
Treatment	Chlorination , Ultraviolet, Distillation, Iodination

HEALTH EFFECTS OF CHEMICAL PARAMETERS

Parameter	BIS Guideline value (maximum allowable)	General & Health effect
Total dissolved solids	2000 mg/L	Undesirable taste; gastro intestinal irritations; corrosion or incrustation
PH	6.5-8.5	Affects mucous membrane; bitter taste; corrosion; affects aquatic life
Alkalinity	600 mg/L	Boiled rice turns yellowish
Hardness	600 mg/L	Poor lathering with soap; deterioration of the quality of clothes; scale forming; skin irritation; boiled meat and food become poor in quality
Calcium	200	Poor lathering and deterioration of the quality of clothes; incrustation in pipes; scale formation
Magnesium	100	Poor lathering and deterioration of clothes; with sulfate laxative
Iron	1.0	Poor or sometimes bitter taste, color and turbidity; staining of clothes materials; iron bacteria causing slime
Manganese	0.3	Poor taste, color and turbidity; staining; black slime

HEALTH EFFECTS OF CHEMICAL PARAMETERS

Parameter	BIS Guideline value (maximum allowable)	General & Health effect
Aluminum	0.2	Neurological disorders; Alzheimer's disease
Copper	1.5	Liver damage; mucosal irritation, renal damage and depression; restricts growth of aquatic plants
Zinc	15	Astringent taste; opalescence in water; gastro intestinal irritation; vomiting, dehydration, abdominal pain, nausea and dizziness
Ammonia	-	Indicates pollution; growth of algae
Nitrite	-	Forms nitrosoamines which are carcinogenic
Nitrate	100	Blue baby disease (methemoglobineamia); algal growth
Sulfate	400	Taste affected; laxative effect; gastro intestinal irritation
Chloride	1000	Taste affected; corrosive
Fluoride	1.5	Dental and skeletal fluorosis; non-skeletal

HEALTH EFFECTS OF CHEMICAL PARAMETERS

Parameter	BIS Guideline value (maximum allowable)	General & Health effect
Phosphate	-	Algal growth
Arsenic	0.05	Toxic; bio-accumulation; central nervous system affected; carcinogenic
Mercury	0.001	Highly toxic; causes 'minamata' disease-neurological impairment and renal disturbances; mutagenic
Cadmium	0.01	Highly toxic; causes 'itai-itai' disease-painful rheumatic condition; cardio vascular system affected; gastro intestinal upsets and hyper tension
Lead	0.05	Causes plumbism-tiredness, lassitudes, abdominal discomfort, irritability, anaemia; bio-accumulation; impaired neurological and motor development, and damage to kidneys
Chromium	0.05	Carcinogenic; ulcerations, respiratory problems and skin complaints
Pesticide	0.001	Affects central nervous system
Detergent	-	Undesirable foaming

~~(?)~~ P = 1,00,000

Avg consumption = 250 lpcd

(a) Estimate the different kinds of demands.

(b) Determine req'd capacity of major components of proposed w/works in city using river as source.

Sol'n.

(a) (i) Avg Daily Demand = 250 × 1,00,000 = 25 MLD / 25000 m³/d

(ii) max'm " " = 1·8 × 25 = 45 MLD / 45,000 m³/d.

(iii) " hourly " = 2·7 × 25 = 67·5 MLD / 67,500 m³/d

(iv) fire Demand = $4637\sqrt{P}\,[1 - 0.01\sqrt{P}]$ = 61 MLD / 61,000 m³/d

(v) total Demand = (ii) + (iv) = 45 + 61 = 106 MLD.

(b) Capacity for different components.

(i) Intake structure ⇒ max'm daily demand = 45 MLD

(ii) pipe mains ⇒ intake to treatment unit = M.D.D = 45 MLD.

(iii) filter and other units = ADD + reserve = 2×25 = 50 MLD.

(iv) lift pumps = 2(ADD) = 2×25 = 50 MLD (24 hr op'n)

⇒ $50 \times \frac{24}{8}$ = 150 MLD (8 hr op'n)

(v) distn system = maximum demand = 106 MLD.

Module 5 : Population Forecasting

Lecture 5 : Population Forecasting

5. POPULATION FORECASTING

Design of water supply and sanitation scheme is based on the projected population of a particular city, estimated for the design period. Any underestimated value will make system inadequate for the purpose intended; similarly overestimated value will make it costly. Changes in the population of the city over the years occur, and the system should be designed taking into account of the population at the end of the design period.

Factors affecting changes in population are:

- increase due to births
- decrease due to deaths
- increase/ decrease due to migration
- increase due to annexation.

The present and past population record for the city can be obtained from the census population records. After collecting these population figures, the population at the end of design period is predicted using various methods as suitable for that city considering the growth pattern followed by the city.

5.1 ARITHMETICAL INCREASE METHOD

This method is suitable for large and old city with considerable development. If it is used for small, average or comparatively new cities, it will give lower population estimate than actual value. In this method the average increase in population per decade is calculated from the past census reports. This increase is added to the present population to find out the population of the next decade. Thus, it is assumed that the population is increasing at constant rate.

Hence, $dP/dt = C$ i.e., rate of change of population with respect to time is constant.

Therefore, Population after n^{th} decade will be $P_n = P + n.C$ (1)

Where, P_n is the population after 'n' decades and 'P' is present population.

Example: 1

Predict the population for the year 2021, 2031, and 2041 from the following population data.

Year	1961	1971	1981	1991	2001	2011
Population	8,58,545	10,15,672	12,01,553	16,91,538	20,77,820	25,85,862

Solution

Year	Population	Increment
1961	858545	-
1971	1015672	157127
1981	1201553	185881
1991	1691538	489985
2001	2077820	386282
2011	2585862	508042

Average increment = 345463

Population forecast for year 2021 is, P_{2021} = 2585862 + 345463 x 1 = 2931325

Similarly, P_{2031} = 2585862 + 345463 x 2 = 3276788

P_{2041} = 2585862 + 345463 x 3 = 3622251

5.2 GEOMETRICAL INCREASE METHOD (OR GEOMETRICAL PROGRESSION METHOD)

In this method the percentage increase in population from decade to decade is assumed to remain constant. Geometric mean increase is used to find out the future increment in population. Since this method gives higher values and hence should be applied for a new industrial town at the beginning of development for only few decades. The population at the end of n^{th} decade 'P_n' can be estimated as:

$$P_n = P\,(1 + I_G/100)^{n} \qquad (2)$$

Where, I_G = geometric mean (%)

P = Present population

N = no. of decades.

Example: 2

Considering data given in example 1 predict the population for the year 2021, 2031, and 2041 using geometrical progression method.

Solution

Year	Population	Increment	Geometrical increase Rate of growth
1961	858545	-	
1971	1015672	157127	(157127/858545) = 0.18
1981	1201553	185881	(185881/1015672) = 0.18
1991	1691538	489985	(489985/1201553) = 0.40
2001	2077820	386282	(386282/1691538) = 0.23
2011	2585862	508042	(508042/2077820) = 0.24

Geometric mean $I_G = (0.18 \times 0.18 \times 0.40 \times 0.23 \times 0.24)^{1/5}$

$= 0.235$ i.e., 23.5%

Population in year 2021 is, $P_{2021} = 2585862 \times (1+ 0.235)^1 = 3193540$

Similarly for year 2031 and 2041 can be calculated by,

$P_{2031} = 2585862 \times (1+ 0.235)^2 = 3944021$

$P_{2041} = 2585862 \times (1+ 0.235)^3 = 4870866$

5.3 INCREMENTAL INCREASE METHOD

This method is modification of arithmetical increase method and it is suitable for an average size town under normal condition where the growth rate is found to be in increasing order. While adopting this method the increase in increment is considered for calculating future population. The incremental increase is determined for each decade from the past population and the average value is added to the present population along with the average rate of increase.

Hence, population after n^{th} decade is $P_n = P + n.X + \{n (n+1)/2\}.Y$ (3)

Where, P_n = Population after n^{th} decade

X = Average increase

Y = Incremental increase

Example: 3

Considering data given in example 1 predict the population for the year 2021, 2031, and 2041 using incremental increase method.

Solution

Year	Population	Increase (X)	Incremental increase (Y)
1961	858545	-	-
1971	1015672	157127	-
1981	1201553	185881	+28754
1991	1691538	489985	+304104
2001	2077820	386282	-103703
2011	2585862	508042	+121760
	Total	1727317	350915
	Average	345463	87729

Population in year 2021 is, P_{2021} = 2585862 + (345463 x 1) + {(1 (1+1))/2} x 87729

= 3019054

For year 2031 P_{2031} = 2585862 + (345463 x 2) + {(2 (2+1)/2)} x 87729

= 3539975

P_{2041} = 2585862 + (345463 x 3) + {(3 (3+1)/2)} x 87729

= 4148625

5.4 GRAPHICAL METHOD

In this method, the populations of last few decades are correctly plotted to a suitable scale on graph (Figure 5.1). The population curve is smoothly extended for getting future population. This extension should be done carefully and it requires proper experience and judgment. The best way of applying this method is to extend the curve by comparing with population curve of some other similar cities having the similar growth condition.

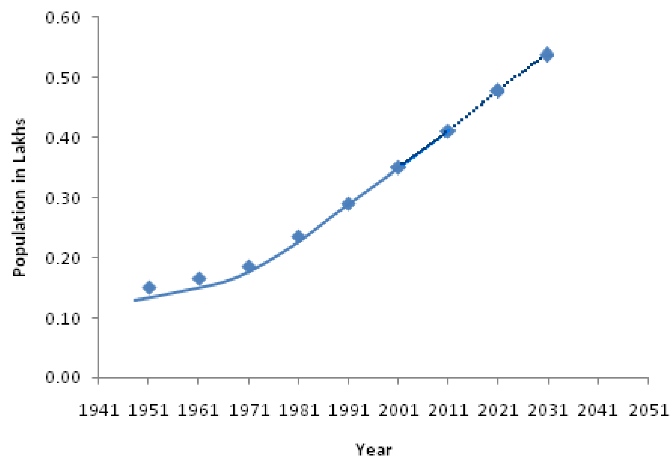


Figure 5.1 Graphical method of population forecasting

5.5 COMPARATIVE GRAPHICAL METHOD

In this method the census populations of cities already developed under similar conditions are plotted. The curve of past population of the city under consideration is plotted on the same graph. The curve is extended carefully by comparing with the population curve of some similar cities having the similar condition of growth. The advantage of this method is that the future population can be predicted from the present population even in the absence of some of the past census report. The use of this method is explained by a suitable example given below.

Example: 4

The populations of a new city X given for decades 1970, 1980, 1990 and 2000 were 32,000; 38,000; 43,000 and 50,000, respectively. The cities A, B, C and D were developed in similar conditions as that of city X. It is required to estimate the population of the city X in the years 2010 and 2020. The population of cities A, B, C and D of different decades were given below:

(i) City A: 50,000; 62,000; 72,000 and 87,000 in 1960, 1972, 1980 and 1990, respectively.

(ii) City B: 50,000; 58,000; 69,000 and 76,000 in 1962, 1970, 1981 and 1988, respectively.

(iii) City C: 50,000; 56,500; 64,000 and 70,000 in 1964, 1970, 1980 and 1988, respectively.

(iv) City D: 50,000; 54,000; 58,000 and 62,000 in 1961, 1973, 1982 and 1989, respectively.

Population curves for the cities A, B, C, D and X are plotted (Figure 5.2). Then an average mean curve is also plotted by dotted line as shown in the figure. The population curve X is extended beyond 50,000 matching with the dotted mean curve. From the curve, the populations obtained for city X are 58,000 and 68,000 in year 2010 and 2020.

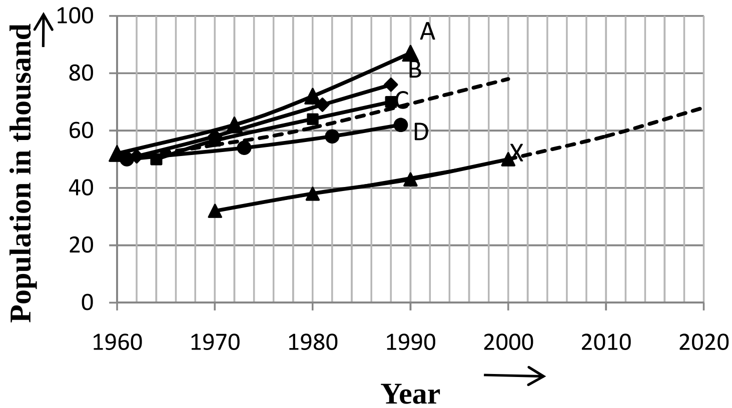


Figure 5.2 Comparative graph method

5.6 MASTER PLAN METHOD

The big and metropolitan cities are generally not developed in haphazard manner, but are planned and regulated by local bodies according to master plan. The master plan is prepared for next 25 to 30 years for the city. According to the master plan the city is divided into various zones such as residence, commerce and industry. The population densities are fixed for various zones in the master plan. From this population density total water demand and wastewater generation for that zone can be worked out. By this method it is very easy to access precisely the design population.

5.7 LOGISTIC CURVE METHOD

This method is used when the growth rate of population due to births, deaths and migrations takes place under normal situation and it is not subjected to any extraordinary changes like epidemic, war, earth quake or any natural disaster, etc., and the population follows the growth curve characteristics of living things within limited space and economic opportunity. If the population of a city is plotted with respect to time, the curve so obtained under normal condition looks like S-shaped curve and is known as logistic curve (Figure 5.3).

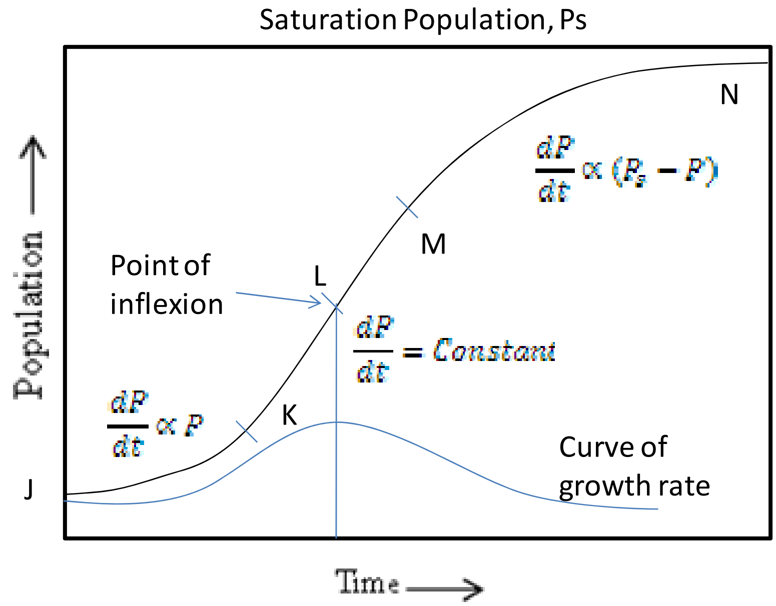


Figure 5.3 Logistic curve for population growth

In Figure 5.3, the curve shows an early growth JK at an increasing rate i.e. geometric growth or log growth, $\frac{dP}{dt} \propto$ P, the transitional middle curve KM follows arithmetic increase i.e. $\frac{dP}{dt}$ = constant. For later growth MN the rate of change of population is proportional to difference between saturation population and existing population, i.e. $\frac{dP}{dt} \propto (P_s - P)$. A mathematical solution for this logistic curve JN, which can be represented by an autocatalytic first order equation, is given by

$$\log_e\left(\frac{Ps-P}{P}\right) - \log_e\left(\frac{Ps-P_0}{P_0}\right) = -K.P_s.t \qquad (4)$$

where, P = Population at any time t from the origin J

P_s= Saturation population

P_0 = Population of the city at the start point J

K = Constant

t = Time in years

From the above equation we get

$$\log_e\left(\frac{Ps-P}{P}\right)\left(\frac{P_o}{Ps-P_o}\right) = - K.P_s.t \qquad (5)$$

After solving we get,

$$P = \frac{P_s}{1+\frac{P_s-P_0}{P_o}log_e^{-1}(-K.P_s.t)} \qquad (6)$$

Substituting $\frac{Ps-P_0}{P_0} = m$ (a constant) (7)

and $- K.P_s = n$ (another constant) (8)

we get, $P = \frac{P_s}{1+m\log_e^{-1}(n.t)}$ (9)

This is the required equation of the logistic curve, which will be used for predicting population. If only three pairs of characteristic values P_0, P_1, P_2 at times $t = t_0 = 0$, t_1 and $t_2 = 2t_1$ extending over the past record are chosen, the saturation population P_s and constant m and n can be estimated by the following equation, as follows:

$$P_s = \frac{2P_0P_1P_2 - P_1^2(P_0+P_2)}{P_0P_2 - P_1^2} \qquad (10)$$

$$m = \frac{Ps-P_0}{P_0}$$

$$n = \frac{2.3}{t_1}\log_{10}\left(\frac{P_0(P_s-P_1)}{P_1(P_s-P_0)}\right) \qquad (11)$$

Example: 5

The population of a city in three consecutive years i.e. 1991, 2001 and 2011 is 80,000; 250,000 and 480,000, respectively. Determine (a) The saturation population, (b) The equation of logistic curve, (c) The expected population in 2021.

Solution

It is given that

$P_0 = 80,000$ $t_0 = 0$

P_1 = 250,000 t_1 = 10 years

P_2 = 480,000 t_2 = 20 years

The saturation population can be calculated by using equation

$$P_s = \frac{2P_0P_1P_2 - P_1^2(P_0 + P_2)}{P_0P_2 - P_1^2}$$

$$= \frac{2 \text{ x } 80{,}000 \text{ x } 2{,}50{,}000 \text{ x } 4{,}80{,}000 - 2{,}50{,}000 \text{ x } 2{,}50{,}000 \text{ x } (80{,}000 + 4{,}80{,}000)}{80{,}000 \text{ x } 4{,}80{,}000 - 2{,}50{,}000 \text{ x } 2{,}50{,}000}$$

= 655,602

We have, $m = \frac{Ps - P_0}{P_0} = \frac{655{,}602 - 80{,}000}{80{,}000} = 7.195$

$$n = \frac{2.3}{t_1} \log_{10} \frac{P_0(P_S - P_1)}{P_1(P_S - P_0)}$$

$$= \frac{2.3}{10} \log_{10} \left(\frac{80{,}000(655{,}602 - 2{,}50{,}000)}{250{,}000(655{,}602 - 80{,}000)} \right)$$

= -0.1488

Population in 2021

$$P = \frac{P_S}{1 + m\log_e^{-1}(n.t)}$$

$$= \frac{6{,}55{,}602}{1 + 7.195 \text{ x } \log_e^{-1}(-0.1488 \text{ x } 30)}$$

$$= \frac{6{,}55{,}602}{1 + 7.195 \text{ x } 0.0117} = 605{,}436$$

Questions

1. Explain different methods of population forecasting.
2. The population data for a town is given below. Find out the population in the year 2021, 2031 and 2041 by (a) arithmetical (b) geometric (c) incremental increase methods.

Year	1971	1981	1991	2001	2011
Population	84,000	1, 15,000	1, 60,000	2, 05,000	2, 50,000

3. In three consecutive decades the population of a town is 40,000; 100,000 and 130,000. Determine: (a) Saturation population; (b) Equation for logistic curve; (c) Expected population in next decade.

Answers:

Q.2. Population in the year 2021, 2031 and 2041

(a) Arithmetical increase method: 291,500; 333,000; 374,500

(b) Geometrical progression method: 327,500; 429,025; 562,023

(c) Incremental increase methods: 296,170; 347,010; 402,520

Q.3. (a) Saturation population: 137,500

(b) Equation for logistic curve: m = 2.437; n = -0.187;

$$P = \frac{137500}{1 + 2.44 \text{ x } \log_e^{-1} (-0.187 \text{ x } t)}$$

(c) Expected population in next decade: 136,283

Unit 2

Water Intake Structures

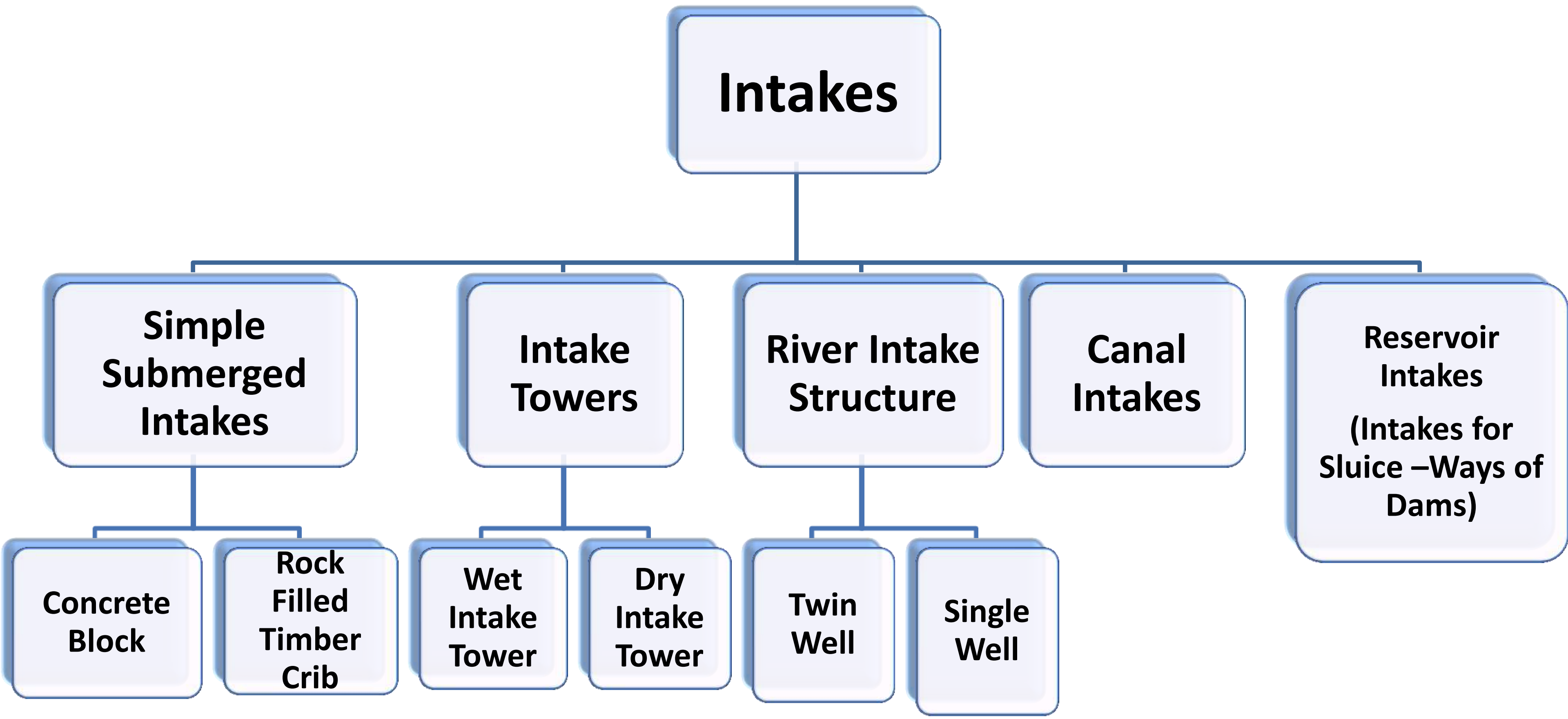
Basic function of the intake structure

- to help in safely withdrawing water from the source over predetermined pool levels and then to discharge this water into the withdrawal conduit (normally called intake conduit), through which it flows up to water treatment plant.

Factors Governing Location of Intake

- As far as possible, the site should be near the treatment plant so that the cost of conveying water to the city is less.
- The intake must be located in the purer zone of the source to draw best quality water from the source, thereby reducing load on the treatment plant.
- The intake must never be located at the downstream or in the vicinity of the point of disposal of wastewater.
- The site should be such as to permit greater withdrawal of water, if required at a future date.
- The intake must be located at a place from where it can draw water even during the driest period of the year.
- The intake site should remain easily accessible during floods and should not get flooded. Moreover, the flood waters should not be concentrated in the vicinity of the intake.

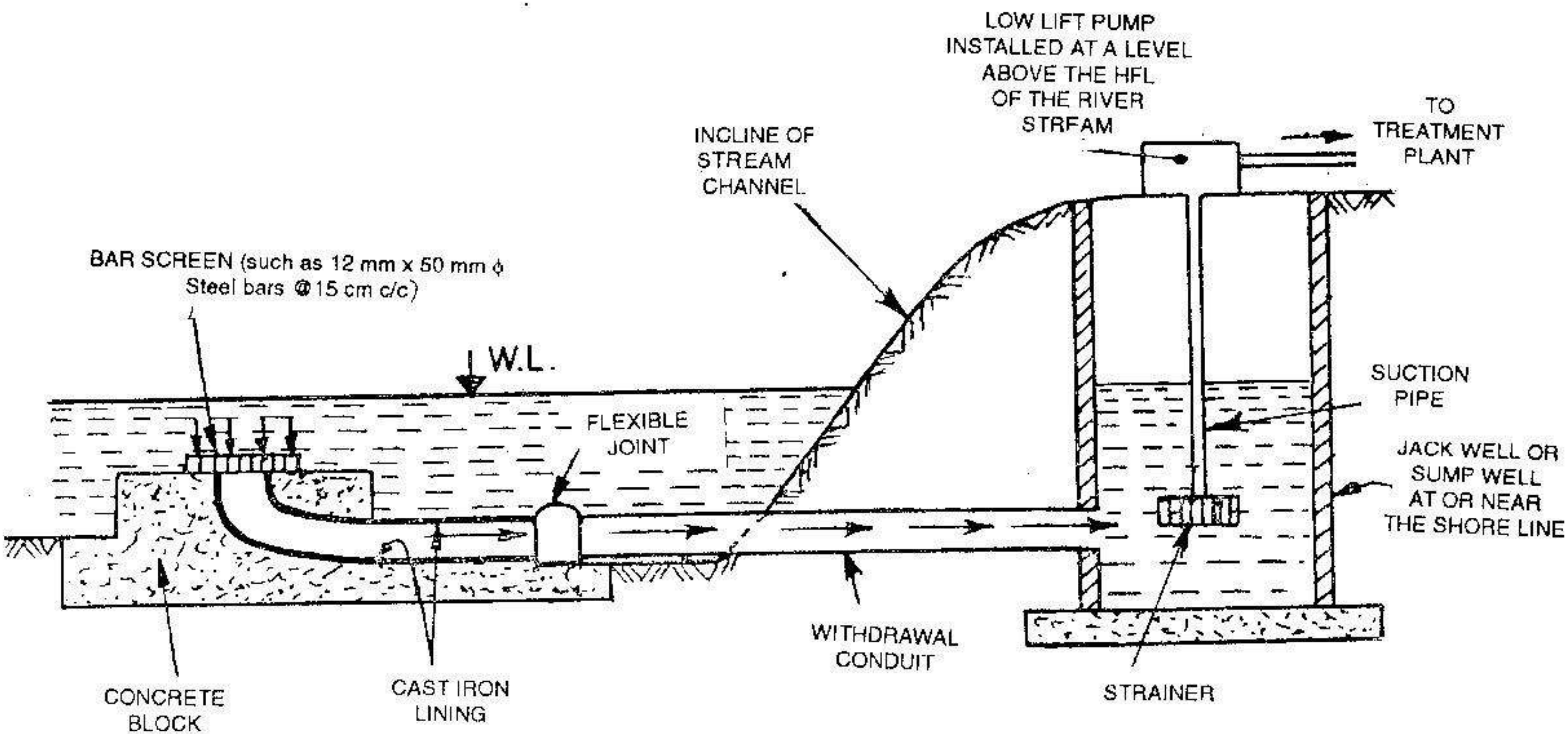
Types of Intake Structures



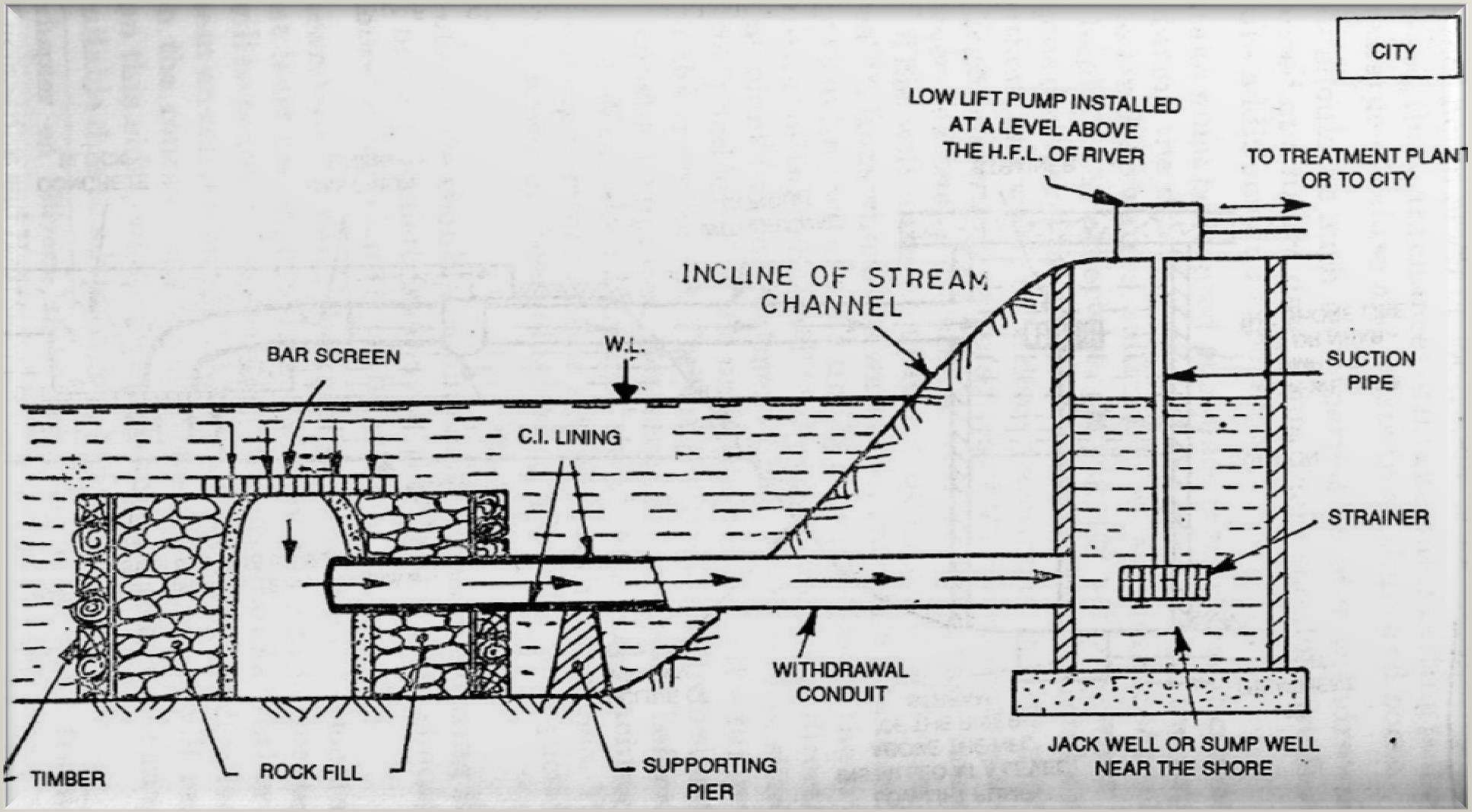
Simple Submerged Intakes

- Consists of simple concrete block or rock filled timber crib to support starting end of withdrawal pipe
- Withdrawal pipe is taken up to sump well or jack well located at shore from where water is lifted by low lift pumps to discharge to water treatment plant
- Intake openings generally covered by screens to prevent entry of debris, ice etc.
- Intake opening is kept at about 2 – 2.5m above the bottom of the lake to avoid entry of silt and sediment
- Placed in rivers or lakes at such points and in deep waters where they may not get buried under sediment
- Cheap and do not obstruct navigation
- Used for small water supply projects from rivers and lakes having little change in water surface elevation throughout the year

Submerged Intake – Simple Concrete Block



Submerged Intake – Rock Filled Timber Crib



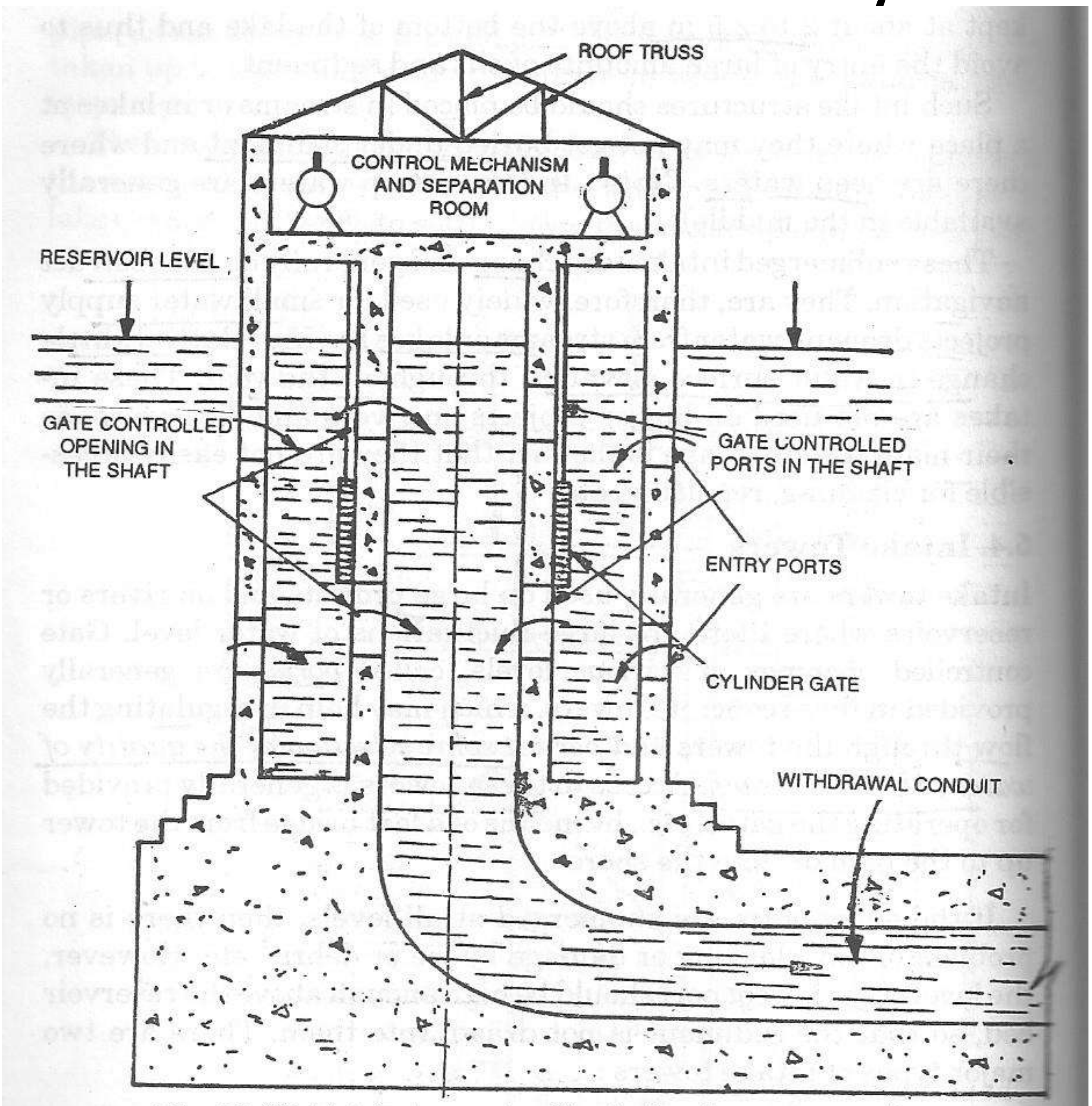
Intake Towers

- Used on large projects and on rivers or reservoirs having large water level fluctuations
- Ports (i.e., openings controlled by gates) are provided to help regulate flow through the towers and permit selection of quality of water to be withdrawn
- Access to towers by means of foot bridge from shore or from dam
- Lowest port high enough above the reservoir bed to prevent entry of sediment
- Types of intake towers
  - Wet Intake
  - Dry Intake

Wet Intakes

- Consist of circular concrete shell having a vertical shaft inside connected to the withdrawal pipe. Water level in the tower is up to the reservoir level
- Both concrete shell and vertical shaft has openings
- Gates are placed on the shaft to control flow of water into the shaft and the withdrawal conduit
- Withdrawal conduits may lie over the bed of the rivers or may be in the form of tunnels below the river bed
- If the water treatment plant is at higher elevation, withdrawal conduit may be taken to sump well for pumping (lifting) the water to treatment plant
- If the water treatment plant is situated at lower elevation , withdrawal conduit may be directly taken to treatment plant

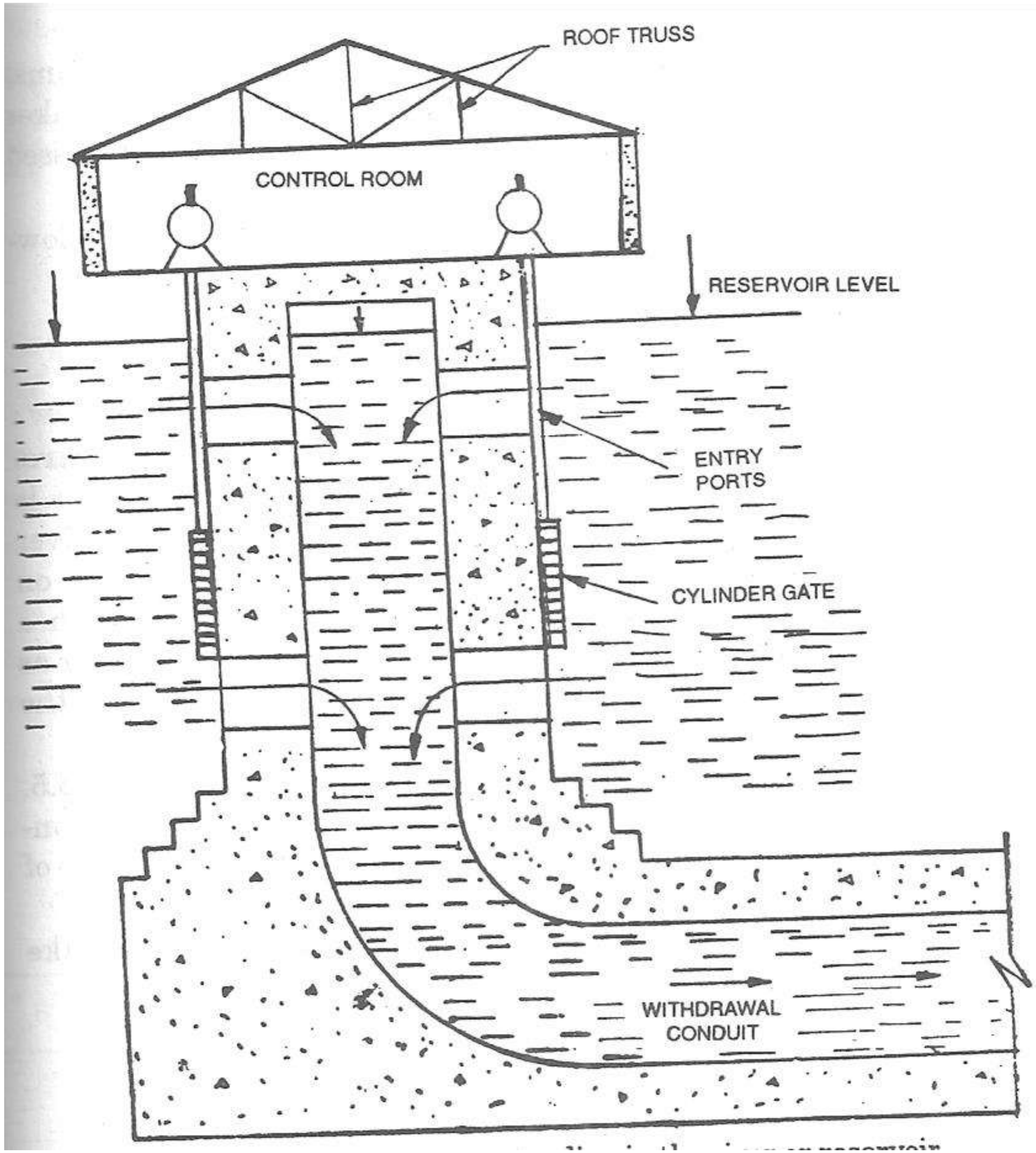
Wet Intake Tower – River/Reservoir



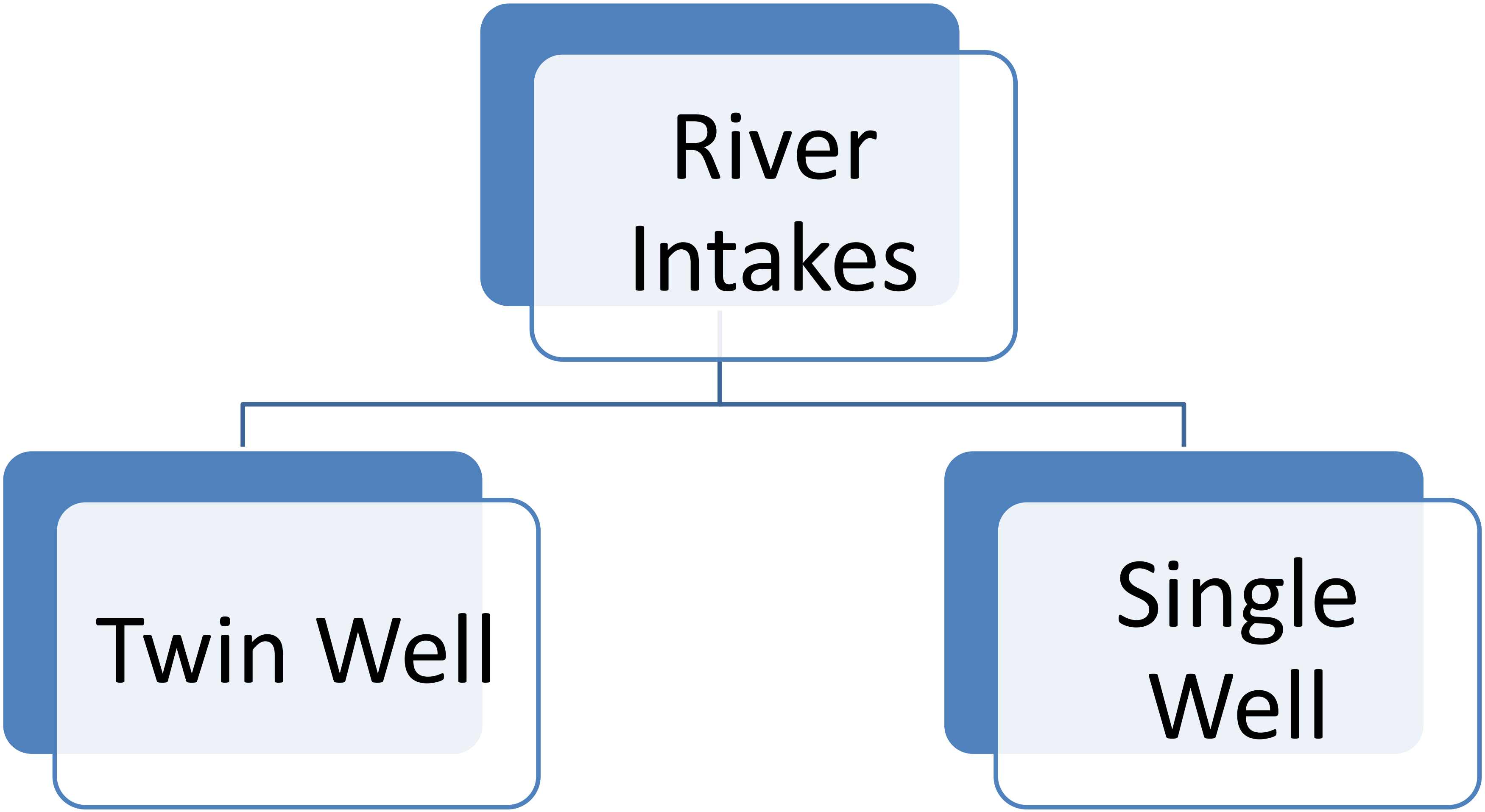
Dry Intakes

- Water is directly drawn into the withdrawal conduit through the gated entry ports
- No water inside the tower if its gates are closed
- When the entry ports are closed, dry intake tower will be subjected to additional buoyant forces and must be of heavier construction than the wet intake towers
- Useful and beneficial to withdraw water from any selected level of the reservoir by opening the port at that level

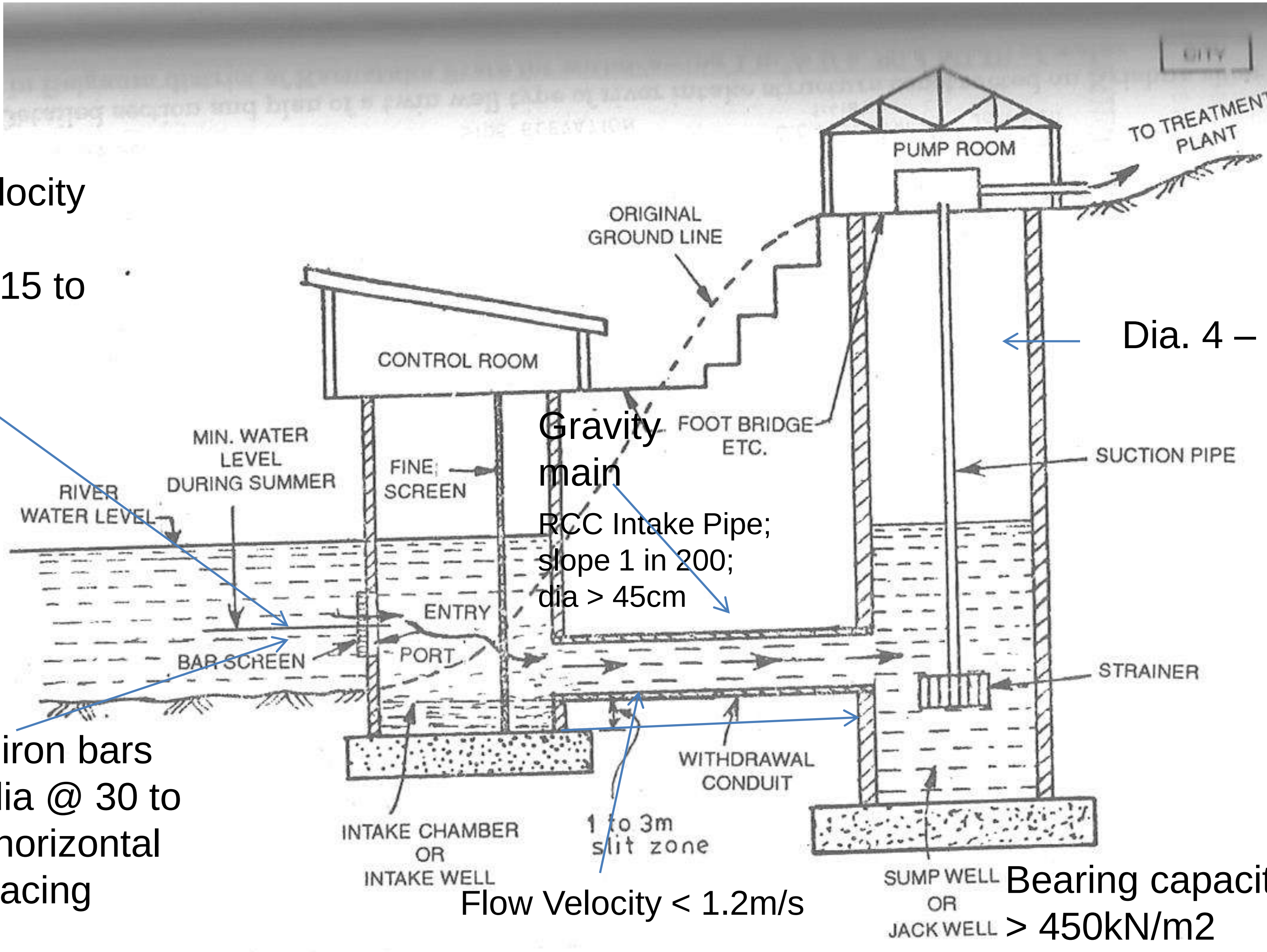
Dry Intake Tower – River/Reservoir



River Intakes



River Intake - Twin Well Type



Flow velocity through screens15 to 20cm/s

Gravity main

RCC Intake Pipe; slope 1 in 200; dia > 45cm

Dia. 4 – 5m

Vertical iron bars 20mm dia @ 30 to 50 mm horizontal clear spacing

Flow Velocity < 1.2m/s

Bearing capacity > 450kN/m2

Twin Well Type of River Intake

- Most commonly used
- Generally constructed on all types of rivers where the river water hugs the river bank – non-alluvial rivers
- Alluvial rivers - above condition obtained by constructing a weir across the river to store water upto pond level, thus making it available near the river bank on under-sluice side
- High-head turbine pumps or centrifugal pumps may be used to lift water from jack well

- Typical river intake consists of
  - Inlet Well
  - Inlet pipe
  - Jack Well
- Inlet Well or Collector Well – Circular/oblong located away from river bank, amidst water
- Masonry or concrete

Twin Well Type River Intake – Detailed Section and Plan (86.4 MLD of Water)

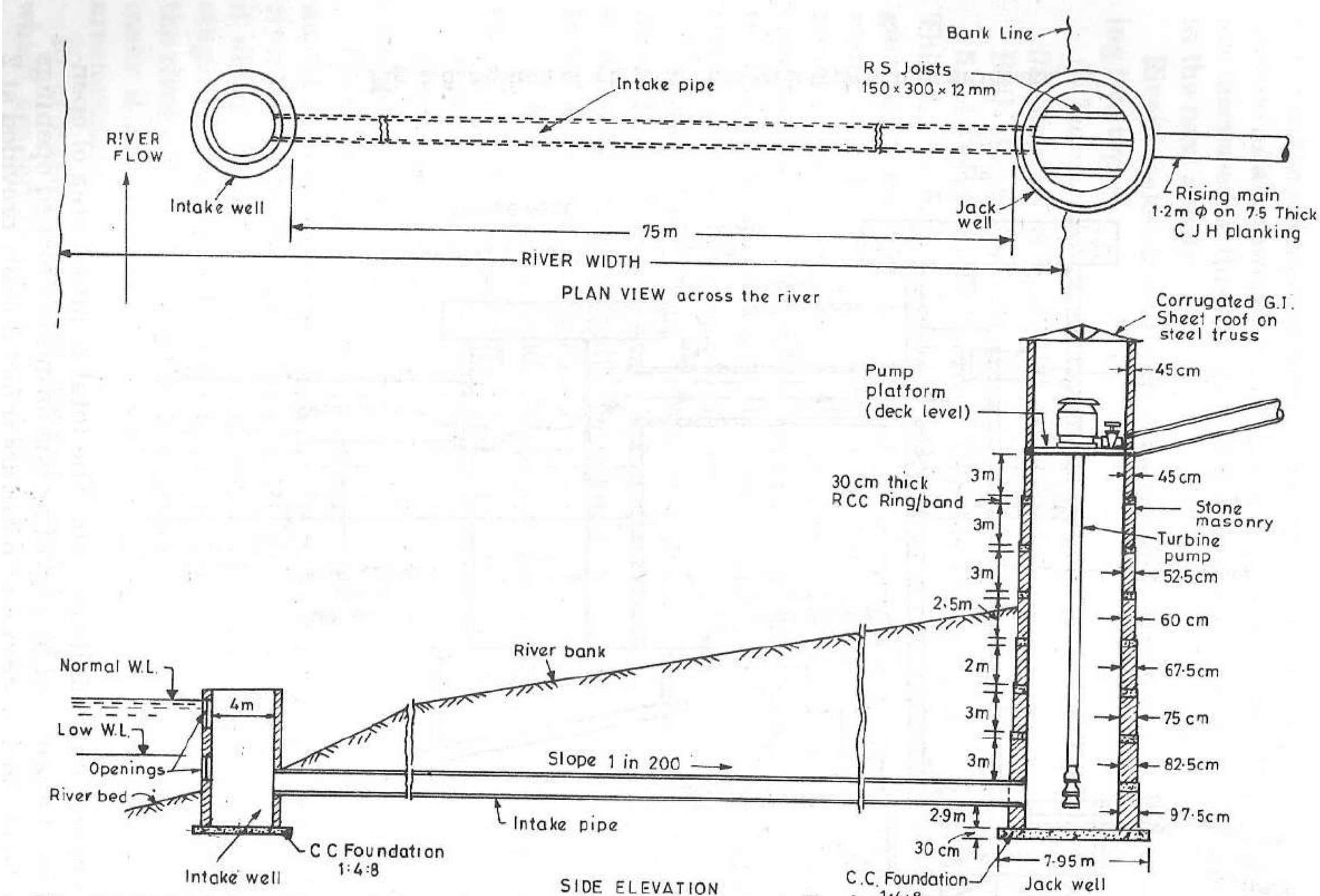
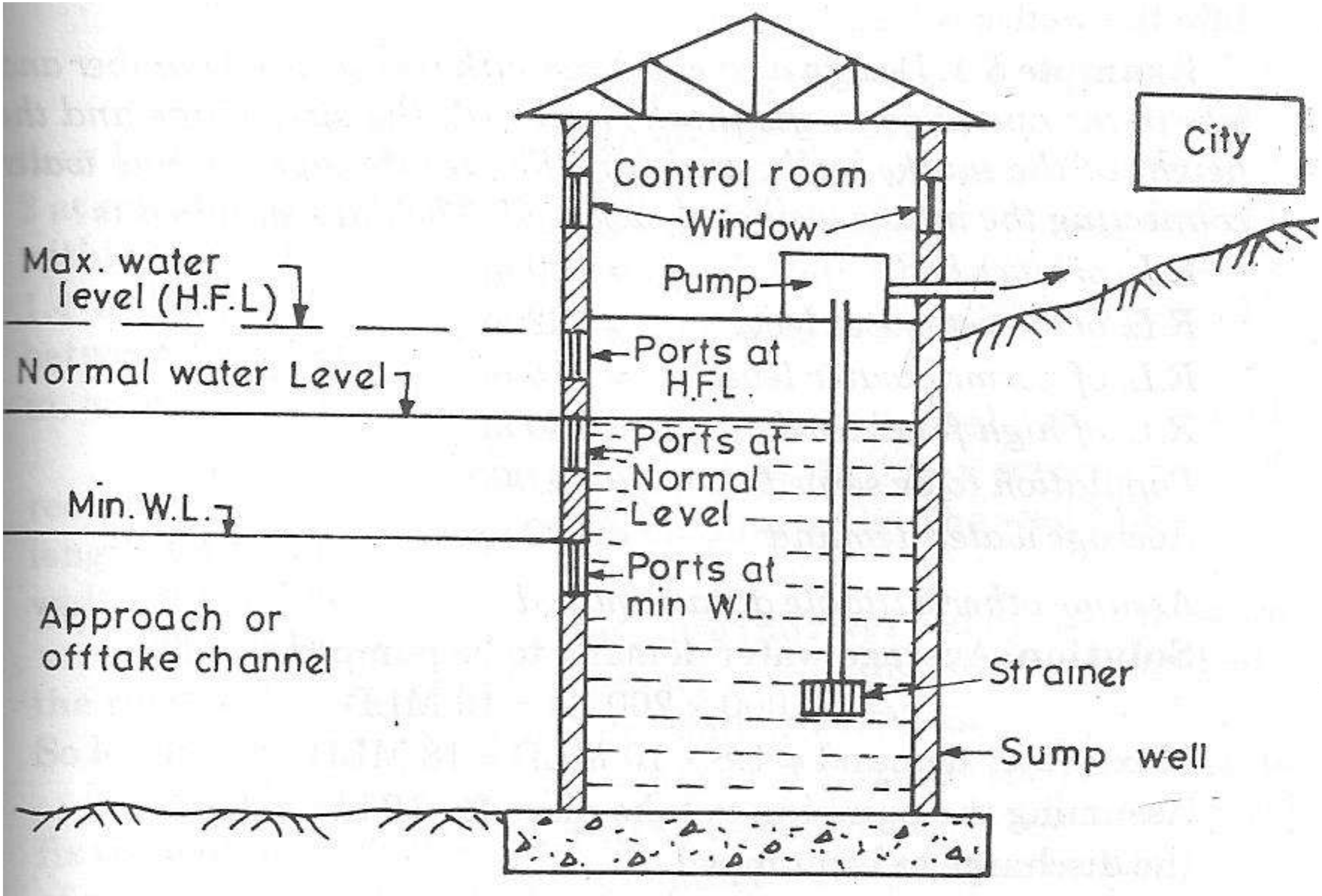


Fig. 5.6. Detailed section and plan of a twin well type of river intake structure constructed on Krishna river in Belgaum district of Karnataka State for withdrawing 1 m^3/s (*i.e.* 86.4 MLD) of water.

Single Well type River Intake

- Alluvial Rivers – water is ponded up by constructing a weir across the river
- Upstream side of weir – a channel is taken off and the intake structure is located in this offtake channel. Water entering this offtake channel may then be collected and lifted for supply to city treatment plant located at higher elevation.

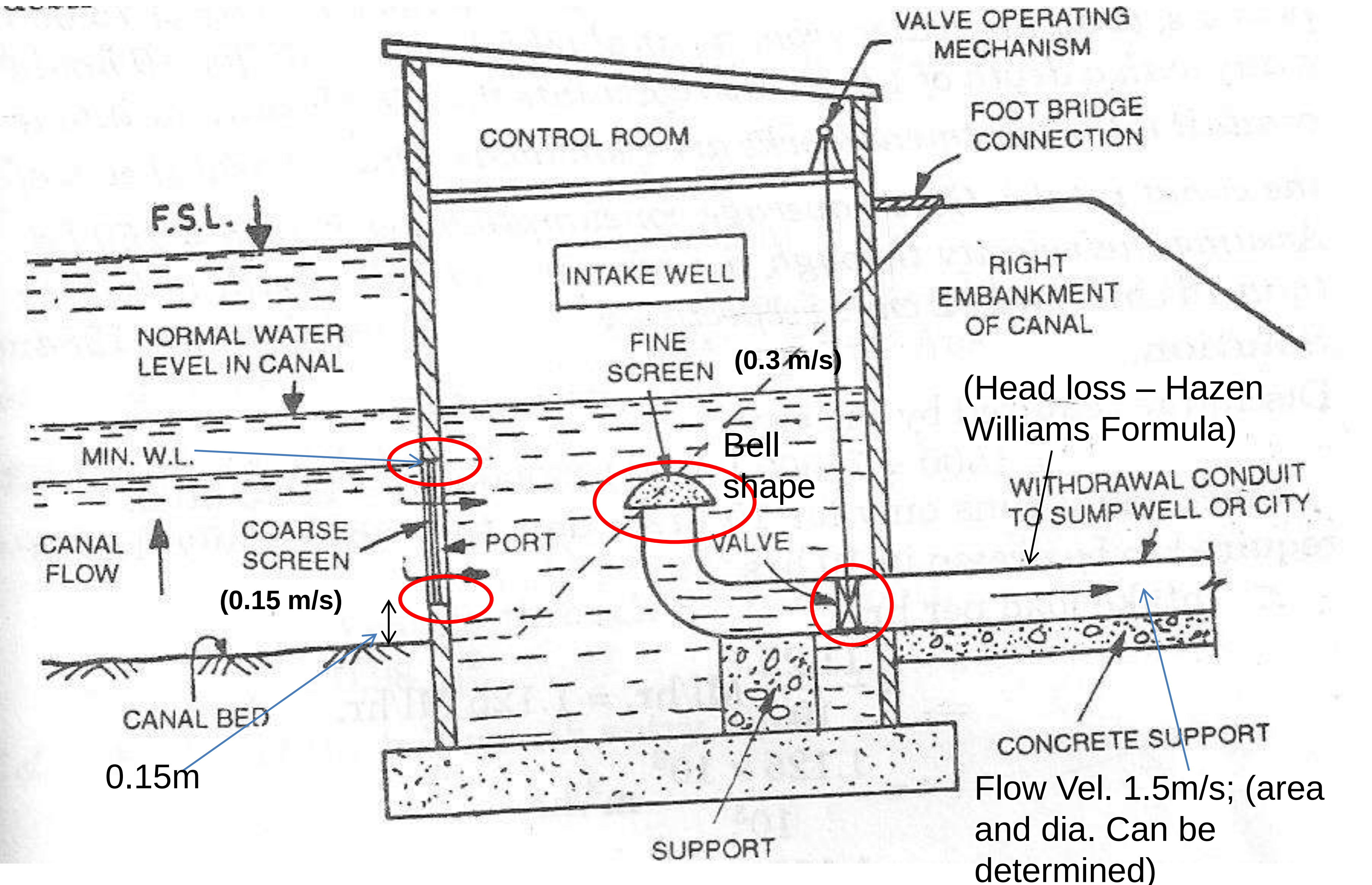
River Intake – Single Well Type located across an off-take channel or an approach channel



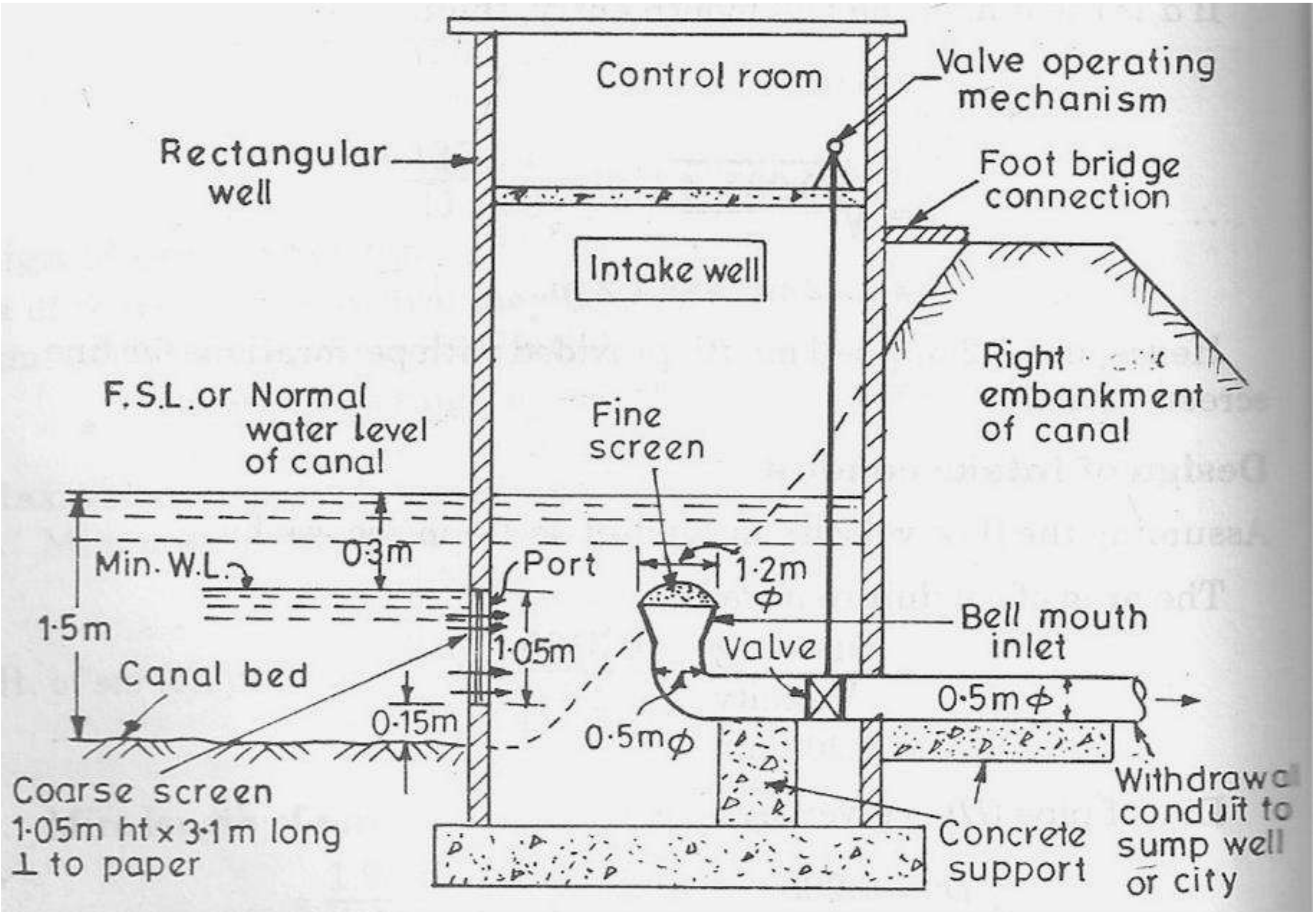
Canal Intakes

- Intake well generally located in the bank of the canal. Water enters the chamber through an inlet pipe covered with a fine screen. The water coming out of the chamber through the outlet conduit may be taken to the sump well or city, as desired.
- Due to construction of intake well in canal, flow area is reduced and hence the flow velocity increases. Hence pitching is done on both upstream and downstream portions of canal near the intake.

Canal Intake Well



Canal Intake Well



Valve Tower situated at Upstream Toe of an Earthen Dam

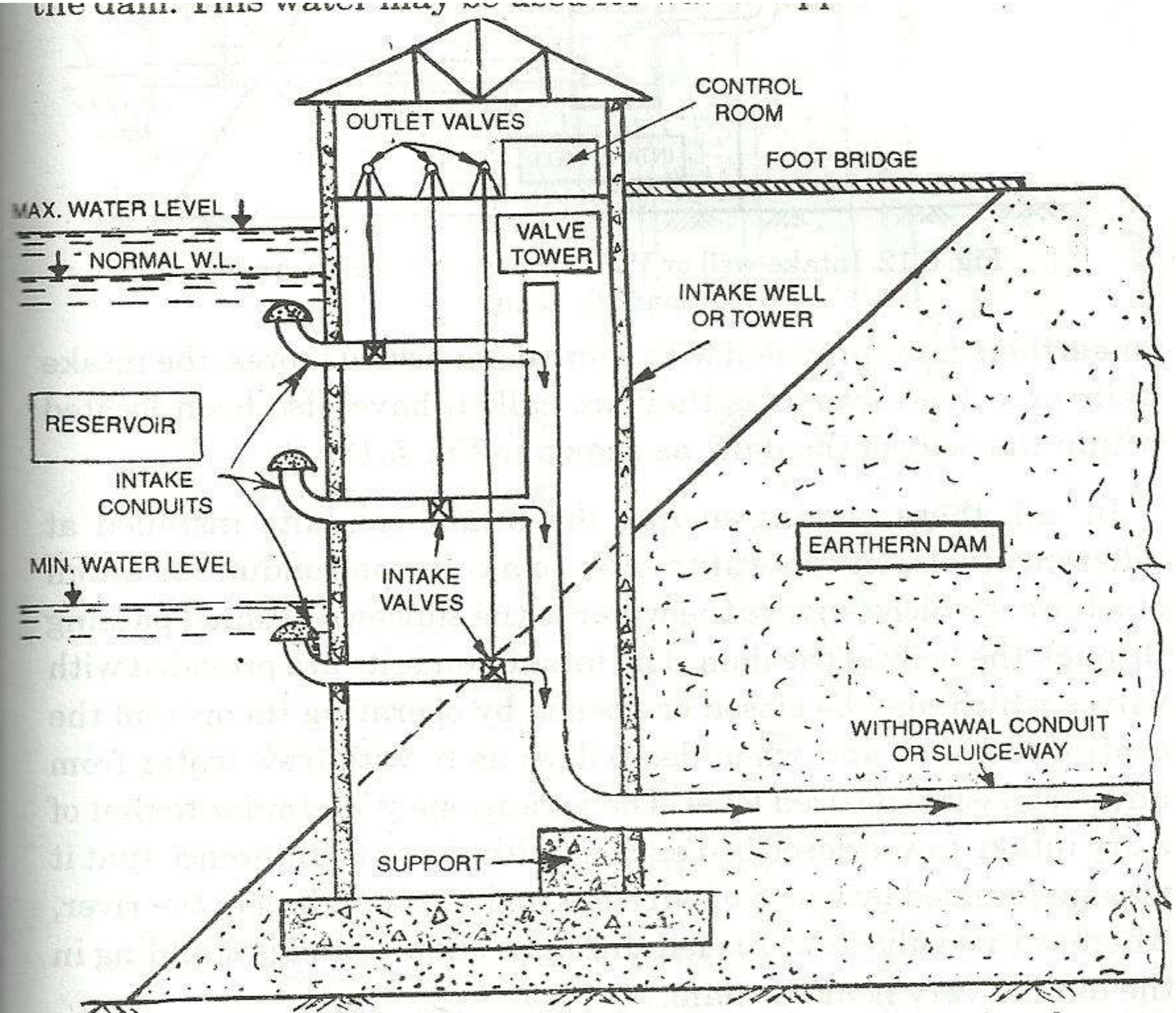
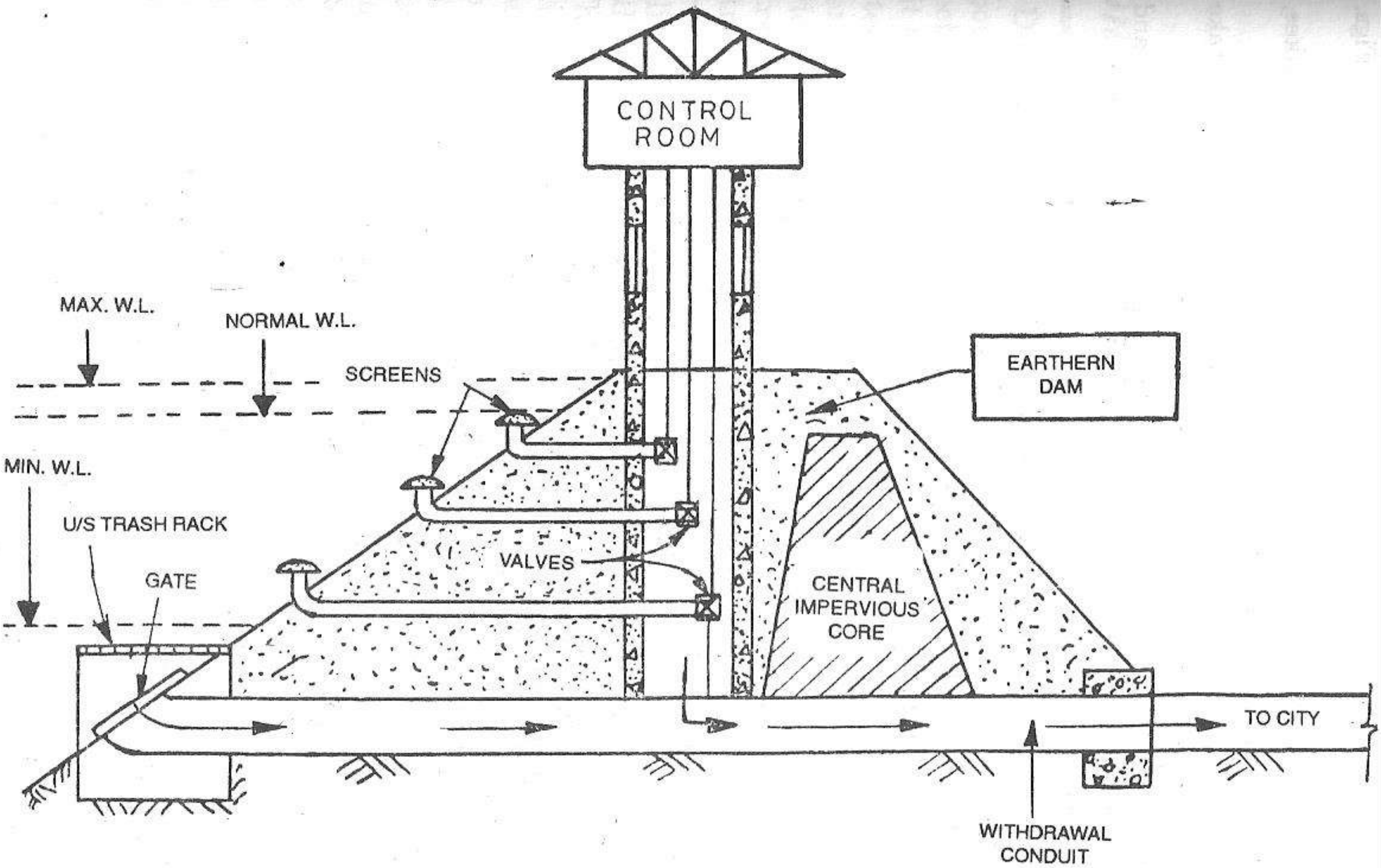


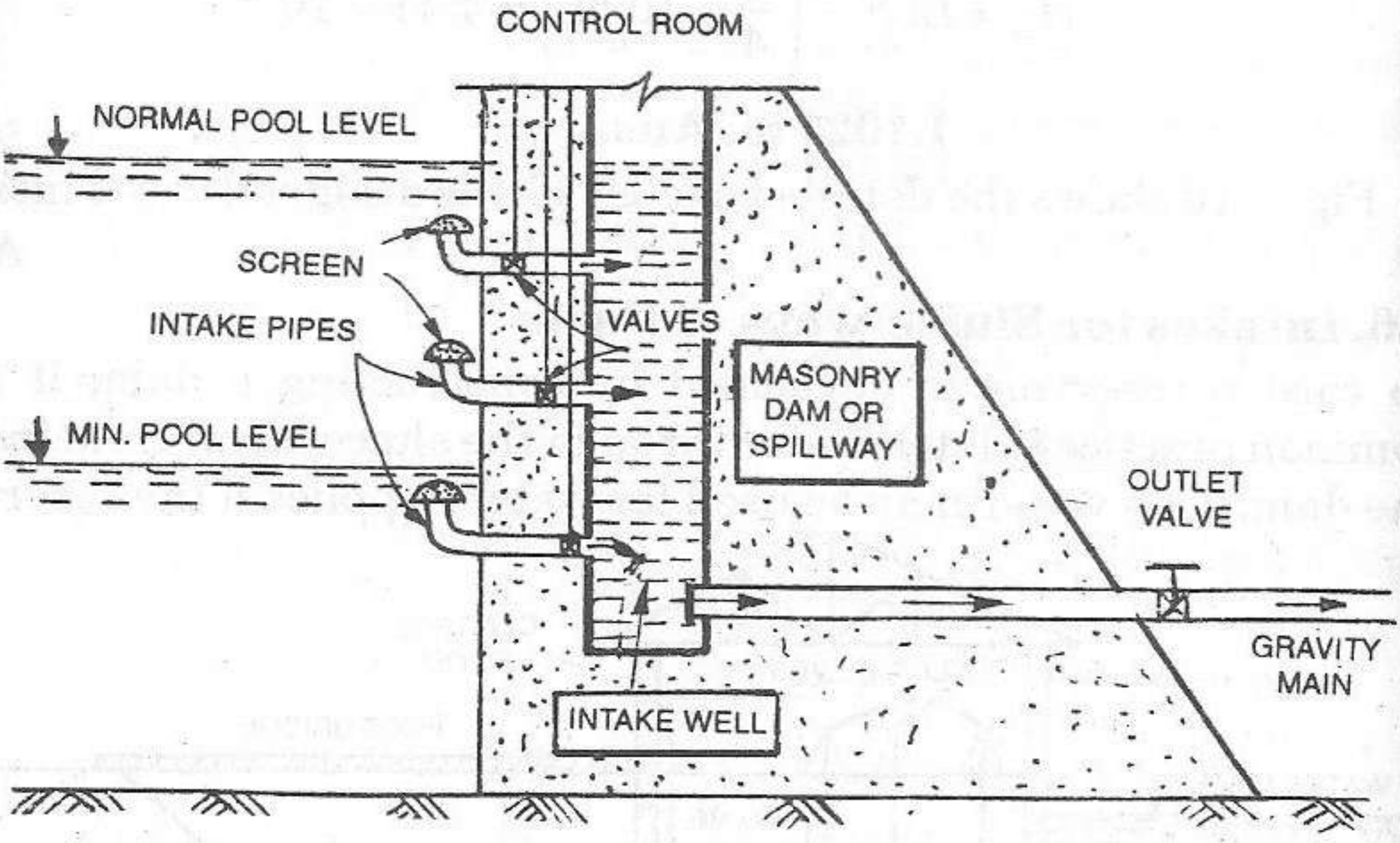
Fig. 5.11. Valve tower situated at the upstream toe of an earthen dam.

*Openings in the dam body.

Valve Tower situated within an Earthen Dam



Intake Well or Valve Tower for Concrete Gravity or Masonry Dams



modern day pumps can easily lift sedimented waters. The jack well can be periodically cleaned manually, by stopping the water entry into the well.

Example 5.1. *Design a river intake with respect to (i) number and size of the openings in the intake well ; (ii) the size, shape and the height of the intake well ; and (iii) the gravity pipe for raw water connecting the intake well and jack well. The data supplied is :*

R.L. of river bed = 100 m
R.L. of lowest water level = 102 m
R.L. of normal water level = 115 m
R.L. of high flood level = 120 m
Population to be served = 50,000
Average water demand = 200 l.p.h.

Assume other suitable data required.

Solution. Average water demand to be pumped

$$= 50{,}000 \times 200 \text{ l/d} = 10 \text{ MLD}$$

Max. water demand = 1.8 × 10 MLD = 18 MLD

Assuming the pumping to take place for 16 hrs a day, the discharge to be pumped

$$= \frac{18 \times 10^6}{10^3 \times 16 \times 60 \times 60} \text{ m}^3/\text{s} = 0.3125 \text{ m}^3/\text{s}.$$

(*i*) and (*ii*) **Design of Inlet Well**

Let us provide an **oblong** shaped inlet well, with openings provided at 3 levels ; one layer of opening(s) shall be kept below RL 102.0 m (lowest river level) ; and the other may be kept below HFL stage *i.e.* below RL 120 m. A middle layer of ports can be provided just below the normal river water level of RL 115 m.

These openings shall be fitted with bar screens made of 20 mm dia steel bars of say 50 mm openings (clear). Let the velocity through the bar screens be limited to 0.16 m/s.

∴ The area of openings required at each level

$$= \frac{Q}{v}$$

$$= \frac{0.3125}{0.16} \text{ m}^2 = 1.95 \text{ m}^2.$$

Let us provide 1 m height of screen openings ; then the clear length of the openings required = 1.95 m.

$$\text{No. of openings required} = \frac{1.95}{0.05} = 39$$

No. of bars = 38

Length occupied by 20 mm φ bars

$$= 38 \times 0.02 = 0.76 \text{ m}$$

∴ Total length of screen

$$= 1.95 + 0.76 = 2.71 \text{ m} ; \text{say } \mathbf{2.8 \text{ m}}.$$

Let us provide 2 ports at each level. The size of each port will then be 1 m ht. × 1.4 m length. In all, there will be 6 screened ports ; 2 at each of the three levels. 2 screened ports will thus be provided within the well steining between RL 102 m to 101 m each having 1.4 m length. 2 other screened ports shall similarly be provided between RL 115 m to 114 m ; and 2 others between RL 120 m to 119 m, as shown in Fig. 5.8.

These ports can be fitted in an oblong well, consisting of rectangular length of 3 m (sufficient to fix 2 bar screens each of length 1.4 m) and provided with circular ends. The well can have a width of say **2 m. Ans.**

This inlet well can be sunk into the river bed by say 3 m below the river bed, as to provide space for accumulation of sand and silt. So let us keep the bottom of inlet well at RL 97 m.

Also, let us provide a free-board of 2 m over the river HFL to fix the bottom level of the roof of the well. Hence, provide invert level of roof at RL 122 m. The height of inlet well will then be 122 m – 97 = **25 m. Ans.**

(*iii*) **Design of gravity pipe connecting intake well and jack well**

The intake pipe shall be designed to flow by gravity at a max. velocity of say 1.2 m/s.

$$\therefore \quad Q = 0.3125 \text{ m}^3/\text{s}$$

$$v = 1.2 \text{ m/s}$$

$$\text{Area of pipe required} = \frac{\pi}{4} \cdot d^2 = \frac{Q}{v} = \frac{0.3125}{1.2}$$

∴ $d = 0.58$ m ; Hence use 60 cm dia R.C.C. intake pipe, giving a velocity of $\dfrac{0.3125}{\frac{\pi}{4}(0.6)^2} = 1.1$ m/s.

Using Manning's formula, we have

$$v = \frac{1}{n} \cdot R^{2/3} \cdot \sqrt{S}$$

$$1.1 = \frac{1}{0.017}\left(\frac{0.6}{4}\right)^{2/3} \cdot \sqrt{S} \qquad \left(\because \; R = \frac{A}{P} = \frac{\frac{\pi}{4}d^2}{\pi d} = \frac{d}{4}\right)$$

or

$$S = \frac{1}{228} \text{ ; say 1 in 200}$$

Hence, lay 0.6 m dia intake pipe at a gradient of 1 in 200. **Ans.**
The details of the designed intake well are shown in Fig. 5.8.

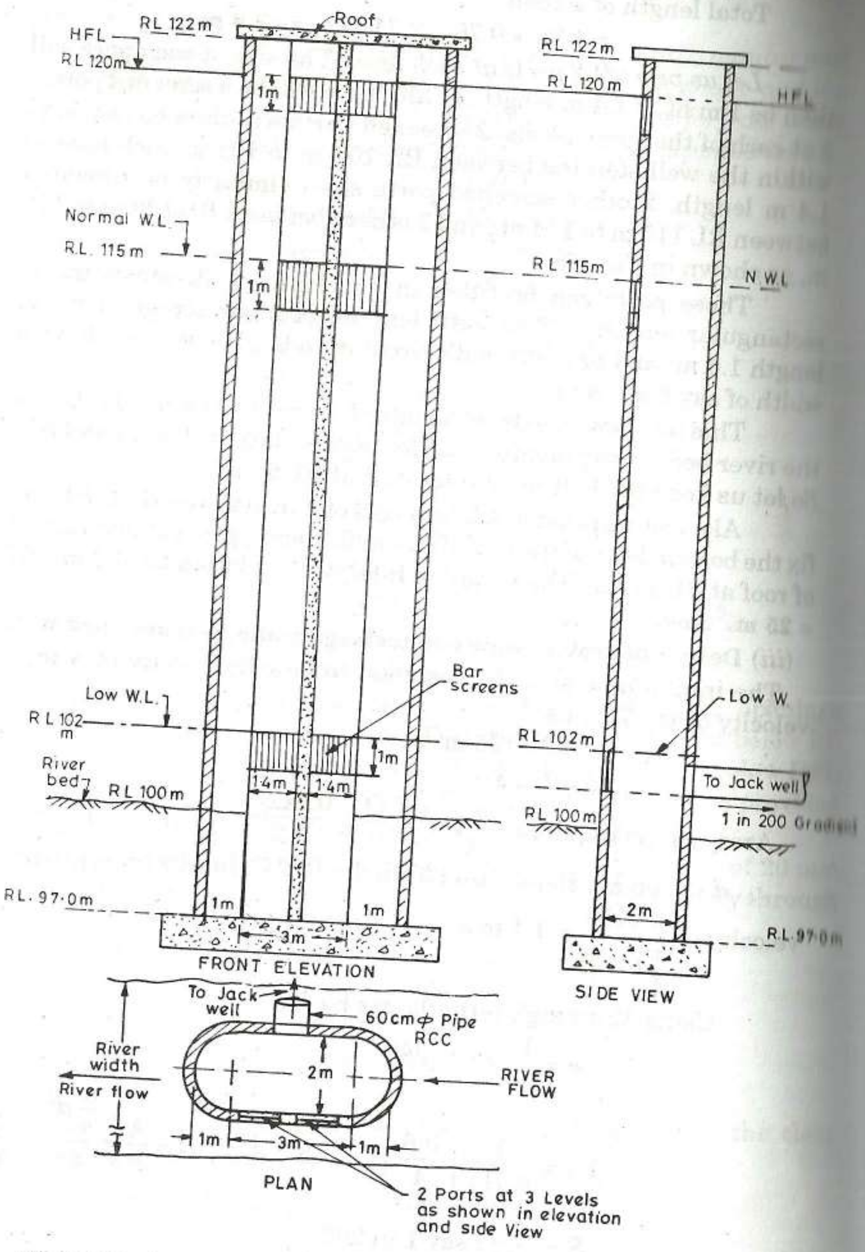


Fig. 5.8. Designed details of the Intake Structure in Example 5.1.

5.6. Canal Intakes

In case of canals, the intake well is generally located in the bank of the canal, and water enters the chamber through an inlet pipe (Fig. 5.9), covered with a fine screen. The water coming out of the chamber through the outlet conduit may be taken to the sump well or city, as desired.

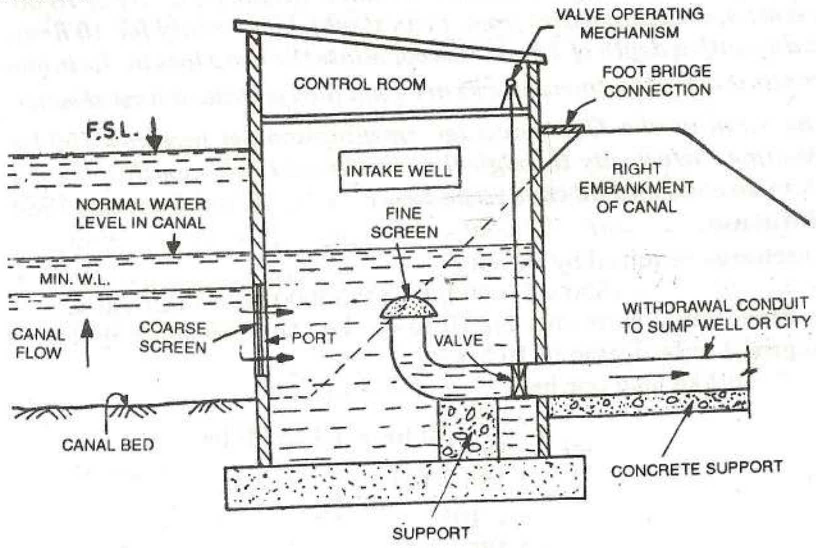


Fig. 5.9. Canal Intake Well.

Since the flow area in the canal is obstructed by the construction of intake well, the flow velocity in the canal increases due to reduction in water way, and hence pitching is generally provided on the upstream as well as downstream portions of the canal near the intake.

The entry of water in the intake well takes through a coarse screen, the top of which is generally provided at minimum water level in the canal, and bottom is about 0.15 m above the canal bed to avoid entry of bed load. An additional fine screen is provided at the inlet end of the withdrawal conduit. This inlet end is of bell mouth shape with perforations of fine screen on its surface. An outlet valve, operating from the top, is provided to control the entry of water into the outlet pipe.

The flow velocity through the outlet conduit is generally kept at about 1.5 m/sec, and this helps in determining the area and dia at the withdrawal conduit.

The area of coarse screen is designed by limiting the flow velocity to as low as 0.15 m/sec or so. The flow velocity through the bell mouth inlet is limited to about 0.3 m/sec or so. The head loss in the intake conduit upto treatment works, can be determined by using Hazen William formula, equation (6.12), as given in the next chapter.

Example 5.2. *Design a bell mouth canal intake for a city of 75,000 persons, drawing water from a canal which runs only for 10 hours a day with a depth of 1.5 m. Also calculate the head loss in the intake conduit if the treatment works are $\frac{1}{4}$ km away. Draw a neat sketch of the canal intake. Given average consumption per person = 150 l/d. Assume the velocity through the screens and bell mouth to be less than 16 cm/s and 32 cm/s respectively.* (Civil Services, 1984)

Solution.

Discharge required by the city

$$= 1500 \times 75000 \text{ l/d} = 11250000 \text{ l/d} = 11.25 \text{ Ml/d.}$$

Since canal runs only for 10 hrs a day, this whole daily flow is required to be drawn in 10 hrs.

$\therefore$ Intake load per hr.

$$= \frac{11.25}{10} \text{ Ml/hr.} = 1.125 \text{ Ml/hr.}$$

$$= \frac{1.125 \times 10^6}{10^3} \text{ m}^3\text{/hr}$$

$$= \frac{1.125 \times 10^3}{60 \times 60} \text{ m}^3\text{/sec} = 0.3125 \text{ m}^3\text{/sec.}$$

Design of Coarse Screen

Area of coarse screen (which may be made as vertical iron bars of 20 mm ϕ @ 3 to 5 cm centre to centre),

$$= \frac{\text{Discharge entering the well through this coarse screen}}{\text{Velocity through the screen}}$$

Max. velocity through this screen is 0.16 m/sec.

$\therefore$ Min. area of screen required

$$= \frac{0.3125}{0.16} \text{ m}^2 = 1.95 \text{ m}^2$$

Ht. of screen provided

$$= 1.5 - 0.15 - 0.3^*$$
$$= 1.05 \text{ m}$$

$\therefore$ Min. length of screen (openings) required

$$= \frac{1.95 \text{ m}^2}{1.05 \text{ m}} \text{ m}^2 = 1.86 \text{ m}$$

*Assuming the min. water level in canal to be 0.3 m below FSL, as shown in Fig. 5.10, thereby keeping the top of screen at 1.5—0.3 m above bed level.

Now, assuming the clear opening widths between vertical bars to be 30 mm (0.03 m) each, we have

the No. of openings $= \frac{1.86}{0.03} = 62$

No. of bars $= 61$

Length occupied by bars of 20 mm ϕ

$$= 61 \times 0.02 \text{ m} = 1.22 \text{ m}$$

Total length of screen

$$= 1.86 + 1.22$$
$$= 3.08 \text{ m} ; \text{ say } 3.1 \text{ m.}$$

Hence, provide 3.1 m length of coarse screen of height 1.05 m in the rectangular intake well, as shown in Fig. 5.10. **Ans.**

Design of Bell mouth entry

Area of bell mouth entry

$$= \frac{\text{Discharge}}{\text{Velocity through the bell mouth}} = \frac{0.3125}{0.32} \text{ m}^2$$
$$= 0.98 \text{ m}^2.$$

If d is the dia. of the bell mouth entry, then

$$\frac{\pi}{4} \cdot d^2 = 0.98$$

$$\therefore \quad d = \sqrt{\frac{0.98 \times 4}{\pi}}$$
$$= 1.12 \text{ m} ; \text{ say } 1.2 \text{ m.}$$

Hence, use 1.2 m ϕ bell mouth provided with perforations for fine screen. **Ans.**

Design of Intake conduit

Assuming the flow velocity in conduit as 1.5 m/sec, we have

The area of conduit required

$$= \frac{\text{Discharge}}{\text{Velocity}} = \frac{0.3125}{1.5} \text{ m}^2$$
$$= 0.208 \text{ m}^2.$$

Dia. of pipe (D) is given by

$$\frac{\pi}{4} D^2 = 0.208$$

$$\therefore \quad D = \sqrt{\frac{0.208 \times 4}{\pi}} = 0.515 \text{ m} ; \text{ say } 0.5 \text{ m}$$

We may hence use 0.5 m dia. conduit. **Ans.**

Flow velocity through this 0.5 m dia. conduit will then be

$$= \frac{0.3125}{\frac{\pi}{4} \times (0.5)^2} = 1.59 \text{ m/sec.}$$

Head loss through the conduit upto treatment works is calculated by equation (6.12), which states that

$$V = 0.85\, C_H \,.\, R^{0.63} \,.\, S^{0.54}$$

where C_H = Coeff. of the pipe material
= 130 for cast iron pipe (from table 6.2)

R = Hydraulic mean depth of pipe
$= \frac{d}{4}$ (for pipes running full)
$= \frac{0.5}{4} = 0.125$ m

V = Flow velocity through the pipe
= 1.59 m/sec

S = slope of the energy line

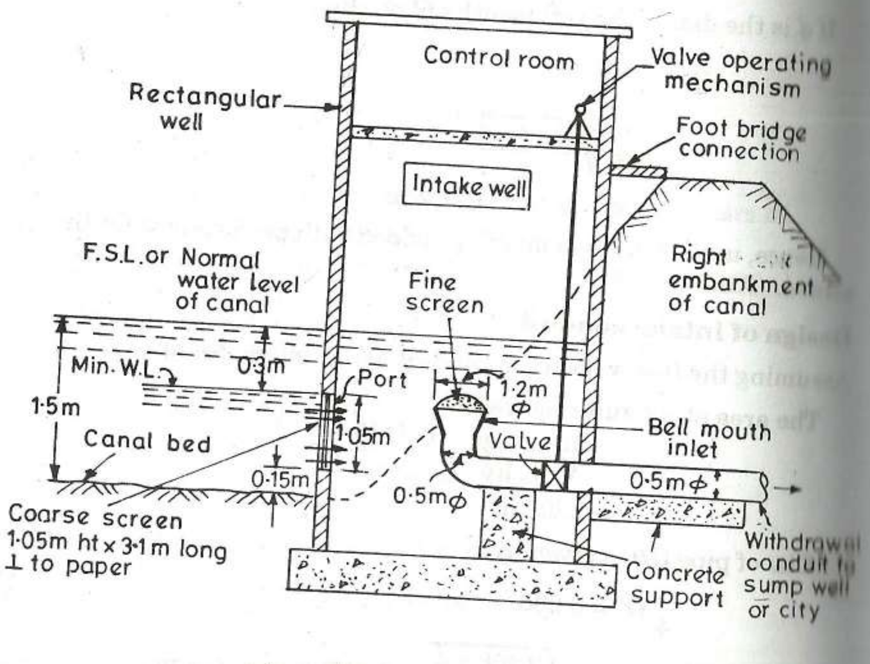


Fig. 5.10. Canal Intake Well for Example 5.2.

$\therefore \quad 1.59 = 0.85 \times 130 \times (0.125)^{0.63} \,.\, S^{0.54}$

or $\quad S^{0.54} = \frac{1.59}{0.85 \times 130 \times (0.125)^{0.63}} = 0.0533$

$\therefore \quad S = (0.0533)^{\frac{1}{0.54}} = (0.0533)^{1.85} = 4.41 \times 10^{-3}$

Now $\quad S = \frac{H_L}{L} = \frac{\text{Head loss}}{\text{Length of pipe}}$

$\therefore \quad H_L = L.\,S = \left(\frac{1}{4} \times 1000\right) \times 4.41 \times 10^{-3}$

$= \mathbf{1.1025\ m.}$ **Ans.**

Fig. 5.10 shows the detailed sketch of this designed canal intake. **Ans.**

5.6. Intakes for Sluice-ways of Dams

In case a reservoir is developed by constructing a dam, it is a common practice to fetch water through the sluiceways* from inside the dam. This water may be used for water supplies if the reservoir

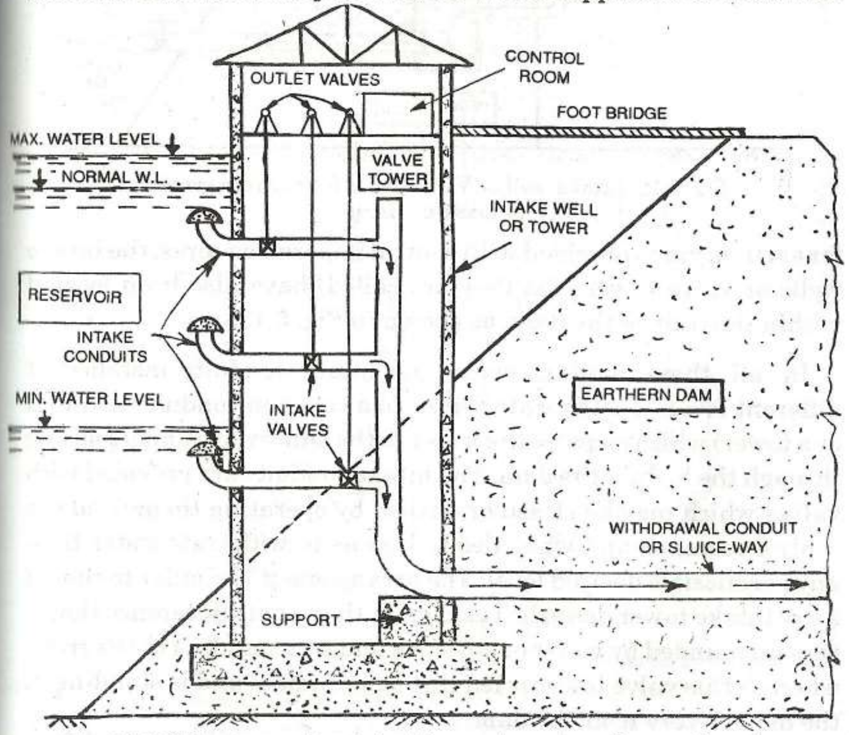


Fig. 5.11. Valve tower situated at the upstream toe of an earthen dam.

*Openings in the dam body.

Appurtenances Commonly Used in a Distribution System | Water Engineering

Article shared by : R Sonowal

In order to make the distribution of water easy and effective various appurtenances are required to be used in a distribution system.

Some of the appurtenances which are commonly used in a distribution system are as follows:

Appurtenance # 1. Valves:

Valves are provided in the pipelines to control the flow of water, to isolate and drain pipeline sections for test, inspection, cleaning and repairs, to regulate pressures and to release or admit air.

The various types of valves commonly used in a distribution system are described below:

i. Sluice Valves or Gate Valves:

Sluice valves or gate valves are the most common type of valves used to regulate the flow of water through the pipelines. A sluice valve consists of a disc or circular gate parallel sided or wedge shaped in cross-section and having a nut which engage with the thread of an operating spindle.

The disc or gate is raised or lowered in grooves with gunmetal or stainless steel sealing faces, through the spindle by turning a hand wheel or by turning the cast iron cap with a wrench, thereby opening or closing the passage of water through the pipe on which it is fixed.

There are two types of spindles for raising the gate, a rising spindle which is attached to the gate and does not rotate with the hand wheel, and a non-rising spindle which is rotated in a screwed attachment in the gate. The direction of rotation for opening the valve is usually anti-clockwise. In the fully open position, the gate is withdrawn clear of the water-way and hence this valve is also designated as full-way valve. Sluice valves are available with threaded, flanged or bell-and-spigot ends.

Sluice valves are sometimes troublesome to operate because they need a big force to open or close against a high unbalanced pressure. Further these valves are not suited for operation in partly open positions as the gates and seating would erode rapidly.

ii. Butterfly Valves:

A butterfly valve consists of a circular disc of elliptical shape in cross-section, housed in a cylindrical valve body which forms virtually a continuation of the pipe itself. Rotation of the valve spindle brings the disc either into closed position or into fully open position in which it is parallel with the pipe axis.

Butterfly valves are used to regulate and stop the flow especially in large size conduits. They are sometimes cheaper than sluice valves for larger sizes and occupy less space. The advantage of butterfly valves being ease of operation due to absence of sliding parts, compact size, reduced chamber or valve house and improved closing and retarding characteristics.

However, butterfly valves involve slightly higher head loss than sluice valves and even in fully open position they offer a fairly high resistance to flow because the thickness of the disc obstructs the flow. Further alike sluice valves butterfly valves are also not suited for operation in partly open positions as the gate would erode rapidly, and require high torques to open them against high pressure.

iii. Globe Valve:

A globe valve consists of a disc connected axially to a vertical spindle and hand is lifted up by the pressure of the incoming water, thus opening the valve. In globe valves the flow changes direction through 90° twice which results in high head losses. These valves are normally used in pipes of small diameter (less than 100 mm) and as water taps.

iv. Check Valves:

These are also known as reflux valves or non-return valves. A check valve allows water to flow in one direction only and the flow in the reverse direction is automatically stopped by it. There are three types of check valves out of which the swing type check valve is widely used. The swing type check valve consists of a gunmetal door (or disc) hinged at its top edge. The door fits tightly against an annular gunmetal seat under its self weight.

When water flows in the direction of arrow the door is lifted up by the pressure of the flowing water and it is held in open position. In open position the door does not cause any obstruction to the flow of water. When the flow of water in this direction stops, the door swings down and again fits over its seat thus valve is closed and the flow of water in the reverse direction is prevented.

The reflux valve is invariably placed in a pumping main so that if the pump fails or stops, water is prevented from flowing back to the pump and thus pumping equipment is saved from possible damage.

v. Air Valves or Air Relief Valves:

When a pipeline is filled with water the air present in the pipeline may be trapped. Similarly the water flowing through a pipeline may have entrained air which may also be trapped. The trapped air tends to accumulate at summits or high points in a pipeline, which usually exist in a pipeline because a pipeline is seldom laid parallel to the hydraulic grade line and it has invariably some rise or fall. The accumulation of air results in a serious blockade to the flow of water that may diminish the area of the pipe available for the flow of water thereby increasing head losses and reducing the discharge through the pipeline.

It is therefore necessary to remove the accumulated air from the pipeline and for this purpose air valves or air-relief valves are provided in the pipeline. The provision of air valves in a pipeline also permits air to enter the pipeline when it is being emptied, or when vacuum occurs in the pipeline due to sudden breakdown of pipeline at low points. If air valves are not provided in a pipeline vacuum may occur at summits or high points and the pipe may collapse, or it may not be possible to drain the pipeline completely.

An air valve consists of a cast iron chamber (circular or rectangular), float, lever and poppet valve. The chamber is connected to the pipeline at its top through a short pipe length. In the normal condition, the chamber is full of water entering from the pipeline. The float therefore touches the roof of the chamber and the poppet valve is held in closed position. When air from the pipeline enters the chamber, it starts accumulating at the top of the chamber.

With more and more air accumulating in the chamber air pressure is built up due to which the water level in the chamber gets depressed, consequently the float is brought down and the valve is opened, accumulated air is thus allowed to escape through the valve. When air escapes, water rises again in the chamber and the float is raised which results in the closing of the valve so that water does not escape through it.

The air valve also helps to admit air into the pipe when the pipe is being emptied or when negative or vacuum pressure is created in the pipe. In this case the water level in the chamber is lowered with the result the float drops and the valve is opened thereby air is admitted into the pipe which helps to drain the pipe completely and also to break the negative or vacuum pressure created at any stage in the pipe.

It is thus observed that an air valve operates automatically while allowing air to escape from or to enter a pipe. The air valves are usually located on both sides of sluice valves at summits, and also on the downstream side of all other sluice valves. Further air valves are also provided at changes in grade to steeper slopes in sections of pipeline not otherwise protected by air valves.

The above described air valve is usually designated as a single orifice air valve in order to distinguish it from another type of air valve termed as double orifice air valve. A double orifice air valve is made up of two cast iron chambers interconnected and provided with separate buoyant balls of different compositions and orifices designed to operate for different conditions of high pressure and low pressure of flow in pipeline.

The balls are vulcanite or rubber-covered and are seated on rubber or metal rings. Each ball is slated against an opening at the top of the chamber when the chamber is full and seals the opening.

When air accumulates at the top of the chamber the water level in the chamber gets depressed due to which the ball drops and the accumulated air escapes through the opening. With the release of the accumulated air the chamber is again filled with water and the ball is raised to seal the opening.

Further when the pipe is being emptied or when negative or vacuum pressure is created in the pipe, the water level in the chamber is lowered, and the ball drops thereby permitting air to be drawn into the pipe, which helps to drain the pipe completely and also to break the negative or vacuum pressure created at any stage in the pipe. For high pressures stainless steel floats are used instead of vulcanite or rubber-covered balls.

vi. Pressure-Relief Valves:

The pressure-relief valves also called overflow towers are provided to keep the pressure in a pipeline below a predetermined value, and thus protect it against the possible danger of bursting due to excessive pressure. When the pressure in a pipe exceeds a predetermined value the valve opens automatically and allows certain amount of water to flow out from the pipe to waste, thereby reducing the pressure in the pipe.

A pressure-relief valve consists of a spring loaded disc. The load on the disc can be adjusted by releasing or compressing the spring with the help of a handle. The valve is fitted on an opening provided at the top of the pipeline. As long as the pressure in the pipe is less than the design value the disc is held tightly fitting against the opening and the valve remains closed.

When the pressure in the pipe exceeds the design value, the disc is forced to be lifted up and certain amount of water is allowed to flow out from the pipe to waste, thereby pressure in the pipe is reduced. With the reduction in pressure in the pipe the disc is forced back to fit against the opening and the valve is again closed.

The pressure-relief valves are located at every point along the pipeline where pressure is likely to be maximum. Thus these valves are often placed along the pipeline at suitable intervals at low points where the pressures are high. Further a pressure relief valve is usually provided on the upstream side of a sluice valve so that the pipe lying on the upstream side of the valve is relieved of water hammer pressure resulting from the sudden closure of the sluice valve.

The pressure-relief valves are generally more useful on small pipelines for which the escape of a relatively small amount of water will alleviate water hammer pressures. However, the pressure-relief valves are not sufficiently responsive to rapid fluctuations of water hammer pressure. As such in order to relieve large pipelines of water hammer pressures various other devices such as air vessels, surge tanks, etc., are used.

vii. Scour Valves or Blow-off Valves or Drain Valves:

The scour valves or blow-off valves or drain valves are provided for completely emptying or draining of the pipe for removing sand or silt deposited in the pipe and for inspection, repair, etc. These are ordinary sluice valves which are located at dead ends and depressions or low points in the pipeline. They discharge into natural drainage or sewer, or empty into a sump from which water can be pumped to waste.

In order to avoid the possibility of water in the pipeline becoming polluted, there should be no direct connection between the valve and the sewer or drain, and also two scour valves are placed in series. Further the outlet into the channel should be above the high water level. However, if the outlet must be below high water, a check valve must be placed to prevent back flow.

Appurtenance # 2. Manholes:

Manholes are provided at suitable intervals along the pipeline. They are helpful during construction and later on serve for inspection and repairs. These are usually spaced 300 to 600 m apart on large pipelines. Their most useful positions are at summits and downstream of main valves. They are commonly provided in the case of steel and concrete pipelines and are less common in the case of cast iron and asbestos cement pipelines.

Appurtenance # 3. Fire Hydrants:

A fire hydrant is an outlet provided in a pipeline for tapping water mainly for the purpose of fire fighting (or fire extinguishing). However, sometimes these may also be used for withdrawing water for certain other purposes such as sprinkling on roads, flushing streets, etc.

When a fire breaks out, water is obtained for firefighting from a nearby fire hydrant through a fire hose. For firefighting usually large quantity of water at high pressure is required in order to make it to reach to the place of occurrence of fire. Thus if water at required pressure is available from a fire hydrant, it can be directly used for firefighting through a fire hose connected to the outlet of the fire hydrant.

However, if water at much higher pressure is required the same is developed by attaching a fire engine or a pump to the fire, hydrant outlet. The fire engine or the pump draws water from the fire hydrant boosts its pressure and the high pressure water coming out from the outlet of the fire engine or the pump is used for firefighting through a fire hose connected to the outlet of the fire engine or the pump. At the end of the fire hose a nozzle is provided to develop a powerful jet of water.

The number of fire hydrants in a distribution system and their location depends on various factors such as chances of fire occurrence, requirement of water for fire fighting, utility of buildings, population of area, etc. Generally fire hydrants are placed at all important road junctions and at intervals not exceeding about 300 m.

Appurtenance # 4. Water Meters:

Water meters are the devices which are installed in pipelines to measure the quantity of water flowing through them. The water flowing through pipelines is supplied to various consumers for domestic, industrial and commercial uses and its measurement is necessary to charge the consumers according to the quantity of water supplied to them.

The water meters may be classified into the following two categories:

(i) Inferential type meters or velocity meters

(ii) Displacement type meters

(i) Inferential Type Meters or Velocity Meters:

The inferential type meters or velocity meters work on the principle that the discharge or rate of flow of water through a pipe of given cross-sectional area is proportional to the velocity of flow, thus higher the velocity of flow more will be the discharge.

The commonly used inferential type meters or velocity meters are:

(a) Rotary or turbine meters

(b) Venturi meters

(a) Rotary or Turbine Meters:

A rotary meter used for measuring small domestic flow consists of a small wheel having a series of radial blades or vanes and mounted on a shaft. It is enclosed in a casing which is provided with inlet and outlet. The wheel is caused to rotate by the water flowing through the meter. The number of revolutions per unit time made by the wheel will depend on the velocity of flow of water, i.e., greater is the velocity of flow higher will be the speed of rotation and vice versa.

The rotation of the wheel actuates a clock-like mechanism through a system of gears and the quantity of water flowing through the meter is registered by means of a system of dials. The meter is calibrated to read directly the total quantity of water flowing through it over a certain period of time.

These meters can be used for measuring small domestic supplies as well as large supplies for commercial and industrial use. Further these meters can be used even if water contains suspended particles or sediment. However, at low flows the accuracy of these meters is comparatively less.

(b) Venturi Meters:

The basic principle on which a venturi meter works is that by reducing the cross-sectional area of the pipe, a pressure difference is created and the measurement of the pressure difference enables the determination of the discharge through the pipe.

A venturi meter consists of (a) an inlet section followed by a convergent cone, (b) a cylindrical throat, and (c) a gradually divergent cone. The inlet section of a venture meter is of the same diameter as that of the pipe, which is followed by a convergent cone.

The convergent cone is a short pipe which tapers from the original size of the pipe to that of the throat of the venturi meter. The throat of the venturi meter is a short parallel sided tube having its cross-sectional area less than that of the pipe.

The divergent cone of the venturi meter is a gradually diverging pipe with its cross-sectional area increasing from that of the throat to the original size of the pipe. At the inlet section and the throat of the venturi meter, pressure taps are provided to facilitate the measurement of pressure difference between these sections. The discharge or the rate of flow of water through a venturi meter is given by –

$$Q = KC\sqrt{h} \qquad \text{...(10.10)}$$

In which,

Q = discharge through venturi meter;

K = constant of venturi meter;

C = coefficient of discharge of venturi meter; and

h = difference of pressure head between the inlet and the throat sections of venturi meter.

A venturi meter is preferably used for measuring the high flows in large pipes, especially for the pipes carrying raw water from the source to the water treatment plant. It is, however, not suitable for measuring small flows.

(ii) Displacement Type Meters:

A displacement type meter measures the rate of flow of water by recording the number of times a container of known volume is filled and emptied. Depending on the type of motion of the moving part in the meter various displacement type meters are available which include reciprocating type, rotary type, oscillating type and nutating-disc meters.

Out of these the nutating-disc meter is commonly used as domestic water meter in United States and the same is briefly described below:

Nutating-Disc Meter:

A nutating-disc meter consists of a disc of hard rubber placed inside a chamber which is provided with inlet and outlet. The water entering the chamber causes the disc to oscillate about its centre with a spiral motion. The oscillations imparted by one complete filling and emptying are recorded by the meter through a gear system in terms of the volume of water passing through it.

WATER SUPPLY APPURTENANCES

INTRODUCTION

The different devices required for controlling the flow of water, for preventing leakage and other purposes in water supply system are called “appurtenances”.

The distribution pipes are provided with various pipe appurtenances or accessories so as to make the distribution of water easy and effective.

NECESSITY OF WATER SUPPLY APPURTENANCES

- The main purpose of water supply appurtenances is to make the distribution of water easy and effective.
- To avoid wastage and leakage of water.
- To change the direction of flow of water in pipe line.
- To make the efficient use of water.
- To control the flow of water in opposite direction in pipe.
- To regulate the flow of water.

REQUIREMENTS OF WATER SUPPLY APPURTENANCES

- It should be strong.
- It should be durable.
- It should be economical.
- It should have resistance to corrosion.
- It should have resistance to internal pressure of water.
- It should be easy to remove & repair.
- It should not affected by chemicals, acids.

VALVES

Valves are mechanical devices that controls the flow and pressure within a system or process. In water works practice, to control the flow of water, to regulate pressure, to release or to admit air, prevent flow of water in opposite direction valves are required

FUNCTIONS OF VALVES

- Stopping and starting flow
- Reduce or increase a flow
- Controlling the direction of flow
- Regulating a flow or process pressure
- Relieve a pipe system of a certain pressure

TYPES OF VALVES

Depending upon different situations and requirements different types of valves are used in the supply system.

1) Sluice valve (stop valve)
2) Check valve (reflux valve)
3) Air relief valve (float valve)
4) Drain valve (blow offs)
5) Zero velocity valve
6) Scour valve
7) Ball valve
8) Fire hydrant

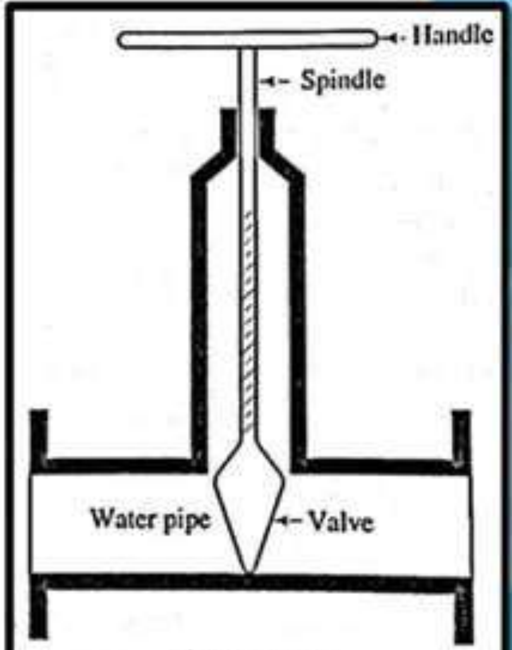
SLUICE VALVE (STOP VALVE)

These are sometimes known as gate valves. This is generally use to control the flow in a pipe line. When a question of repair is needed, this valve close the supply of water beyond the valve in the pipe line.

This is made of cast iron having a brass or stainless steel mounting at its end fitted with a pipe. A circular wedge shaped disc attached to the end of a threaded spindle (stem) passing through a gland. This is connected to a handle by means of a threaded spindle. This can be used to control or regulate the flow.

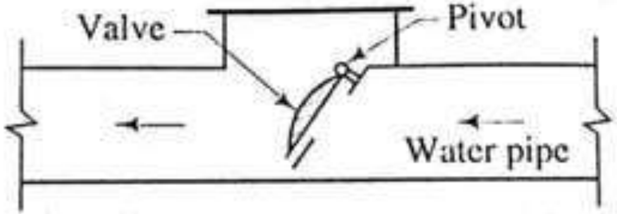
SLUICE VALVE (STOP VALVE)

These valves are cheaper, offers less resistance to the flow of water than other valves. The entire supply system is divided into blocks by providing these valves at appropriate places. They are provided in straight pipeline at 150-200m intervals. When two pipe lines intersect, valves are fixed in both sides of intersection. For long straight mains, the sluice valves can be installed at a distance of about 1km also to divide the pipe in different sections.



Sluice valve

CHECK VALVE (REFLUX VALVE)



Reflux valve

This is sometimes called as non-return valves. A reflux valve is an automatic device which allows water to go one direction only. The swing type of reflux valve is widely used practice.

When the water moves in the direction of arrow, the valve swings or rotates around the pivot and is kept in open position due to the pressure of water. When the flow of water in this direction ceases. The water tries to flow in a backward direction. But this valve prevents passage of water in the reverse direction.

TYPES OF CHECK VALVES

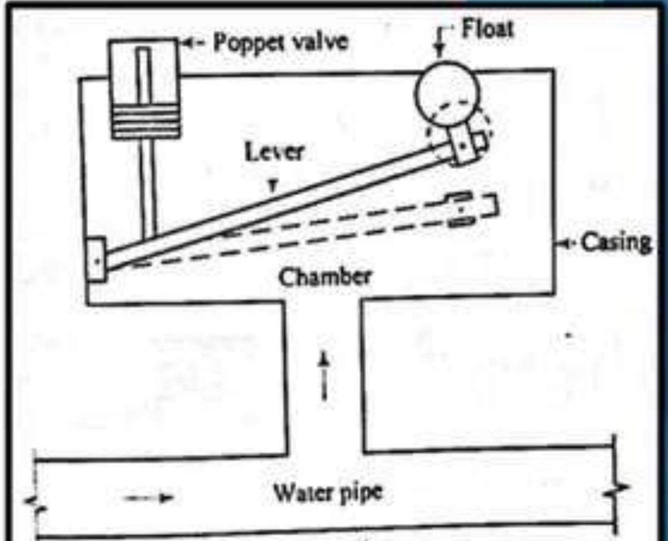
1. Swing check valve
2. Lift check valve

Swing check valve

lift check valve

AIR RELIEF VALVE (FLOAT VALVE)

In longer pipe lines, air accumulates at high points of the line which interfaces with stream line flow of water. At such points air valves are provided which remove the accumulated air automatically. This valve has one or two hollow float chamber. There are air opening at the top and the valves are connected to the main as indicated in the figure. Float chamber normally remains full of water. When air fills it, the water level goes down and the float falls, thereby openings the air opening at the top through which air escapes out, after which chamber again fills up with water and takes the float up which closes the air openings.



Air valve

AIR RELIEF VALVE (FLOAT VALVE)

An air valve consists of a cast-iron chamber, float, lever and poppet valve shown in figure. The chamber may be circular or rectangular in shape. A poppet valve is a valve that is lifted bodily.

DRAIN VALVE (BLOW OFFS)

These are also called wash out valves they are provided at all dead ends and depression of pipelines to drain out the waste water. These are ordinary valves operated by hand.

ZERO VELOCITY VALVE

Zero velocity valve called as water hammer arrester. The principle behind the design of this valve is to arrest the forward moving water column at zero momentum i.e. when its velocity is zero and before any return velocity is established.

ADVANTAGES OF ZERO VELOCITY VALVES

1. Controlled closing characteristics.
2. Low loss of head due to streamlined design.

SCOUR VALVE

These are similar to blow off valves. They are ordinary valves operated by hand. It is placed at every depression in a pipe line. Mud and sludge get collected in the pipes at these depressions which generally occur when pipes cross valleys, etc. the valve is essentially mounted on a branch of the main pipe line at the lowest point. When the valve is worked, it removes the dirt due to high velocity of water. After the complete removal of silt, the value is to be closed.

BALL VLAVE

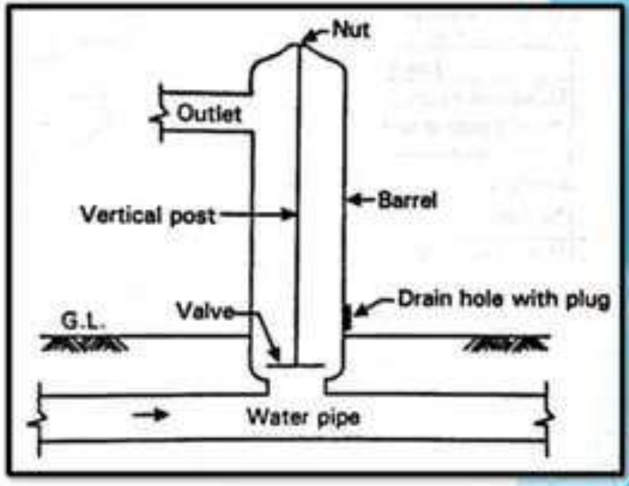
A Ball valve is a quarter-turn rotational motion valve that uses a ball-shaped disk to stop or start flow. If the valve is opened, the ball rotates to a point where the hole through the ball is in line with the valve body inlet and outlet. If the valve is closed, the ball is rotated so that the hole is perpendicular to the flow openings of the valve body and the flow is stopped

FIRE HYDRANT

A hydrant is an outlet provided in water pipe for tapping water mainly in case of fire. They are located at 100 to 150m apart the roads and also at junction roads.

They are of two types namely

1. Flush hydrant
2. Post hydrant

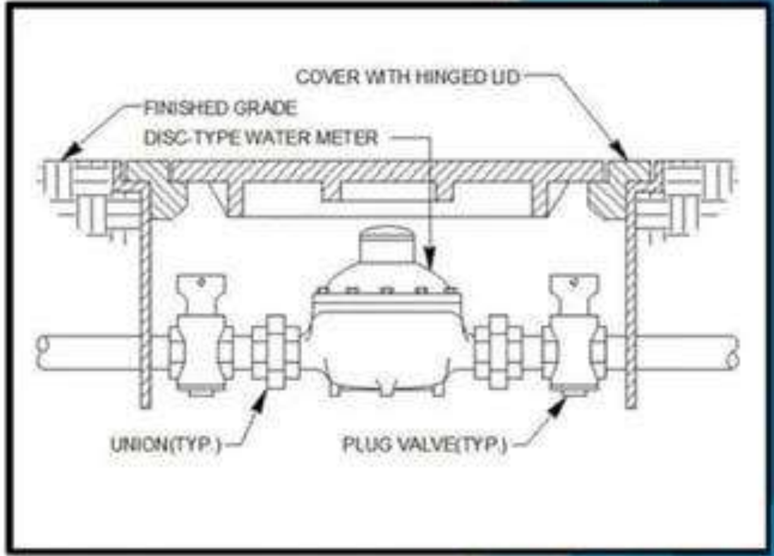


REQUIREMENTS OF A GOOD FIRE HYDRANT

- Should be cheap.
- Easy to connect with hose or motor pump.
- Easily detachable and reliable.
- It should function properly and should not go out of order during operation.
- It should permit undisturbed flow of water when being fully opened.

WATER METER

To determine the quantity of water flowing through pipes, water meters are installed. The readings obtained from the meters help in working out the quantity of water supplied and thus the consumers can charged accordingly. The water meters are usually installed to supply water to houses, industries, hotels, big institutions, etc. Metering prevents the wastage of purified water.



REQUIREMENTS OF GOOD METER

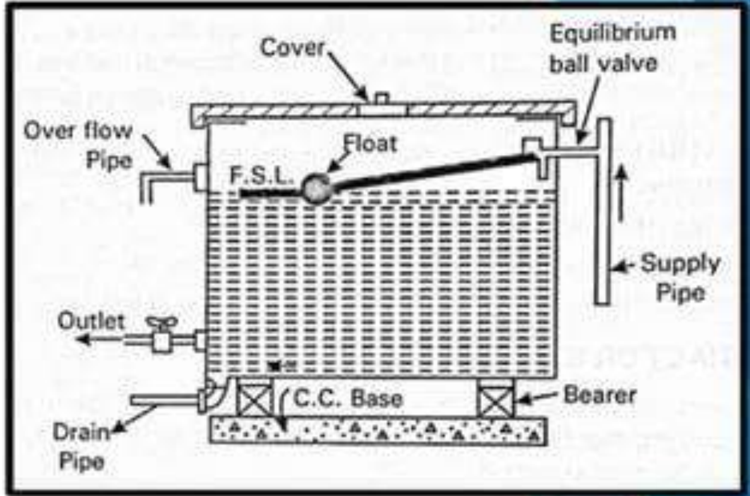
- It should not offer any resistance to the flow of water.
- It should measure the discharge up to 2% accuracy.
- All its parts should be of non-corrosive alloy.
- It can be easily maintained and repaired.
- It should be economical.
- It should have screen on its inlet side, to exclude the clay, silt, grit, etc.
- It should be capable of registering even small quantity of flow of water.

CLASSIFICATION OF WATER METERS

1. Positive displacement type meters
2. Velocity meters.

STORAGE TANKS

Storage tanks may be kept on the roof of the building or on the ground and should be water tight. The storage tank should be placed in such a position so that the discharge of water can be readily seen. The tank should be provided with over flow pipe and drain pipe near the bottom to clean the tank. The storage tanks are provided with outlet pipes to draw the water.



STORAGE TANKS

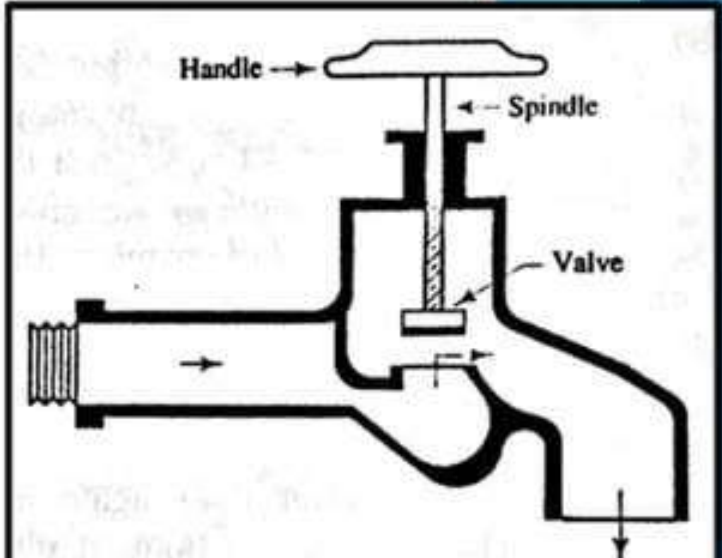
CONSTRUCTION DETAILS

Storage tanks are the small tanks installed above the roof level of the buildings and intended to serve the requirements of water storage of the buildings. A storage tank may be constructed of masonry or reinforced cement concrete when the size is to be large.

The storage tank is usually supported on the roof slab of the building or on separate bearers so as to distribute the load uniformly. The tank should be located in an easily accessible position and should be able to easy inspection and cleaning.

BIB COCK

These are the water taps which are attached at the end of water pipes and from which the consumers obtain water. Bib cocks are available of various patterns. Figure shows typical bib cock. It is operated from a handle and when handle is turned, the opening from which water comes out, gets increased in size. The bib cocks may also be of push and they operate automatically. They open out when a slight push is given and close down as soon as the push is removed or withdrawn.



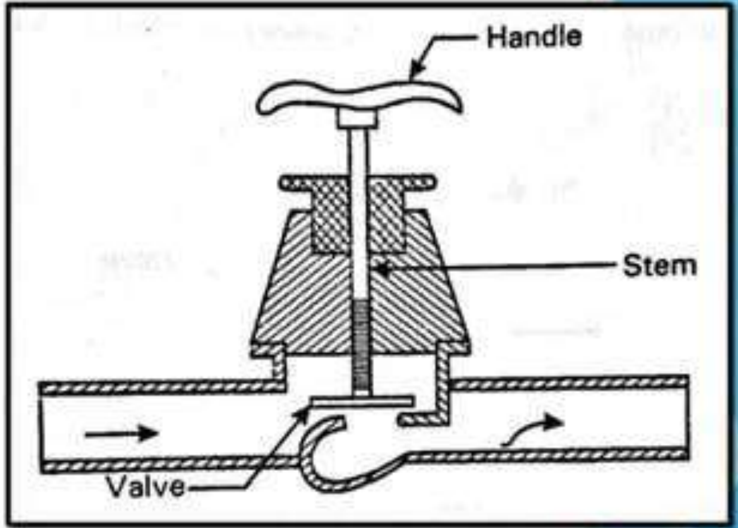
Bib cock

BIB COCK

The bib cocks should be water tight. The leaky bib cocks are the source of waste of water. The below table gives an idea of water lost due to leaky bib cocks in a continuous system of water supply. It is therefore advisable to repair or replace such leaky bib cocks as early as possible.

STOP COCK

These are small sized sluice valves and they are installed in service pipes serving the bib cocks. They operate on the same principle of sluice valve and they are used up to sizes of about 50mm. they are placed on water pipe leading to flushing tanks, wash basins, water tanks, etc. It should be of size sufficient to pass the required discharge through service pipe.



STOP COCK

It is provided before the water meter service line. Stop cock is housed in a suitable masonry chamber with a removable cover and is fixed in the street close to the boundary wall in an accessible position. It controls the supply to the building from the water main. The purpose of stop cock is to stop the supply of water. The temporary disconnections are made at the stop cock while permanent disconnections are made at ferrule.

Conveyance or Conduits

Definition: a pipe, channel or tube through which liquid, gas or electrical wires can pass

There are two stages in the transportation of water:

1.Conveyance of water from the source to the treatment plant.

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

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

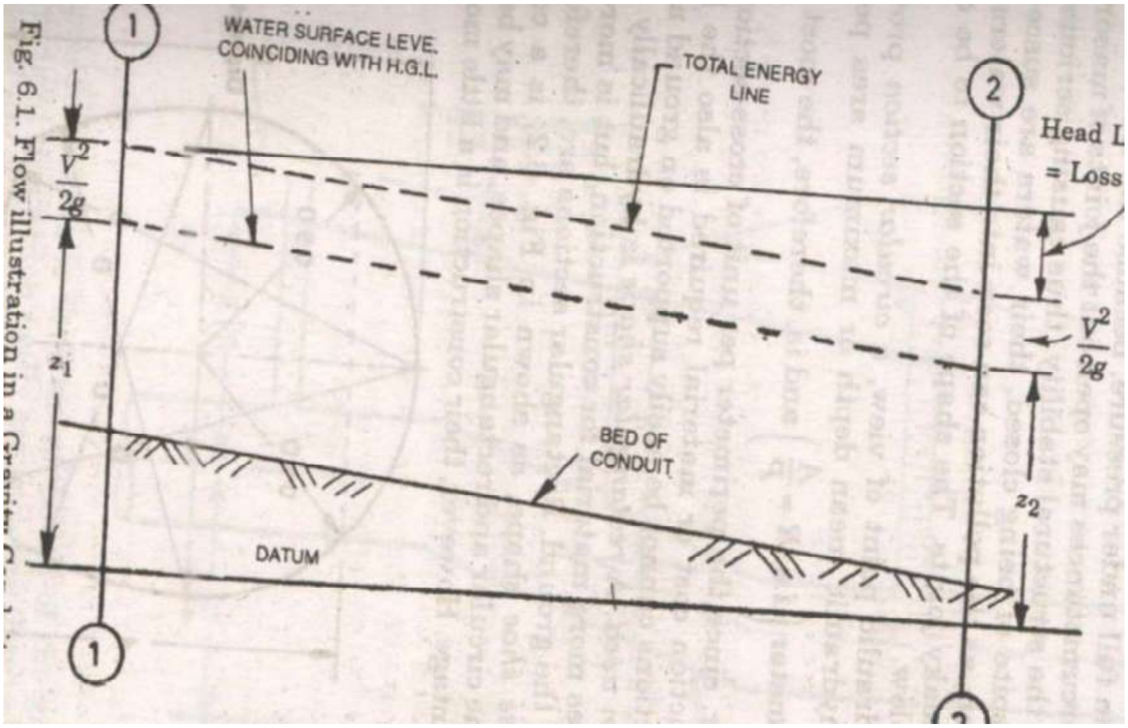
Free Flow System

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

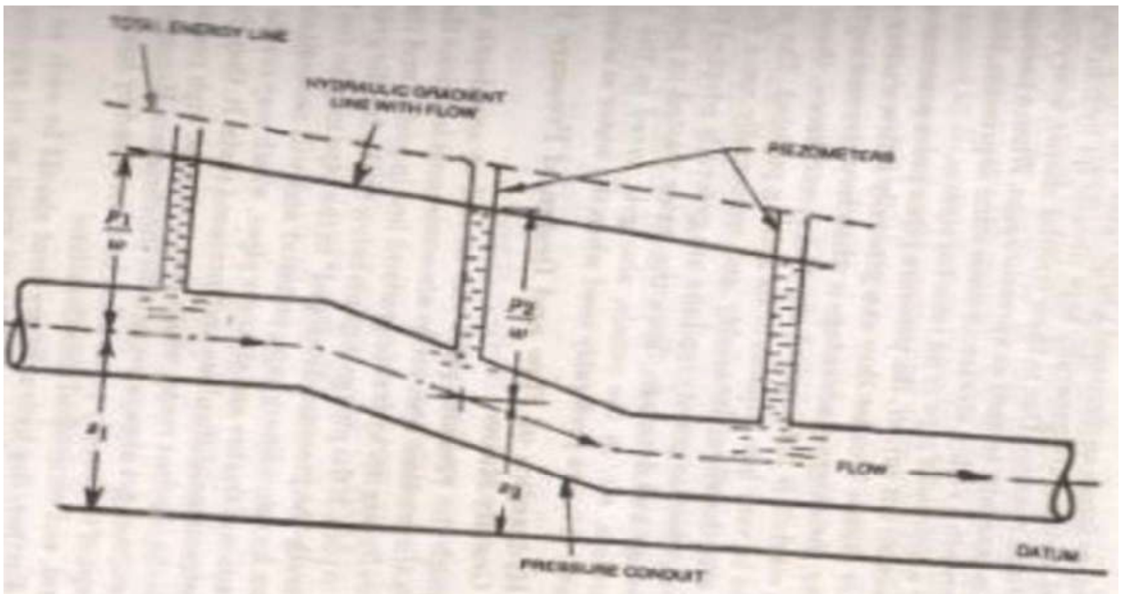
Pressure System

- In pressure conduits, which are closed conduits, the water flows under pressure above the atmospheric pressure.
- The bed or invert of the conduit in pressure flows is thus independant of the grade of the hydraulic gradient line and can, therefore, follow the natural available ground surface thus requiring lesser length of conduit.
- The pressure aqueducts may be in the form of closed pipes or closed aqueducts and tunnels called *pressure aqueducts or pressure tunnels* designed for the pressure likely to come on them. Due to their circular shapes, every pressure conduit is generally termed as a *pressure pipe*. When a pressure pipe drops beneath a valley, stream, or some other depression, it is called a depressed pipe or an *inverted siphon*.
- Depending upon the construction material, the pressure pipes are of following types: Cast iron, steel, R.C.C, hume steel, vitrified clay, asbestos cement, wrought iron, copper, brass and lead, plastic, and glass reinforced plastic pipes.

Free Flow/Gravity System



Pressure System



Forces Acting on Pressure Conduits

1. Internal pressure of water·
2. Water hammer pressures;
3. Pressure due to external loads (when buried under the ground).
4. Temperatures stresses (when laid above the ground).
5. Longitudinal stresses due to flow around bends· or change in cross-section.
6. Flexural stresses (when laid over support.$ atinterv.a1~ or on bridges).

Forces Acting on Pressure Conduits

Internal Pressure of Water: The pressure exerted on the walls of the pipe by the flowing water, in the form of Hoope's tension, is the internal pressure. The circumferential tensile stress produced is given as:

$$\sigma_1 = \frac{p_1 d}{2t} \text{ in kN/m}^2$$

where p_1 = Internal static pressure in kN/m^2.
d = Diameter of the pipe in metres.
t = Thickness of the pipe shell in metres.
σ_1 = Circumferential tensile stress to be counteracted by providing Hoope's reinforcement.

Forces Acting on Pressure Conduits

Water Hammer Pressure: When a liquid flowing in a pipeline is abruptly stopped by the closing of a valve, the velocity of the water column behind, is retarded, and its momentum is destroyed. This exerts a thrust on the valve and additional pressure on the pipe shell behind. The more rapid the closure ofthe valve, the more rapid is the change in momentum, and hence, greater is the additional pressure developed. The pressures so developed are known as water hammer pressures and may be so high as to cause bursting of the pipe shell (due to increased circumferential tension) if not accounted for in the designs. The maximum pres.sure developed in pipe lines due to water hammer is given by
the formula

$$p_2 = \frac{14.762 \cdot V}{\sqrt{1 + \frac{K \cdot d}{t}}}$$

where V = Velocity of water just before the closing of the valve in m/sec.

d = Diameter of pipe in metres.

t = Thickness of pipe shell in metres.

K = Constant

$$= \frac{\text{Modulus of elasticity of pipe material}}{\text{Bulk modulus of elasticity of water}}$$

Forces Acting on Pressure Conduits

Stress due to External Loads. When large pipes are buried deep under the ground, the weight of the earth-fill may produce large stresses in the pipe material. The stress due to the external earth fill load is given by

$$f = 22.7 \frac{h \cdot d^2}{t}$$

where h = depth of the earth-fill above the crown in metres.

d = diameter of pipe in metres.

f = stress produced in kN/m^2.

Forces Acting on Pressure Conduits

Temperatures Stresses: When pipes are laid above the ground, they are exposed to the atmosphere and-are, therefore, subjected to temperature changes. They expand during day time and contract at night. If this expansion or contraction· is prevented due to fixation or friction over the supports, longitudinal stresses are produced in the pipe material. The amount of these stresses may be calculated by the formula

$$f = E \cdot \alpha \cdot T$$

where E = Modulus of elasticity of the pipe material.

α = Co-efficient of expansion of the pipe material.

T = Change in temperature in °C.

Forces Acting on Pressure Conduits

(5) **Stresses due to Flow Around Bends and Change in Cross-Section.** Whenever the velocity of a flow (either magnitude or direction) changes, there is a change in the momentum, and therefore, by Newton's Second Law, a force is exerted, which is proportional to the rate of change of momentum. The force required to bring this change in momentum comes from the pressure variation within the fluid and from forces transmitted to the fluid from the pipe walls.

The free-body diagram of various forces acting on the water contained in a horizontal pipe bend is shown in Fig. 23.1. Applying momentum equation, and resolving the forces in x and y direction, we get

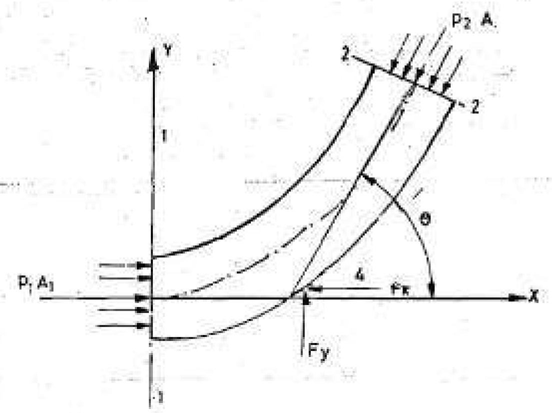


Fig. 23.1. Forces at a pipe bend.

$$p_1 A_1 - F_x - p_2 A_2 \cos\theta = \frac{\gamma_w Q}{g}\left[V_2 \cos\theta - V_1\right] \qquad \text{...(23.13)}$$

and

$$F_y - p_2 A_2 \sin\theta = \frac{\gamma_w Q}{g}\left[V_2 \sin\theta\right] \qquad \text{...(23.14)}$$

where p_1 and p_2 are the pressures, V_1 and V_2 are the velocities at sections 1-1 and 2-2 respectively. The forces F_x and F_y are the forces which are transmitted from the pipe to the water. An equal and opposite force must, therefore, be developed in the form of stresses in the pipe wall. Similar forces will be developed when the cross-sectional area of the pipe is suddenly changed, as shown in Fig. 23.2.

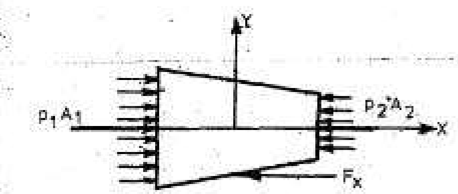


Fig. 23.2. Forces at a change in X-section of a pipe.

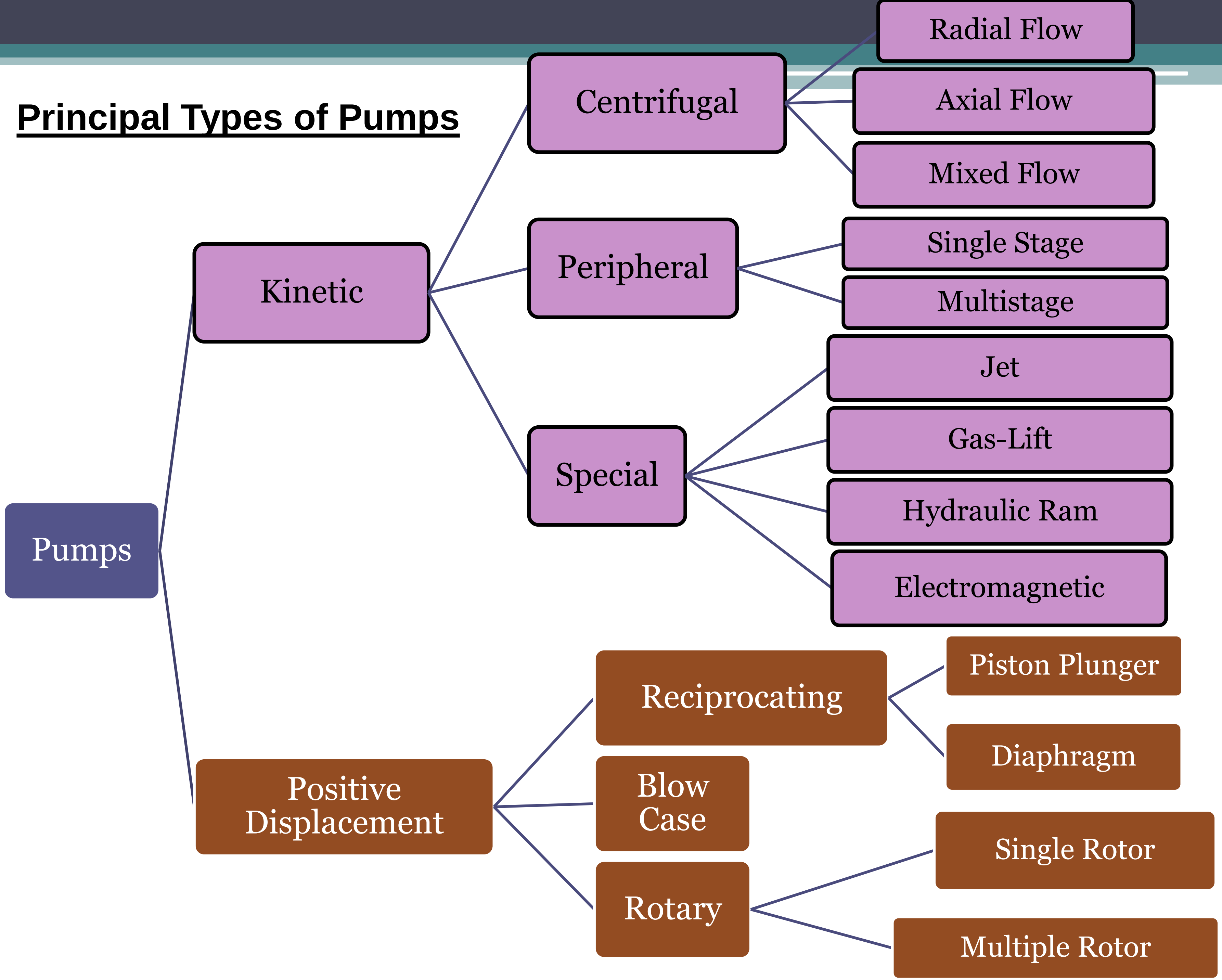
Due to these impressed external forces or stresses, the pipe line may be thrown out of alignment as and when such situations arise, unless held firmly by anchoring it in massive blocks of concrete or stone masonry.

Forces Acting on Pressure Conduits

Flexural –Stresses: Many-a-times steel pipes--are laid cover concrete supports, built above the ground; and sometimes the rainwater, etc. may wash off the ground from below the pipes at intervals. Under all such circumstances, bending stresses get produced in the pipe, since the pipe then act&. "like a beam with loads resulting from the weight of the pipe, weight of water in the pipe and any other superimposed loads: The stresses caused by this beam action may be determined by usual methods of analysis applied to the beams. However, these stresses are generally negligible except for long spans or where there are huge superimposed loads.·

Pumps

Principal Types of Pumps



Classification of Pumps

- According to
- Principle of Operation
  - Kinetic-Energy Pumps
  - Positive Displacement Pumps
- Field of Application (i.e. liquids handled)
- Operational Duty (i.e. Head and Capacity)
- Type of Construction
- Method of Drive

Principal Components of Kinetic Energy Pumps

- Impeller – Rotating element. Imparts energy to the liquid being pumped
- Shaft – on which impeller is mounted
- Pump Casing – includes inlet and outlet passages
- Frame – supports pump casing

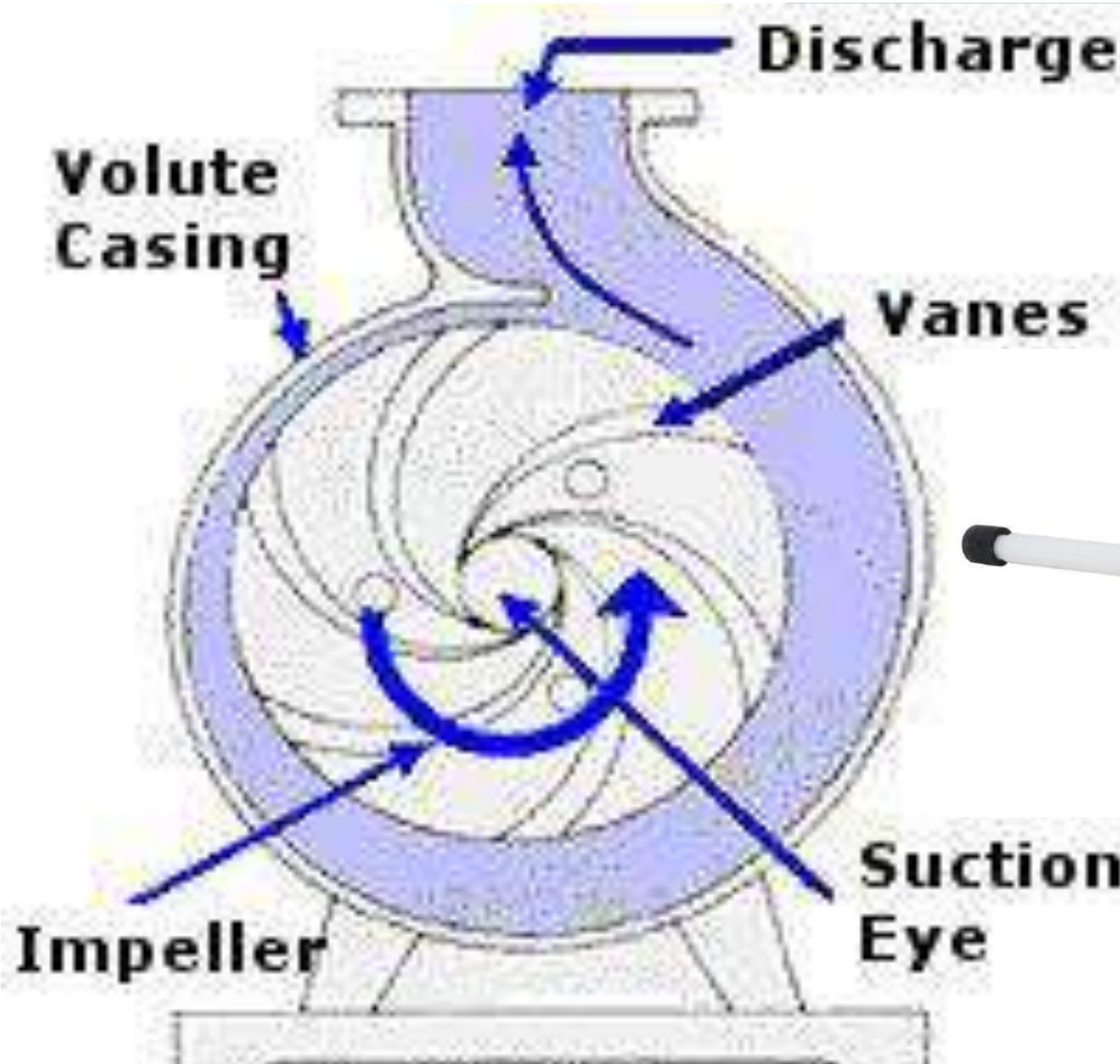


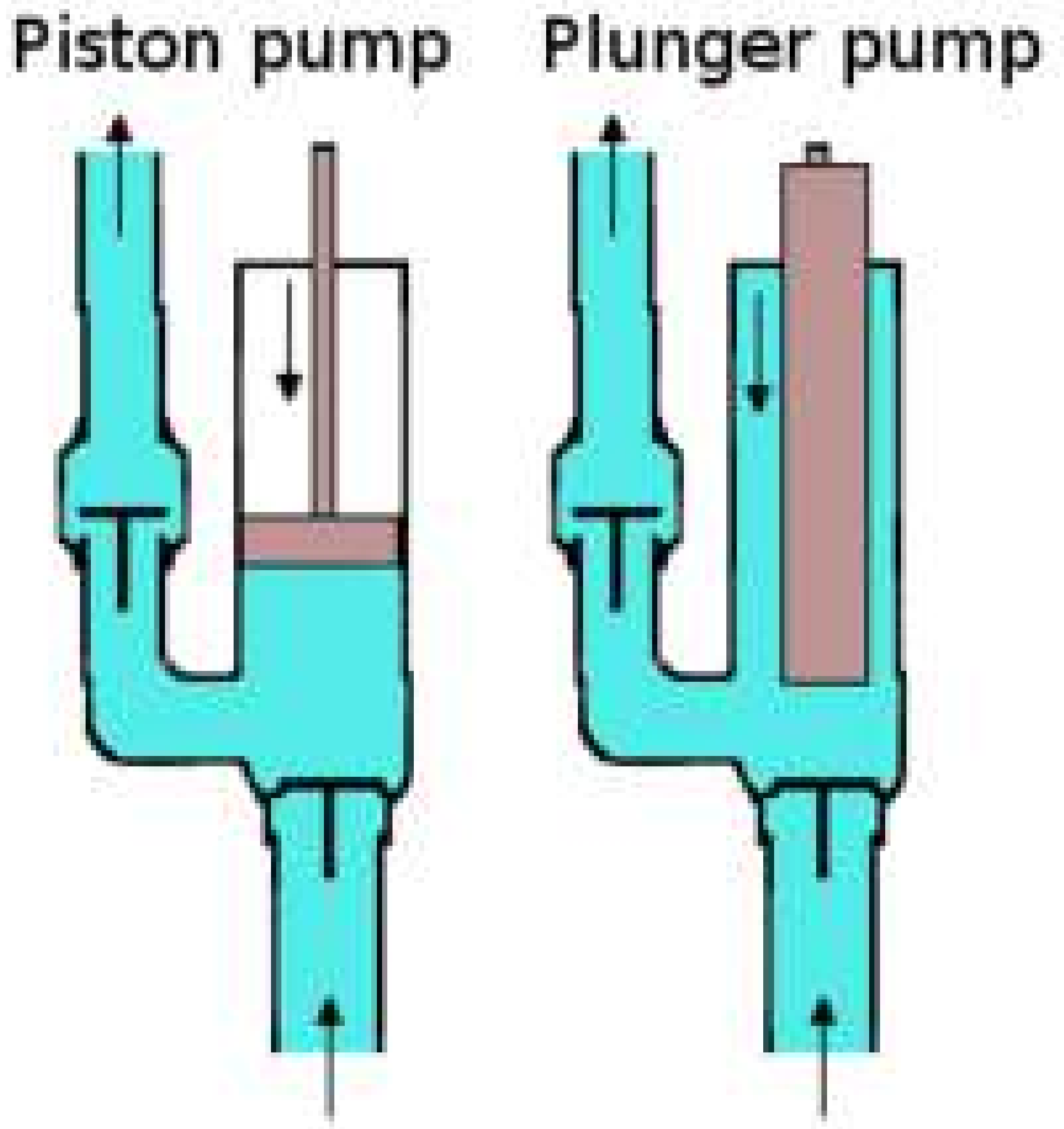
FIG 1

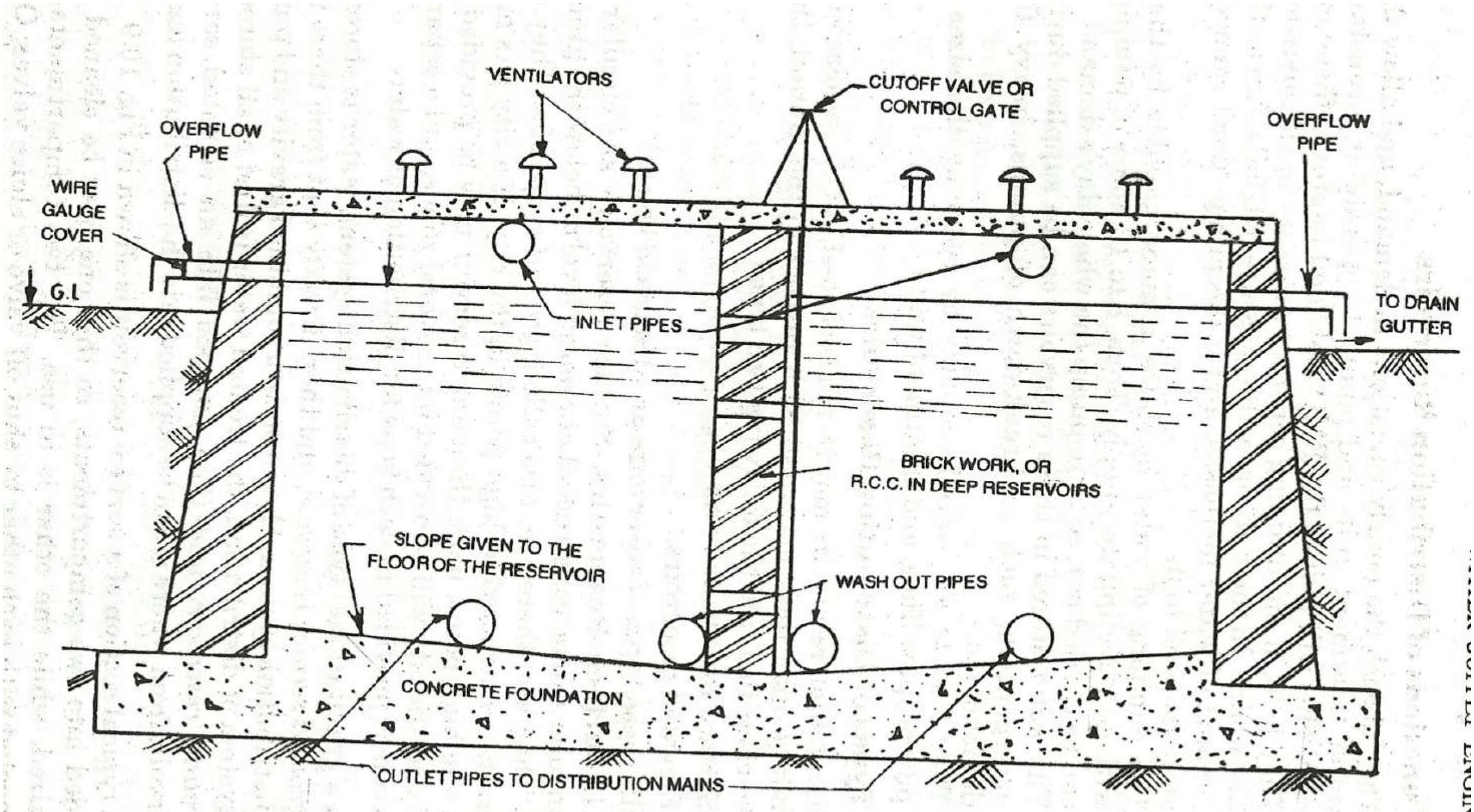
Pump Drive Units

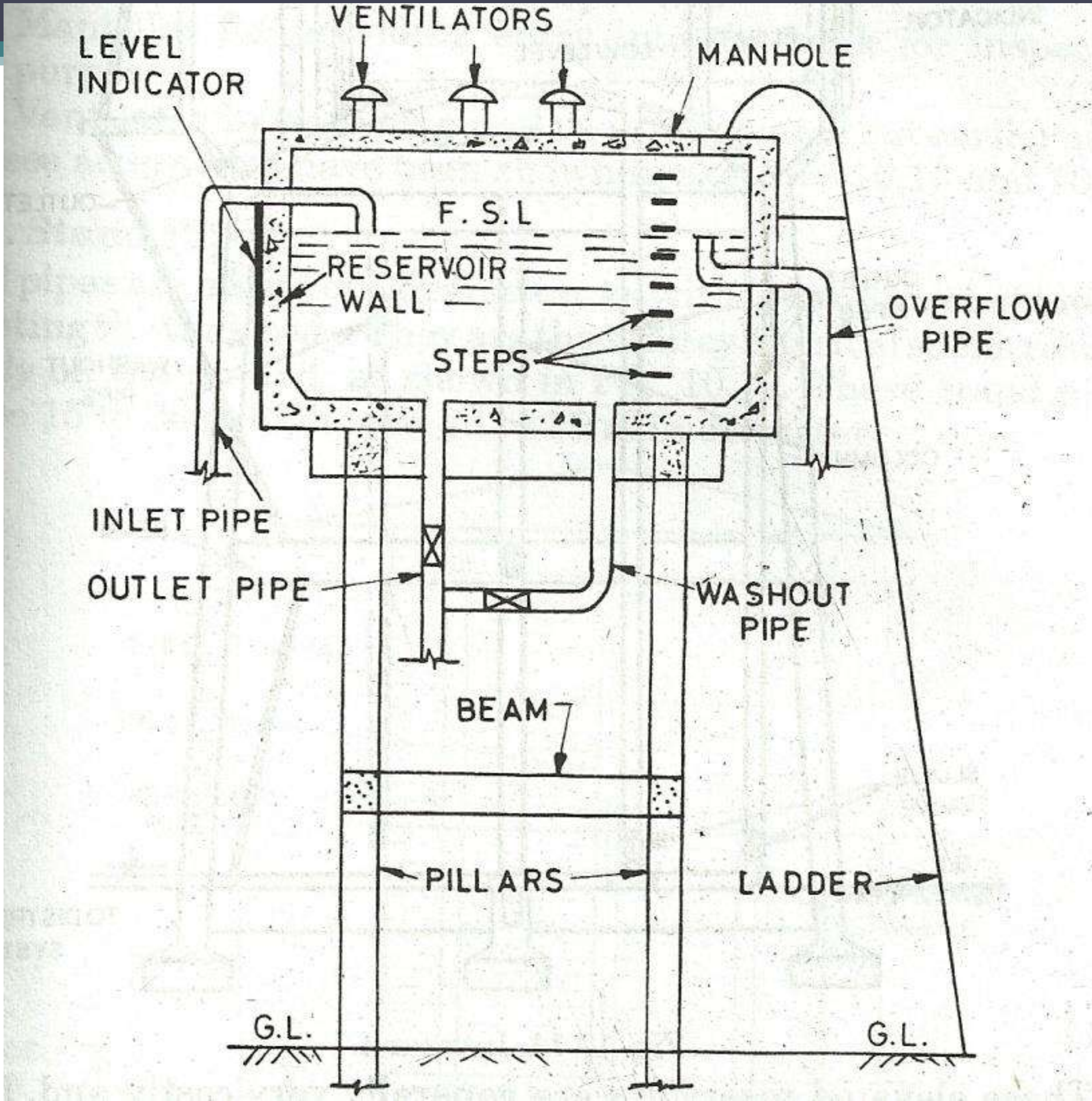
- Electric Motors – Direct Connected
- Electric Constant-Speed Motors Coupled to Variable-Speed Devices
- Internal-Combustion Engines and Gas Turbines
- Fluid-Driven Pumps

Pump Application Terminology and Usage

- Capacity
- Head
- Pump Efficiency
- Power Input


Piston pump
Plunger pump


VENTILATORS
CUTOFF VALVE OR
CONTROL GATE
OVERFLOW
PIPE
OVERFLOW
PIPE
WIRE
GAUGE
COVER
G.L
TO DRAIN
GUTTER
INLET PIPES
BRICK WORK, OR
R.C.C. IN DEEP RESERVOIRS
SLOPE GIVEN TO THE
FLOOR OF THE RESERVOIR
WASH OUT PIPES
CONCRETE FOUNDATION
OUTLET PIPES TO DISTRIBUTION MAINS



VENTILATORS
LEVEL INDICATOR
MANHOLE
F. S. L
RESERVOIR
WALL
STEPS
OVERFLOW PIPE
INLET PIPE
OUTLET PIPE
WASHOUT PIPE
BEAM
PILLARS
LADDER
G.L.
G.L.

of the $\mathscr{F}$'s from one reservoir to another with the $g\,\Delta z$ term between the same two reservoirs. When the proper set of flows has been chosen, these will all agree. For this three-branch, one-node example, the trial-and-error method is quite easy (Prob. 6.60). For more complex examples, it is not. A widely used systematic procedure for solving this type of system was developed by Cross [13]. Computer programs are available to carry out that solution [14].

6.13 ECONOMIC PIPE DIAMETER

From the foregoing we can easily calculate the flow rate, given the pipe diameter and pressure drop, or calculate the pipe diameter, given the flow rate and pressure drop, and so forth. A much more interesting question is, Given the flow rate, what size of pipe should we select? It is possible that the choice is dictated by aesthetics; e.g., the pipe goes through a lobby, and we want it to be the same size as other exposed pipes in the lobby. Or the choice may be dictated by the supply; e.g., we have on hand a large amount of surplus 4-in pipe which we want to use. Most often the choice is based on economics; the engineer is asked to make the most economical selections, all things considered.

For economic analysis we must consider two possibilities:

1. The fluid is available at a high pressure and eventually will be throttled to a low pressure, so the energy needed to overcome friction losses may come from the available pressure drop.
2. The fluid is not available at a high pressure, so a pump or compressor is needed to overcome the effects of fluid friction.

The first is simple: We select the smallest size of pipe which will carry the required flow with the available pressure drop. Example 6.5 is that case.

If the effects of friction must be overcome by a pump or compressor, then the total annual costs of the pump pipeline system are the following:

1. Power to run the pump
2. Maintenance charges on pump and line
3. Capital-cost charges for both line and pump

How these change with increasing line size is sketched in Fig. 6.20. The figure indicates the following:

1. The larger the pipe diameter, the greater the capital charges. The cost of pipeline is roughly proportional to the pipe diameter; bigger pipes cost more to buy, require more expensive supports, take longer to install, etc. The cost of the pump is proportional to the cost of the pipe and is included in it.
2. The maintenance cost is not affected much by pipe size.

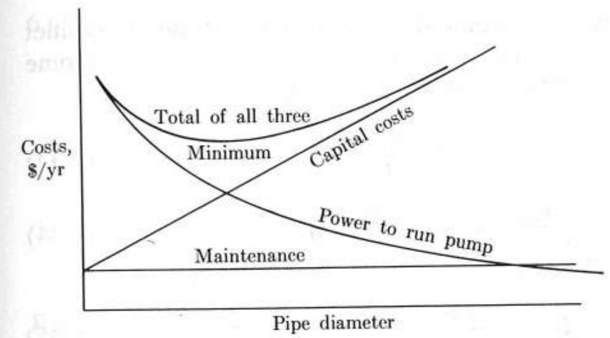


FIGURE 6.20

3. The pumping cost goes down rapidly as the pipe size goes up. The pumping cost is proportional to the pressure drop (see Example 6.3), which for turbulent flow is proportional to the velocity to the 1.8 to 2.0 power divided by the diameter. The velocity (for constant flow rate) is proportional to the reciprocal of the square of the diameter, so the pumping cost is proportional to the reciprocal of the diameter to the 4.6 to 5 power.

As Fig. 6.20 shows, the sum of these has a rather sharp minimum. This minimum occurs at the economic pipe diameter. Recognize here that we are taking the sum of a power cost during some finite period, e.g., a year, and the annual charge for owning the pipeline and the pump, whose lifetime will be many years. There are a variety of sophisticated ways of doing this, treated in books on plant design [15]. Here we consider the *simplest possible* kind of economic analysis:

$$\text{Purchase price} = \text{PP} \cdot \text{pipe diameter} \cdot \text{pipe length} \tag{6.39}$$

where the purchase price is what we would have to pay a contractor for both supplies and labor to build the complete pipeline and pump for us and PP is a constant with dimensions \$/[inch (of diameter) · ft (of length)].

$$\text{Annual capital charge} = \text{CC} \cdot \text{purchase price} \tag{6.40}$$

where capital charge (CC) is a constant, with dimension (1/year) and

$$\text{Annual pumping cost} = \text{PC} \cdot \text{pump power} \tag{6.41}$$

where pumping cost (PC) is a constant with dimensions \$/[hp · year].

As shown in Fig. 6.20, the maintenance cost is practically independent of the pipe diameter, so we do not include it in the analysis. We then wish to find the minimum of

$$\text{Total annual cost} = \text{PC} \cdot \text{Po} + \text{CC} \cdot \text{PP} \cdot \text{diameter} \cdot \text{length} \tag{6.42}$$

Assuming that the pipe is horizontal, we may apply Bernoulli's equation from the pump inlet, point 1, to the pipe outlet, point 2, and see that there is no change in elevation or velocity. We assume that the pressure at the pump inlet is the same as the pressure at the pipe outlet; i.e., the pump has to overcome only the effects of friction. Then from Eq. 6.16 we have

$$\frac{-dW_{\text{a.o.}}}{dm} = \mathcal{F} = 2f\,\frac{\Delta x}{D}\,V^2 \tag{6.43}$$

$$\text{Po} = \frac{-dW_{\text{a.o.}}}{dm}\,\dot{m} = 2f\,\frac{\Delta x}{D}\,V^2\dot{m} \tag{6.44}$$

but we have

$$V = \frac{\dot{m}}{\rho(\pi/4)D^2} \tag{6.45}$$

and therefore

$$\text{Po} = \frac{\dot{m}^3 2f\,\Delta x\,(4/\pi)^2}{\rho^2 D^5} \tag{6.46}$$

Substituting Eq. 6.43 and the cost of the pipe in Eq. 6.39, we find

$$\text{Total annual cost} = \text{PC}\cdot\dot{m}^3 2f\,\Delta x\left(\frac{4}{\pi}\right)^2\frac{1}{\rho^2}\cdot\frac{1}{D^5} + \text{CC}\cdot\Delta x\cdot\text{PP}\cdot D \tag{6.47}$$

We now differentiate the total annual cost with respect to diameter D and set the derivative equal to zero:

$$0 = \frac{d(\text{cost})}{dD} = \text{PC}\cdot\dot{m}^3 2f\,\Delta x\left(\frac{4}{\pi}\right)^2\frac{1}{\rho^2}\cdot\frac{-5}{D^6} + \text{CC}\cdot\Delta x\cdot\text{PP} \tag{6.48}$$

Solving for D_{econ}, we find

$$D_{\text{econ}} = \left[\frac{10\cdot\text{PC}\cdot\dot{m}^3 f(4/\pi)^2(1/\rho^2)}{\text{CC}\cdot\text{PP}}\right]^{1/6} \tag{6.49}$$

This equation shows that the economic pipe diameter is independent of how long the pipe is. This should be no surprise: Both the pumping and capital costs are proportional to the pipe length. The equation also shows that the economic diameter is proportional to the friction factor to the one-sixth power; hence, we can use a rough estimate of the friction factor and make very little error.

Example 6.17. We wish to transport 200 gal/min of water 5000 ft in a horizontal, schedule 40, carbon-steel pipe. We will install a pump to overcome the friction loss. Given the economic data shown below, what is the economic pipe diameter?

$$\text{PC} = \frac{\$270}{\text{hp}\cdot\text{yr}} \qquad \text{PP} = \frac{\$2}{\text{in of diameter}\cdot\text{ft of length}} \qquad \text{CC} = \frac{0.40}{\text{yr}}$$

First we guess that the pipe will have an inside diameter of 3 in. Then from Table 6.2 we have $\varepsilon/D = 0.0018/3 = 0.0006$. The friction factor will probably be about 0.0042. The mass flow rate is 200 gal/min · 8.33 lbm/gal = 1666 lbm/min. Substituting these and the values of PC, CC, and PP in Eq.

6.49 produces

$$D_{\text{econ}} = \left[\frac{\dfrac{\$270}{\text{hp}\cdot\text{yr}}\cdot\left(\dfrac{1666\ \text{lbm}}{\text{min}}\right)^3\cdot 10\cdot 0.0042\cdot\left(\dfrac{4}{\pi}\right)^2\cdot\left(\dfrac{\text{ft}^3}{62.3\ \text{lbm}}\right)^2}{0.4/\text{yr}\cdot\$2/(\text{in}\cdot\text{ft})}\right.$$
$$\left.\cdot\left(\frac{\text{hp}\cdot\text{min}}{3.3\times10^4\ \text{ft}\cdot\text{lbf}}\cdot\frac{\text{lbf}\cdot\text{s}^2}{32.2\ \text{lbm}\cdot\text{ft}}\cdot\frac{\text{min}^2}{3600\ \text{s}^2}\cdot\frac{\text{ft}}{12\ \text{in}}\right)\right]^{1/6}$$
$$= (5.95\times10^{-4}\ \text{ft}^6)^{1/6} = 0.290\ \text{ft} = 3.48\ \text{in} = 0.088\ \text{m}$$

Because of the approximate nature of the economic data used, a 4-in pipe would probably be selected. It would be appropriate to check the assumed friction factor (Prob. 6.62). ■

Because calculations such as these are long and tedious, companies that install many pipelines have solved the problem for a large number of cases and have summarized the results in convenient form. The most popular method is to calculate the economic velocity:

$$\text{Economic velocity} = \frac{\text{volumetric flow rate}}{(\pi/4)(\text{economic diameter})^2} \tag{6.50}$$

Substituting for the economic diameter from Eq. 6.49, we find

$$V_{\text{econ}} = \frac{\dot{m}/\rho}{\dot{m}(1/\rho^{2/3})f^{1/3}\cdot\text{constant}} = \text{constant}\cdot\frac{1}{f^{1/3}\rho^{1/3}} \tag{6.51}$$

This equation says that for a given set of cost data the economic velocity is independent of the mass flow handled and dependent on only the fluid density and the friction factor. More thorough analyses and far more complicated cost equations lead to substantially the same conclusion. For example, for schedule 40 carbon-steel pipe, Boucher and Alves [16] give the data shown in Table 6.4.

The table refers to turbulent flow only. For laminar flow, the value of f goes up quite rapidly as the viscosity increases, making the economic velocity go down. Oil companies spend more money pumping viscous liquids (crude oils, asphalt, heating oils, etc.) than do any other companies; therefore they have made up the most convenient economic-velocity plots for laminar flow.

TABLE 6.4
Economic velocity for schedule 40, carbon-steel pipe

Fluid density, lbm/ft	Economic velocity, ft/s
100	5.1
50	6.2
10	10.1
1	19.5
0.1	39.0
0.01	78.0

Figure 6.21 shows such a plot. It can be used to rapidly select the economic pipe diameter for laminar flow, subject to the restriction that the economic data on the line to be installed must be the same as those shown on the plot. Figure 6.21 has nomenclature similar to that of Fig. 6.13, and the comments on the latter are applicable here. Figure 6.21 also shows the economic diameter for turbulent flow.

Why does App. A.4 show the velocity in feet per second for all the water flows given? From Table 6.4 and Fig. 6.21 we can see that for water (which is almost always in turbulent flow in industrial equipment) an economic velocity is almost always about 6 ft/s. Thus, working engineers often simply select pipe sizes for water or similar fluids by looking at App. A.4 for the pipe size which gives a velocity of about 6 ft/s (2 m/s).

Table 6.4 and Fig. 6.21 are for one set of costs; for other costs the results are different. However, because of the $\frac{1}{6}$ factor in Eq. 6.49, the different costs change the economic diameter very little (see Prob. 6.66).

6.14 FLOW AROUND SUBMERGED OBJECTS

The flow around a submerged object is generally more complicated than the flow in a straight pipe or channel, because it is two- or three-dimensional. To understand the *details* of the flow around any submerged object, we must first take up the subjects of potential flow and the boundary layer, which we do in Chaps. 10 and 11.

Frequently we are not interested in the details of the flow but only in the practical problem of predicting the force on a body due to the flow of fluid around it. For example, the airplane designer wants to know the "air resistance" of the plane to select the right engine, the submarine designer wants to know the "water resistance" to determine how fast the submarine can go, and the designer of a chimney wants to know the maximum wind force on it to decide how much bracing is needed. These forces are now all called *drag forces*, following aeronautical engineering terminology. By using experimental data on such flows we can treat the problems as if they were one-dimensional.

Probably the first systematic investigation of drag forces was undertaken by Isaac Newton [17], who dropped hollow spheres from the inside of the dome of St. Paul's Cathedral in London and measured their rate of fall. He calculated that the drag force on a sphere should be given by

$$\text{Drag force} = F = \pi r^2 \rho_{\text{air}} \frac{V^2}{2} \tag{6.52}$$

Subsequent workers found that this equation had to be modified by introducing a coefficient, which we call the *drag coefficient* C_d. This coefficient is not a constant equal to 1, as Newton believed, but varies with varying conditions, as we will see. Introducing it and dividing both sides of Eq. 6.52 by the cross-sectional area of the sphere, we find

$$\frac{F}{A} = C_d \rho \frac{V^2}{2} \tag{6.53}$$

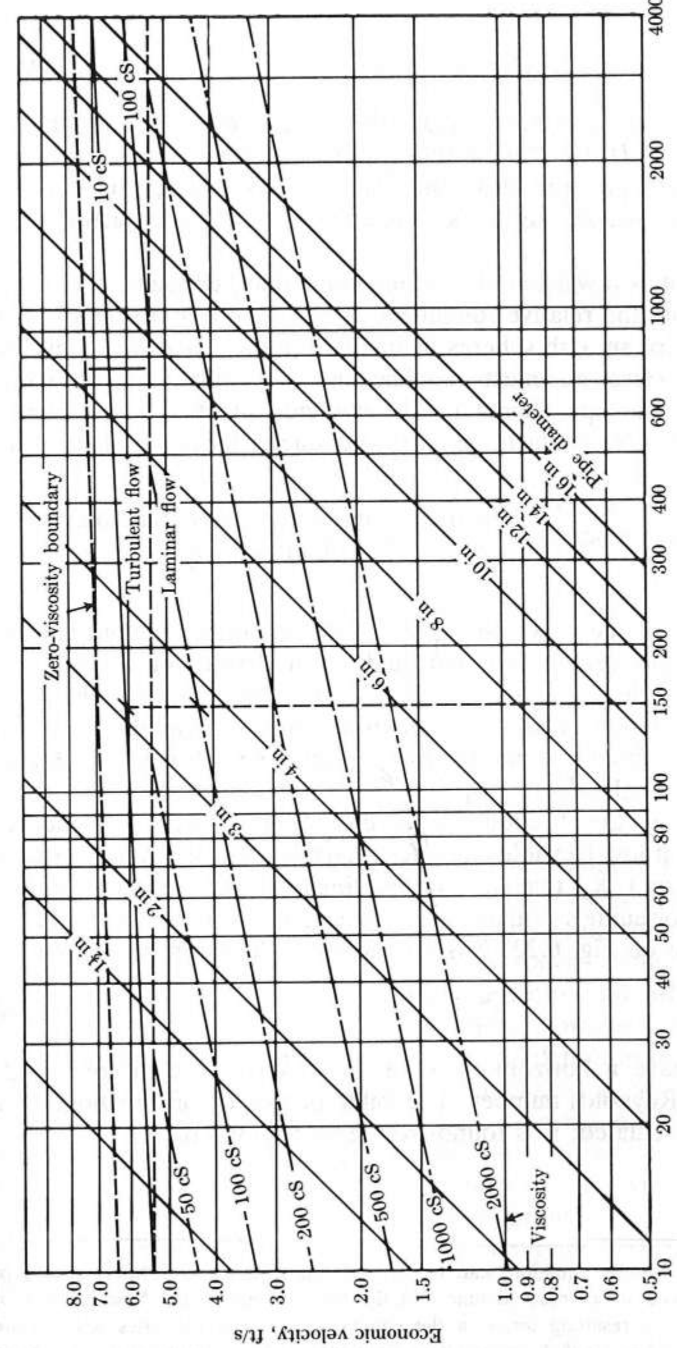


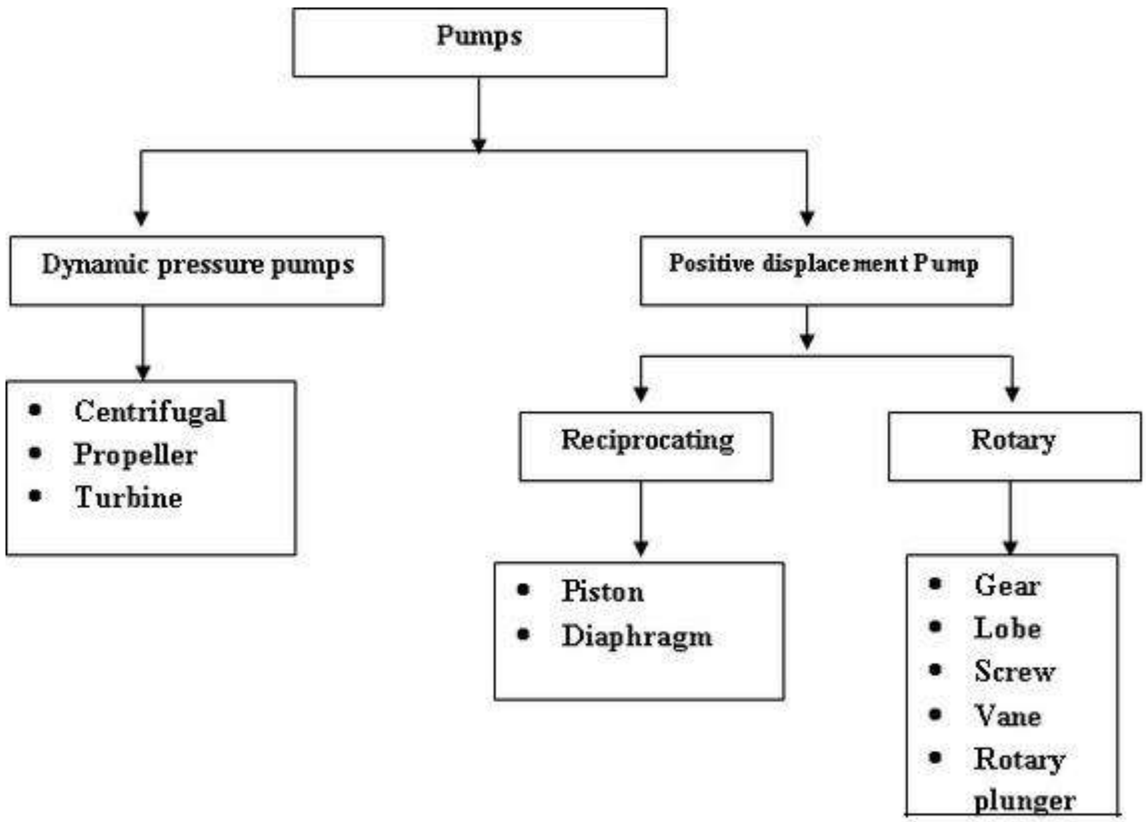
FIGURE 6.21
Economic pipe size for pumped liquids (carbon-steel pipe). Assumptions: Pumping cost = \$135 per horsepower-year; line cost = \$1 per inch of diameter per foot; fixed charges per year on line = 0.40 times line cost; liquid specific gravity = 0.80 (not very critical). Examples: for 150 gal/min and 200 cSt, use the 4-in line; for 150 gal/min and 10 cSt, use the 3-in line. (These prices are from the early 1960s. Current prices are higher, but they have risen more or less together, so that the economic pipe sizes have not changed much.) (Courtesy of the Board of Engineers, Standard Oil Company of California.)

Unit 4: Centrifugal Pumps:

Purpose: To lift the liquid to the required height.

Pump: A hydraulic machine which converts mechanical energy of prime mover (Motors, I.C. Engine) into pressure energy

Classification of Pumps



Application:

1. Agriculture & Irrigation

2. Petroleum

3. Steam and diesel Power plant

4. Hydraulic control system

5. Pumping water in buildings

6. Fire Fighting

Positive Displacement:

Amount of liquid taken on suction side is equal to amount of liquid transferred to deliver side. Hence discharge pipe should be opened before starting the pump to avoid the bursting of casing.

Rotodynamic Pump:

Increase in energy level is due to a combination of centrifugal energy, Pressure energy and kinetic energy. i.e. fluid is not displaced positively from suction side to delivery side. Pumps can run safely even the delivery valve is closed.

Centrifugal Pump: Mechanical energy of motor is converted into pressure energy by means of centrifugal force acting on the fluid.

Sr. No.	Centrifugal Pump	Inward Flow Turbine
1	It consumes power	It produces power
2	Water flows radially outward	Water flows radially inward from periphery
3	Flow from low pressure to high pressure	Flow from high pressure to low pressure
4	Flow is decelerated	Flow is accelerated

Construction and working of centrifugal Pump

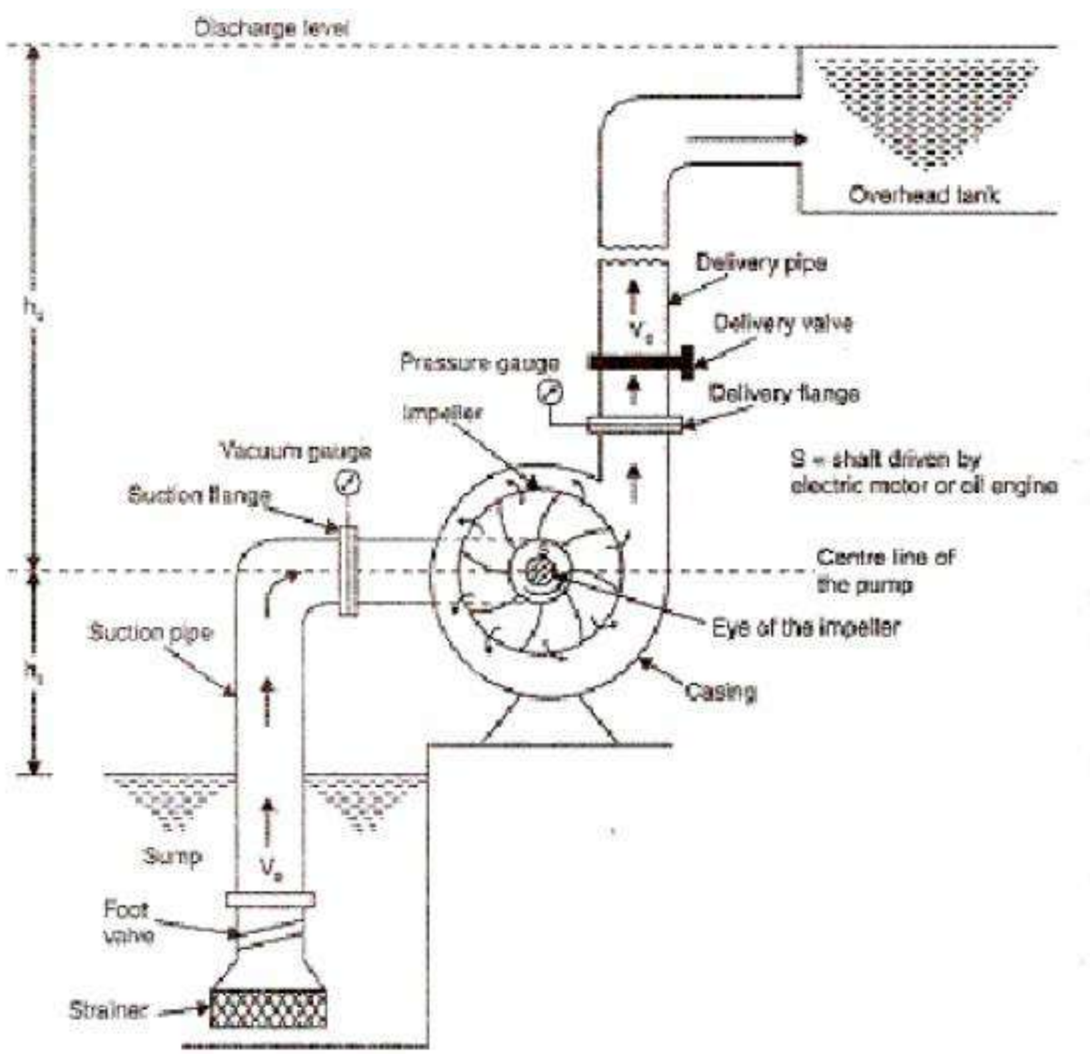
Components:

1. Impeller: A wheel with series of backward curved vanes.
2. Casing: Air tight chamber surrounding the impeller.
3. Suction Pipe: One end is connected in eye and other is dipped in a liquid.
4. Delivery pipe: One end is connected to eye, other to overhead tank.
5. Foot valve: Allow water only in upward direction.
6. Strainer: Prevent the entry of foreign particle/material to the pump

Working of Centrifugal Pump:

When a certain mass of fluid is rotated by an external source, it is thrown away from the central axis of rotation and centrifugal head is impressed which enables it to rise to a higher level.

1. The delivery valve is closed and pump is primed i.e. suction pipe, casing and portion of delivery pipe up to the delivery valve are completely filled with water so that no air pocket is left.
2. Keeping the delivery valve is closed the impeller is rotated by motor, strong suction is created at the eye.
3. Speed enough to pump a liquid when is attained delivery valve is opened. Liquid enter the impeller vane from the eye, come out to casing.
4. Impeller action develops pressure energy as well as velocity energy.
5. Water is lifted through delivery pipe upto required height.
6. When pump is stopped, delivery valve should be closed to prevent back flow from reservoir.



Types of casing

1. **Volute Casing:** Area of flow gradually increases from the eye of impeller to the delivery pipe. Same as shown in fig of components. Formation of eddies.

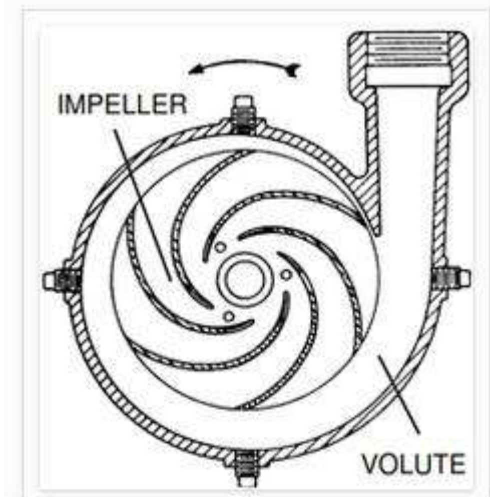


Fig: Volute casing

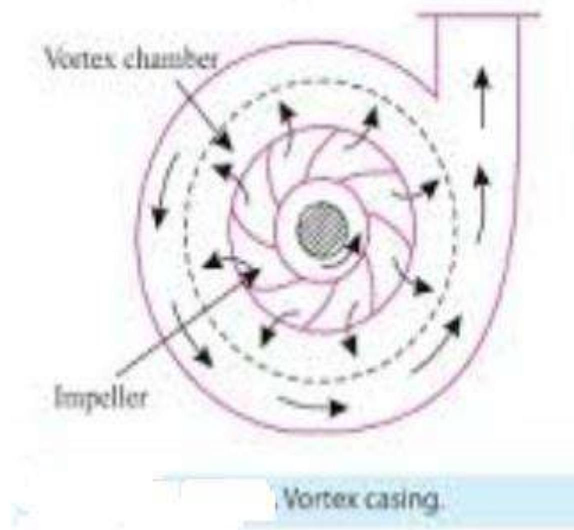
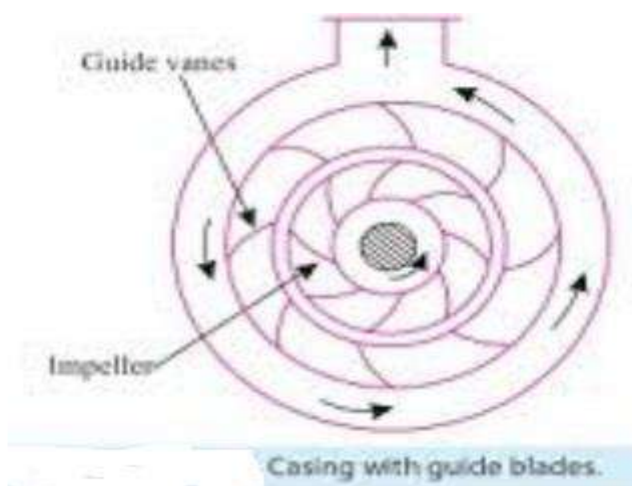


Fig: Vortex casing

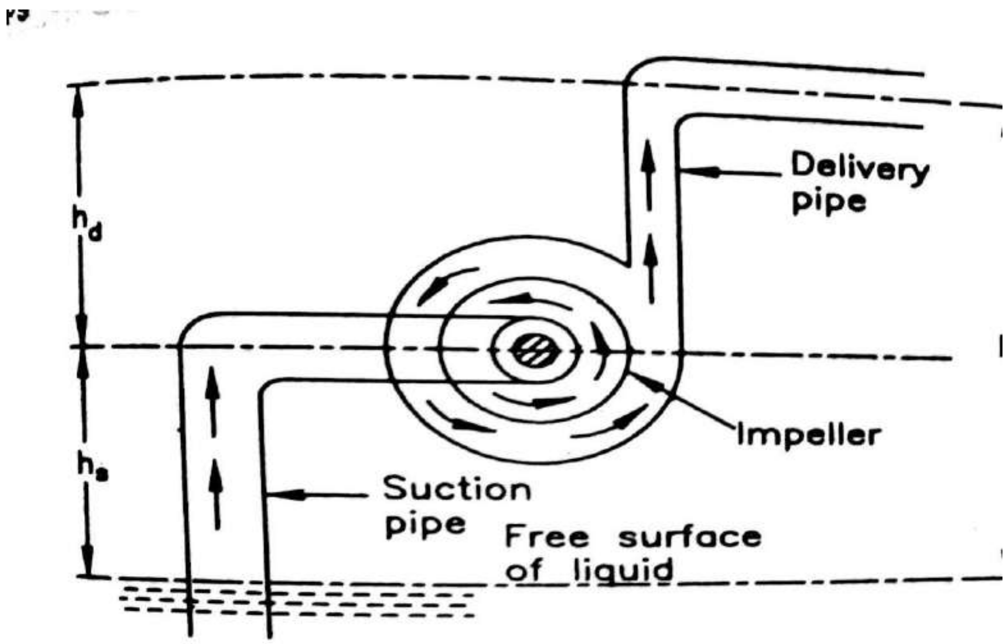
2. **Vortex casing:** Circular chamber provided between the impeller and volute chamber.

   Loss of energy due to formation of eddies is reduced.

3. **Casing with guide blades:** Casing impeller is surrounded by a series of guide vanes mounted on a ring which is known as diffuser. Water enters the impeller without shock.



Various head of centrifugal Pump



The heads of a centrifugal pump are as follows:

(1)Suction head (2) delivery head

(3)Static head (4) Monometric head

1. Suction head (h_s) : It is vertical distance between level of sump and eye of an impeller. It is also called suction lift.
2. Delivery head (h_d): It is the vertical distance between between eye of an impeller and the level at which water is delivered.
3. Static head (H_s): It is sum of suction head and delivery head. It is given by

   $H_s = (h_s + h_d)$
4. Manometric head (H_m): The head against which the centrifugal Pump has to work. It is given by following equations:

   (i) H_m = (Head imparted by the impeller to the water) –

   (Loss of head in the pump impeller and casing)

   $$H_m = \frac{V_{w2} u_2}{g} - (h_{Li} + h_{Lc})$$

   Where, h_{Li}= Loss in impeller

   h_{lc} = Loss in casing

$H_m = \frac{V_{w2} u_2}{g}$ (if losses are neglected)

(ii) H_m = Static head + losses in pipes + Kinetic head at delivery

$= H_s + (h_{fs} + h_{fd}) + \frac{V_d^2}{2g}$

$= (h_s + h_d) + (h_{fs} + h_{fd}) + \frac{V_d^2}{2g}$ -------------------------------(8)

Where,

h_s and h_d = Suction and delivery head

h_{fs} and h_{fd} = Loss of head due to friction in suction and delivery pipe.

V_d = Velocity pipe in delivery pipe.

(iii) H_m = (Total head at outlet of pump) – (Total head at inlet of Pump)

Total head at outlet = $\frac{P_d}{\rho g} + \frac{V_d^2}{2g} + Z_d = h_d + \frac{V_d^2}{2g} + Z_d$

Total head at inlet = $\frac{P_s}{\rho g} + \frac{V_s^2}{2g} + Z_s = h_s + \frac{V_s^2}{2g} + Z_s$

$H_m = (h_d + \frac{V_d^2}{2g}) - (h_s + \frac{V_s^2}{2g})$ ------------------------------------(9)

Inlet and outlet velocity triangles for Centrifugal Pump

Work done By Impeller on liquid

1. Liquid enters eye of impeller in radial direction i.e. $\alpha = 90^0$, $V_{w1} = 0$, $V_1 = V_{f1}$
2. No energy loss in impeller due to eddy formatting
3. No loss due to shock at entry
4. Velocity distribution in vanes is uniform.

Let,

N = Speed of impeller (rpm)

$\omega = Angular\ velocity = \frac{2\pi n}{60}$ (rad/s)

Tangential velocity of impeller

$u_1 = \omega R_1 = \frac{\pi D_1 N}{60}$ m/s

$u_2 = \omega R_2 = \frac{\pi D_2 N}{60}$ m/s

V_1 = Absolute velocity of water at inlet

$V_{w1} = Velocity\ whirl\ at\ inlet$

$V_{r1} = Relative\ Velocity\ at\ inlet$

$V_{f1} = velocity\ of\ flow\ at\ inlet$

α = angle made by V_1 at inlet with direction of motion of vane

$\theta =$ Angle made by V_{r1} at inlet with direction of motion of vane

V_1 , V_{w1}, V_{r1}, V_{f1}, β, ϕ -----Corresponding values at outlet

A Centrifugal pump is the reverse of radially inward flow reaction turbine.

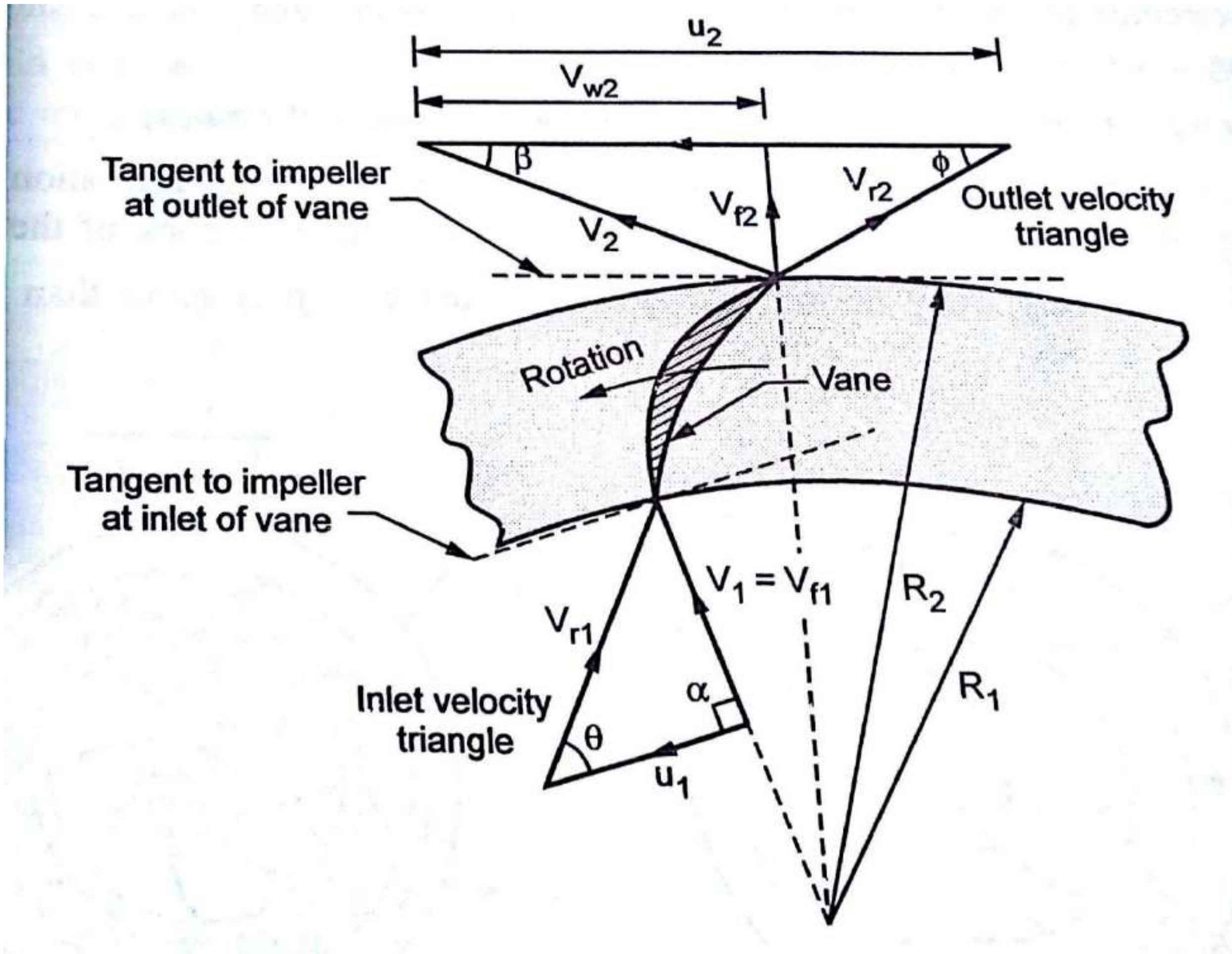


Fig. : Velocity triangle for an impeller

Work done by water on runner of turbine per sec per unit weight of water = $\frac{1}{g}(V_{w1}u_1 \pm V_{w2}u_2)$

W.D. by impeller on water per sec per unit weight of water = - (WD in case of turbine)

$$= -\frac{1}{g}(V_{w1}u_1 \pm V_{w2}u_2)$$

W.D = $\frac{1}{g}(V_{w2}u_2 - V_{w1}u_1)$----- ----------------------(1)

Eqn. (1) is known as Euler momentum equation for pump or Euler head.

Since radial entry $V_{w1} = 0$ *and* $V_1 = V_{f1}$

W.D. per unit weight = $\frac{1}{g}(V_{w2}u_2)$ N-m/N ------------------------ (2)

Q = Area x velocity of flow

Q = $\pi D_1 B_1$ x V_{f1}

Continuity equation Q = $\pi D_1 B_1$ x $V_{f1} = \pi D_2 B_2$ x V_{f2}

From the outlet velocity triangle

$V_{r2}{}^2 = V_{f2}{}^2 + (u_2 - V_{w2})^2$

$V_{f2}{}^2 = V_{r2}{}^2 - (u_2 - V_{w2})^2$--------------------------(3)

Also,

$V_{f2}{}^2 = V_2{}^2 - V_{w2}{}^2$-------------------------------------(4)

From equation 3 and 4

$V_2{}^2 - V_{w2}{}^2 = V_{r2}{}^2 - (u_2 - V_{w2})^2$

$V_2{}^2 - V_{w2}{}^2 = V_{r2}{}^2 - u_2{}^2 + 2u_2V_{w2} - V_{w2}{}^2$

$2u_2V_{w2} = V_2{}^2 + u_2{}^2 - V_{r2}{}^2$

$u_2V_{w2} = \frac{1}{2}(V_2{}^2 + u_2{}^2 - V_{r2}{}^2)$

Similarly from inlet velocity triangle

$u_1V_{w1} = \frac{1}{2}(V_1{}^2 + u_1{}^2 - V_{r1}{}^2)$

Putting in equation 1

W.D = $\frac{1}{g}\left[\frac{1}{2}\left(V_2{}^2 + u_2{}^2 - V_{r2}{}^2\right) - \frac{1}{2}(V_1{}^2 + u_1{}^2 - V_{r1}{}^2)\right]$

W.D = $\frac{V_2{}^2 - V_1{}^2}{2g} + \frac{u_2{}^2 - u_1{}^2}{2g} + \frac{V_{r1}{}^2 - V_{r2}{}^2}{2g}$---------------------------(5)

W.D per sec/unit weight =Increase in K.E head +Increase in static pressure + Change in K.E due to retardation

Equation 5 is known as fundamental equation centrifugal Pump.

Losses in Centrifugal Pump

1. Hydraulic losses : Friction loss shock , eddy losses
2. Mechanical losses: Bearing friction, impeller
3. Leakage losses: leakage of liquid

Efficiencies of a Centrifugal Pump

1. Manometric efficiency (η_{mano}):

$$\eta_{mano} = \frac{Manometric\ head}{head\ imparted\ by\ impeller} = \frac{H_m}{\frac{V_{w2}u_2}{g}} = \frac{g\ H_m}{V_{w2}u_2}$$

Francis Turbine,

$$\eta_{b=}\frac{V_{w1}u_1}{gH}$$

2. Volumetric Efficiency (η_v)

$$\eta_v = \frac{Liquid\ discharged\ per\ second\ from\ the\ Pump}{Quantity\ of\ liquid\ passing\ per\ second\ through\ the\ impeller}$$

$$= \frac{Q}{Q+q}$$

Where,

Q = Actual liquid discharged at the pump outlet per second

q = Leakage of liquid per second from impeller

3. Mechanical efficiency (η_{mech}):

$$\eta_{mech} = \frac{Poer\ at\ Impeller}{Power\ at\ shaft} = \frac{\rho g Q(\frac{V_{w2}u_2}{g})}{P}$$

4. Overall efficiency η_o

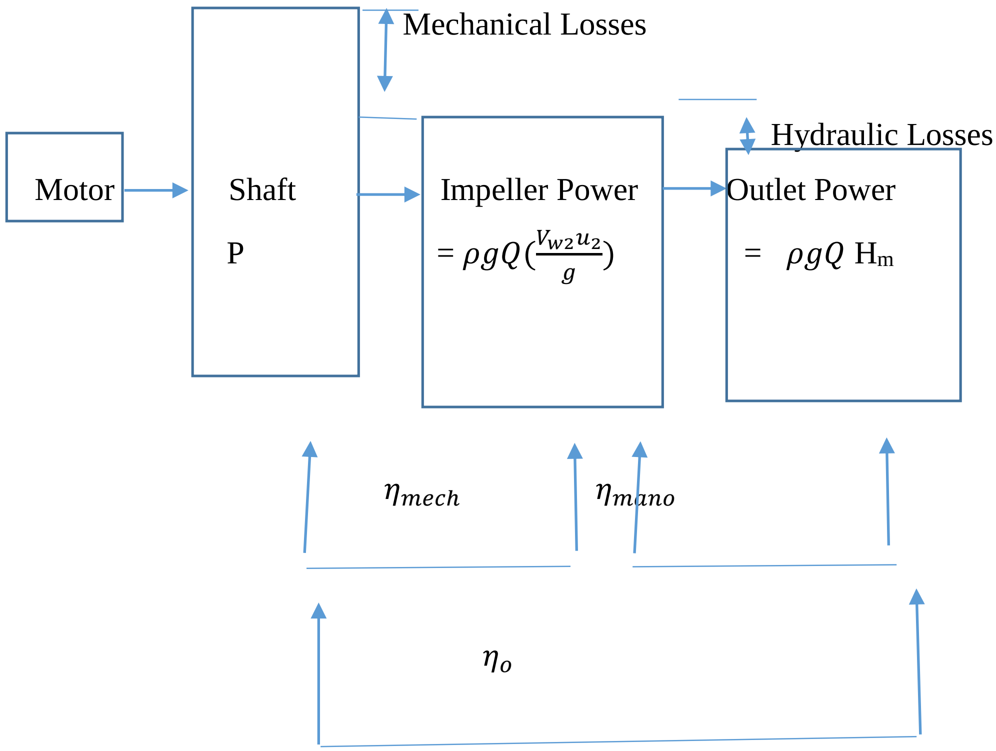
$$\eta_o = \frac{Output\ Power\ of\ Pump}{input\ Power\ of\ pump} = \frac{\rho g Q\ \text{Hm}}{P}$$

$$\eta_o = \eta_{mech} \text{ x } \eta_{mano}$$

Turbine,

$$\eta_o = \frac{p}{\rho g Q\ \text{Hm}}$$

The various losses and corresponding efficiencies of a centrifugal Pump are tabulated as follow



Effect of Outlet blade angle on Manometric Efficiency η_{mano}

At outlet of an impeller the energy available in liquid has the pressure energy equal to the sum of manometric head (H_m) and velocity head $(\frac{V_2^2}{2g})$

Neglecting the losses in pump we have

$$\frac{V_{w2} u_2}{g} = H_m + (\frac{V_2^2}{2g})$$

$$H_m = \frac{V_{w2} u_2}{g} - \frac{V_2^2}{2g}$$

From outlet velocity triangle,

$V_2^2 = V_{w2}^2 + V_{f2}^2$ and

$$V_{w2} = u_2 - \frac{V_{f2}}{tan\ \phi}$$

$$= u_2 - V_{f2} \cot \phi$$

Substituting the above values in Hm equation

$$H_m = \frac{(u_2 - Vf2 \cot \phi) u_2}{g} - \frac{(u_2 - Vf2 \cot \phi)^2 + V_{f2}^2}{2g}$$

After simplification we get,

$H_m = \frac{u_2^2 - V_{f2}^2 cosec^2 \phi}{2g}$

Substituting this value in Manometric Efficiency η_{mano},

$\eta_{mano} = \frac{u_2^2 - V_{f2}^2 cosec^2 \phi}{2u_2(u_2 - \text{Vf2 cot } \phi)}$ ---------------------(A)

- In the equation (A) if we vary the value of ϕ from 20^0 to 90^0 by keeping the other parameters constant then η_{mano}, is between 0.73 to 0.47
- If we further reduce the value of ϕ (below 20^0), it increases the efficiency but also results in long size of blades and increased friction losses.
- Therefore the discharge vane angle(ϕ) is kept more than 20^0 for a centrifugal pump.

Cavitation

Whenever the pressure in the pipe falls below the vapour pressure corresponding to the existing temperature of the liquid, the liquid will vaporize and bubbles are formed collapse and this process is continued rapidly and creates high pressure which can damage the impeller very easily. This phenomenon is known as cavitation which is highly undesirable. The cavitation is generally occurs in centrifugal pumps near the inlet of the impeller.

Thomas cavitation factor

The cavitation factor is used to indicate whether it will occur or not. The cavitation factor σ for pump is given by

$$\sigma = \frac{NPSH}{H_m}$$

If the value of σ is less than the critical value of σ_c , then the cavitation occurs in the pump.

$$\sigma_c = 1.03 \ x \ 10^{-3} x \left[N_s^{4/3}\right]$$

Where N_s = Specific speed of the pump

The cavitation in the pump can be avoided by

- reducing the velocity in the suction pipe, and avoiding the bends
- reducing h_{fs} in suction pipe by using smooth pipe,
- reducing the suction head and
- Selecting the pump whose specific speed is low.

Effects of cavitation

It is undesirable as it has following disadvantages.

1. The large number of vapour bubbles formed are carried with liquid a high pressure region is reached, where these bubbles suddenly collapse. This includes the rush of surrounding liquid and produces shock and noise. This phenomenon is known as ***water hammer***.
2. The surface of blades and impeller are worn out because of bursting of bubbles.
3. The water hammer phenomenon is fatigue for the metal parts and it reduces the life by blow action.

Net Positive suction head (NPSH)

The term is very commonly used in pump industry because the minimum suction conditions are specified in terms of NPSH

Let,

P_1= Absolute pressure at inlet of the Pump

P_a = Absolute atmospheric pressure

P_v = Vapour pressure of the liquid

V_s = Velocity suction pipe.

h_{fs} = losses in suction pipe

H_a = Atmospheric pressure head

H_v = vapour pressure head

NPSH = Absolute pressure head at inlet – Vapour pressure head + Inlet (suction) velocity head

$$NPSH = \frac{P_1}{\rho g} - \frac{P_v}{\rho g} + \frac{V_s^2}{2g} \quad \text{----------------(i)}$$

But absolute pressure head at inlet of pump is given by

$$\frac{P_1}{\rho g} = \frac{P_a}{\rho g} - \left(\frac{V_s^2}{2g} + h_s + h_{fs}\right)$$

Substituting the above value in equation (i)

$$NPSH = \frac{P_a}{\rho g} - \left(\frac{V_s^2}{2g} + h_s + h_{fs}\right) - \frac{P_v}{\rho g} + \frac{V_s^2}{2g}$$

$$NPSH = \frac{P_a}{\rho g} - \frac{P_v}{\rho g} - h_s - h_{fs}$$

$$NPSH = H_a - H_v - h_s - h_{fs} \quad \text{--------------------------------------(24)}$$

- The NPSH is also defined as the net head required to make the liquid flow through suction pipe from sump to impeller.
- NPSH term is also used to check cavitation in pump

Required NPSH

- It is value given by pump manufacturer
- This value can be determined experimentally and it varies with pump design, speed of the pump and capacity of the pump.

Available NPSH

- When pump is installed the value of available NPSH is calculated from equation 24
- The available NPSH should be greater than required NPSH for cavitation free operation of Pump.

Priming of centrifugal Pumps:

- The priming of centrifugal pump is the process of filling the suction pipe, casing of the pump and portion of the delivery pipe from outside source of the fluid to be raised.
- This removes the air, gas or vapour from these parts.
- Priming is done before the starting the pump
- It is necessary to avoid discontinuity of flow or dry running of pump
- The dry running of pump may result in rubbing and seizing of the wearing rings and cause severe damage.
- Also when the pump is running with air instead of water, the head generated is in terms of meters of air. But as the density of air very low, the generated head of air in terms of equivalent meter of water head is negligible and hence water may not be sucked from the pump.

For all above reason priming is necessary.

The following are the some of the methods for priming the centrifugal pump.

i. Priming of small pumps: It is done by pouring the fluid into the funnel provided for priming. During this the air vent valve is kept open and priming is continued till all the air is removed.

ii. Priming of large Pumps: It is done by removing the air from casing and suction pipe with the help of vacuum pump or by an ejector. This helps in drawing the liquid from sump and fill the pump with liquid.

There are some pumps having internal constructions for supply of liquid in suction pipe known as ***self-priming pumps***

Installation of Centrifugal Pump

The following steps are used for efficient installation of the centrifugal Pump.

i. Location of Pump
ii. Suction piping
iii. Delivery piping
iv. Foundation
v. Grouting
vi. Alginment

i. Location
- The pump unit should be located close to the water surface to minimize the vertical suction lift. The suction lift of length more than 5 m must be avoided.

ii. Suction piping:
- Suction pipe must be continuously flooded have length of 3 times diameter for straight run and it can accommodate a strainer.
- Entire suction piping should be inclined slightly and all the flanged joints should be fitted with gasket and be airtight.

iii. Deliver piping
- The discharge valve must be of butterfly or ball or globe type if it is used as flow or pressure throttling device.
- The maximum flow velocity in the discharge line should not exceed 2 m/s

iv. Foundation and grouting
- The pump must be installed on a base plate. The base plate is attached to a foundation and grouting is placed between it.
- The foundation and grouting will help to damp out the vibrations.

v. Alignment

- The pump alignment is extremely important.
- The suction and discharge piping should be naturally aligned with pump.
- The alignment should be done prior to grouting it and it is checked after grouting and during startup.

Specific Speed of a centrifugal pump

It is defined as the speed of geometrically similar pump which would deliver one cubic meter of liquid per second against a unit head (one meter)

The discharge through impeller of a centrifugal pump is given by

Q = Area x velocity of flow

$= \pi DB \; x \; V_f$

Q $\propto D \; x \; B \; x \; V_f$---------------------------(i)

Q $\propto \; D^2 \; x \; V_f$ (as B $\propto D$)------------(ii)

Now tangential velocity is given by

u = $\frac{\pi DN}{60}$

u $\propto DN$-----------------------------(iii)

Also from the relation of tangential velocity (u) and flow velocity (V_f) to the manometric head (H_m),

u $\propto V_f \propto \sqrt{H_m}$------------------------(iv)

Now substituting the value of u from eqn. (iv) in equation (iii) we get

$\sqrt{H_m} \; \propto DN$

D $\propto \frac{\sqrt{H_m}}{N}$ --------------------------(v)

Substitute iv and v in equation (ii) we get

Q $\propto \frac{H_m}{N^2}$ x $\sqrt{H_m}$

Q = K$\frac{H_m^{3/2}}{N^2}$ -----------(vi) K= constant of proportionality

From the definition of of specific speed of if H_m= 1, Q= 1 m^3/s then N = N_s

1= K$\frac{1^{3/2}}{N_s^2}$, K = N_s^2

Substituting the value of k in equation (vi) we get

$$Q = N_s^2 \frac{H_m^{3/2}}{N^2}$$

$$N_s = \frac{N\sqrt{Q}}{H_m^{3/4}}$$

Minimum speed for starting of Centrifugal Pump

For minimum speed to start the pump

$$\frac{u_2^2 - u_1^2}{2g} \geq H_m \quad \text{------------------------(a)}$$

$$and \qquad \eta_{mano} = \frac{g\,H_m}{V_{w2}u_2}$$

$$H_m = \eta_{mano} \text{ x } \frac{V_{w2}u_2}{g}$$

Also $u_1 = \frac{\pi D_1 N}{60}$ and $u_2 = \frac{\pi D_2 N}{60}$

Substituting above value in equation a

$$\frac{u_2^2 - u_1^2}{2g} = \eta_{mano} \text{ x } \frac{V_{w2}u_2}{g}$$

$$u_2^2 - u_1^2 = 2\,\eta_{mano} V_{w2} u_2$$

$$\left(\frac{\pi D_2 N}{60}\right)^2 - \left(\frac{\pi D_1 N}{60}\right)^2 = 2\,\eta_{mano} V_{w2} u_2$$

$$\left(\frac{\pi N}{60}\right)^2 (D_2^2 - D_1^2) = 2\,\eta_{mano} V_{w2} u_2$$

$$\left(\frac{\pi N}{60}\right)^2 (D_2^2 - D_1^2) = 2\,\eta_{mano} V_{w2} \, x \, \frac{\pi D_2 N}{60}$$

$$\left(\frac{\pi N}{60}\right)(D_2^2 - D_1^2) = 2\,\eta_{mano} V_{w2} D_2$$

$$N = \frac{2\,\eta_{mano} V_{w2} D2}{(D_2^2 - D_1^2)} \text{ x } \frac{60}{\pi}$$

$$N_{min} = \frac{120\,\eta_{mano} V_{w2} D_2}{\pi\,(D_2^2 - D_1^2)} \text{----------------------------(18)}$$

Performance characteristics of Centrifugal Pump

The following are the important characteristics curves of centrifugal pump.

i. Main characteristics curves

ii. Operating characteristics curves

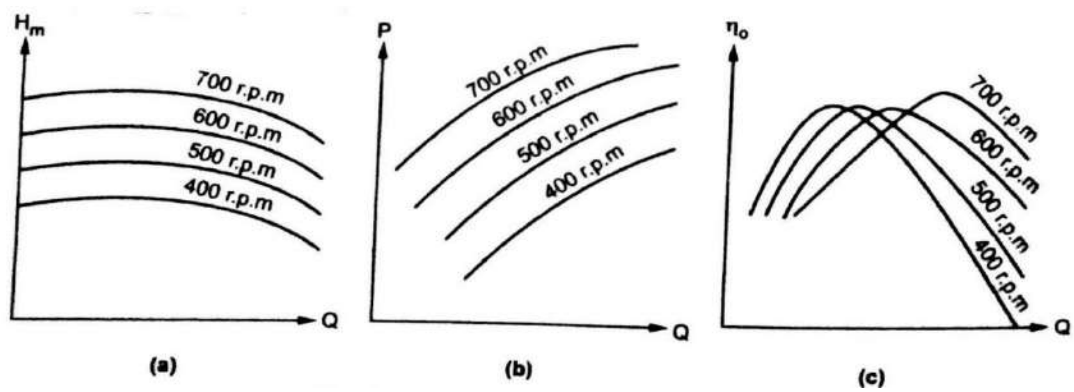
iii. Constant efficiency curves or Muschel curves

iv. Constant head and constant discharge curves.

1. Main characteristics curves

The main characteristics curves are obtained by keeping the pump at constant speed and varying the discharge over desired range.

The discharge is varied by means of deliver valve. For different values of discharge the measurements are taken or calculated for manometric head, shaft power and efficiency These curve are useful in evaluating the performance of pump at different speeds.



2. Operating characteristics curve

The maximum efficiency occurs when centrifugal pump operates at the constant designed speed.

If the speed is kept constant, the variation in manometric head power and efficiency with respect to discharge gives the operating characteristic curves for pump.

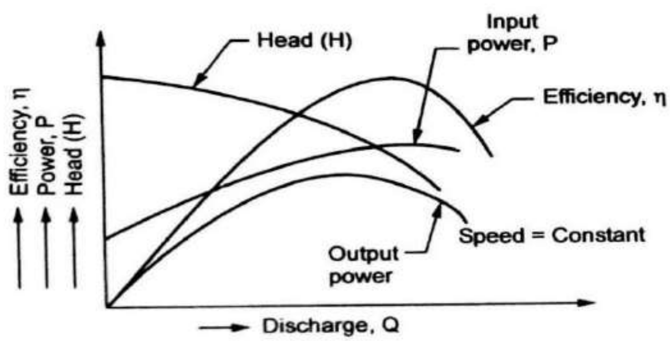


Fig. : Operating characteristics curves of a pump

3. Constant efficiency curve

   The constant efficiency or iso efficieny curve gives the performance of pump over its entire range of operations.

   With the help of data obtained in main characteristic curves the constant efficiency curves are plotted.

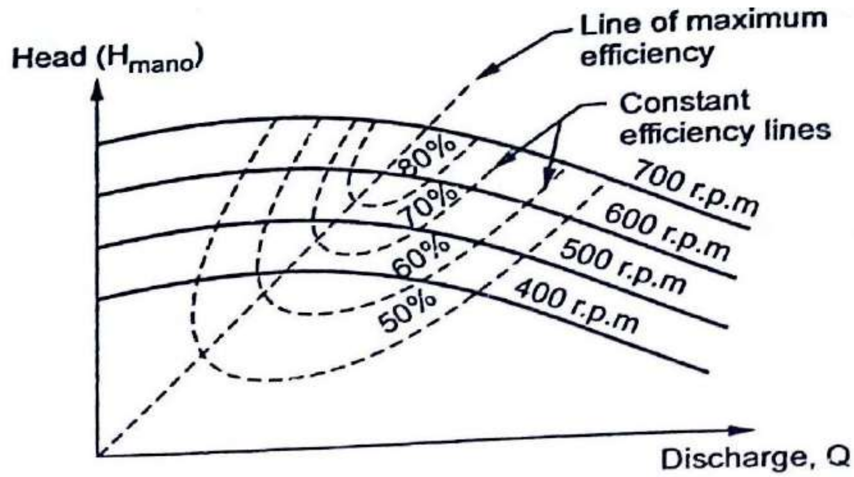


Fig. : Constant efficiency or Muschel curve

4. Constant head and constant discharge curves

   These curves are helpful in determining the performance of variable speed pump.

   These curves are plotted as follows.

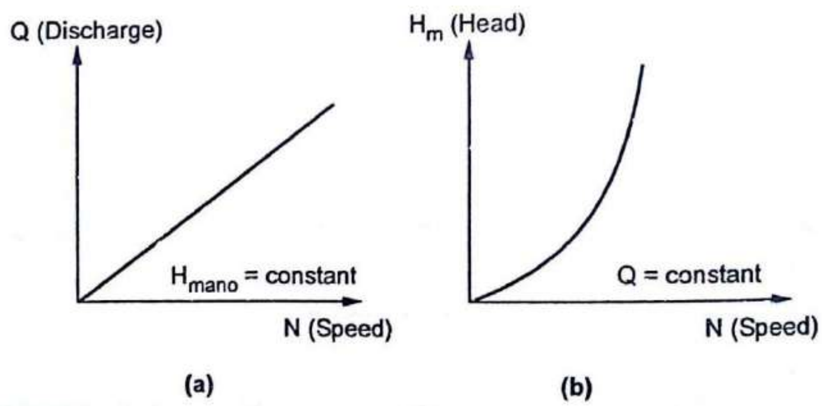


Fig. : (a) Q v/s N and (b) H_m v/s N curves of a centrifugal pump

Multistage Centrifugal Pump

A multistage centrifugal pump consist of two or more identical impellers monted on the same shaft or on different shafts.

To produce the heads higher than that of using single impeller keeping the discharge constant. This is achieved by ***Series arrangement of pumps***

To discharge the large quantity of fluid keeping the head constant. This is achieved by ***parallel arrangement of pumps.***

Series Arrangement of Pumps

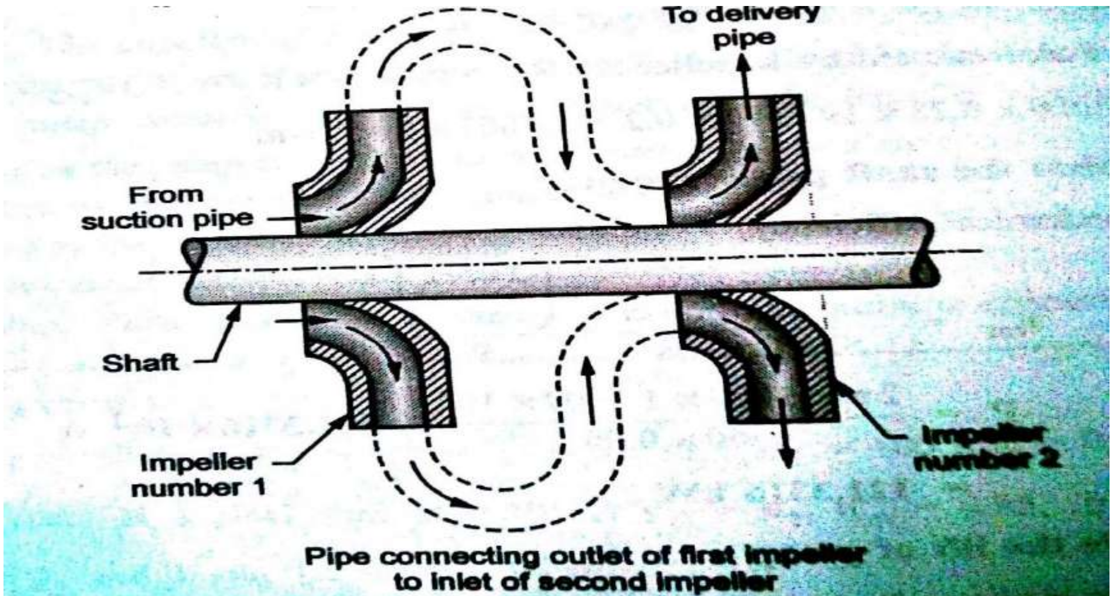


Fig. : Two-stage pumps with impellers in series

The discharge from first impeller having high pressure is fed to second impeller through guided passage.

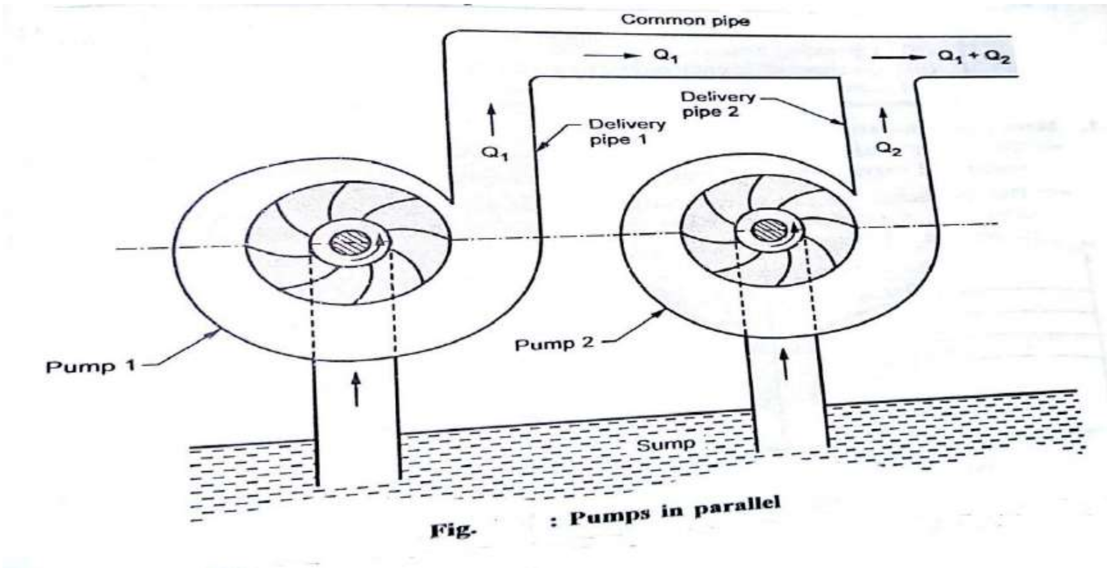
The pressure at the outlet of second impeller will be more than the pressure at the outlet of first impeller.

If the more number of impellers are mounted on the same shaft in series arrangement then the pressure will be increases further.

For each stage, the head developed will be H_m hence for number of stages (n) total head developed will be given by

$H_{total} = n \times H_m$

Parallel Arrangement of Pumps



To obtain a high discharge at relatively small head number of impellers are mounted in parallel arrangement.

The pumps are arranged such that each of these pump is working separately to lift the liquid from common sump and deliver it to the common delivery pipe

In this arrangement the head remains constant and the discharge of each pump gets added to give large quantity of liquid at the outlet

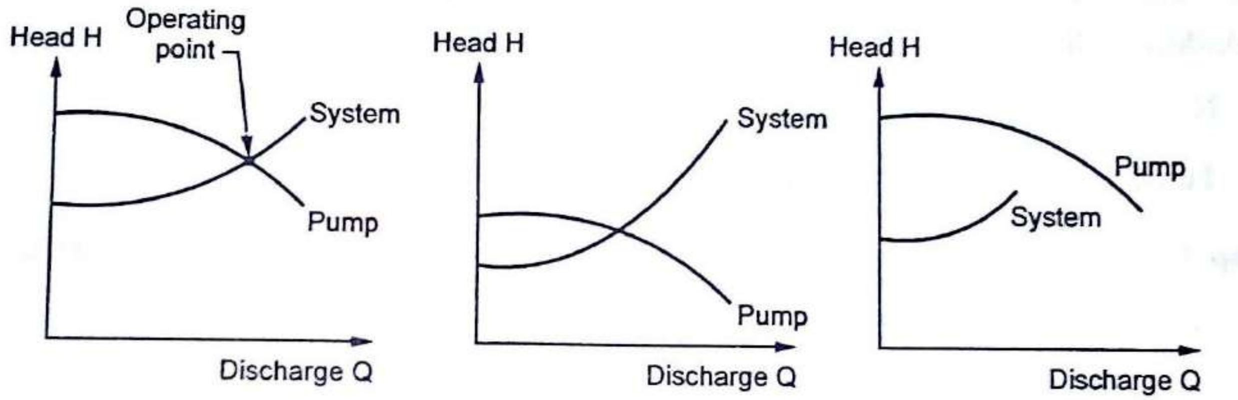
$Q_{total} = Q_1 + Q_2 + \ldots\ldots Q_n$

Selection pump based on system resistance curve

The pump manufacture always gives the head discharge characteristic curve for their manufactured pump and operated under different test conditions.

But in actual application this pump is required to operate under different conditions with respect to suction and discharge pipelines elbows and number of valves.

The user of the pump find out his system requirement and a head discharge curve is drawn. This curve is called as system resistance curve or system characteristic curve. As shown in following figure.



(a) System resistance curve (b) Undersized pump (c) Oversized pump

Now the pump characteristics curve (supplied by manufacture) are superimposed on system characteristic curve.as shown in above figure.

The point of intersection represent the operating point of pump .

If the pump can not meet the head and discharge requirements of the pump the it is called as undersized or under capacity pump. (refer fig (b))

If the pump delivers much higher head and discharge than the requirements the it is called ad oversized pump.(refer fig. c)

Selection of Pumps:

Selection of pump is based on the specific speed for the pump.

The specific speed is calculated from the values of discharge (Q) head (H) and speed (N)

For low heads of about 6 m and large discharge, axial flow pumps are used.

For high heads, radial flow pumps are used.

If it is possible to increase the speed for low specific pump, multistage pump are suitable.

Depending upon type of impeller, the pump is selected for particular operation as follows

i) Shrouded type impeller are used for pumping fresh and clean water.

ii) Unshrouded or propeller type impeller is used for pumping solid-liquid mixture.

iii) Mixed flow impellers with diffusers vanes are used for deep well or submersible pumps.

Introduction to Pumping Systems

Chapter 6

What Is In This Chapter?

1. The function of pumping systems
2. Common pump types
3. The basic theory of operation of centrifugal pumps
4. The basic theory of operation of diaphragm pumps
5. The major components of a pumping system, including the building and piping system
6. Terms used to identify common pumps and their components
7. The weight of a cubic foot of water
8. How to convert between cubic feet and gallons
9. The difference between force and pressure and what impacts them
10. How to convert between psi and feet of head
11. The difference between psi and feet of head
12. The relationship between flow in cubic feet per second and gallons per minute
13. The terms used to describe static and dynamic hydraulic conditions
14. Headloss and its causes
15. The terms used to describe pumping conditions

Key Words

- Amperage
- Axial Flow Pumps
- Can Turbine Pumps
- Cavitation
- Centrifugal Force
- Centrifugal Pump
- Close-coupled Pumps
- Concentric Reducer
- Displacement Pumps
- Dynamic Pumps
- Eccentric Reducer
- End Suction Centrifugal Pumps
- Energy
- Foot Valve
- Force
- Frame-mounted Pumps
- Headloss
- Horsepower
- Impeller
- Inertia
- Line Shaft Turbine Pumps
- Mechanical Seal
- Packing
- Pressure
- Pump Bowl
- Seal Water
- Shroud
- Split Case Pumps
- Static
- Stuffing Box
- Submersible Turbine Pumps
- Suction Head
- Suction Lift
- Total Dynamic Head
- Velocity Head
- Vertical Turbine Pumps
- Volute

Lesson Content

This lesson provides an overview of the major pumping-related components found in small water systems. The lesson focuses on descriptions of components, common names, and general function.

Pump Stations

Functions

Pumping stations in small communities are used for the following purposes:

- Remove water from a source, such as a river, lake, reservoir, well, spring, or muskeg pond.
- Move water from the treatment plant to the distribution system or reservoir.
- Circulate water through a distribution system.
- Maintain pressure in the distribution system.
- Circulate glycol through a heat exchanger or heating loop.
- Pump chemicals into the system.

Major Components

A pump station is composed of four sets of components:

- The building
- The hydraulic system: the pump and related piping
- The electrical system: the motor and its related components
- The control system: pressure, flow, and level switches

Pump Station Buildings

Introduction

In medium-to-large facilities, pumping stations are usually separate buildings. In small systems, while they can be separate buildings, they are normally associated with the treatment plant, watering point, or other buildings.

Basic Consideration

Regardless of the design, most pumping station buildings are designed with the door opening out to allow access should there be a broken water line in the building. In addition, the buildings should be vandal-resistant, well-heated in the winter, and properly vented in the summer.

Hydraulic System

Pump Types

The pumps used in small water systems can be divided into two general categories. The basic difference between the two types is their response to changes in discharge pressure.

- **Dynamic pumps**[1] – Dynamic pumps are used in conditions where high volumes are required and a change in flow is not a problem. As the discharge pressure on a dynamic pump is increased, the quantity of water pumped is reduced. One type of dynamic pump, centrifugal pumps, are the most common pump used in water systems. Dynamic pumps can be operated for short periods of time with the discharge valve closed.
- **Displacement pumps**[2] – Displacement pumps are used in conditions where relatively small, but precise, volumes are required. Displacement pumps will

[1] Dynamic Pumps – Pumps in which the energy is added to the water continuously and the water is not contained in a set volume.

[2] Displacement Pumps – Pumps in which the energy is added to the water periodically and the water is contained in a set volume.

not change their volume with a change in discharge pressure. Displacement pumps are also called positive displacement pumps. The most common positive displacement pump is the diaphragm pump used to pump chlorine and fluoride solutions. Operating a displacement pump with the discharge valve closed will damage the pump.

- Pumps
  - Dynamic Pumps
    - End Suction Centrifugal
    - Split Case
    - Vertical Turbines
    - Special Effect Pumps
      - Jet pumps
      - Regenerative turbines
      - Vortex pumps
  - Displacement Pumps
    - Reciprocating
      - Piston
      - Diaphragm
    - Rotary
      - Peristaltic
      - Progressive cavity
      - Multiple gear - lobe

Centrifugal Pumps - Pumping Theory

Energy Input Device

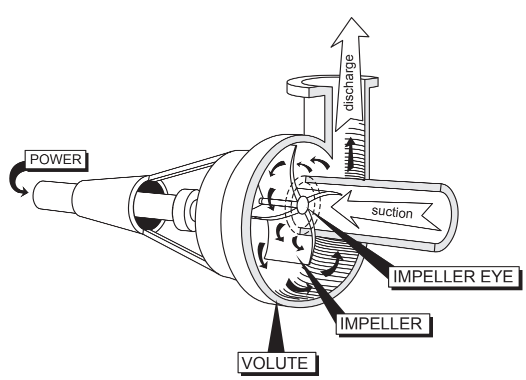
A pump is a device that puts **energy**[3] into the water. This energy can be expressed in two ways: an increase in pressure or an increase in flow.

Centrifugal Pumps – Energy Input

If you were to cut a section out of the top of a pipe and use a canoe paddle to move the water, you would have a pump. It would not be very efficient, but you would be inputting energy into the water. If you reshaped the paddle into an **impeller**[4], you would be able to place more energy into the water. The energy would be transferred from the impeller to the water due to the friction between the impeller and the water. However, water would splash out onto the floor. This is because **centrifugal force**[5] causes the water to fly outward away from the impeller.

The Pump Case

If you surrounded the impeller with a case, you could control the water and obtain a more efficient energy transfer. The case that you would use is volute (spiral-shaped). **Volute**[6] is a geometrical shape, like a circle or a square. For example, a snail shell is volute-shaped. The shape of the case helps to determine the direction of rotation of the pump.



[3] Energy – The ability to do work. Energy can exist in several different forms, such as heat, light, mechanical, electrical, or chemical. Energy can neither be created nor destroyed, but can be transferred from one form to another. Energy exists in one of two states: potential or kinetic.

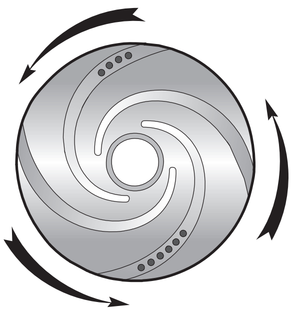
[4] Impeller – A rotating set of vanes designed to impart rotation to a mass of fluid.

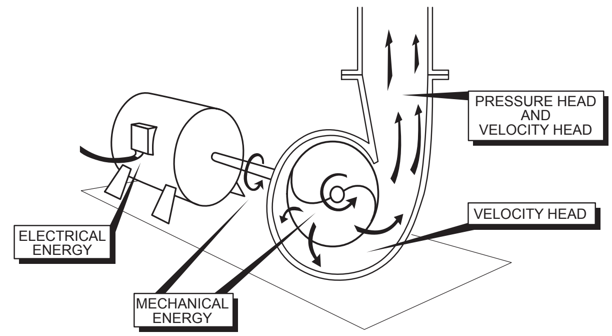
[5] Centrifugal force – The force that when a ball is whirled on a string, pulls the ball outward. On a centrifugal pump, it is the force that throws water from the spinning impeller.

[6] Volute – The spiral-shaped casing surrounding a pump impeller that collects the liquid discharged by the impeller.

Pump Rotation

The direction of rotation can be determined when looking into the suction side of the volute case. For example, in the case below, the direction of rotation is counter-clockwise.





In summary, there are two theories that explain how a **centrifugal pump**[7] works:

- Energy transfer – the transfer of energy from the shaft to the impeller and from the impeller to the water.
- Centrifugal force – the force used to throw the water from the impeller.

[7] Centrifugal Pump – A pump consisting of an impeller fixed on a rotating shaft and enclosed in a casing, and having an inlet and discharge connection. The rotating impeller creates pressure in the liquid by the velocity derived from centrifugal force.

Centrifugal Pumps Configuration

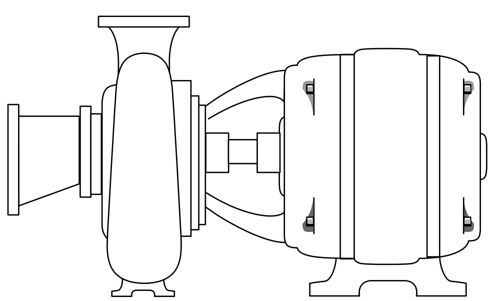
Three Different Configurations

Centrifugal pumps can be divided into one of three classifications based on their configuration: **end suction centrifugal**[8], **split case**[9], and **vertical turbines**[10].

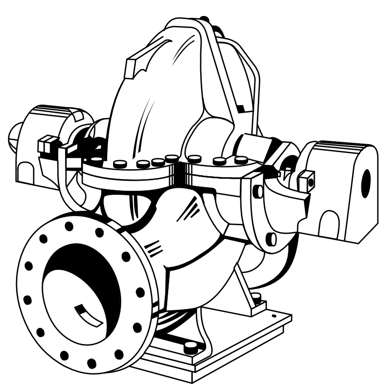
[8] End Suction Centrifugal Pumps – The most common style of centrifugal pump. The center of the suction line is centered on the impeller eye. End suction centrifugal pumps are further classified as either frame-mounted or close-coupled.

[9] Split Case Pumps – A centrifugal pump designed so that the volute case is split horizontally. The case divides on a plane that cuts though the eye of the impeller.

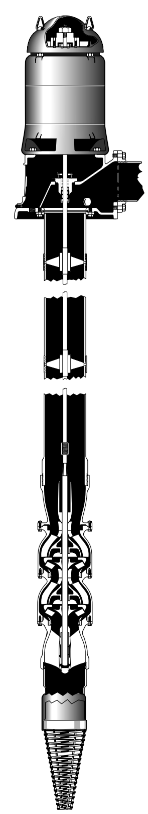
[10] Vertical Turbine Pumps – A classification of centrifugal pumps that are primarily mounted with a vertical shaft; the motor is commonly mounted above the pump. Vertical turbine pumps are either mixed or axial flow devices.



End suction centrifugal



Split case

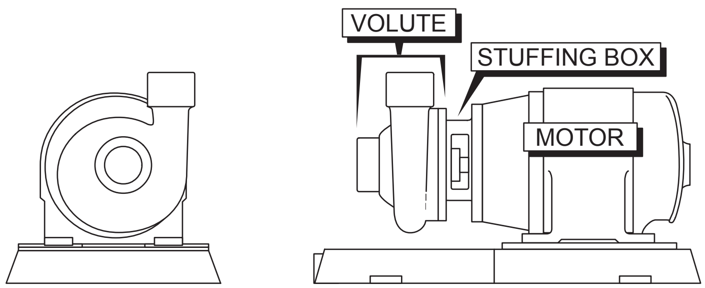


Vertical turbine

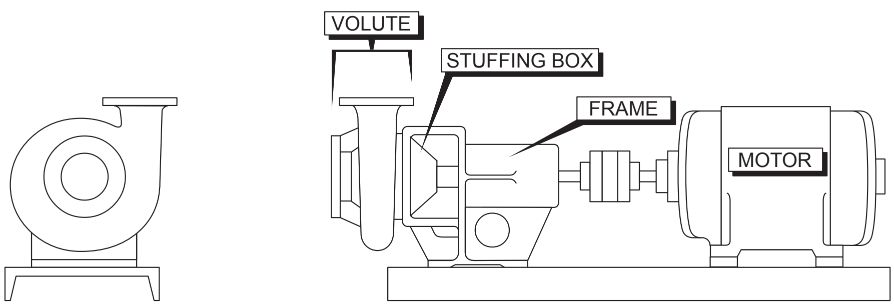
End Suction Centrifugal - Types

The end suction centrifugal pump is the most common centrifugal pump and the one we have in mind when we think about centrifugal pumps. There are two types of end suction pumps:

- **Close-coupled**[11] – A close-coupled pump has only one shaft and one set of bearings: the motor shaft and bearings. The pump impeller is placed directly onto the motor shaft. Close-coupled pumps require less space and are less expensive than frame-mounted pumps.



- **Frame-mounted**[12] – A frame-mounted pump has a shaft and bearings separate from the motor. A coupling is required to get the energy from the motor to the pump.



For safety purposes, couplings should have guards installed.

Split Case Pumps

Split case pumps are unique. The case has a row of bolts that allow half of the case to be removed, providing access to the entire rotating assembly for inspection or removal. These pumps are normally found as fire service pumps and circulation pumps in medium-to-large communities. The circulation pumps in Nome and Fairbanks are split case pumps.

Vertical Turbines

There are four styles of vertical turbines: **line shaft**[13], **axial flow**[14], **can turbine**[15] and the **submersible turbine**[16]. The vertical turbine and the submersible turbine are found in rural communities in Alaska. The primary difference between the vertical turbine and the submersible turbine is the position of the motor. The pumping assembly is the same. Submersible turbine pumps in Alaska can range from 5 gpm to 100 gpm or more.

[11] Close-coupled Pumps – End suction centrifugal pumps in which the pump shaft and motor shaft are the same. The pump bearings and motor bearings are also the same. The impeller is attached directly onto the end of the motor shaft.

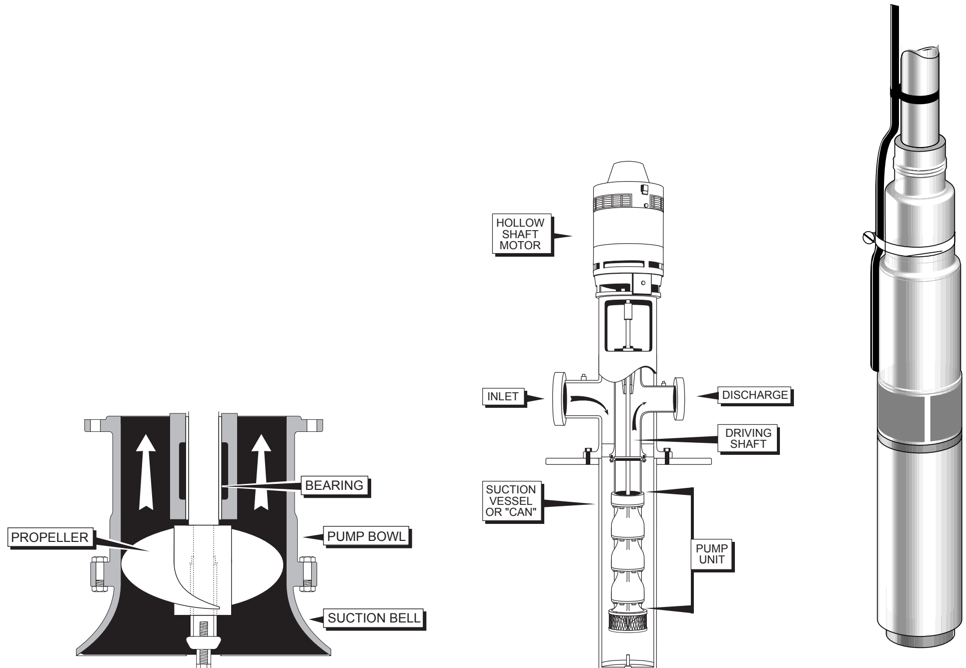
[12] Frame-mounted Pumps – End suction centrifugal pumps designed so that the pump bearings and pump shaft are independent of the motor. This type of pump requires a coupling between the pump and the motor in order to transfer energy from the motor to the pump.

[13] Line Shaft Turbine Pumps – A type of vertical turbine. In this type of vertical turbine, the motor is mounted above the ground, and the pump unit is mounted below the water surface. A column extends from the pump to a discharge head found just below the motor. A shaft extends on a straight line from the center of the motor to the pump. The pump may be mounted a few feet to several hundred feet away from the motor.

[14] Axial Flow Pumps – A type of vertical turbine that uses a propeller instead of an impeller. In axial flow pumps, the energy is transferred into the water so that the direction of the flow is directly up the shaft.

[15] Can Turbine Pumps – A type of line shaft turbine. The pump assembly is mounted inside of a sealed can. The inlet is mounted opposite the outlet on the discharge head. The can must always be under pressure.

[16] Submersible Turbine Pumps – A style of vertical turbine pump in which the entire pump assembly and motor are submersed in the water. The motor is commonly mounted below the pump.



Axial flow turbine   Can turbine   Submersible turbine

End suction Centrifugal and Split Case Components

Shaft and Bearings

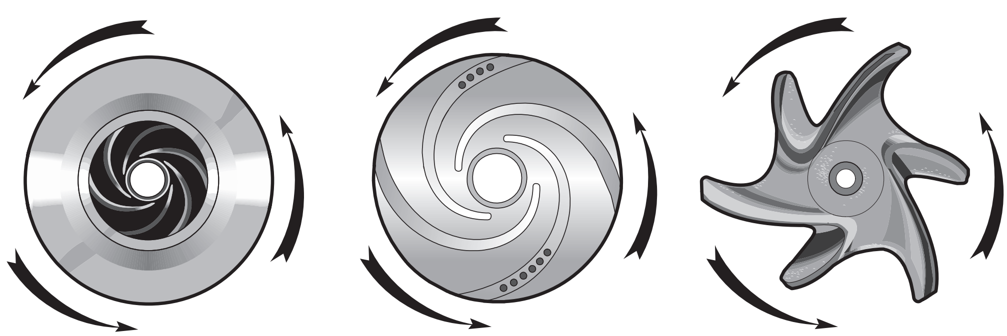
The shaft is used to transfer energy from the motor to the impeller. The most common shaft materials are high carbon steel and stainless steel. Each shaft is supported by bearings that support loads along the shaft, called thrust loads, and loads at right angles to the shaft, called radial loads. The bearings may or may not be part of the motor.

Impellers

The energy is transferred from the shaft to the impeller and from the impeller to the water. There are three types of impellers, based on the number of **shrouds**[17]:

- Closed impeller – When an impeller has a shroud in the front and in the back.
- Semi-open impeller – When there is only a shroud in the back of the impeller.
- Open impeller – When there are no shrouds.

The impeller type is selected by the pump manufacturer to meet specific conditions.



Closed   Semi-open   Open

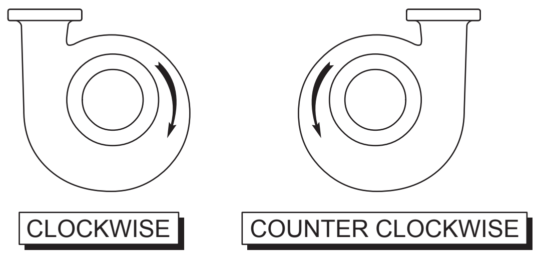
[17] Shroud – The front and/or back of an impeller.

Wear Rings

With closed impellers, the impeller fits very close to the case. As a result, the case is worn by material passing from the high-pressure side to the low-pressure side of the impeller. To protect the case, brass or stainless steel wear rings are inserted into the case.

Volute Case

Around the impeller is the volute case. The volute case gathers the water thrown from the impeller and directs it in a single direction.



Backing Plate

Behind the volute case is the backing plate. The backing plate seals the back of the volute case area.

Stuffing Box

Attached to, and sometimes part of, the backing plate is the **stuffing box**[18]. The stuffing box is where material that controls the leakage of water from around the shaft is placed. The material placed in the stuffing box is either **packing**[19] or a **mechanical seal**[20].

Packing/Mechanical Seals

Packing and mechanical seals serve the same purpose: they control leakage through the stuffing box. Packing is composed of some type of fiber, like cotton, and some type of lubricant, like graphite or Teflon™. A mechanical seal is composed of two finely machined surfaces, one hard and one soft, that prevent water from passing. When installing packing, joints should be staggered.

Packing Gland

In order to control leakage with packing, pressure must be placed on the packing. This pressure is applied by the packing gland, two pieces of metal at the back of the stuffing box.

Lantern Ring

It is often desirable to lubricate and cool the packing with external water or oil. When water is used, it is called **seal water**[21] or flush water. The seal water is distributed into the stuffing box through the lantern ring, which is commonly a brass ring with holes that allow the water to easily pass.

Shaft Sleeve

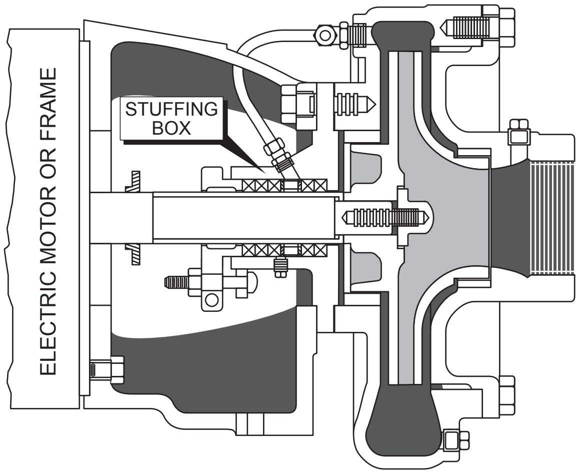
To protect the shaft from damage due to the packing, a shaft sleeve can be installed. A shaft sleeve is a brass or stainless steel sleeve that fits tightly over the shaft.

[18] Stuffing Box – That portion of the pump that houses the packing or mechanical seal. Usually referred to as the dry portion of the pump. The stuffing box is located in back of the impeller and around the shaft.

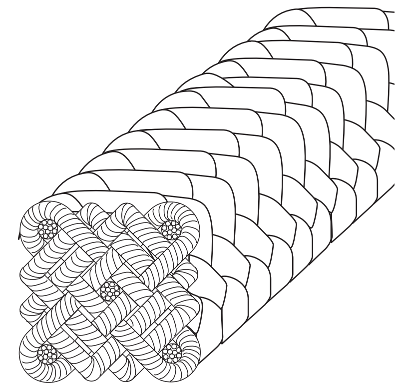
[19] Packing – Material made of woven animal, plant, mineral, or metal fiber and some type of lubricant, placed in rings around the shaft of a pump and used to control the leakage from the stuffing box.

[20] Mechanical Seal – A mechanical device used to control leakage from the stuffing box of a pump and usually made of two flat surfaces, one of which rotates on the shaft. The two flat surfaces are of such close tolerances as to prevent the passage of water between them.

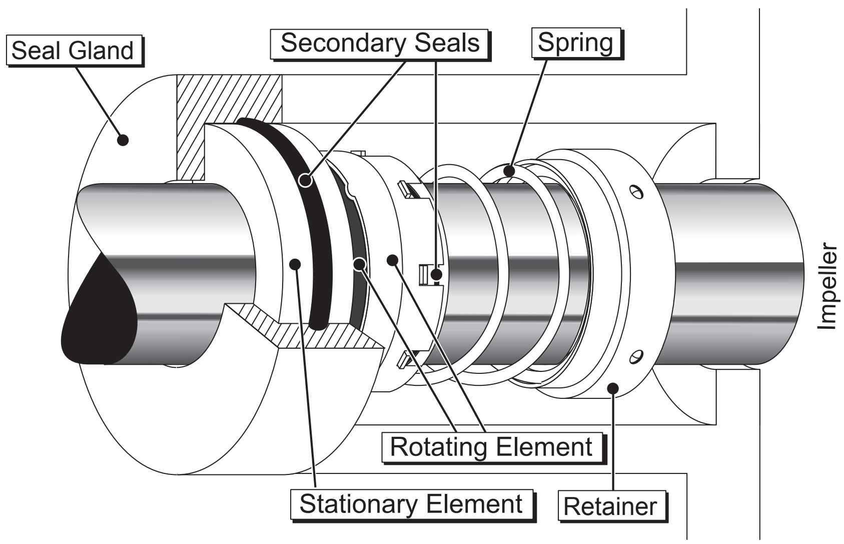
[21] Seal Water – The water supplied to the stuffing box to lubricate and flush the packing or the mechanical seal.



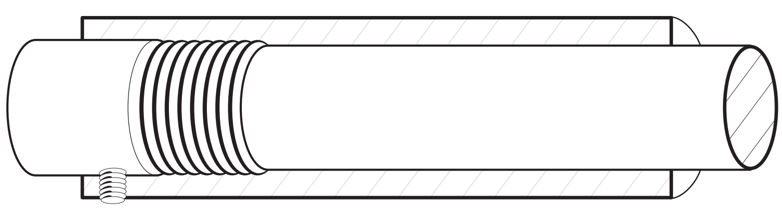
Stuffing box



Packing



Mechanical seal



Shaft sleeve threaded to shaft

Review

1. List the two major categories of pumps.

2. How is energy transferred from the impeller of a centrifugal pump to the water?

3. The energy placed into the water by a pump can be expressed as an increase in _______________ and an increase in _______________.

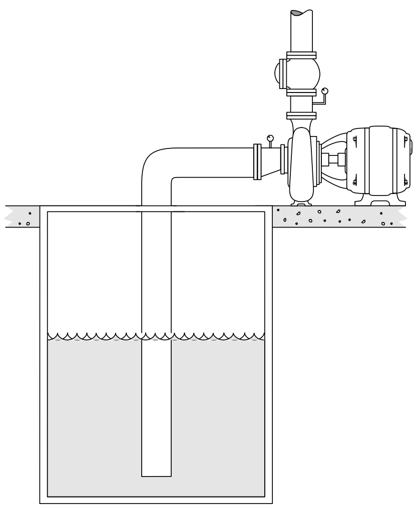
End suction Centrifugal and Split Case Piping

Suction Conditions

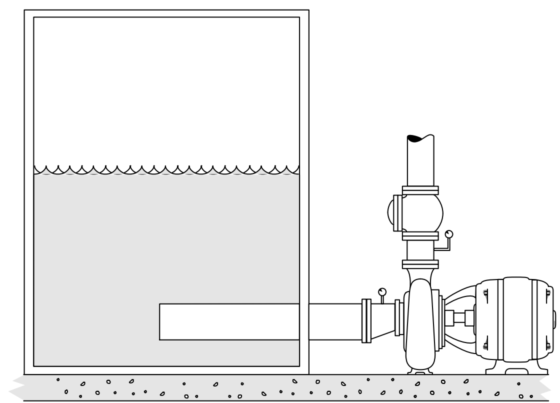
End suction and split case pumps can be installed in **suction lift**[22] or **suction head**[23] conditions. (See Hydraulics section for a more detailed explanation.) The piping system associated with the pump varies slightly depending on the suction conditions. Since the suction lift condition is the most difficult, it is used in the following description.

[22] Suction Lift – A pumping condition where the eye of the impeller of the pump is above the surface of the water from which the pump is pumping.

[23] Suction Head – A pumping condition where the eye of the impeller of the pump is below the surface of the water from which the pump is pumping.



Suction lift



Suction head

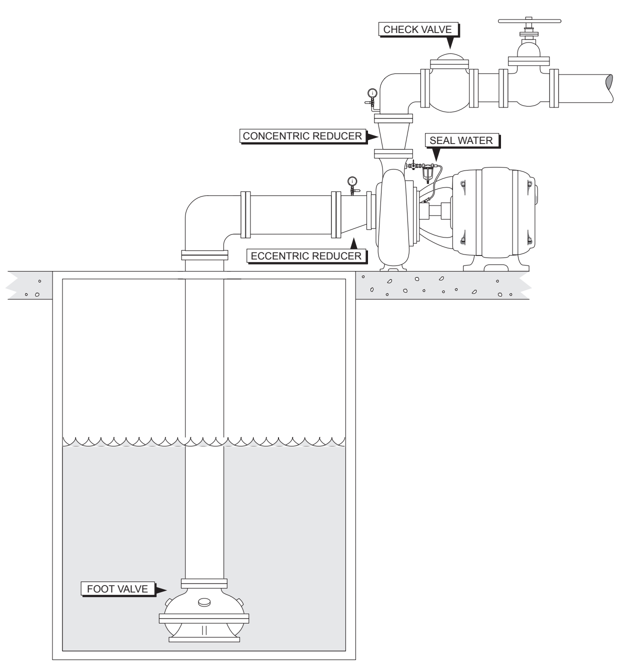
Suction Piping

Most pumps in a suction lift condition require a **foot valve**[24] on the end of the suction line to prevent the pump from losing prime. Most foot valves are large globe valves. The suction piping is usually designed one pipe size larger than the inlet of the pump with smooth piping material and fittings. Isolation valves on the suction side of a pump should only be gate or ball valves. Butterfly valves cause high **headloss**[25]. As the piping reaches the pump, it is reduced to meet the pump connection using an **eccentric reducer**[26]. The eccentric reducer prevents air accumulation in the piping.

[24] Foot Valve – A one-way valve placed at the entrance of a suction line that is opened by the flow of water. The purpose of the valve is to prevent reverse flow.

[25] Headloss – The loss of energy as a result of friction, commonly expressed in feet. The loss is actually a transfer to heat.

[26] Eccentric Reducer – A device used to connect a large pipe to a smaller pipe so that one edge of both pipes is aligned.



[27] Concentric Reducer – A device used to connect a large pipe to a smaller pipe so that the center lines of both pipes are aligned.

Discharge Piping

The discharge side of a pump usually starts with a **concentric reducer**[27], which takes the pipe up to one pipe size larger than the pump discharge. An isolation valve, preferably a gate or ball valve, is normally installed on the discharge. To reduce repair costs, a flange-by-flange spool or expansion joint is placed between the isolation valve and the pump.

Controlling Flow and Pressure

Ball valves and wide body globe valves are used to control flow and pressure from a pump as well as reduce water hammer during shutdown.

Check Valve

To prevent the flow of water back through the pump, a check valve is often placed in the discharge line. If there is a flow or pressure control valve, then a check valve is not necessary.

Gauges

To evaluate pump operating conditions, pressure gauges are placed on the suction and discharge sides of a pump. Ball valves are installed at the base of the gauges to allow easy replacement and to shut the gauges off when not in use, thus extending their life.

Seal Water

Seal water is usually supplied from the discharge of the volute case. If the seal water is obtained from some other source, a pressure gauge should be installed in the seal water line in order to assure that flow is in the correct direction, and backflow protection should be provided with an air gap.

Vertical Turbine Components

Line Shaft and Submersible

Vertical turbines, as discussed here, include line shaft and submersible turbines.

Inlet

[28] Pump Bowl - The case that functions as a volute case on a mixed flow vertical turbine.

Water enters the vertical turbine through the suction bell. It then passes into the **pump bowl**[28]. The bowl serves the same function as the volute case on an end suction centrifugal. This is where energy is transferred to the water by the impellers.

Impellers

Most line shaft and submersible turbines have more than one impeller. Each impeller and pump bowl is referred to as a pump stage. Adding stages increases the discharge pressure of the pump, but not its flow.

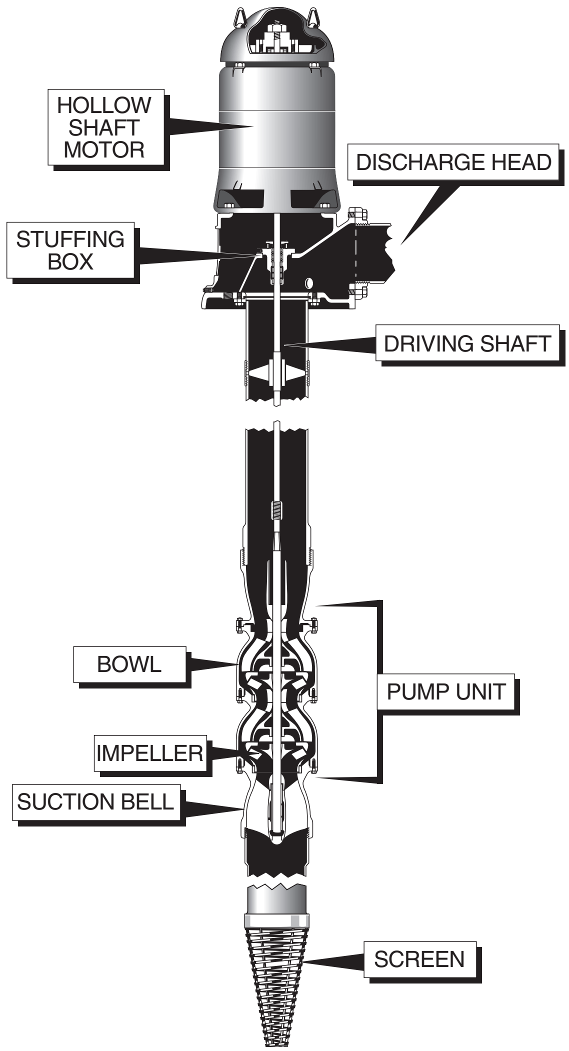
Column

Water passes out of the pump bowl assembly and into the column. In the center of the column is the pump shaft, which may be lubricated with water or oil.

Discharge Head

The large cast iron component at the top of the pump is the discharge head. It is here that the direction of flow is changed from vertical to horizontal. The discharge head also contains the stuffing box and the mechanical seal or packing.

Motor
On top of the discharge head is the pump motor. The motor can be removed from the pump by removing a nut on the pump shaft located on the top of the motor. The motor can then be lifted off the pump shaft for maintenance.

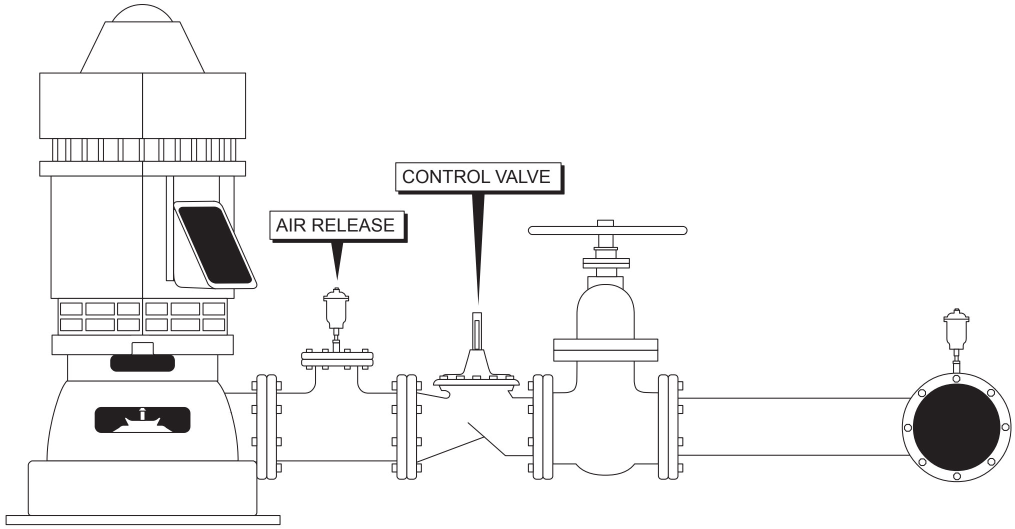


Lineshaft turbine

Vertical Turbine Special Piping
Reversal of Flow
When a vertical turbine is shut down, water runs back down the column or drop line. Line shaft turbines have special non-reversing ratchets built into the motor to prevent the pump from spinning backwards. Small submersible turbines are installed with a check valve at the top of the pump to prevent water from running backwards through the pump.

Air Control
To prevent contamination from entering the discharge line through the stuffing box, an air valve is placed on the discharge line. This valve allows air in and, when the pump starts, allows the air out.

Flow – Pressure Control
Like the end suction centrifugal, flow and pressure control with vertical turbines is accomplished using wide body globe valves and butterfly valves.



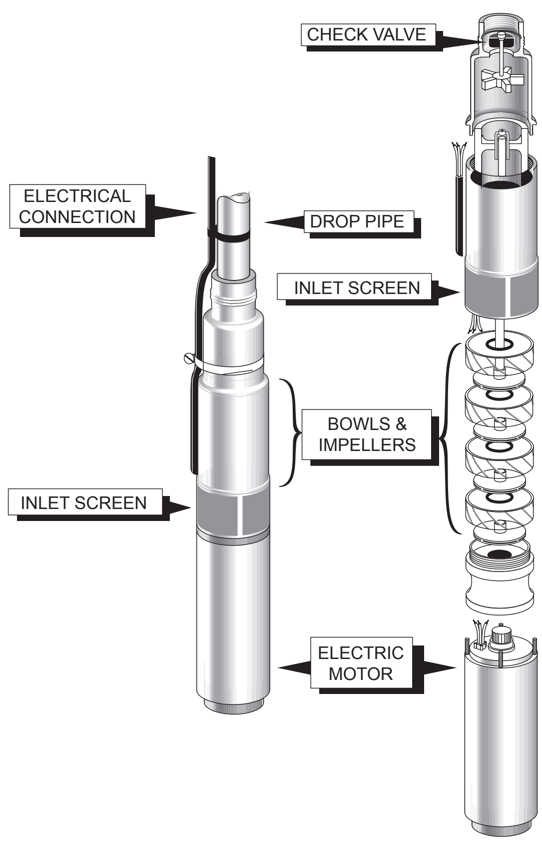
Submersible Turbine Components

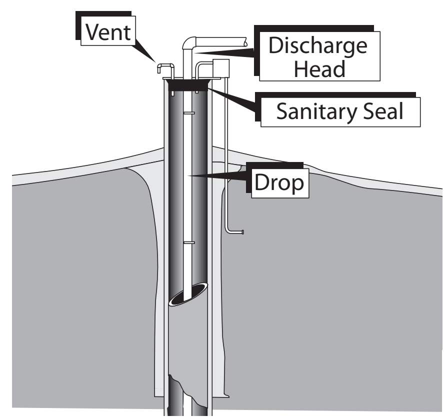
Inlet

The water inlet into a submersible turbine is between the pump and the motor. Water moves through pump bowls that are, in most cases, identical to those of the line shaft turbine.

Drop Pipe

Water moves up from the submersible turbine, through the drop pipe, and out the discharge head.





Cavitation

Cavitation is the condition where vapor bubbles are formed in a flowing liquid when the pressure of the liquid falls below its vapor pressure. Once the bubbles reach an area where the pressure increases above vapor pressure, the bubbles collapse thereby creating small areas of high temperature and emitting shock waves.

Cavitation in a centrifugal pump occurs when the inlet pressure falls below the design inlet pressure or when the pump is operating at a flow rate higher than the design flow rate. When the inlet pressure in the flowing liquid falls below its vapor pressure, bubbles begin to form in the eye of the impeller. Once the bubbles move to an area where the pressure of the liquid increases to above its vapor pressure, the bubbles collapse thereby emitting a "shock wave." These shock waves can pit the surface of the impeller and shorten its service life. The collapse of the bubbles also emits a pinging or crackling noise that can alert the operator that cavitation is occurring.

Cavitation is undesirable because it can damage the impeller, cause noise and vibration, and decrease pump efficiency.

Positive Displacement Pumps

Major Components

While there are several different types of positive displacement pumps available, this section is limited to those commonly used in small water systems.

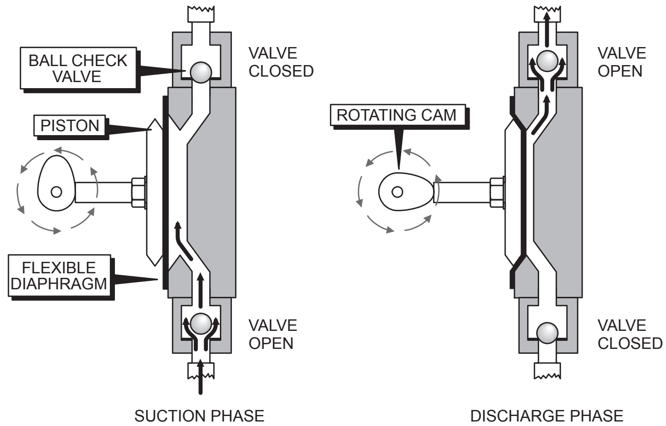
Never pump against a closed discharge or suction valve when using any positive displacement pump. This could result in severe damage to personnel and/or equipment.

Diaphragm Pumps

The diaphragm pump is composed of the following:

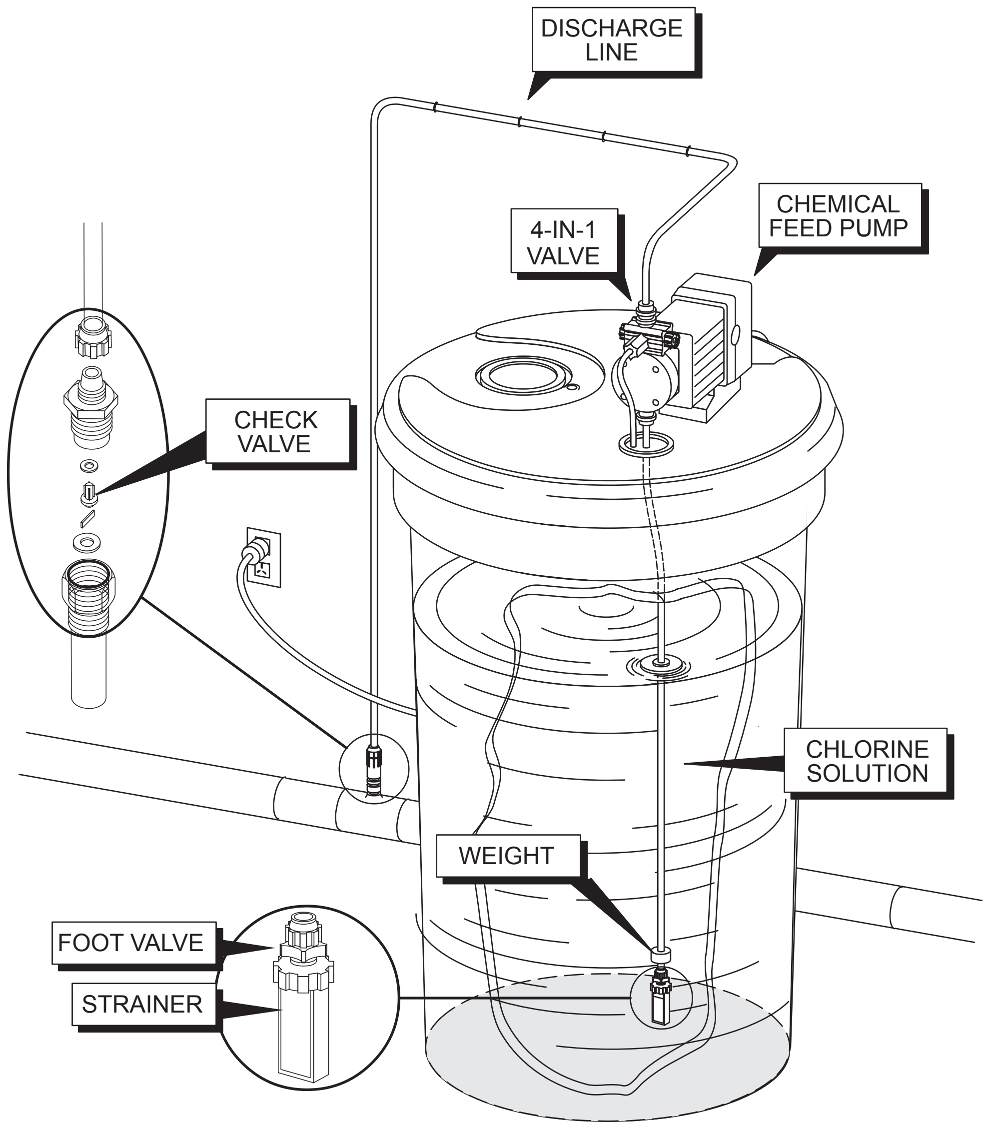
- A chamber used to pump the fluid
- A diaphragm operated by either electric or mechanical means
- Two valve assemblies: a suction valve assembly and a discharge valve assembly

When the diaphragm is pulled back, a vacuum is created in the chamber in front of the diaphragm. This vacuum causes the discharge valve to be forced closed against its seat. The vacuum allows atmospheric pressure to push fluid up against the outside of the suction valve, opening the valve and filling the chamber. When pressure is returned to the diaphragm, forcing it toward the front of the chamber, the increased pressure causes the suction valve to be forced closed and the discharge valve to be forced open. The fluid is pushed out of the chamber, and the pumping cycle starts over.



Piping System

The piping system for diaphragm pumps used to pump chemicals is relatively simple. There are a foot valve and screen on the suction line and a check valve on the end of the discharge line. The foot valve prevents loss of prime. The discharge check valve prevents the system water from flowing back into the chemical feed tank.



Piping System

Peristaltic Pumps

A peristaltic pump is a type of positive displacement pump used for pumping a variety of fluids, such as chemicals and sludges. The fluid is contained within a flexible tube fitted inside a circular pump casing. A rotor with a number of rollers (or shoes) is attached to a rotating arm that compresses the flexible tube. As the rotor turns, the part of tube under compression closes, thus forcing the fluid to be pumped through the tube. This works much like squeezing toothpaste out of a tube.

Since they have no moving parts in contact with the fluid, peristaltic pumps are inexpensive to manufacture. Their lack of valves, seals, and glands makes them comparatively inexpensive to maintain, and the use of a hose or tube makes for a relatively low-cost maintenance item compared to other pump types.

It is important to select tubing with appropriate chemical resistance towards the liquid being pumped. Types of tubing commonly used in peristaltic pumps include polyvinyl chloride (PVC), silicone rubber, and fluoropolymer. Trade names include Tygon™ and Viton™.

Progressive Cavity Pumps

A progressive cavity pump moves fluid by means of a rotary screw or rotor turning within a stationary stator. The flow rate is proportional to the rotation rate of the pump. Progressive cavity pumps are designed to transfer fluid or fluids with suspended solids. They are frequently used to pump sludge, but can be used to meter large volumes of chemicals in a precise manner.

Operation

As the rotor turns, "humps" built into the rotor move within cavities in a synthetic rubber stator. This action squeezes material out of the end of the pump in much the same way as with peristaltic pumps. These pumps should always run with a fluid inside to lubricate the pump. A progressive cavity pump should never be operated against a closed valve.

Basic Hydraulic Terms and Concepts

This brief discussion on hydraulics is intended as a background necessary to understand the pumping and piping systems at a beginning level. The lesson is divided into two parts; 1) basic hydraulic terms and concepts and 2) pumping hydraulics.

Weight-Volume Relationship

Weight per Cubic Foot

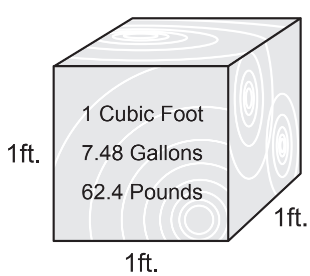
Cubic feet and gallons are both used to describe a volume of water. There is a defined relationship between these two methods of measurement. The specific weight of water is defined relative to a cubic foot. One cubic foot of water weighs 62.4 pounds. This relationship is true only at a temperature of 4°C and at a **pressure**[29] of one atmosphere (called standard temperature and pressure). However, the weight varies so little that for practical purposes we use this weight from a temperature of 0°C to 100°C.

[29] Pressure – The force exerted on a unit area. Pressure = Weight x Height. In water, it is usually measured in psi (pounds per square inch). One foot of water exerts a pressure of 0.433 pounds per square inch.

1 ft^3 H_2O= 62.4 lbs

Volume per Cubic Foot

At standard temperature and pressure, one cubic foot of water contains 7.48 gallons. With these two relationships we can determine the weight of one gallon of water. This is accomplished by dividing the weight (62.4 lbs) by the volume in gallons (7.48 gallons per cubic foot).



$$\text{wt of gal of water} = \frac{62.4 \text{ lbs}}{7.48 \text{ gal}} = 8.34 \text{ lbs/gal}$$

Summary
1 ft^3 H_2O = 7.48 gallons
1 gallon H_2O = 8.34 pounds

Conversion ft^3 to gallons
With this information we can convert cubic feet to gallons by simply multiplying the number of cubic feet by 7.48 gal/ft^3.

Example – Conversion ft^3 to gallons

Find the number of gallons in a reservoir that has a volume of 668.5 ft^3.

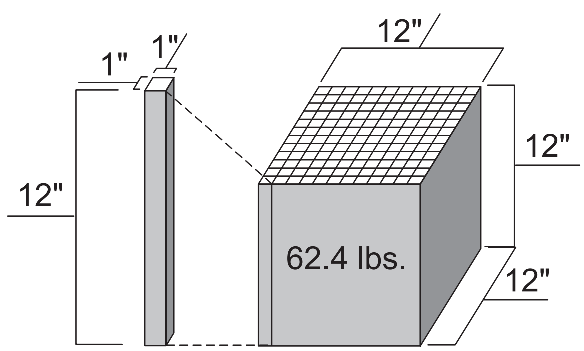
668.5 ft^3 x 7.48 gal/ft^3 = 5,000 gallons

Force and Pressure

Force
In the English system **force**[30] and weight are often used in the same way. The weight of the cubic foot of water is 62.4 pounds. The force exerted on the bottom of the one foot cube is 62.4 pounds. If we have two cubes stacked on top of one another, the force on the bottom will be 124.8 pounds.

[30] Force – Influence (as a push or pull) that causes motion. Physics - The mass of an object times its acceleration: F = ma.

Pressure
Pressure is a force per unit of area, pounds per square inch or pounds per square foot are common expressions of pressure. The pressure on the bottom of our cube is 62.4 pounds per square foot. It is normal to express pressure in pounds per square inch (psi). This can be accomplished by determining the weight of one square inch of our cube one foot high. Since the cube is 12 inches on each side, the number of square inches on the bottom surface of the cube is 12 x 12 = 144 in^2. Now by dividing the weight by the number of square inches we can determine the weight on each square inch.



$$psi = \frac{62.4 \text{ lbs/ft}}{144 \text{ in}^2} = 0.433 \text{ psi/ft}$$

This is the weight of a column of water one inch square and one foot tall. If the column of water were two feet tall and the pressure would be 2 ft x 0.433 psi/ft = 0.866 psi.

1 ft of water = 0.433 psi

Conversion feet to psi
With the above information we can convert feet of **head**[31] to psi by multiplying the feet of head times 0.433 psi/ft.

[31] Head – The measure of the pressure of water expressed as height of water in feet: 1 psi = 2.31 feet of head.

Example – Conversion feet to psi

A reservoir is 40 feet tall. Find the pressure at the bottom of the reservoir.

40 ft x 0.433 psi/ft = 17.3 psi

Conversion of psi to feet

The conversion of psi to feet is simply made by dividing the psi by 0.433 psi/ft.

Example – Conversion of psi to feet

Find the height of water in a tank if the pressure at the bottom of the tank is 12 psi.

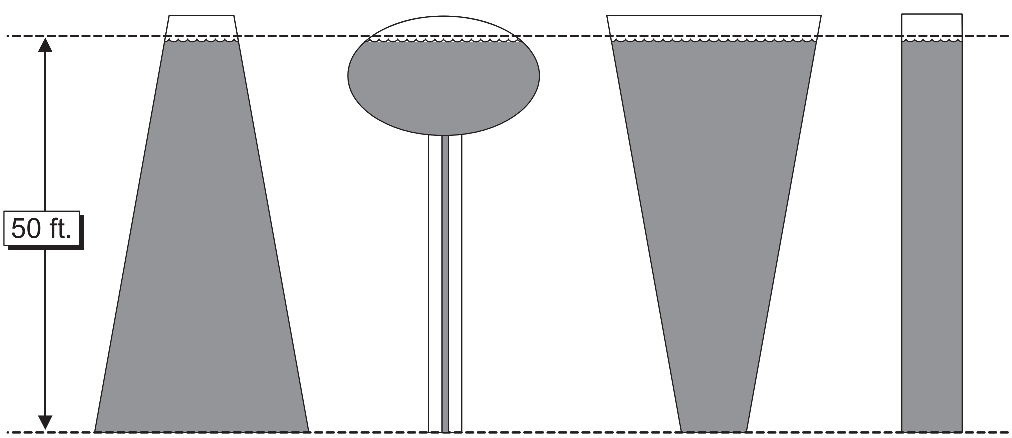
12 psi ÷ 0.433 psi/ft = 27.7 ft

Pressure and Head

Pressure is directly related to the height of a column of fluid. This height is called head or feet of head. From the discussion above we see there is a direct relationship between feet of head and pressure. The relationship is that for every one foot of head there is a pressure of 0.433 psi.

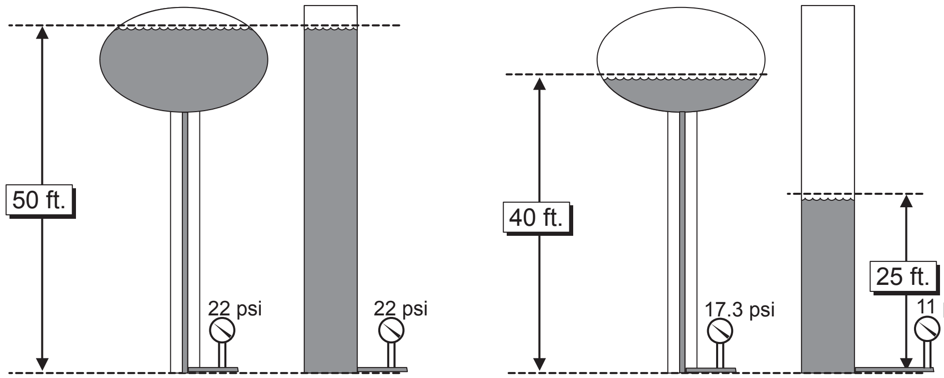
Pressure Relative to Container Size

The pressure at the bottom of a container is affected only by the height of water in the container and not by the shape of the container. In the drawing below there are four containers all of different shapes and sizes. The pressure at the bottom of each is the same.



Pressure and Volume

The pressure exerted at the bottom of a tank is relative only to the head on the tank and not the volume of water in the tank. For example, below are two tanks each containing 5000 gallons. The pressure at the bottom of each is 22 psi. If half of the water were drained from the tanks the pressure at the bottom of the elevated tank would be 17.3 psi while the pressure at the bottom of the standpipe would be 11 psi.



Velocity and Flow

Velocity

Velocity is the speed that the water is moving along a pipe or through a basin. Velocity is usually expressed in feet per second, ft/sec.

Flow

Flow is commonly expressed in gallons per minute (gpm) and/or cubic feet per second (cfs). There is a relationship between gallons per minute and cubic feet per second. One cubic foot per second is equal to 448.8 gallons per minute.

1 cfs = 448.8 gpm

Flow Equation

The basic equation for determining flow is as follows:

$Q = V \times A$

Where:
Q = cfs (ft^3/sec)
V = ft/sec
A = ft^2

Static and Dynamic Conditions

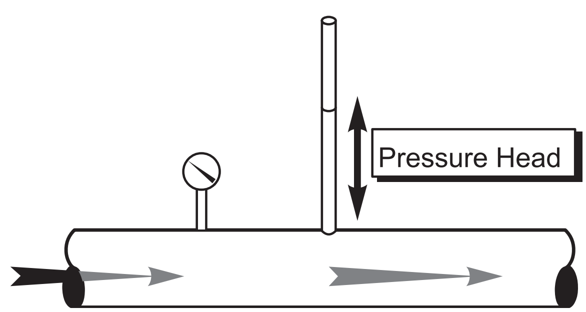
Static Pressure

The pressure measured when there is no water moving in a line or the pump is not running is called **static**[32] pressure. This is the pressure represented by the gauges on the tanks in the discussion above.

[32] Static – A non-moving condition.

Dynamic Pressure

When water is allowed to run through a pipe and the pressure (called pressure head) measured at various points along the way we find that the pressure decreases the further we are from the sources.



Headloss
The reason for this reduction in pressure is a phenomenon called headloss. Headloss is the loss of energy (pressure) due to friction. The energy is lost as heat.

Explanation
When we hear that the headloss in a certain pipe is 25 feet, that means the amount of energy required to overcome the friction in the pipe is equivalent to the amount of energy that would be required to lift this amount of water straight in the air 25 feet.

Factors Contributing to Headloss
In a pipe, the factors that contribute to headloss include the following:
- Roughness of pipe
- Length of pipe
- Diameter of pipe
- Velocity of water

Comparison of Factors
In general, if the roughness of a pipe were doubled the headloss would double. If the length of the pipe were doubled the headloss would double. If the diameter of a pipe were doubled the headloss would be cut in half and if the velocity of the water in a pipe were doubled the headloss would be increased by about four times. It should be apparent that velocity, more than any other single factor, affects headloss. To double the velocity we would have to double the flow in the line.

Example – Headloss

500 feet of four inch line with a flow of 110 gpm has a headloss of 7.5 feet. At a flow of 220 gpm, the headloss jumps to 26 feet or an increase of 3.5 times.

Fittings and Headloss
Each type of fitting has a specific headloss depending upon the velocity of water through the fitting. For instance the headloss though a check valve is two and one quarter times greater than through a ninety degree elbow and ten times greater than the headloss through an open gate valve.

Pumping Hydraulics

Basic Terms
Static Head
Static head is the distance between the suction and discharge water levels when the pump is shut off. Static head conditions are often indicated with the letter Z.

Suction Lift
Suction lift is the distance between the suction water level and the center of the pump impeller. This term is only used when the pump is in a suction lift condition. A pump is said to be in a suction lift condition any time the eye (center) of the impeller is above the water being pumped.

Suction Head
Suction head is the distance between the suction water level and the center of the pump impeller when the pump is in a suction head condition. A pump is said to be in

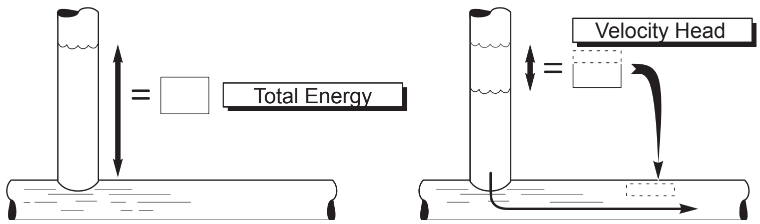
a suction head condition any time the eye (center) of the impeller is below the water level being pumped.

Velocity Head

Velocity head[33] is the amount of energy required by the pump and motor to overcome **inertia**[34] and bring the water up to speed. Velocity head is often shown mathematically as $V^2/2g$. (g is the acceleration due to gravity – 32.2 ft/sec^2).

[33] Velocity Head – The amount of energy required to bring a fluid from standstill to its velocity. For a given quantity of flow, the velocity head will vary indirectly with the pipe diameter.

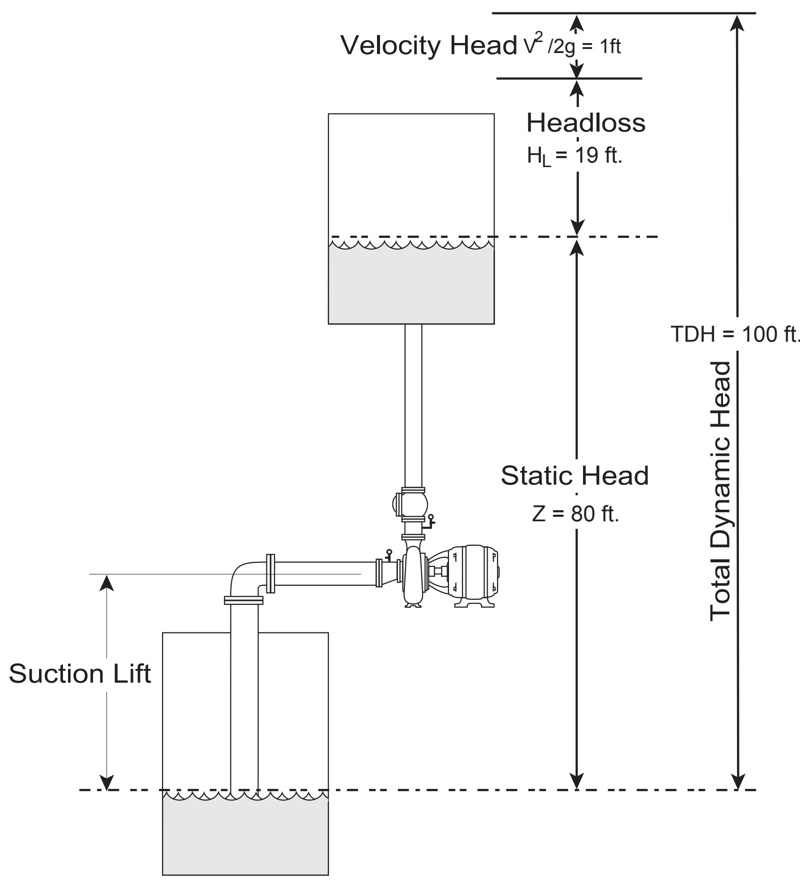
[34] Inertia – The tendency of matter to remain at rest or in motion



Total Dynamic Head

Total dynamic head[35] (TDH) is a theoretical distance. It is the static head, velocity head and headloss required to get the water from one point to another.

[35] Total Dynamic Head (TDH) – The total energy needed to move water from the center line of a pump (eye of the first impeller of a lineshaft turbine) to some given elevation or to develop some given pressure. This includes the static head, velocity head and the headloss due to friction.



Components of total dynamic head

Horsepower

Horsepower[36] is a measurement of the amount of energy required to do work. Motors are rated in horsepower. The horsepower of an electric motor is called brake horsepower. The horsepower requirements of a pump are dependent on the flow and the total dynamic head.

[36] Horsepower – A measurement of work, 33,000 foot pounds per minute of work is 1 horsepower.

Horsepower and Amperage

The horsepower output of an electric motor is directly reflected to the **amperage**[37] that the motor draws. Any increase in horsepower requirements will give a corresponding increase in amperage.

[37] Amperage – The measurement of electron flow.

Pump Response

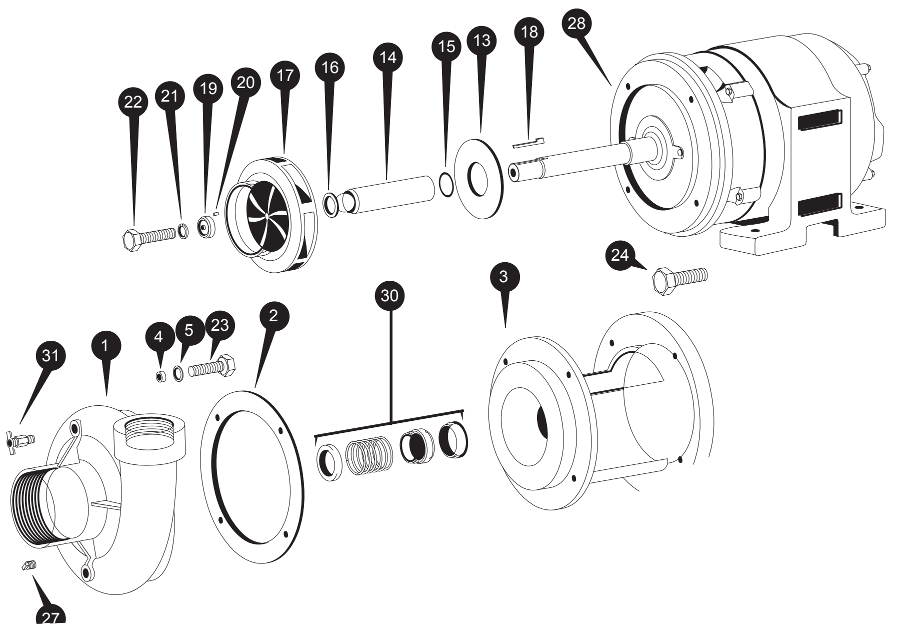
For centrifugal pumps, as the total dynamic head is increased the pump will pump less water and will require less horsepower.

Identification

Identify the components indicated in the drawing below.

______ A. Volute case ______ B. Mechanical seal ______ C. Impeller

______ D. Stuffing box ______ E. Shaft sleeve



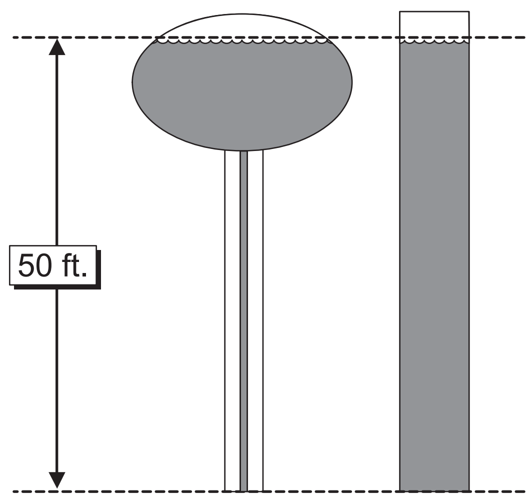
Review

1. One cubic foot of water weighs__________ pounds, and contains ___________ gallons.

1. One gallon of water weighs _____________lbs.

1. Looking at the two reservoirs below, will the pressure at the bottom be:

   A. The same
   B. Greater in the tank on the left
   C. Greater in the tank on the right



1. A tank contains 500 cubic feet. This converts to how many gallons?

1. A flow of one cubic foot per second is equivalent to __________ gpm.

1. Headloss is the result of _____________. The energy given off as a result of headloss is given off as _____________.

1. What term is used to describe the difference between the level of water in a well and the level of water in the reservoir when the pump is shut down?
   ____

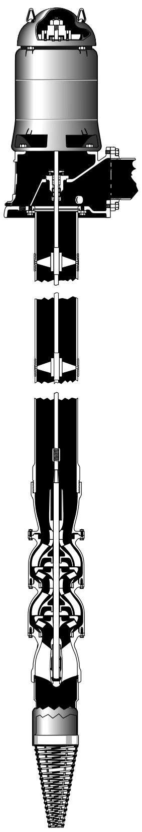
1. What units are used to measure the energy required to do the work of pumping water?
   ____

1. It is 60 feet in elevation from the level of water at the top of the reservoir to the pump house. What is the static water pressure at the pump house?

Identification

Identify the three pumps below by configuration.

1. 2.

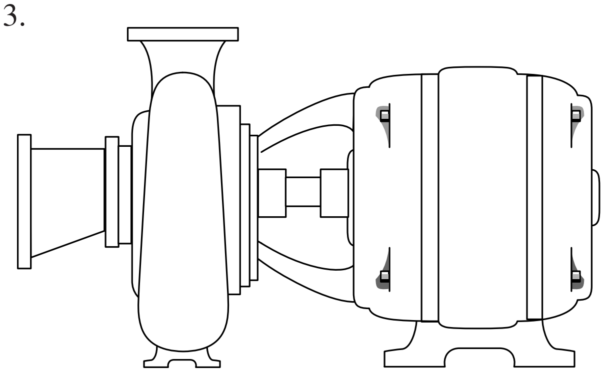


1. ______________________________

2. ______________________________

3. ______________________________

3.



Identify the components indicated in the drawing below.

A. ____________

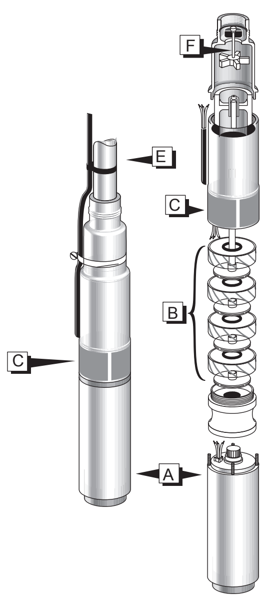
B. ____________

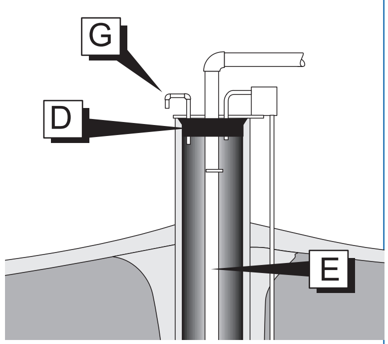
C. ____________

D. ____________

E. ____________

F. ____________





Introduction to Pumping Systems Quiz

1. Which type of pump is frequently used to pump water from wells?
   A. Progressive cavity pumps
   B. Submersible turbine pumps
   C. Reciprocating pumps
   D. Circulating pumps

2. What is the purpose of pump mechanical seals?
   A. Keep leakage off slippery floors
   B. Prevent leakage between the pump casing and shaft
   C. Provide an effective backflow prevention device
   D. Seal water to maintain pump prime

3. What is the primary purpose of priming a pump?
   A. Ensure the pump operates freely
   B. Fill the volute with water
   C. Prevent backflow
   D. Start the seal water flow

4. The component of a centrifugal pump sometimes installed on the end of the suction pipe is called the:
   A. Volute
   B. Foot valve
   C. Impeller
   D. Packing

5. Positive displacement pumps should never be operated:
   A. Backward
   B. With a closed discharge or suction valve
   C. Without supervision
   D. Without a concentric reducer

6. Pumps that are used to feed chemicals should:
   A. Never be run in auto
   B. Never be run dry
   C. Always be controlled by a flow switch
   D. Always be controlled by a level sensor

7. Packing should be adjusted when:
   A. Excessive leakage from the discharge pipe is noticed
   B. Excessive leakage from the stuffing box is noticed
   C. Pump prime is lost
   D. The pump is shut down

8. Closed impellers should be used for:
   A. When the pump is used to pump sludge
   B. When the pump is used to circulate glycol
   C. When the pump is used to pump chemicals
   D. When the pump is used to boost pressure

9. Check valves are used to:
   A. Control leakage from the stuffing box
   B. Ensure pump is isolated from the system for maintenance
   C. Prevent water from flowing in reverse
   D. Fill water storage tanks

10. Pump couplings are used to:
    A. Ensure pump is properly connected to discharge piping
    B. Connect the motor to the pump
    C. Provide cooling water for the stuffing box
    D. Keep the pump primed

11. One cubic foot of water weighs _______________ pounds and contains _______________ gallons.
    A. 8.34 lbs, 7.48 gallons
    B. 7.48 lbs, 62.4 gallons
    C. 11.3 lbs, 5 gallons
    D. 62.4 lbs, 7.48 gallons

12. One gallon of water weighs _______________ lbs.
    A. 3.42 lbs
    B. 7.48 lbs
    C. 8.34 lbs
    D. 4.56 lbs

13. A tank contains 500 cubic feet. This converts to how many gallons?
    A. 3740 gallons
    B. 66.8 gallons
    C. 4170 gallons
    D. 59.9 gallons

14. A flow of one cubic foot per second is equivalent to _______________ gpm.
    A. 62.4
    B. 179.5
    C. 7.48
    D. 448.8

15. Headloss is the result of ______________. The energy given off as a result of headloss is given off as ______________.
    A. Pressure, head
    B. Friction, heat
    C. Flow, electricity
    D. Weight, noise

16. What term is used to describe the difference between the level of water in a well and the level of water in the reservoir when the pump is shut down?
    A. Drawdown
    B. Static head
    C. Well yield
    D. Dynamic head

17. Describe Total Dynamic Head (TDH).
    A. Total pressure a pump will pump
    B. Composed of headloss, velocity head, and static head.
    C. Amount of pressure in a well
    D. A toilet on a submarine

18. What is the difference between suction lift and suction head?
    A. Total dynamic head in the pumping system
    B. Static head between the pump suction and discharge.
    C. Relationship between the eye of the impeller of the pump and the surface water from which the pump is pumping.
    D. There is no difference

19. What units are used to measure the energy required to do the work of pumping water?
    A. Microns
    B. Horsepower
    C. Foot-pounds
    D. Gallons per minute

20. It is 60 feet in elevation from the level of water at the top of the reservoir to the pump house. What is the static water pressure at the pump house?
    A. 500.4 psi
    B. 25.98 psi
    C. 138.6 psi
    D. 448.8 psi