

# CIVIL ENGINEERING

## Environmental Engineering



Comprehensive Theory  
*with Solved Examples and Practice Questions*





### **MADE EASY Publications Pvt. Ltd.**

**Corporate Office:** 44-A/4, Kalu Sarai (Near Hauz Khas Metro Station), New Delhi-110016 | **Ph. :** 9021300500

**Email :** infomep@madeeasy.in | **Web :** www.madeeasypublications.org

## **Environmental Engineering**

Copyright © by MADE EASY Publications Pvt. Ltd.

All rights are reserved. No part of this publication may be reproduced, stored in or introduced into a retrieval system, or transmitted in any form or by any means (electronic, mechanical, photo-copying, recording or otherwise), without the prior written permission of the above mentioned publisher of this book.



**MADE EASY Publications Pvt. Ltd.** has taken due care in collecting the data and providing the solutions, before publishing this book. In spite of this, if any inaccuracy or printing error occurs then **MADE EASY Publications Pvt. Ltd.** owes no responsibility. We will be grateful if you could point out any such error. Your suggestions will be appreciated.

## **EDITIONS**

First Edition : 2015  
Second Edition : 2016  
Third Edition : 2017  
Fourth Edition : 2018  
Fifth Edition : 2019  
Sixth Edition : 2020  
Seventh Edition : 2021  
Eighth Edition : 2022  
Ninth Edition : 2023  
Tenth Edition : 2024  
Eleventh Edition : 2025  
**Twelfth Edition : 2026**

# CONTENTS

## Environmental Engineering

SECTION

A

### Water Supply Engineering

#### CHAPTER 1

##### Water Demand ..... 1-26

1.1	Introduction .....	1
1.2	Water Demand .....	1
1.3	Various Types of Water Demand .....	1
1.4	The Per Capita Demand (q).....	5
1.5	Factors Affecting Losses and Wastes .....	7
1.6	Variation in demand .....	7
1.7	Design Period of Water Supply Unit .....	10
1.8	Population Forecasting .....	11
	<i>Objective Brain Teasers</i> .....	21
	<i>Conventional Brain Teasers</i> .....	25

#### CHAPTER 2

##### Sources of Water .....27-57

2.1	Introduction .....	27
2.2	Geological Factors governing the occurrence of ground water .....	28
2.3	Zones of Under-ground water .....	28
2.4	Movement of Ground water .....	29
2.5	Geological Formations.....	30

2.6	Some important terms .....	31
2.7	Sources of Ground Water .....	33
2.8	Yield of an Open Well .....	38
2.9	Interference among wells.....	49
2.10	Well Loss .....	51
2.11	Non-equilibrium formula for confined aquifers (Unsteady radial flows) .....	52
	<i>Objective Brain Teasers</i> .....	54
	<i>Conventional Brain Teasers</i> .....	56

#### CHAPTER 3

##### Water Quality : Definition, Characteristics and Perspective ..... 58-97

3.1	Introduction .....	58
3.2	The Hydrologic Cycle and Water Quality.....	58
3.3	Water Quality Parameters.....	59
3.4	Physical Water Quality Parameter.....	60
3.5	Chemical Water Quality Parameters .....	64
3.6	Biological Water Quality Parameter .....	82
	<i>Objective Brain Teasers</i> .....	86
	<i>Conventional Brain Teasers</i> .....	95

**CHAPTER 4****Treatment of Water.....98-200**

4.1	Introduction .....	98
4.2	Types of Treatment.....	98
4.3	Pre-Treatment .....	101
4.4	Sedimentation .....	105
4.5	Sedimentation tank .....	109
4.6	Plain sedimentation tank.....	111
4.7	Sedimentation aided with Coagulation .....	120
4.8	Coagulation Sedimentation plant.....	127
4.9	Filtration.....	137
4.10	Slow Sand Filter .....	141
4.11	Rapid Sand Filter (Gravity Type) .....	144
4.12	Pressure Filters.....	155
4.13	Disinfection.....	156
4.14	Minor Method.....	157
4.15	Chlorination.....	159
4.16	Types of Chlorination .....	163
4.17	Testing of Chlorine Residuals .....	167
4.18	Kinetics of Disinfection .....	168
4.19	Factors affecting bactericidal efficiency of chlorine .....	171
4.20	Water Softening .....	171
4.21	Miscellaneous Treatment.....	178
	<i>Objective Brain Teasers</i> .....	181
	<i>Conventional Brain Teasers</i> .....	198

**CHAPTER 5****Distribution System..... 201-219**

5.1	Introduction .....	201
5.2	Systems of Water Supply.....	201
5.3	Methods of Water Distribution .....	201
5.4	Layouts of Distribution System .....	202
5.5	Pressure in the Distribution System.....	205
5.6	Detection of Leakage in Distribution System .....	205
5.7	Analysis of Network of Pipes .....	206
5.8	Appurtenances in Plumbing System.....	209
5.9	Water Supply System Plumbing.....	210
5.10	Service Connection.....	211
5.11	Water Storage for Buildings.....	212
5.12	Balancing Reservoir/Service Reservoir .....	212
	<i>Objective Brain Teasers</i> .....	216
	<i>Conventional Brain Teasers</i> .....	218

**CHAPTER 6****Conduits and Appurtenances..... 220-244**

6.1	Introduction .....	220
6.2	Conduits for Water Supply .....	220
6.3	Calculation of Head loss caused by Pipe Friction .....	221
6.4	Forces Acting on Pressure Conduits .....	224
6.5	Types of Pipes .....	226
6.6	Joints in Water Supply Pipes.....	231
6.7	Corrosion in Pipes (Metals).....	233
6.8	Pipe Appurtenances .....	234
6.9	Testing of the Pipe Lines .....	238
6.10	Economical Diameter of the Pumping Mains .....	239
	<i>Objective Brain Teasers</i> .....	240
	<i>Conventional Brain Teasers</i> .....	242

## SECTION

## B

## Waste Water Engineering

## CHAPTER 7

**Waste Water Characteristics ..... 245-268**

7.1	Introduction .....	245
7.2	Characteristics of Sewage .....	245
7.3	Determination of BOD .....	251
7.4	BOD-Curve .....	254
7.5	Population Equivalent .....	258
7.6	Relative Stability .....	260
7.7	Some Important Ratios .....	260
	<i>Objective Brain Teasers</i> .....	263
	<i>Conventional Brain Teasers</i> .....	267

## CHAPTER 8

**Biochemical Reactions in Treatment of Waste Water .....269-275**

8.1	Introduction .....	269
8.2	Biochemical Reactions.....	269
	<i>Objective Brain Teasers</i> .....	275

## CHAPTER 9

**Disposing of the Sewage Effluents.....276-298**

9.1	Introduction .....	276
9.2	Disposal by Dilution .....	276
9.3	Dilution of waste water in Rivers .....	278
9.4	Factors affecting self purification of natural stream	281
9.5	Zone of Pollution in River Stream .....	281
9.6	Indices of Self Purification .....	282
9.7	Oxygen deficit of a polluted river stream .....	283
9.8	Disposal of Waste Water in Lakes .....	288
9.9	Biological Zones in Lakes.....	289
9.10	Productivity of Lake .....	290
9.11	Disposal of Waste Water in Sea Water .....	290
9.12	Disposal on Land .....	291
	<i>Objective Brain Teasers</i> .....	294
	<i>Conventional Brain Teasers</i> .....	297

## CHAPTER 10

**Design of Sewerage System and Sewer Appurtenances ..... 299-344**

10.1	Introduction .....	299
10.2	Types of sewage and sewage system.....	299
10.3	Types of Collection System .....	300
10.4	Egg Shaped Sewer .....	303
10.5	Estimation of Sewage discharge.....	304
10.6	Estimation of Storm discharge .....	305
10.7	Determination of flow velocities.....	307
10.8	Maximum & minimum velocities to be generated in sewers .....	309
10.9	Hydraulic Characteristics of Circular sewer sections running full or partially full.....	312
10.10	Sewer Materials .....	316
10.11	Laying of Sewer Pipes .....	322
10.12	Sewer Appurtenances .....	325
10.13	Corrosion of Concrete Sewers.....	334
10.14	Ventilation of sewer .....	335
10.15	Maintenance and cleaning of Sewer .....	336
	<i>Objective Brain Teasers</i> .....	337
	<i>Conventional Brain Teasers</i> .....	342

## CHAPTER 11

**Treatment of Sewage..... 345-460**

11.1	Introduction .....	345
11.2	Treatment Methods .....	345
11.3	Classification of treatment process.....	347
11.4	Screening.....	350
11.5	Comminutors .....	352
11.6	Disposal of Screenings.....	353
11.7	Grit Removal Basins .....	353
11.8	Detritus Tanks .....	361
11.9	Skimming Tanks and Vacuators.....	362
11.10	Sedimentation .....	363
11.11	Secondary Treatment Through Biological Filtration of Sewage .....	367
11.12	Secondary Settling Tanks or Humus Tanks.....	381
11.13	Digestion of Primary and Secondary Sludge .....	382

11.14 Sludge Digestion Tank or Digesters (Aerobic Suspended Culture) .....	391
11.15 Disposal of Digested Sludge .....	395
11.16 activated sludge process (aerobic suspended culture).....	399
11.17 Design Consideration Involved in an Activated Sludge Plant .....	408
11.18 rotating biological contactors .....	419
11.19 Aerobic Stabilization Units .....	420
11.20 Anaerobic Stabilisation Units.....	427
<i>Objective Brain Teasers</i> .....	441
<i>Conventional Brain Teasers</i> .....	457

**CHAPTER 12****Solid Waste Management ..... 461-489**

12.1 Introduction .....	461
12.2 Municipal Solid Wastes.....	461

12.3 Functional Elements of Solid Waste Management...	463
12.4 Industrial Waste Water .....	485
<i>Objective Brain Teasers</i> .....	488

**CHAPTER 13****Ventilation of Buildings for Controlling Indoor Air Pollution..... 490-505**

13.1 Introduction .....	490
13.2 Effects of Occupancy of a Space .....	490
13.3 Purpose of Ventilation .....	491
13.4 Systems of Ventilation.....	491
13.5 Traps in Sanitary Plumbing System .....	495
13.6 System of Plumbing .....	498
13.7 Sanitary Fitting and Other Accessories.....	502
13.8 Ventilation of House Drains .....	503
13.9 Antisiphonage Pipes .....	504
<i>Objective Brain Teasers</i> .....	505

## SECTION

## C

**Air & Noise Pollution Engineering****CHAPTER 14****Air Pollution ..... 506-556**

14.1 Introduction .....	506
14.2 Classification of Air Pollutants Based on Sources .....	506
14.3 Various Pollutants Causing Pollution of Air.....	507
14.4 Suspended Particulate matter (SPM) .....	509
14.5 Effects of Air Pollution.....	512
14.6 Photochemical Air Pollution.....	515
14.7 Photochemical Smog.....	516
14.8 Composition and Structure of the Atmosphere.....	516
14.9 Acid Rain .....	516
14.10 Global Warming .....	517
14.11 Ozone Layer Depletion.....	519
14.12 Meteorology and Natural Purification Process .....	519
14.13 Elemental Properties of the Atmosphere .....	519
14.14 Control of Air Pollution.....	521
14.15 Air Quality Index (AQI) .....	523
14.16 Control Devices for Particulates .....	523
14.17 Control Devices for Gaseous Pollutants .....	533

14.18 Automotive Emission Control .....	539
14.19 Dispersion of Air Pollutants into the Atmosphere....	540
14.20 Negative Lapse Rate and Inversion.....	542
14.21 Impact of Winds on Dispersion of Pollutants .....	543
14.22 Plume Behaviour.....	544
14.23 Design of Stack Height .....	546
<i>Objective Brain Teasers</i> .....	548
<i>Conventional Brain Teasers</i> .....	556

**CHAPTER 15****Noise Pollution.....557-569**

15.1 Introduction.....	557
15.2 The Effects of Noise .....	557
15.3 Characteristics of Sound and its Measurement .....	558
15.4 Noise Rating Systems .....	562
15.5 Important Definition .....	564
15.6 Sources of Noise and Their Noise Levels.....	565
15.7 Noise Abatement and Control .....	565
<i>Objective Brain Teasers</i> .....	567

# Water Demand

CHAPTER

1

Section - A

## 1.1 INTRODUCTION

Environmental engineering is the branch of engineering that deals with the applications of scientific and engineering principles to the improvement and maintenance of the environment with the goals of protecting human health, preserving the valuable ecosystem found in nature and enhancing the quality of human life. In this course of environmental engineering, we will mainly focus on the water demand, its quality parameter, treatment process and in the similar way for waste water we will discuss about its quality, treatment and disposal.

Whenever an engineer is given the design the duty to design a water supply scheme for a particular section of the community, it becomes imperative upon him, to first of all, evaluate the amount of water available and the amount of water demanded by the public. In this chapter, we are going to study about later part of his duty i.e. to evaluate water demand. We will learn about various types of demands that need to be fulfilled. We will also study about variations, in demands. In the later part of chapter, we will learn some of the methods that are used for purpose of population forecasting.

## 1.2 WATER DEMAND

Estimation of demand for water is the key parameter in planning a water supply scheme. The agriculture sector consumes more than 80 percent of total water potential created in our country. The remaining portion is utilized to meet domestic, industrial and other demands.

The improvement in life-style and associated industrial development of a nation pushes up the per capita demand for water.

## 1.3 VARIOUS TYPES OF WATER DEMAND

The prediction of precise quantity of water demanded by the public is very difficult, because there are so many variable factors affecting water consumption. There are some certain thumb rules and empirical formulas, which are used to assess this quantity, which may give fairly accurate results.

There are different types of water demands, which are as follows:

### 1.3.1 Domestic Water Demand

Domestic water demand includes the water required in private building for drinking, cooking, bathing, gardening purposes etc. which may vary according to the living conditions of the consumers. The total domestic water consumption is near about 50 to 60% of the total water consumptions. The IS code caps a limit on domestic water consumption between 135 to 225 lpcd.

As per IS code, the minimum domestic water demand under ordinary conditions for a town with full flushing system should be taken as 200 lpcd although it can be minimized upto 135 lpcd for economically weaker section and LIG colonies (low income group) depending upon prevailing conditions. The breakup 200 lpcd and 135 lpcd is given in table 1 and table 2.

Minimum domestic water consumption (Annual average) for Indian towns and cities with full flushing systems as per	
Use	Consumption in liters per head per day (l/h/d)
Drinking	5
Cooking	5
Bathing	25
Washing of clothes	15
Washing of utensils	15
Washing and cleaning of houses and residence	15
Lawn watering and gardening	45
Flushing of water closets, etc.	45
<b>Total</b>	<b>200</b>

Minimum domestic water consumption (Annual average) for weaker sections and LIG colonies in small Indian Towns and cities	
Use	Consumption in (l/h/d)
Drinking	5
Cooking	5
Bathing	55
Washing of clothes	20
Washing of utensils	10
Washing and cleaning of houses and residences	10
Flushing of water closets, etc.	30
<b>Total</b>	<b>200</b>

NOTE



In developed and an efficient country like USA, this figure usually goes as high as 340 lpcd. This is because more water is consumed in rich living standards, in air-conditioning, air-cooling, bathing in bath tub, dish washing of utensils, car washing, home laundries, garbage grinders, etc.

### 1.3.2 Industrial Water Demand

The industrial water demand expresses the water required for industries which are either existing or are likely to be started in future, in the city for which water supply is being planned. This water requirement will thus vary with the types and number of industries present in the city. In industrial cities, the per capita requirement may finally be computed to be as high as 450 lpcd as compared to the normal industrial requirement of 50 lpcd. The approximate quantities of water required by different industries per unit of their production are shown in table below:

Water Required by Certain Important Industries		
Name of Industry	Unit of Production	Approximate Quantity of Water required per unit of production/raw material in kilo litres
1. Automobiles	Vehicle	40
2. Fertilizers	Tonne	80 - 200
3. Leather	Tonne (or 1000 kg)	40 (or 4)
4. Paper	Tonne	200 - 400
5. Petroleum Refinery	Tonne (Crude)	1 - 2
6. Sugar	Tonne (Crushed cane)	1 - 2
7. Textile	Tonne (goods)	80 - 140
8. Distillery (Alcohol)	kilo litre	122 - 170

### 1.3.3 Institutional and Commercial Water demand

Water requirements of institutions such as hospitals, hotels, restaurants, schools and colleges, railway stations, offices, factories etc. should also be assessed and provided for, in addition to domestic and industrial water demands. However, the requirement will vary with nature of city and with the number and type of commercial establishments and institutions present in it.

On an average, a per capita demand of 20 lpcd is usually considered to be enough to meet of such commercial and institutional water requirements although, this demand may be as high as 50 lpcd for highly commercial cities.

**The individual requirements would be as follows:**

1. Schools/Colleges : 45 to 135 lpcd
2. Offices : 45 lpcd
3. Restaurants : 70 lpcd
4. Cinema and theatres : 15 lpcd
5. Hotels : 180 lpcd
6. Hospitals : 340 lpcd (when beds is less than 100), and 450 lpcd (when beds exceed 100)
7. Airports : 70 lpcd
8. Railway : 70 lpcd (for junction with bathing facility)

The individual approximate water requirements of such institutions/commercial units are shown in table below:

Water Requirements for Commercial Buildings (as per IS code)		
S.No.	Type of building	Average consumption in (lpcd)
1.	<b>Factories</b>	
	(a) Where bathrooms are required to be provided	45
	(b) Where no bathrooms are required	30
2.	<b>Hospitals (Including laundry, per bed)</b>	
	(a) Number of beds less than 100	340
	(b) Number of beds exceeding 100	450
3.	Nurses homes and medical quarters	150
4.	Hostels	135
5.	Hotels (per bed)	180
6.	Restaurants (per seat)	70
7.	Offices	45
8.	Cinemas, auditoriums and theatres (per seat)	15
9.	<b>Schools</b>	
	(a) Day scholars	45
	(b) Residentials	135

### 1.3.4 Demand for Public Uses

This includes water requirement for parks, gardening, washing of roads etc. A nominal amount, not exceeding 5% of the total consumption may be provided to meet this demand. A figure of 10 lpcd is usually added on this account while computing total water requirements.

### 1.3.5 Fire Demand

In densely populated and industrial areas, fire generally breakout and may lead to serious damages, if not controlled effectively. Big cities, therefore, generally maintain full fire fighting squads. Fire fighting personnel require sufficient quantity of water, so as to throw it over the fire at high speed. A provision should, therefore be made in modern public water scheme for fighting fire breakouts.

The quantity of water required for extinguishing fires should be easily available and kept in storage reservoirs. When a fire breaks out, fire hydrants are fitted in water mains at about 100 to 150 meters apart and fire fighting pumps are immediately connected into them by fire brigade personnel. These pumps then throw water at very high pressure on fire. The minimum water pressure available at fire hydrants should be of the order of 100 to 150 kN/m<sup>2</sup> and should be maintained even after 4 to 5 hours of constant use of fire hydrant.

Now, to estimate the quantity of fire demand, consider a city having population of 50 lakhs. Suppose, in this city, 6 fires break out in a day and each fire stands for 3 hours. Generally, 3 jet streams are simultaneously thrown i.e. one burning property and one each one adjacent property on either side of burning property. The discharge of water stream should be about 1100 lit/minutes. Now, total amount of water required for fire in this city shall be given as

$$= 6 \times (3 \times 1100) \times (3 \times 60) = 3564000 \text{ litre/day}$$

$$\text{So, the amount of water required per person} = \frac{35,64,000}{50\text{lakhs}} < 1 \text{ litre per capita day}$$

Thus, from the above example, it can be stated that total amount of water required for fire demand is less than 1 lpcd.

#### Calculation of Fire Demand

- (i) For cities having population exceeding 50,000, the water required in kilo litre may be computed using the relation.

Kilo litre of water required =  $100\sqrt{P}$ , where  $P$  = Population in thousand

- (ii) **Kuchling's Formula** : It states that

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

- (iii) **Freeman's Formula** : It states that  $Q = 1136 \left[ \frac{P}{5} + 10 \right]$

- (iv) **National Board of Fire Underwriters Formula** :

- **For Central congested high valued city**

(i) When population is less than or equal to 2 Lakhs, then  $Q = 4637\sqrt{P} [1 - 0.01\sqrt{P}]$

(ii) When population is more than 2 Lakhs, a provision for 54,000 litres/minute may be made with an extra additional provision of 9,100 to 36,400 litres/minute for a second fire.

- **For a residential city**

The required draft for fire-fighting may be as follows:

(i) Small or low building = 2200 litres/minute

(ii) Larger or Higher building = 4,500 litres/minute

(iii) High values residency, apartments, tenements = 7650 to 13500 litres/minute

(iv) Three storeyed buildings in densely built up section = upto 27000 litres/minute

- **Buston's Formula** : It states that,  $Q = 5663\sqrt{P}$

In all the above formulas,  $Q$  is amount of water required in litre per minute and  $P$  is population in thousands.



All the above formulas suffer from the drawback that they are not related to the type of district served and give equal results for industrial and non-industrial areas.

**Example 1.1**

Compute the 'fire demand' for a city of 2 lakh population by any two formulae (including that of the National Board of Fire Underwriters)

**Solution:**

(i) The rate of fire demand as per National Board of Fire Underwriters Formula for a central congested city whose population is less than or equal to 2 Lakh is given by

$$Q = 4637\sqrt{P} [1 - 0.01\sqrt{P}] = 4637\sqrt{200} [1 - 0.01\sqrt{200}]$$

$$= 56303.08 \text{ l/min} = \frac{56303.08 \times 60 \times 24}{10^6} \text{MLD} = \mathbf{81.08 \text{ MLD}}$$

(ii) Kuchling's formula,  $Q = 3182\sqrt{P} = 3182\sqrt{200} \text{ l/min} = \frac{45000.27 \times 24 \times 60}{10^6} = 64.8 \text{MLD}$

**1.3.6 Water Required to Compensate Losses in Thefts and Wastes**

This includes the water lost in leakage due to bad plumbing or damaged meters, stolen water due to unauthorised water connections, and other losses and wastes. These losses should be taken into account while estimating the total requirements.

Even in the best managed water works, this amount may, be as high as 15% of the total consumption, which is nearly 55 lpcd.

**1.4 THE PER CAPITA DEMAND (q)**

It is the annual average amount of daily water required by one person and includes the domestic use, industrial use and commercial use, public use, waste thefts etc.

It may be, therefore expressed as Per Capita Demand(*q*) in litres per day per person ... (i)

$$= \frac{\text{Total yearly water requirement of the city in litres (i.e V)}}{365 \times \text{Design Population}}$$

Thus, total yearly requirement of city can be estimated using eq. (i) provided that per capita demand is already known or assumed.

For an average Indian city, as per recommendation of I.S. code, the per capita demand(*q*) may be taken as given in table.

Break up for per capita demand (q) for an average Indian City	
Use	Demand in lpcd
(i) Domestic Use	200 (59.7% or 60%)
(ii) Industrial Use	50
(iii) Commercial Use	20
(iv) Civic or Public Use	10
(v) Waste and thefts, etc.	55
(vi) Fire demand	< 1
Total = 335 = Per Capita Demand (q)	

### 1.4.1 Factors Affecting Per Capita Demand

The annual average demand for water (i.e. per capita demand) considerably varies for different towns or cities. This figure generally ranges between 100 to 360 lpcd for Indian conditions. The variations in total water consumption of different cities or towns depend upon various factors, which must be thoroughly studied and analysed before fixing the per capita demand for design purpose. These factors are discussed below:

#### (a) Size of the City

Per capita demand ( $q$ ) of water is generally large in big cities as compared to those of small cities. The reason for this can be the fact that in big cities, huge quantities of water are required for maintaining clean and healthy environments. For example, big cities are generally sewered and as such require large quantities of water.

On an average, per capita demand for Indian towns may vary with population as given, in table.

Variation in Per Capita Demand ( $q$ ) with population in India		
S. No.	Population	Per Capita Demand in lpcd
1.	Less than 20000	110
2.	20000 - 50000	110 - 150
3.	50000 - 2 Lakhs	150 - 240
4.	2 Lakhs - 5 Lakhs	240 - 275
5.	5 Lakhs - 10 Lakhs	275 - 335
6.	Over 10 Lakhs	335 - 360

#### (b) Climatic Conditions

At hotter and dry places, the consumption of water is generally more, because more of bathing, cleaning, air-coolers, air-conditioning etc. are involved. Similarly, in extremely cold countries, more water may be consumed, because the people may keep their taps open to avoid freezing of pipes and there may be more leakage from pipe joints since metal contracts with cold.

#### (c) Types of Gentry and Habits of People

Rich and upper class communities generally consume more water due to their affluent living standards. Communities of middle class consumes average amount of water. Poor slum dwellers consume very low amount of water. The amount of water required is therefore directly dependent upon economic status of consumers.

#### (d) Industrial and Commercial Activities

The pressure of industrial and commercial activities at a particular place increase the water consumption by large amount. Many industries require huge amounts of water and as such increases per capita demand.

#### (e) Quality of Water Supplies

If the quality and taste of the supplied water is good, it will be consumed more, because in that case, people will not use other sources such as private wells, hand pumps, etc. Similarly, certain industries such as boiler feeds, etc., which require standard quality waters will not develop their own supplies and will use public supplies, provided the supplied water is upto their required standards.

#### (f) Pressure in the Distribution Systems

If the pressure in the distribution pipes is high and sufficient to make the water reach at 3<sup>rd</sup> or even 4<sup>th</sup> storeys, water consumption shall be definitely more.

This water consumption increases because of two reasons:

- (i) People living in upper storey will use water freely as compared to the case when water is available scarcely to them.
- (ii) The losses and wastes due to leakage are considerably increased if their pressure is high. For example, if the pressure increase from 20 m head of water (i.e. 200 kN/m<sup>2</sup>) to 30 m head of water (i.e. 300 kN/m<sup>2</sup>), the losses may go up by 20 to 30 percent.

**(g) Development of Sewerage Facilities**

The water consumption will be more, if the city is provided with 'flush system' and shall be less if the old 'conservation system' of latrines is adopted.

**(h) System of Supply**

Water may be supplied either continuously for all 24 hours of the day, or may be supplied only for peak period during morning and evening. The second system, i.e. intermittent supplies, may lead to some saving in water consumption due to losses occurring for lesser time and a more vigilant use of water by the consumers.

**(i) Cost of Water**

If the water rates are high, lesser quantity may be consumed by the people. This may not lead to large savings as the affluent and rich people are little affected by such policies.

**(j) Policy of Metering and Method of Charging**

When the supplies are metered, people use only that much of water as much is required by them. Although metered supplies are preferred because of lesser wastage. It generally leads to lesser water consumption by poor and low income group, leading to unhygienic conditions.

## 1.5 FACTORS AFFECTING LOSSES AND WASTES

The various factors on which losses and wastes of water depend, are as follows:

- (i) Water Tight Joints
- (ii) Pressure in the Distribution system
- (iii) System of supply
- (iv) Metering
- (v) Unauthorized connections

## 1.6 VARIATION IN DEMAND

### 1.6.1 Variations in Demand

Till now, the per capita demand (q) that we have discussed is based on annual consumption of water. It was, therefore, also termed as annual average daily consumption per person. As we know that there is wide variation in different days of month, in different hours of day, and even in different minutes of hour, therefore annual average demand alone, although very useful, is not sufficient.

**Seasonal variations** occur due to larger use of water in summer, lesser use in winter and much less in rainy season. These variations may also be caused by seasonal use of water in industries such as processing of cash crops at time of harvesting etc.

**Daily variations** reflect household and industrial activity. For example, water consumption is generally high on Sundays and holidays.

**Hourly variation** reflects variation of water demand on an hourly basis.

These normal variations in demand or draft should generally be assessed and known in order to design supply pipes, service reservoirs, distributary pipes etc.

### 1.6.2 Assessment of normal variation

Variance in demand of water decrease with increase in size of town. The maximum demands are generally expressed as ratio of their means. Generally, following figures are adopted:

#### (a) Maximum daily consumption

It is generally taken as 180 percent of average daily consumption.

Hence, Maximum daily demand =  $1.8 \times$  average daily demand =  $1.8 q$

Here, it is to be noted that averaging in daily demand is done over an year, and hence, the average daily demand means annual daily demand.

#### (b) Maximum hourly demand

It is taken as 150 percent of its average hourly demand. Hence, maximum hourly demand for a day with maximum daily demand i.e. peak demand =  $1.5 \times$  average hourly demand of day with maximum daily demand

$$\begin{aligned} &= 1.5 \times \left( \frac{1.8 \times q}{24} \right) = 2.7 \times \left( \frac{q}{24} \right) \\ &= 2.7 \times \text{Annual average hourly demand} \end{aligned}$$

**NOTE:** Maximum hourly demand of day with maximum daily demand is known as peak demand.

As per goodrich formula,

Ratio of peak demand to average demand,

$$p = 1.8t^{-0.1}$$

where  $t =$  time in days from  $\frac{1}{24}$  to 365

So, when  $t = 1$  day (for daily variation)

$$p = 1.8 \times (1)^{-0.1} = 1.8$$

$$\Rightarrow \frac{\text{Maximum daily demand}}{\text{Average daily demand}} = 1.8$$

Similarly, when  $t = 7$  days (for weekly variation)

$$p = 1.8(7)^{-0.1} = 1.48$$

$$\Rightarrow \frac{\text{Maximum weekly demand}}{\text{Average weekly demand}} = 1.48$$

The GOI manual on water supply has recommended the following values of the peak factor, depending upon the population.

Peak Factor		
S.No.	Population	Peak Factor
1.	Upto 50000	3.0
	50001 - 200000	2.5
	Above 2 Lakh	2
2.	For Rural water supply scheme, where supply is effected through stand post for only 6 hours	3

Evidently, the peak factor tends to reduce with increasing population.

### 1.6.3 Coincident draft

The probability of breaking out of fire on day of maximum hourly draft is very meagre. Hence, for general community purposes,

Total draft = Maximum of the two i.e.,

(i) Sum of maximum daily demand and fire demand.

or

(ii) maximum hourly demand

When the maximum daily demand is summed up with fire demand for calculating total draft, it is known as coincident draft.

#### Example 1.2

A water supply scheme has to be designed for a city having a population of 1,00,000. Estimate the important kinds of drafts which may be required to be recorded for an average water consumption of 250 lpcd. Also record the required capacities of the major components of the proposed water works system for the city using a river as the source of supply. Assume suitable data..

#### Solution:

(i) Average daily draft = (per capita average consumption in lpcd) × population  
 = 250 × 1,00,000 litres/day = 250 × 10<sup>5</sup> litres/day = 25 MLD

(ii) Maximum daily draft may be assumed as 180% of annual average daily draft

$$\therefore \text{Maximum daily draft} = \frac{180}{100} [25 \text{ MLd}] = 45 \text{ MLD}$$

(iii) Maximum hourly draft of the maximum day: It may be assumed as 270 percent of annual average hourly draft

$$\therefore \text{Maximum hourly draft of maximum day} = \frac{270}{100} [25 \text{ MLd}] = 67.5 \text{ MLD}$$

(iv) Fire flow may be worked out from

$$Q = 4637\sqrt{P} [1 - 0.01\sqrt{P}] = 4637\sqrt{100} [1 - 0.01\sqrt{100}] = 41733 \text{ l/min}$$

where  $P$  = in thousand population

$$= \frac{41733 \times 60 \times 24}{10^6} \text{million litres/day} = 61 \text{ MLD}$$

Coincident draft = maximum daily draft + fire draft

$$= 45 + 61 = \mathbf{106 \text{ MLD}}$$

which is greater than the maximum hourly draft of 67.5 MLD



It shows that the distribution system has to be designed for 106 MLD instead of 67.5 MLD, which proves that the fire allowance considerably affects the design of distribution system.

## 1.7 DESIGN PERIOD OF WATER SUPPLY UNIT

A water supply scheme includes huge and costly structures (such as dams, reservoirs, treatment works, penstock pipes, etc.) which cannot be replaced or increased in their capacities, easily and conveniently. For example, the water mains including the distributing pipes are laid underground, and cannot be replaced or added easily, without digging the roads or disrupting the traffic. In order to avoid these future complications of expansion, the various components of a water supply scheme are purposely made larger, so as to satisfy the community needs for a reasonable number of years to come. This future period or the number of years for which a provision is made in designing the capacities of the various components of the water supply scheme is known as **design period**. The design period should neither be too long nor should it be too short.

### 1.7.1 Factors Governing the Design Period

The design period cannot exceed the useful life of the component structure, and is guided by the following considerations:

1. Useful life of component structures and the chances of their becoming old and obsolete. Design period should not exceed their respective values.
2. Ease and difficulty that is likely to be faced in expansions, if undertaken at future dates.
3. Amount and availability of additional investment likely to be incurred for additional provision.
4. The rate of interest on the borrowings and the additional money invested.
5. Anticipated rate of population growth, including possible shifts in communities, industries and commercial establishment.

### 1.7.2 Design Period Values

Water supply projects, under normal circumstances, may be designed for a design period of 30 years excluding completion time of 2 years. The design period recommended by the GOI manual on water supply for designing the various components of a water supply projects are given below:

Design periods for components of a water supply scheme		
S.No.	Item	Design period in years
1.	Storage by dams	50
2.	Intake works	30
3.	Pumping	
	(i) Pump house	30
	(ii) Electric motors and pumps	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 units	30
7.	Clear water reservoirs at the head works, balancing tanks, and Services reservoirs (over-head or ground level)	15
8.	Distribution system	30

### 1.7.3 Effect of variations of demand on design capacities of different components of a water supply scheme.

Figure show given below a possible layout of water scheme when a well or river is used as source of water, needing pumping equipments.

Similarly, if a dam and reservoir is used, then possible layout of water supply scheme.

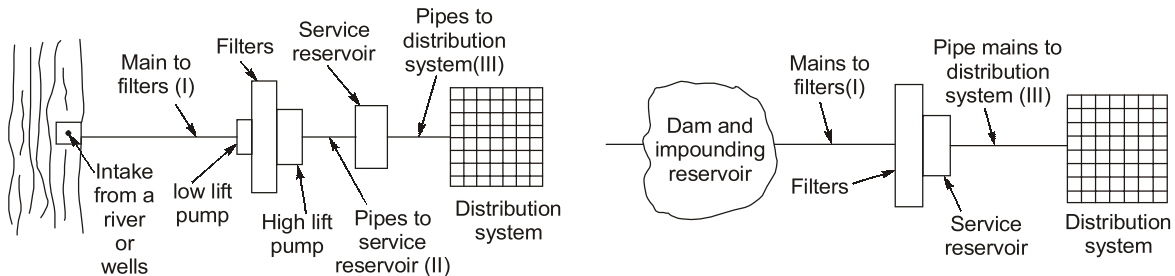


Fig: Layouts of water supply schemes.

**NOTE:** As dam is used in later case, therefore pumping of water is not required.

The various units involved in these supply schemes should be designed to serve the variations in demand along with average daily demand and maximum daily demand when it arises. The following recommendations may be adopted for designs of different components.

- (a) **Source of supply** : It may be designed for **maximum daily demand** or **average daily demand** depending upon other conditions.
- (b) **Pipe mains** : The pipes (I and II in figure above) taking water from source upto service reservoir may be designed for **maximum daily demand**.
- (c) **Filter and Other units** : They are also generally designed for maximum daily demand. However, sometimes, due to break-downs and repairs, they are designed for twice the average daily demand.
- (d) **Pumps** : Pumps lifting the water may be designed for **maximum daily demand**. For safety against repairs and break-downs, maximum daily demand is taken as twice the average daily demand for designing of these pumps.
- (e) **Distribution system** : It also includes the pipes carrying water from service reservoir to distribution system i.e. Type III pipes shown in figure above.  
These should be designed for maximum hourly draft of **maximum day or coincident draft** whichever is more.
- (f) **Service reservoir** : It is designed to take care of hourly fluctuations, fire demands, emergency reserves and provision required when pumps have to pump the entire's day water in fewer than 24 hours.

## 1.8 POPULATION FORECASTING

As we have discussed that water supply units are designed for a longer duration say 30 years, therefore it becomes essential to estimate the population at end of design period. There are various method available for forecasting of population depending upon the growth rate etc. of town or city for which the method is to be employed. In this section, we will discuss about factors affecting population forecasting and methods of forecasting.

**Example 1.8**

In two periods of each 20 years, a city has grown from 30,000 to 1,70,000 and then to 3,00,000. Determine (a) The saturation population, (b) The equation of logistic curve, (c) The expected population after the 60 years from the start.

**Solution :** (1) In this equation, we have

$$P_0 = 30,000, P_1 = 1,70,000, P_2 = 3,00,000$$

$$t = 0, t_1 = 20 \text{ years}, t_2 = 40 \text{ years}$$

Using equation,  $P_s = \text{Saturation Population} = \frac{2P_0P_1P_2 - P_1^2(P_0 + P_2)}{P_0P_2 - P_1^2} = 3,25,478$

(2)  $m = \frac{P_s - P_0}{P_0} = \frac{3,25,478 - 30,000}{30,000} = 9.85$

$$n = \frac{1}{20} \log_e \left[ \frac{30,000(3,26,000 - 1,70,000)}{1,70,000(3,26,000 - 30,000)} \right] = -0.119$$

∴ Equation of logistic curve is

$$P = \frac{P_s}{1 + m \log_e^{-1}(nt)} = \frac{3,25,478}{1 + 9.85 \log_e^{-1}(-0.119)}$$

(3) If  $t = 60 \text{ years}$

then,  $P = \frac{3,25,478}{1 + 9.85 \log_e^{-1}(-0.119 \times 60)} = 3,22,957$



**OBJECTIVE BRAIN TEASERS**

- Q.1** Consider the following statements:  
The daily per capita consumption of water apparently increase with
1. higher standard of living of people
  2. availability of sewerage in the city
  3. metered water supply
  4. wholesome and potable public supply of water
- Which of the above statements are correct?
- (a) 1, 2 and 3      (b) 2, 3 and 4  
(c) 1, 3 and 4      (d) 1, 2 and 4
- Q.2** As compared to geometrical increase method of forecasting population, arithmetical increase method gives
- (a) Lesser value      (b) Higher value  
(c) Same value      (d) Accurate value
- Q.3** The total domestic consumption in a city water supply, is assumed

- (a) 20%      (b) 30%  
(c) 40%      (d) 60%

**Q.4** The fire demand for ascertaining the empirical formula

$$Q = 1136 \left[ \frac{P}{5} + 10 \right]$$

- (a) Kuchling's formula  
(b) Buston's formula  
(c) Freeman's formula  
(d) Underwriter's formula

**Q.5** According to Goodrich, the ratio of peak demand rate to mean demand is

- (a)  $\frac{\text{Maximum daily demand}}{\text{Average daily demand}} = 180\%$   
(b)  $\frac{\text{Maximum weekly demand}}{\text{Average weekly demand}} = 148\%$   
(c)  $\frac{\text{Maximum monthly demand}}{\text{Average monthly demand}} = 128\%$   
(d) All of the above

- Q.26 The distribution system in water supplies is designed on the basis of
- average daily demand
  - peak hourly demand
  - coincident draft
  - greater of (b) and (c)
- Q.27 The multiplying factor, as applied to obtain the peak hourly demand, in relation to the average daily demand (per hour of course), is
- 1.5
  - 1.8
  - 2.0
  - 2.7

**Direction:** Each of the next consists of two statements, one labelled as the 'Assertion (A)' and the other as 'Reason (R)'. You are to examine these two statements carefully and select the answers to these items using the codes given below:

**Codes:**

- Both A and R are individually true and R is the correct explanation of A
  - Both A and R are individually true but R is not the correct explanation of A
  - A is true but R is false
  - A is false but R is true
- Q.28 **Assertion (A):** The leakage losses are less when the water supply is intermittent.  
**Reason (R):** Pressure is less in intermittent water supply.

**ANSWER KEY**

1. (d)    2. (a)    3. (d)    4. (c)    5. (d)  
6. (c)    7. (a)    8. (b)    9. (d)    10. (c)  
11. (c)    12. (c)    13. (d)    14. (d)    15. (c)  
16. (a)    17. (a)    18. (b)    19. (b)    20. (c)  
21. (c)    22. (b)    23. (b)    24. (c)    25. (a)  
26. (d)    27. (d)    28. (c)

**HINTS & EXPLANATIONS**

3. (d)  
Total domestic consumption in a city water supply is assumed to 55 to 60%

4. (c)

$$\text{The freeman's formula } Q = 1136 \left[ \frac{P}{5} + 10 \right]$$

6. (c)

$$\text{The constant } m \text{ in logistic curve } m = \frac{P_s - P_0}{P_0}$$

11. (c)

Year	Population	Decadal increase
1970	40,000	6000
1980	46,000	7000
1990	53,000	5000
	2000	58,000

$$\therefore \text{Design growth rate} = \frac{6000 + 7000 + 5000}{3} = 6000 \text{ per decade}$$

In 2010 population will be

$$P = 58000 + 6000 = 64000$$

Population	Increase	% Increase
5000	2000	40
7000	1400	20
8400		

So, Growth rate per decade,

$$k = \sqrt[3]{0.4 \times 0.2} = 0.283$$

So, population at end of next decade  
=  $8400(1 + 0.283) = 10777.2$   
 $\approx 10778$

12. (c)

Population after  $n$  years

$$P_n = P_0 + n\bar{x}$$

$\bar{x}$  is arithmetic design growth rate per decade

$$\text{Given } P_0 = 28000$$

$$\text{For } n = 20, P_{20} = 48000$$

$$\therefore \bar{x} = \frac{48000 - 28000}{20} = 10000 \text{ per decade}$$

The population when design capacity will be reached,

$$P_n = \frac{6000 \times 1000}{150} = 40000$$

$\therefore$  Number of years to reach the plant at design capacity,

$$\eta = \frac{P_n - P_0}{\bar{x}} = \frac{40000 - 28000}{10000} = 1.2 \text{ decade} = 12 \text{ years}$$

20. (d)

Water treatment units are generally designed for maximum daily demand. However, sometimes, to consider repair and break down cost, maximum daily demand is taken as twice of average daily demand.



### CONVENTIONAL BRAIN TEASERS

**Q.1** (i) The population of 5 decades from 1930 to 1970 are given in table below. Find out the population after one, two and three decades beyond the last known decade, by using arithmetic increase method.

Year	1930	1940	1950	1960	1970
Population	25000	28000	34000	42000	47000

(ii) Compute the population of the year 2000 and 2006 for a city whose population in the year 1930 was 25000, and in the year 1970 was 47000. Make use of geometric increase method.

**Solution :**

(i) The given data in question table is extended in table below, so as to compute the increase in population ( $x$ ) for each decade (col. 3), the total increase, and average increase per decade ( $\bar{x}$ ), as shown

Year	Population	Increase in population ( $x$ )
(1)	(2)	(3)
1930	25000	
1940	28000	3000
1950	34000	6000
1960	42000	8000
1970	47000	5000
Total		22000
Average increase per decade ( $\bar{x}$ )		$\bar{x} = \frac{22000}{4} = 5500$

The future populations are now computed by using equation as,

$$P_n = P_0 + n \cdot \bar{x}$$

∴ (a) Population after 1 decade beyond 1970

$$\begin{aligned} P_{1980} &= P_1 = P_{1970} + 1 \cdot \bar{x} \\ &= 47000 + 1 \times 5500 \\ &= 52500 \end{aligned}$$

(b) Population after 2 decades beyond 1970

$$\begin{aligned} P_{1990} &= P_2 = P_{1970} + 2 \cdot \bar{x} \\ &= 47000 + 2 \times 5500 \\ &= 58000 \end{aligned}$$