CIVIL ENGINEERING

Environmental Engineering

Comprehensive Theory
with Solved Examples *and* Practice Questions

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CHAPTER

1

Section - A

Water Demand

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 focuses 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 needs 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 $l$pcd.

As per IS code, the minimum domestic water demand under ordinary conditions for a town with full flushing system should be taken as 200 $l$pcd although it can be minimized upto 135 $l$pcd 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	
Lawn watering and gardening	15
Flushing of water closets, etc.	45
Total	200

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
Total	200

NOTE

In developed and an efficient country like USA, this figure usually goes as high as 340 $l$pcd. 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 $l$pcd as compared to the normal industrial requirement of 50 $l$pcd. 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 *l*pcd for highly commercial cities.

The individual requirements would be as follows:

1. Schools/Colleges : 45 to 135 *l*pcd
2. Offices : 45 *l*pcd
3. Restaurants : 70 *l*pcd
4. Cinema and theatres : 15 *l*pcd
5. Hotels : 180 *l*pcd
6. Hospitals : 340 *l*pcd (when beds is less than 100), and 450 *l*pcd (when beds exceed 100)
7. Airports : 70 *l*pcd
8. Railway : 70 *l*pcd (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 (*l*pcd)
1.	Factories	
	(a) Where bathrooms are required to be provided	45
	(b) Where no bathrooms are required	30
2.	Hospitals (Including laundry, per bed)	
	(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.	Schools	
	(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 *l*pcd 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^2 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

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

So, the amount of water required per person $= \dfrac{35{,}64{,}000}{50\text{lakhs}} < 1$ 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 $Q = 1136\left[\dfrac{P}{5} + 10\right]$

(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 $Q = 4637\sqrt{P}\left[1 - 0.01\sqrt{P}\right]$
  - (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.

NOTE 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

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

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

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

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 *l*pcd.

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 *l*pcd**
(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^{rd} or even 4^{th} 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^2) to 30 m head of water (i.e. 300 kN/m^2), 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 × average hourly demand of day with maximum daily demand

$$= 1.5 \times \left(\frac{1.8 \times q}{24}\right) = 2.7 \times \left(\frac{q}{24}\right)$$

$= 2.7 \times$ Annual average hourly demand

> **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,

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

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

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

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

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

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

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

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

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 50001 - 200000 Above 2 Lakh	3.0 2.5 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 *l*pcd. 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

$$= 250 \times 1{,}00{,}000 \text{ litres/day} = 250 \times 10^5 \text{ litres/day} = 25 \text{ MLD}$$

(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

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

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

$$= 45 + 61 = \textbf{106 MLD}$$

which is greater than the maximum hourly draft of 67.5 MLD

NOTE: 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 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.

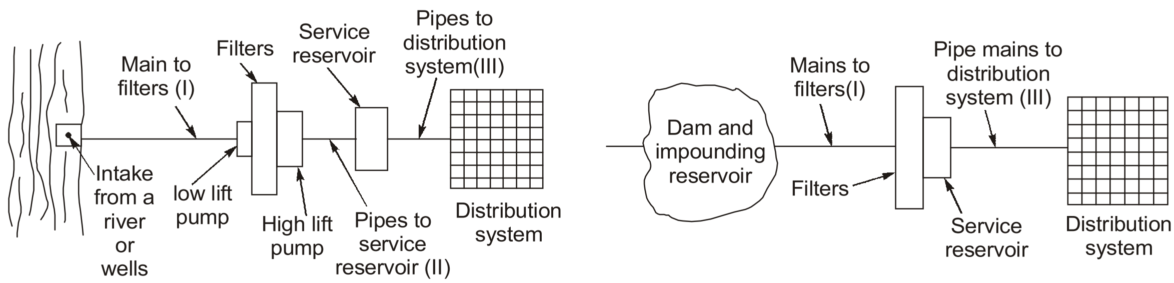

Fig: Layouts of water supply schemes.

> **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.

1.8.1 Population data

The present population of a town or a city can be best determined by conducting an official enumeration, called census. The government of every country carries these official surveys at intervals of say about 10 years. Data collected from population census is used by department of water supply schemes to understand the trend of growth of population.

1.8.2 Population Growth

Growth of population is of great concern for the people engaged in policy planning and decision making at the national level. Population growth means the change (increase or decrease) of population size between two dates.

However, a population increasing in size is said to have a positive growth rate and the one declining is to have a negative growth rate.

The number of inhabitants of a country depends on (i) The rate of growth in population and (ii) Migrations

In order to predict the future population, as correctly as possible, it is necessary to know the factors affecting population growth. The three main factors responsible for changes in population are:

(i) Births (ii) Deaths (iii) Migrations

All these factors are influenced by social and economic factors and conditions prevailing communities.

(i) The Birth rates may decrease due to excessive family planning practices and legalized abortions. Spread of education and development of extra recreational facilities for the people, also tend to reduce the birth rates.

(ii) The death rates may decrease with the development and advancement of medical facilities, thereby controlling infant mortality rates and adult death rates due to control of infections and other diseases.

(iii) The migrations are dependent upon the industrialization and commercialization of the particular cities or towns. People generally migrate from villages to cities where livelihood are available.

Besides these three main factors, some other factors like war, natural havocs and disasters may also bring about sharp reduction in the population. Considering all these factors, arithmetic balancing is done to arrive at the future population. It can be expressed as $\boxed{P_t = P_0 + (B - D) - (I - E)}$

where, P_0 and P_t refer to the size of population at the beginning and end of a time period, and B, D, I and E refers to the number of births, deaths, immigration and emigration respectively during period under consideration.

1.8.3 Growth Rate Curve

When all the unpredictable factors such as war, or natural disasters do not produce sudden changes, the population would probably follow the growth curve as discussed in the theory of demographic transition. This curve is S-shaped as shown in figure and is known as "**the logistic curve**". According to this curve, rate of growth of population varies from time to time.

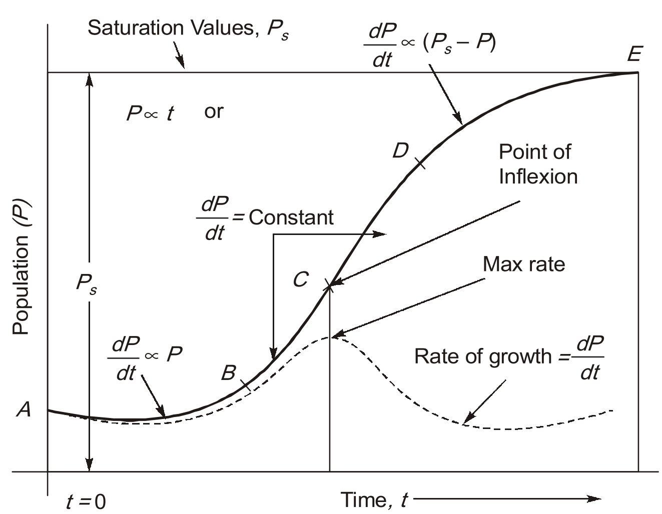

Fig. Growth Rate Curve

The curve represents early growth AB at an increasing rate $\left(\text{i.e. geometric or log growth, } \frac{dP}{dt} \propto P\right)$

and late growth *DE* at a decreasing rate $\left[\text{i.e. first order } \frac{dP}{dt} \propto (P_S - P)\right]$ as the saturation value (P_S) is approached. The transitional middle curve BD follows an arithmetic increase $\left(i.e. \frac{dP}{dt} = \text{constant}\right)$.

What the future holds for a given population, depends upon, as to where the point lie on the growth curve at a given time.

i.e. in *AB* → $\frac{dP}{dt} \propto P$ → increasing growth rate

in *BCD* → $\frac{dP}{dt}$ = Constant → Constant growth rate

in *DE* → $\frac{dP}{dt} \propto (P_s - P)$ → Decreasing growth rate , P_s = Saturation value

1.8.4 Population Forecasting Methods

The various methods which are generally adopted for estimating future populations by engineers are described in this section. Some of these methods are used when design period is small, and some are used when the design period is large. The particular method to be adopted for a particular case or for a particular city depends largely upon the factor discussed in these methods and the selection is left to the discretion and intelligence of the designer. It is to be noted that none of these methods is exact and all the methods are based on law of probability.

(a) Arithmetic Increase Method

In this method, a constant increment of growth in population is observed periodically. This method is of limited application, mostly used in large and established towns where future growth has been controlled.

This method is based upon the assumption that the population increase at a constant rate, i.e. the rate of change of population with time $\left(\text{i.e. } \frac{dP}{dt}\right)$ is constant.

i.e. $$\frac{dP}{dt} = \text{Constant} = k(\text{say}) \quad \text{...(i)}$$

⇒ $$dP = k\,dt$$

Integrating both sides

⇒ $$\int_{P_1}^{P_2} dP = k\int_{t_1}^{t_2} dt$$

$$P_2 = P_1 + k(t_2 - t_1) \quad \text{...(ii)}$$

Here P_2 and P_1 represent the population at time t_2 and t_1 respectively. This time period is usually reckoned in decades. *k* is the rate of increase of population per unit time (decade), thus $(t_2 - t_1)$ = Number of decades.

The equation (ii) can be rewritten as, $\boxed{P_n = P_0 + n \cdot \bar{x}}$

where P_n = Prospective or forecasted population after n decades from the present (i.e. last known census)

P_0 = Population at present (i.e. last known census)

n = Number of decades between now and future

$\bar{x}$ = Average (arithmetic mean) of population increase in the known decades.

Example 1.3 The population of 5 decades from 1930 to 1970 are given below in table 1.7. Find out the population after one, two and three decades beyond the last known decade, by using arithmetic increase method.

Year	Population
1930	25,000
1940	28,000
1950	34,000
1960	42,000
1970	47,000

Solution: The given data in table is extended in table, 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 (1)	Population (2)	Increase in population (x) (3)
1930	25,000	
1940	28,000	3000
1950	34,000	6000
1960	42,000	8000
1970	47,000	5000
Total		22,000
Average increase per decade ($\bar{x}$)		$\bar{x} = \frac{22000}{4} = 5,500$

The future populations are now computed by using equation as $P_n = P_0 + n \cdot \bar{x}$

$\therefore$ (a) Population after 1 decade beyond 1970

$$= P_{1980} = P_1 = P_{1970} + 1 \cdot \bar{x}$$
$$= 47,000 + 1 \times 5500 = 52,500$$

(b) Population after 2 decades beyond 1970

$$= P_{1990} = P_2 = P_{1970} + 2 \cdot \bar{x}$$
$$= 47,000 + 2 \times 5500 = 58,000$$

(c) Population after 3 decades beyond 1970

$$= P_{2000} = P_3 = P_{1970} + 3 \cdot \bar{x}$$
$$= 47,000 + 3 \times 5500 = \mathbf{63,500}$$

(b) Geometric Increase Method

The method of Geometric progression is applicable to the cities with unlimited scope for future expansion and where a constant rate of growth is anticipated. This method is also known as **uniform increase method.**

The basic difference between arithmetic and geometric progression or increase method of population forecasting is that, in Arithmetic method no compounding is done whereas, in Geometric method compounding is done every decade. To have better understanding of difference between arithmetic increase method and geometric increase method, consider a city having population of 1 lakh.

If the growth rate of population is 10% per decade, then at end of first decade from now, population will be 1.1 lakhs by both the methods. But at the end of 2nd decade, population will be 1.21 lakh by geometric increase method whereas it will be 1.2 lakh only by arithmetic increase method. The computations in these two methods i.e. arithmetic and geometric increase are thus comparable to simple and compound interest computations respectively.

In Geometric increase method, a constant value of percentage growth rate per decade (k) is analogues to the rate of compounding interest per annual.

Thus, population after one decade can be given by, $P_1 = P_0 + \frac{k}{100}P_0 = P_0\left(1 + \frac{k}{100}\right)$

Similarly, population after n decades $\boxed{P_n = P_0\left(1 + \frac{k}{100}\right)^n}$

Where, P_0 refers to initial population i.e. at the end of last known census.