Environmental and Sanitary Engineering
PART 1: WATER SUPPLY ENGINEERING
Environmental and Sanitary Engineering (Syllabus)
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Text Books:
1. Water Supply and Sewerage by: E. W. Steel and T. J. McGhee
2. Water Supply and Wastewater Engineering (Part 1 and 2) by: D.Lal and A. K. Upadhyay

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PART 1: WATER SUPPLY ENGINEERING

Lecture 1: Introduction

Sanitary Engineering: The branch of civil engineering associated with the supply of water, disposal of sewage, other public health services and the management of water and sewage in civil engineering.

Sanitary Engineer:

1. An expert or specialist in the branch of civil engineering associated with the supply of water, collect and disposal of sewage, and other public health services.
2. An engineer whose training or occupation is in sanitary engineering.
3. An engineer specializing in the maintenance of urban environmental conditions conductive to the preservation of public health.

Work of sanitary engineering:

The development of sanitary engineering has paralleled and contributed to the growth of cities. Without an adequate supply of safe water, the great city could not exist, and life in it would be both unpleasant and dangerous unless and other wastes were promptly removed. The concentration of population in relatively small areas has made the task of the sanitary engineer more complex.

Groundwater supplies are frequently inadequate to the huge demand and surface waters, polluted by cities, towns, and villages on watersheds, must be treated more and more elaborated as the population density increases. Industry also demands more and better water from all available sources. The river receives ever-increasing amounts of sewage and industrial wastes, thus requiring more attention to sewage treatment, stream pollution, and the complicated phenomena of self-purification.

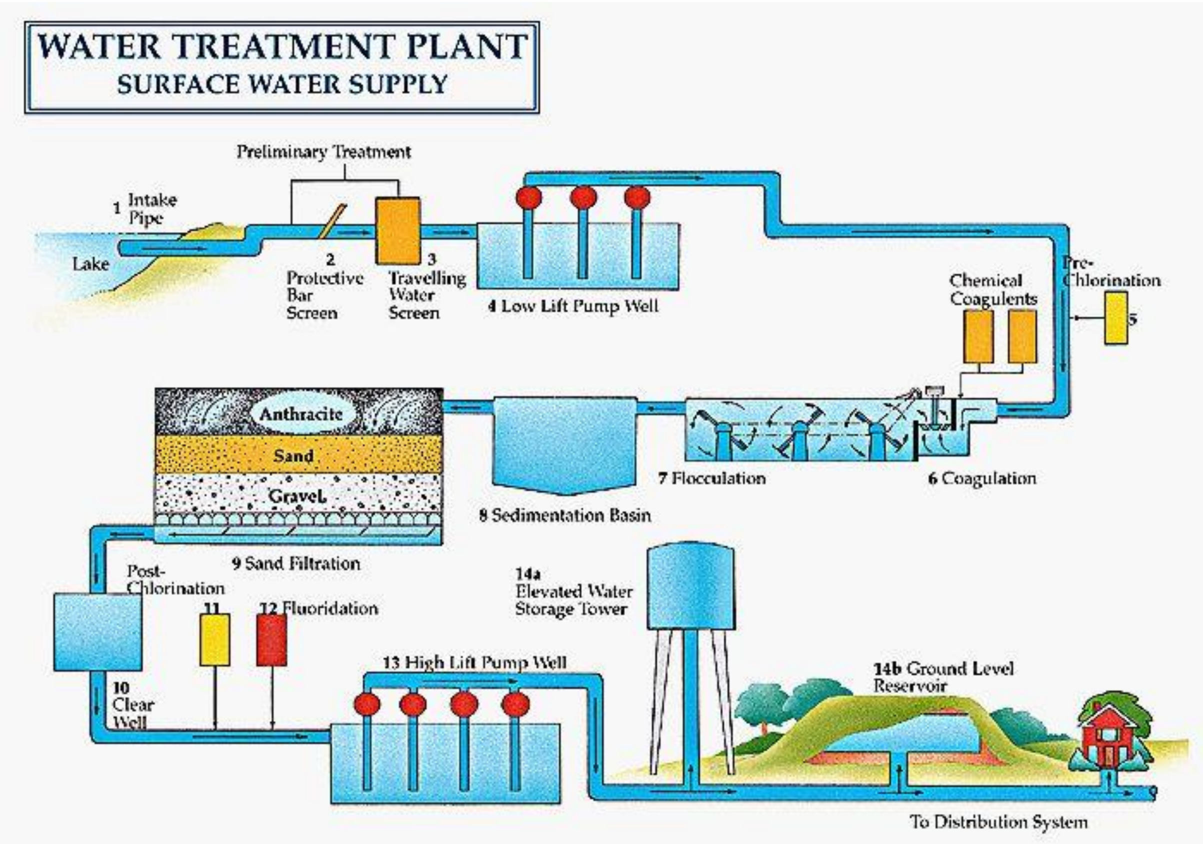
The public looks to the sanitary engineer for assistance in such matters as design, construction, and operation of water and sewage works are treated, the control of malaria by mosquito control, the eradication of other dangerous insects, rodent control collection and disposal of municipal refuse, industrial hygiene, and sanitation of housing and swimming pools. The activities just given, which are likely to be controlled by local or state health departments, are sometimes known as public health or environmental engineering, terms which while descriptive are not accepted by all engineering. The terms, however, are indicative of the important place the engineer holds in the field of public health and in the prevention of diseases.

EPA: Environmental Protection Agency

NPSES: National Pollutional Discharge Elimination System

FWPCA: Federal Water Pollution Control Administration

USPHS: U.S. Public Health Service



Water Treatment Plant

Wastewater Treatment Plant

Lecture 2: Quantity of Water

Water Consumption

In the design of any waterworks project it is necessary to estimate the amount of water that is required. This involves determining the number of people who will be served and their per capita water consumption, together with an analysis of factors that may operate to affect consumption.

It is usual to express water consumption in liters or gallons per capita per day, obtaining this figure by dividing the total number of people in the city into the total daily water consumption. For many purposes the average daily consumption is convenient. It is obtained by dividing the population into the total daily consumption averaged over one year.

$$\text{Water consumption}\left(\frac{\text{L}}{(\text{Cap. day})}\right) = \frac{\text{Total daily water consumption }(\frac{\text{L}}{\text{day}})}{\text{Total number of people in the city (Capita)}}$$

$$\text{Average daily consumption}\ \left(\frac{\text{L}}{(\text{Cap. day})}\right) = \frac{\text{Total daily consumption averaged over one year}\ (\frac{\text{L}}{\text{day}})}{\text{Total population in the city (Capita)}}$$

$$\text{Average daily per capita demand}\left(\frac{\text{L}}{(\text{Cap. day})}\right) = \frac{\text{Quantity Required in Months}\ (\frac{\text{L}}{\text{day}})}{(360\ \text{x Population (Capita)})}$$

If this average demand is supplied at all the times, it will not be sufficient to meet the fluctuations.

Consumption for various purposes (Water Demand):

1. Domestic or Residential use 40 – 60% of the total water demand.
2. Industrial use 25 - 30%.   a) domestic,   b) industrial process
3. Commercial use 10 - 15%.
4. Public use 5 - 10%.
5. Fire demand.

For calculating the total water demand 10 - 15% is added for losses and wastage.

The table shows same typical commercial and public water demand flows

Type	Rate	Type	Rate
Hospital	950 L/bed/ d	Shopping center	6 L/m^2 floor area/d
School	76 L/student/ d	Barber shop	210 L/ chair/d
Rest home	380 L/ bed/d	Laundry	3000 L/machine/d
Restaurant	30 L/customer/d	Airport	10 L/passenger/d
Public parks	1.5 L/m^2/d	Car wash	209 L/ car/d
Store	40 L/person/d	Factory	100 L/employee/d

Domestic or Residential demand:

Domestic demand (volume/time) = rate of consumption (volume/time/capita) × population (capita)

Industrial demand:

For water used in industrial processing, Symons formula maybe used water demand =12.2 m^3/ 10^3 m^2 floor area per day. The table shows typical industrial water demands:

Type of industry	Quantity m^3/metric ton
Dairy	2 - 3
Chemicals	8 - 10
Meat packing	15 - 25
Canning	30 - 60
Paper	200 - 800
Steel	260 - 300
Textile	250 - 350
Petroleum	80 gallon/barrel

Consumption for various purposes (Summary):

Type of Consumption	Use	Purposes	Depend upon	Average Water Demand (L/c.d)	Percentage of Total
Domestic	Houses, hotels, etc	Sanitary, culinary, drinking, washing, bathing, air conditions of residences and irrigation or sprinkling of	Living conditions of consumers	190-340	50

		privately owned gardens or lawns			
Commercial and industrial	Industrial and Commercial plants	Water process according to floor area per day ($12.2m^3/1000m^2$)	Local conditions	200	15-30
Public	Public building and public service	- City halls, jails, and school. - flushing streets and fire protection	Local conditions	50-75	10
Loss and waste	Uncounted	Network, equipment	Execution degree	50-75	10

Factors affecting water consumption (per capita demand):

1. Size of the city: Per capita demand for big cities is generally large as compared to that for smaller towns as big cities have sewered houses.
2. Presence of industries and commerce.
3. Quality of water: If water is aesthetically and medically safe, the consumption will increase as people will not depend to private wells, etc.
4. Cost of water.
5. Pressure in the water distribution system.
6. Climatic conditions.
7. Characteristics of population: Habits of people and their economic status.
8. Policy of metering and charging method: Water tax is charged in two different ways: on the basis of meter reading and on the basis of certain fixed monthly rate.

9. Efficiency of waterworks administration: Leaks in water mains and services; and unauthorized use of water can be kept to a minimum by surveys.

Fluctuations in Rate of Demand

1. Annual or yearly variation:
2. Seasonal variation: The demand peaks during summer. Firebreak outs are generally more in summer, increasing demand. Therefore, there is seasonal variation.
3. Monthly variation:
4. Weekly variation:
5. Daily variation: Depends on the activity. People draw out more water on holidays and Festival days, thus increasing demand on these days.
6. Hourly variations are very important as they have a wide range. During active household working hours i.e. from six to ten in the morning and four to eight in the evening, the bulk of the daily requirement is taken. During other hours the requirement is negligible. Moreover, if a fire breaks out, a huge quantity of water is required to be supplied during short duration, necessitating the need for a maximum rate of hourly supply.

Therefore, an adequate quantity of water must be available to meet the peak demand. To meet all the fluctuations, the supply pipes, service reservoirs and distribution pipes must be properly proportioned. The water is supplied by pumping directly and the pumps and distribution system must be designed to meet the peak demand. The effect of monthly variation influences the design of storage reservoirs and the hourly variations influences the design of pumps and service reservoirs. As the population decreases, the fluctuation rate increases. Figure above shows variation of water consumption with time.

Goodrich formula to estimate the percentage of annual average consumption ($p = 180\,t\ -0.1$)

Where: p = percentage of the annual average consumption for time t

t = time in day (2hr/24 – 360). Hence; day (t=1), weekly (t=7), monthly (30) and yearly (360).

The formula gives the percentage of the maximum daily as 180 percent, the weekly consumption as 148 percent, and the monthly as 128 percent of the average daily demand. The maximum hourly consumption is likely to be about 150 percent of the maximum for that day.

Maximum hourly demand of maximum day i.e. Peak demand in certain area of a city will affect design of the distribution system while minimum rate of consumption is of less important than maximum flow but is required in connection with design of pump plants, usually it will vary from (25-50) percent of the daily demand.

Average daily demand = Average water consumption (L/Cap.day) × NO. of population

Maximum daily demand = p × average daily demand = 1.8 × average daily demand

Maximum weekly demand = p × average daily demand = 1.48 × average daily demand

Maximum monthly demand = p × average daily demand = 1.28 × average daily demand

Maximum hourly demand = p × maximum daily demand = 1.5 × maximum daily demand = 1.5 × 1.8 × average daily demand = 2.7 × average daily demand

Minimum hourly demand = p × maximum daily demand = 0.5 × maximum daily demand = 0.5 × 1.8 × average daily demand = 0.9 × average daily demand

The table below shows a proposal of the average domestic water demand. In Iraq it is assumed to be 400 L/c/d.

Single family	Rate L/c/d
Low income	270
Medium income	310
High income	380

Peaks of water consumption in certain areas of a city will affect design of the distribution system.

Fire demand

Firefighting systems: a) with water, b) without water

a) Firefighting systems using water

1. Hydrants: an outdoor system
2. Hose reel: an indoor system
3. Sprinkler: an indoor system

b) Firefighting systems without water

Fire extinguishers are used with engineering criteria for location and number of cylinders. It should not be used for: 1) electrical risk, 2) flammable liquids.

Fire demand formulas: The per capita fire demand is very less on an average basis but the rate at which the water is required is very large. The rate of fire demand is sometimes treated as a function of population and is worked out from following empirical formulas:

a)- Insurance Service Office Formula (ISO):

$\mathrm{F_{gpm}} = 18\,\mathrm{C}\,(A_{ft^2})^{0.5}$ $F_{L/min} = 223.18\,\mathrm{C}\,(A_{m^2})^{0.5}$ $\frac{\mathrm{FL}}{\mathrm{sec}} = 3.724\,\mathrm{C}\,(A_{m^2})^{0.5}$

F = Fire demand

C = Coefficient related to the type of construction material (0.6–1.5), 1.5 wood frame, 1 ordinary frame as brick & 0.6 resistance material.

A = Total floor area (ft^2) ($m^2 = 10.76\ ft^2$) excluding the basement of the building.

Limitations:

1. One fire per day
2. Fire duration 4-10 hr
3. F = 500-8000 gpm

b)- National Board of Fire Underwriters (NBFU):

$\mathrm{G_{gpm}} = 1020\sqrt{P} \times \left(1 - 0.01\sqrt{P}\right)$ & $G_{m^3} 3.86\sqrt{P} \times \left(1 - 0.01\sqrt{P}\right)$

G= fire demand

P = population in thousand (10^3)

Limitations:

1. One fire per day
2. Fire duration 4 -10 hr
3. P $\leq 200 \times 103$ capita

	Authority	Formulae (P in thousands)	Q for lakh (Population)
1	American Insurance Association	Q (L/min)=4637 $P^{0.5}$ (1-0.01 $P^{0.5}$)	41760
2	Kuchling's Formula	Q (L/min)=3182 $P^{0.5}$	31800
3	Freeman's Formula	Q (L/min)= 1136.5(P/5+10)	35050
4	Ministry of Urban Development Manual Formula	Q (kilo liters/d)=100 $P^{0.5}$ for P>50000	31623

General limitation for Fire flow requirement

Details	Fire flow requirement (gpm)	
	gpm	L/min
In general case	8000	30240
For one story construction	6000	22680
The minimum fire flow	500	1890
The total for all purposes for single fire	12000	45360

To calculate the amount of water required for fire-fighting to a group of houses single and dual:

Distance between adjacent units		Required fire flow (gpm)	
ft	m	ft	m

> 100	> 30	500	1890
31-100	9.5-30.5	750-1000	2835-3780
11-30	3.4-9.2	1000-1500	3780-5670
≤ 10	≤ 3	1500-2000	5670-7560

The amount of water required for firefighting must suffice as a minimum for four hours, most of the residential campus designed on the basis of the need for a period of 10 hours. So the times the fire depends on the amount of flow:

Required fire flow		Duration (hr)
gpm	L/min	
< 1000	< 3780	4
1000-1250	3780-4725	5
1250-1500	4725-5670	6
1500-1750	5670-6615	7
1750-2000	6615-7560	8
2000-2250	7560-8505	9
> 2250	> 8505	10

Forecasting Population

To design any waterworks element, the total water demand should be calculated for adopt period of design. It is necessary to estimate the maximum population expected to be served by the designed facility for any time in the future.

To estimate the growing number of population the following methods are used:

1. Arithmetic method: Assumes a constant growth rate ($\Delta P/\Delta t$ = constant)

$Pf = Po + K\ \Delta t$

Pf = Population in the future (capita)

Po = Base population (capita)

K = Growth rate = $\Delta P/\Delta t$ (capita/ time)

Δt = Time increment between Pf and Po time

2. Geometric method: The growth rate is proportional to population ($\Delta P/\Delta t \approx P$)

$In\ Pf = In\ Po + \bar{k}\ \Delta t$

Pf = Population in the future (capita)

Po = Base population (capita)

$\bar{k}$ = [In P_1 - In P_2]/Δt (In capita/ time)

Δt = Time increment between Pf and Po

3. $P_f = P_0 \times (1 + i)^n$

Density of population

Population density, considering a whole city, rarely exceeds an average of (7500-10000 capita per km^2). More important to the designer engineer, solving water and sewerage problems, are the densities in particular areas:

Area	Density (capita per km^2)
The sparsely built-up residential sections	
Closely built-up single-family residential areas with small lots	8,800-10,000
Apartment and tenement districts	2,500-250,000
Commercial districts	High variable according to development

Periods of design and water consumption data required:

Detail	Design period (year)	Design criteria
Development of source		The design capacity of the source should be adequate to provide the maximum daily demand anticipated during the design period.
For Groundwater For Surface Water	5 50	
Pipelines from source	> 25	The design capacity of the pipe lines should be based upon average consumption at the end of the design period.
Water treatment plant	10-15	Most WTP will be designed for average daily flow at the end of the design period. Hydraulic design should be based upon maximum anticipated flow.
Pumping plant	10	Pump selection requires knowledge of maximum flow including fire demand, average flow, and minimum flow during the design period.
Amount of storage	Minimum cost	Design requires knowledge of average flow, fire demand, maximum hour, maximum week, and maximum month, as well as the capacity of the source and pipe lines from the source.
Distribution system	Indefinite	Maximum hourly flow including fire demand is the basis for design.

Solved problems

Problem 2.1: Find the maximum daily domestic demand for a population of 1000 capita with a rate of 300 L/c/d?

Solution:

Average domestic daily demand=1000 ×300=300 ×10^3 L/day=300 m^3/day

Maximum daily demand =1.8 x average daily demand=1.8 ×300=540 m^3/day

Problem 2.2: For the above Problem find the maximum demand if p = 250%?

Average domestic daily demand=1000 ×300=300 ×10^3 L/day=300 m^3/day

Maximum daily demand =2.5 × average daily demand=2.5 ×300=750 m^3/day

Problem 2.3: A 6-story building was constructed for an engineering company. The building is an ordinary type structure with 10^3 m^2 for each floor. Determine: the maximum rate, and the total storage, for both domestic and fire demand in L/c/d. Knowing that the building can serve 22 × 10^3 capita having an average water consumption rate of 200 L/c/d?

Solution:

Average domestic demand = 22000 × 200 = 4.4 × 10^6 L/day

Maximum daily demand = Average domestic demand ×1.8 = 4.4 ×10^6×1.8=7.92 ×10^6 L/day

$F_{(gpm)} = 18C \; A_{ft^2}^{0.5} = 18\times1\times(1000\times10.76\times6)^{0.5} = 4574 gpm = 17288 L/\min = 24.89\times10^6 L/day$

Maximum rate = 7.92 ×10^6 + 24.89 ×10^6 = 32.81 ×10^6 L/day for 10 hours = 1491 L per capita/day

The total flow required during this day would be:

$7.92\times10^6 + 24.89\times10^6 \times\frac{10}{24} = 18.29\times10^6$ liter $= \frac{18.29\times10^6}{22000} \approx 832$ per capita/day

Problem 2.4: A 4 story wooden building, each floor is 509 m^2. This building is adjacent to a 5-story ordinary type building, each floor is

900 m^2. Determine the fire flow in m^3/hr for each building, and both buildings if they are connected?

Solution:

For wooden building:

$F_{(gpm)}$ =18C $A_{ft^2}^{0.5}$ =18×1.5× $(509×10.76×4)^{0.5}$ =3996.306gpm=15126.02L/min=21.79×10^6L/day

For ordinary building:

$F_{(gpm)}$ =18C $A_{ft^2}^{0.5}$ =18×1.0× $(900×10.76×5)^{0.5}$ =3960.81gpm=14991.696L/min=21.59×10^6L/day

By using the fractional area:

$Total\ area = 4 \times 509 + 5 \times 900 = 6536\ m^2$

$Fraction\ for\ wooden\ building = \frac{4\times509}{6536} = 0.311$

$Fraction\ for\ ordinary\ building = \frac{5\times900}{6536} = 0.689$

$Total\ \ fire\ \ flow = 18 \times \sqrt{6536 \times 10.76} \times [1.5 \times 0.311 + 1 \times 0.689] = 18 \times 265.173 \times 1.1555 = 5515.333 gpm = 1252.533 \frac{m^3}{hr} = 30060.77 \frac{m^3}{day}$

Problem 2.5: For the data given find the population in year 2035.

Year	1965	1975	1985	1995	2005
Population	24700	29000	33500	38100	32000

Solution:

						Arithmetic method			Geometric method		
Information	Year	Population	ΔP	Δt	K	$K_{Average}$	Pt	K	$K_{Average}$	LN (Pt)	Pt
	1965	24700									
	1975	29000	4300	10	430			0.016049			
	1685	33500	4500	10	450			0.014425			
	1995	38100	4600	10	460			0.012867			

Base year	2005	32000	6100	10	610	487.5		-0.01745	0.006473		
Period design (t)	30										
First stage	2020						39312.5			10.47059	35263.05
Second stage	2035						4662.5			1056769	38858.83

Problem 2.6: For the data given find the population in year 2035 by using arithmetic and geometric method, and average daily demand, maximum daily demand, weekly daily demand, and monthly daily demand as well as the maximum and minimum hourly demand. Also determine the fire water demand and total water demand if the water consumption of 500 liters per capita per day?

Year	1965	1975	1985	1995	2005
Population	25000	32000	42500	55000	69000

Solution:

			Arithmetic method					Geometric method			
Information	Year	Population	ΔP	Δt	K	$K_{Average}$	Pt	K	$K_{Average}$	LN (Pt)	Pt
	1965	25000									
	1975	32000	7000	10	700			0.024686			
	1685	42500	10500	10	1050			0.028377			
	1995	55000	12500	10	1250			0.025783			
Base year	2005	69000	14000	10	1400	1100		0.022677	0.025381		
Period design (t)	30										
First stage	2020						85500			11.52257	100969.5
Second stage	2035						102000			11.90328	147751.2

If adopting the arithmetic method:

Average daily demand = 500 × 102000=51000000 L/day=51000 m^3/day

Maximum daily demand =1.8 × average daily demand=1.8 ×51000=91800 m^3/day

Maximum weekly demand =1.48 × average daily demand=1.48 ×51000=75480 m^3/day

Maximum monthly demand =1.28 × average daily demand=1.28 ×51000=65280 m^3/day

Maximum hourly demand =1. 5 × Maximum daily demand=1.5 ×91800=137700 m^3/day

Minimum hourly demand =0. 5 × Maximum daily demand=0.5 ×91800=45900m^3/day

Fire demand for 10 hr duration:

$F = 1020 \times \sqrt{P} \times \left(1 - 0.01 \times \sqrt{P}\right) = 1020 \times \sqrt{102} \times \left(1 - 0.01 \times \sqrt{102}\right) \approx 9261 gpm \approx 50476\ m^3/day$

Problem 2.7: A community has an estimated population of 40×10^3 capita in a period of 25 years ahead. The present population is 30×10^3 capita with a daily water consumption of 20×10^3 m^3/d. The existing water treatment plant (WTP) has a maximum design capacity of 45.6×10^3 m^3/day, assuming an arithmetic growth rate; determine for how many years this plant will reach its design capacity.

Solution:

$$\text{Rate of consumption} = \frac{20 \times 10^3}{30 \times 10^3} = 0.667 \times 10\ m^3/(\text{Capita. day})$$

$$k = \frac{\Delta \text{P}}{\Delta \text{t}} = \frac{40 \times 10^3 - 30 \times 10^3}{25} = 400\ \text{capita/year}$$

Maximum daily demand = Average domestic demand × 1.8

$$45.6 \times 10^3 = 1.8 \times (30 \times 10^3 + 400 \times \Delta\text{t}) \times 0.667 \Rightarrow \Delta\text{t} \approx 20\ \text{year}$$

Problem 2.8: A community has an estimated population 20 year hence which is equal to 35000. The present population is 28000, and present average water consumption is 16×10^6 L/day. The existing water treatment plant has a capacity of 5 mgd. Assuming an

arithmetic rate of population growth determine in what year the existing plant will reach its design capacity?
Solution:

$$\textbf{Average daily consumption} = \frac{\mathbf{16 \times 10^6 l/day}}{\mathbf{28000}\ \boldsymbol{capita}}$$

$$= \mathbf{571.42\ l\boldsymbol{iter}\ per\ capita/day}$$

$$\textbf{Water treatment capacity} = \mathbf{5 \times 10^6 \times 3.785}$$

$$= \mathbf{18.925 \times 10^6\ l/day}$$

$$\boldsymbol{Number\ of capita\ t\ the\ nd\ of\ design\ period\ WTP}$$

$$= \frac{\mathbf{18.925 \times 10^6}\ \boldsymbol{l/day}}{\mathbf{571.42}\ \boldsymbol{l/c.d}} \approx \mathbf{33120}$$

$$k = \frac{PO - P}{\Delta t} = \frac{35000 - 28000}{20} = 350$$

$$P_f = P_O + kt \Rightarrow 33120 = 28000 + 350t \Rightarrow t = 14.628 \approx 15 year$$

Problem 2.9: Determine the fire flow required for a residential area consisting of homes of ordinary construction, 2500 ft^2 in area, 10 ft apart. What total volume of water must be provided to satisfy the fire demand of this area?
Solution:
From (Table 2-3 page 18 STEEL), the residential fire flow = 1500 gpm

$$F(gpm) = 18\mathrm{CA}_{\mathrm{ft}^2}^{0.5} = 18 \times 1 \times (2500)^{0.5} = 900 gpm$$

$$Water\ demand = 900 + 1500 = 2400\ gpm = 9084\ L/min = 545040\ l/hr$$

$$V = 545040\ l/hr \times \frac{10}{24} \times \frac{1m^3}{1000l} = 227m^3$$

Problem 2.10: A residential area of a city has a population density of 15000 capita per km^2 and an area of 120000 m^2. If the average water flow is 300 L/capita.day. Estimate the maximum rate to expected in m^3/sec?
Solution:

$$A = \frac{120000}{1000000} = 0.12km^2 \quad \& P = 15000 \times 0.12 = 1800\, capita$$

$$Averagre\ daily\ demand = 300 \frac{L}{cap.day} \times 1800 = 540000 \frac{L}{day}$$

$$= 540m^3/day$$

$$Maximum\ daily\ demand = 1.8 \times 540 \frac{m^3}{day} = 972 \frac{m^3}{day} = 40.5 \frac{m^3}{hr}$$

$$= 0.011m^3/sec$$

$$G = 1020 \times \sqrt{1.8} \times \left(1 - 0.01 \times \sqrt{1.8}\right) 1350.113gpm$$

$$= 5110.177Lpm = 5.11 \frac{m^3}{min} = 0.085 \frac{m^3}{sec}$$

$$= 7358.655m^3/day$$

$Maximum\ daily\ demand = 972 + 7358.659 = 8330.659 \frac{m^3}{day} =$

$0.096m^3/sec$

$Total\ volume\ daily\ demand = 972 + 7358.655 \times \frac{10}{24} =$

$4038.105 \frac{m^3}{day} = 0.0467m^3/sec$