Water and Wastewater Engineering
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Lecture - 4
Water and Wastewater Quantity Estimation (Continued)

Last class we were discussing about population forecast. We have seen that in any water supply system the quality as well quantity is very very important. And if you want to meet the quality based upon the beneficial use we can achieve it by various treatment processes. But when we talk about the treatment plant design we should know what amount of water is to be treated. So how can we find out this one? For that purpose we should know what is the population to be served and what is the per capita water demand and what are the other water uses in that particular area. If we know all these parameters then we can find out what is the total quantity of water that needs to be treated and based upon that one we can design the treatment plants.

And we have also seen that whenever we talk about a water treatment plant or a wastewater treatment plant the design period is very very important because we are not designing the treatment plant for a particular time not for the current situation but it should also be able to serve the requirement for the future also. So usually the water treatment plants are designed for 20 to 40 years deign period. But the various facilities in water treatment systems have various design periods.

For example, we have discussed in detail about the dams. Usually when we design a dam the design period is usually 50 years. But when we talk about the treatment plants; the pumps and other mechanical units it will be having a design period of 10 to 15 years. Then, if you want to predict the population at that time because the treatment system should be able to meet the requirement at that time also so we have to predict the population then only we will be able to find out what is the quantity requirement. So how can we do this population prediction; that’s why we use various population forecasting methods.

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Factors affecting

1. Economic factor
2. Social facilities
3. Community life
4. Development program
5. Communication links
6. Unforeseen factors
7. Development programs
8. Tourism

We have seen the various factors affecting this population because the population will be increasing or decreasing in an area so the various factors affecting the population are economical factor, social facilities, community life, developmental program, communication links, unforeseen factors, developmental programs and tourism. we have seen all these factors in detail in the last class and we have also discussed what all are the various methods of population forecasting and we have seen in detail about demographic method, arithmetic increase method, incremental increase method, geometrical increase method and decreasing rate of growth. So these methods we have seen in detail and we have also discussed at what circumstances we can go for each and every method.

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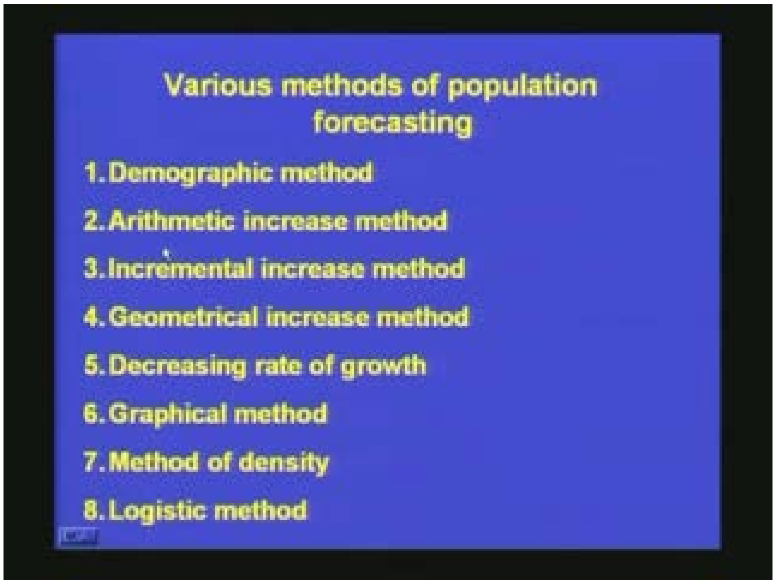

Various methods of population forecasting

1. Demographic method
2. Arithmetic increase method
3. Incremental increase method
4. Geometrical increase method
5. Decreasing rate of growth
6. Graphical method
7. Method of density
8. Logistic method

And we have seen that arithmetical method usually under predicts the population so it can be used for a well established society. But when we use this geometrical increase method it will be over predicting the population. So, if you want to find out the population in a newly established area then it is always better to go for geometrical increase method. And today we will discuss in detail about other methods like graphical method, method of density, logistic method, etc in detail and we will be also talking about the water demand from various sectors.

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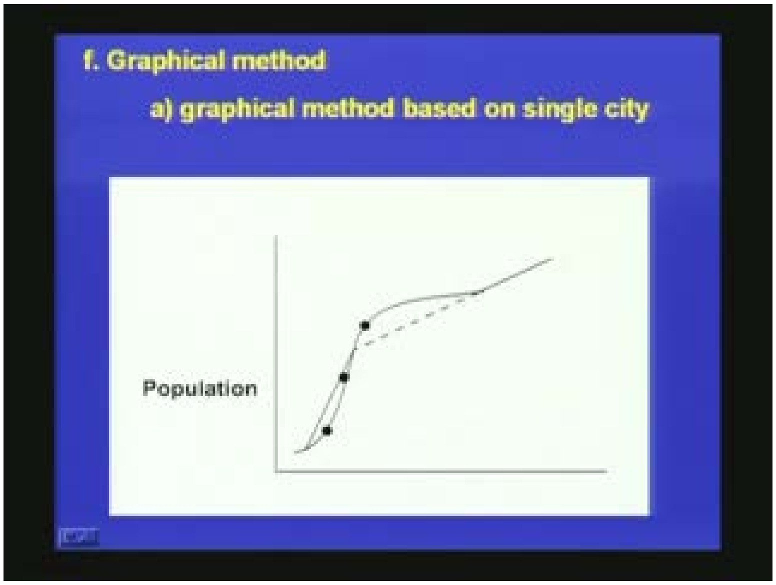

f. Graphical method

a) graphical method based on single city

So first we will talk about graphical method. This is yet another method of population forecasting. And graphical method can be used in two cases; first one is the graphical method based on a single city and next one is graphical method based on cities in similar growth pattern. So we will see in detail what this is.

Graphical method based on a single city means we have population information about an existing city for many years. This data we can get from the census records because we know that every ten years we have the population data for any place. So what we have to do, in this graphical method you plot the population of the existing city with respect to time like this so we will be getting the points like this (Refer Slide Time: 5:32). So you will know the trend of the population growth in that area. So first draw this curve and we can extrapolate this curve to get the future population. when we do the extrapolation we should be very very careful because we should be well aware of the situation in that place and you should be aware of the population growth pattern in that area and we have to consider all the factors whatever we were discussing earlier when we want to extrapolate this one.

So, a well experienced person with proper judgment can do the extrapolation properly and to get the best fit you can go for the least square method. So once again I will explain: In graphical method based on a single city what we have to do, we have to collect the population, information, whatever is available about that city and you plot the curve population versus year so you will be getting a curve so from that one we can make out what is the trend of population increase in that area. By proper judgment and by understanding the prevailing situations in that area we can extrapolate this line and get the future population. So this method is very very simple but it may not be very accurate.

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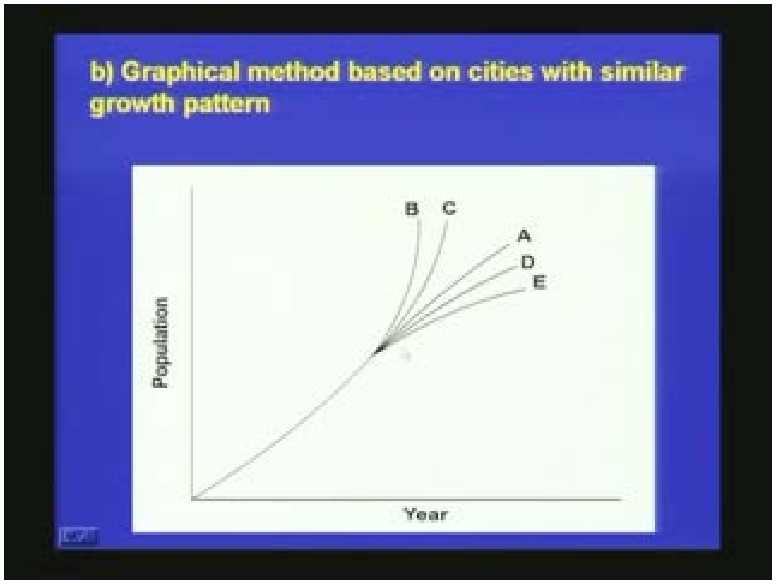

b) Graphical method based on cities with similar growth pattern

Now the second method coming under graphical method is based up on cities with similar growth pattern. So this can be used for a city. We don’t have any information about the city but we know some other cities which is having the same growth pattern as the city of concern. So what we have to do at that case. so you take the population growth pattern of the other city which is having the same pattern of growth of the city of interest then what you have to do, you plot the population versus time or year then you will be getting some line like this for the city which is having the same type of pattern.

So, if you want to get the population growth pattern of the city of interest what we can do, we can take the same trend or if you know something is going to change there or some situation or some condition is going to be different than the existing other similar city then we can make modification accordingly and select the suitable growth pattern. This is another method. Again this method is also not so accurate. Now, the next method is the method of density. This is relatively a simple method. So what we are doing is, we know, whenever we construct or we plan a city it will be having various zones, we will be having residential zone, industrial zone, institutional zone, commercial zone, etc so we know what is the area coming under each and every zone and if you know the growth pattern or the rate of population density increase then we will be able to forecast the population in each zone.

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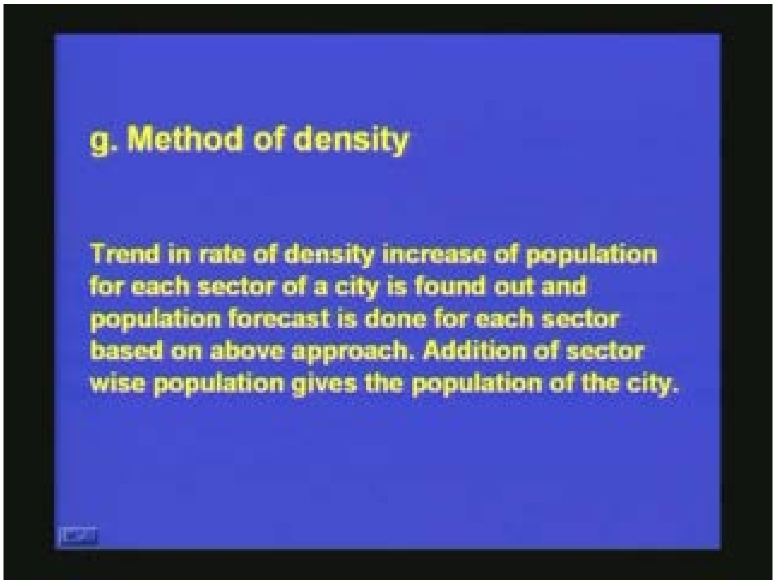

g. Method of density

Trend in rate of density increase of population for each sector of a city is found out and population forecast is done for each sector based on above approach. Addition of sector wise population gives the population of the city.

And if you know the population under each sector then if you want to find out the total population what we can do is find out the population in individual sectors and sum it up then you will be getting the total population of that area. So that is what I have written here. The trend in rate of density increase of population for each sector of a city is found out and population forecast is done for each sector based on above approach. Addition of sector wise population gives the population of the city. So we have to find out the rate of density increase of population in residential area separately, industrial area separately, commercial area separately and institutional area separately. And there are some other rules. Because if you have residential area and if the residential area consists of flats; two bedroom flats or three bedroom flats or independent bungalows so depending upon the area we can find out the population because for two bedroom apartments we consider maximum population in an apartment is around 5 so based upon that one we can find out what is the total population coming under a particular area. So that method is employed in method of density. This is an easy method but it may not be predicting the population very accurately.

Now we will see the last method. This is known as logistic method. This is the most scientific way of predicting the population, so most scientific way of predicting the population and we know that population projection can be mathematically modeled with a logistic or S shaped growth curve.

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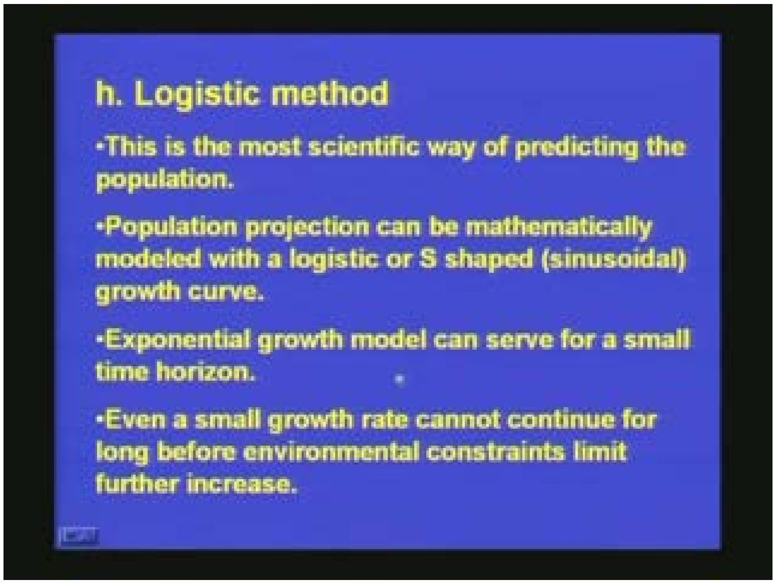

h. Logistic method

- This is the most scientific way of predicting the population.
- Population projection can be mathematically modeled with a logistic or S shaped (sinusoidal) growth curve.
- Exponential growth model can serve for a small time horizon.
- Even a small growth rate cannot continue for long before environmental constraints limit further increase.

Exponential growth model can serve for a small time horizon and even a small growth rate cannot continue for long before environmental constraints limit further increase.

So I will explain in detail. Logistic curve is the most scientific way of predicting the population. What we are doing here is, if you are assuming that, just like in geometrical increase method what we are assuming is, the population is increasing exponentially. So, if the population is increasing exponentially what happens, the population will be increasing drastically and that system will not be able to sustain such type of a population so definitely there will be a decrease in weight of growth. For example, if you take the case of microbial growth curve this will explain what is happening in a system if the growth follows an exponential path.

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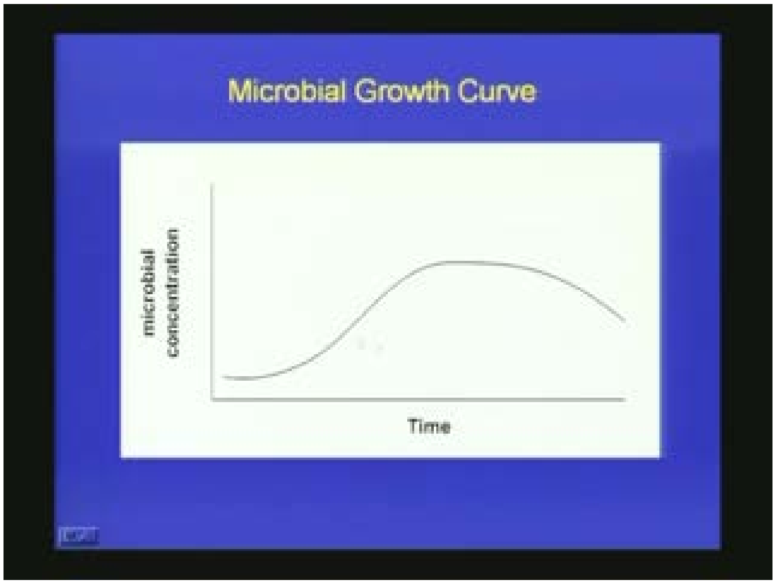
Microbial Growth Curve

We have a container, in that one we are supplying enough nutrients and food for the microorganism for their growth and the environmental conditions provided in that system is conducive for microbial growth. So initially we are adding a very small amount of microorganism to the reactor or the system. So what will happen, enough food is available and the environmental conditions are conducive so the microorganisms will start growing. This is what is given here. So initially you are adding a small concentration of the microorganisms to the system. So the microorganism will take some time to get acclimatized to the system. So that is why, if you see the microbial concentration increase with respect to time, initially it will be almost negligible so this time is known as lack period.

Anyway we will see this one in detail when we talk about biological wastewater treatment. This period is known as the lack period because it is getting acclimatized to the changed environmental conditions. Once it gets acclimatized to the changed environmental conditions there is no restriction for the microbial growth. So what is happening is the microbes starts growing at an exponential rate so this is known as exponential growth face or low growth face. So the microbial concentration keeps on increasing, if it follows this one what will happen is, with respect to time the curve will be going as something like that (Refer Slide Time: 13:02) and I have already mentioned that the system will be having unlimited amount of food and enough nutrients are there environmental conditions are conducive.

But even then if you watch the system or if you measure the microbial concentration with respect to time we can see that it is not going to follow this path but it will be following this path. After sometime the exponential growth phase will be changing to stationary growth phase. That means the microbial concentration or the net microbial concentration increase is negligible or net concentration increase is zero. This is known as the stationary phase. And after sometime what will happen, the microbial concentration will start decreasing.

Why it is happening like this?

If you watch the population growth in any society or any community it also will be following this trend. The reason is, because the microorganisms are growing exponentially here the population also is increasing drastically. So definitely what will happen, whatever food is available the microorganism will be competing to take the food that is one reason and another thing is because of the microbial growth there will be lot of byproduct generated so all these byproducts will be getting accumulated in the system so that can cause toxicity to the microorganism or there will be a crowding affect and resources crunch in the system so definitely that is going to affect the population so the growth rate is coming down and it is reaching the rate of increase will be zero then afterwards it will be decreasing.

So, if you understand this microbial growth curve we can use the same principle to find out the human population increase also. That also will be following this trend. This is the basic principle behind the logistic method. In logistic method we assume that the population growth follows an S curve or a sigmoidal curve. We can see that this is the S curve and here we are representing x and y, x axis is representing time.

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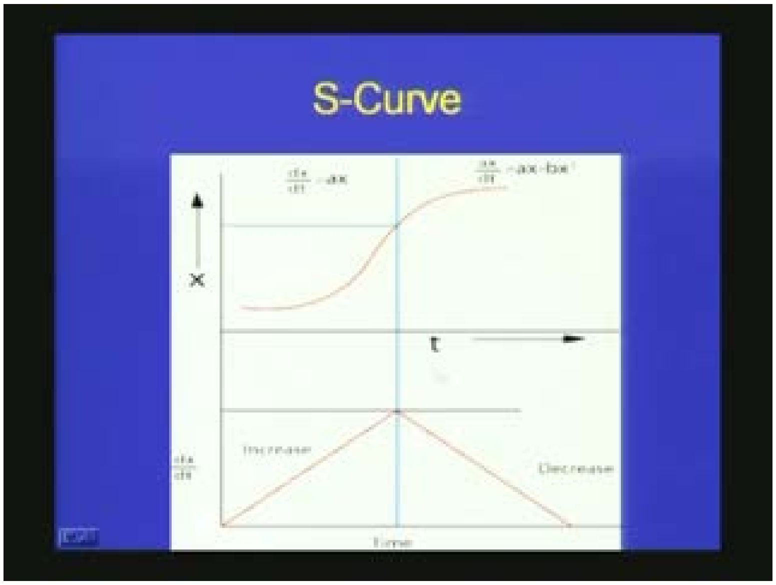

S-Curve

And with respect to time how the x is increasing, that will be following an S shape. So here if you want to find out what is the slope dx by dt that is equal to a into x the equation of this portion and here it is dx by dt is equal to ax minus bx squared. Or if you want to find out the slope of this curve up to this portion the point of inflation what is happening the slope keeps on increasing. So we can see that this is the dx by dt. dx by dt is nothing but the slope of this curve. Up to here (Refer Slide Time: 16:01) we can see that the slope is increasing and after this point what is happening, the slope keeps on decreasing so same thing will be happening if you look into the population density rate or population growth rate.

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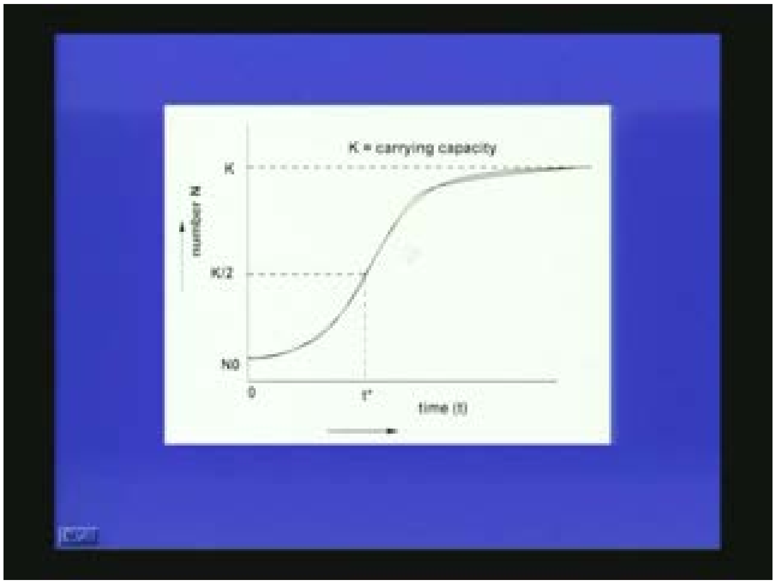

If you want to represent the population then we can go for this type of a curve. So you have initially a population of N0 so the population is very very less and that system or that locality can take care of much more population. Initially the population will be increasing exponentially. We can see here, after sometime this t star, the rate of increase will be decreasing. That means the slope dN by dt if you find out, the slope will be negative and after certain time what will happen, the population will be reaching a saturation value. We can see that at this point, it is becoming asymptotic and no further increase. This k value is known as the carrying capacity of the system. That means if you have a system this is the maximum population the system can take care. That is what is the significance of carrying capacity and this t star is also very very important. The t star is nothing but the time corresponding to the population which is equal to k by 2 that means it is half of the carrying capacity. This t star will give you the point of inflation and after that one what is happening, the population growth rate will be decreasing. This is the way we can represent scientifically the population growth rate in any community.

If you want to accurately predict the population this is the best method to follow. Now we will see using this method how can we predict the population or how can we find out the population after a particular or specified period of time. This is what I was telling you, the rate of change of population; dN by dt is nothing but rate of change of population or rate of population growth.

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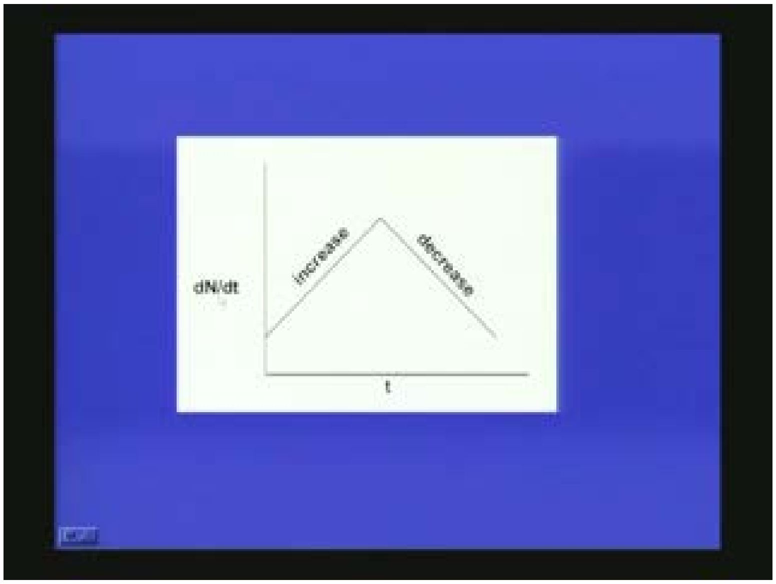

Initially it will be increasing. You can see that the slope is increasing or the rate of population growth is increasing and after some time it is decreasing. Thus, based upon this one if you want to find out the population at a given time how can we do that. We will see the mathematical expressions for this analysis.

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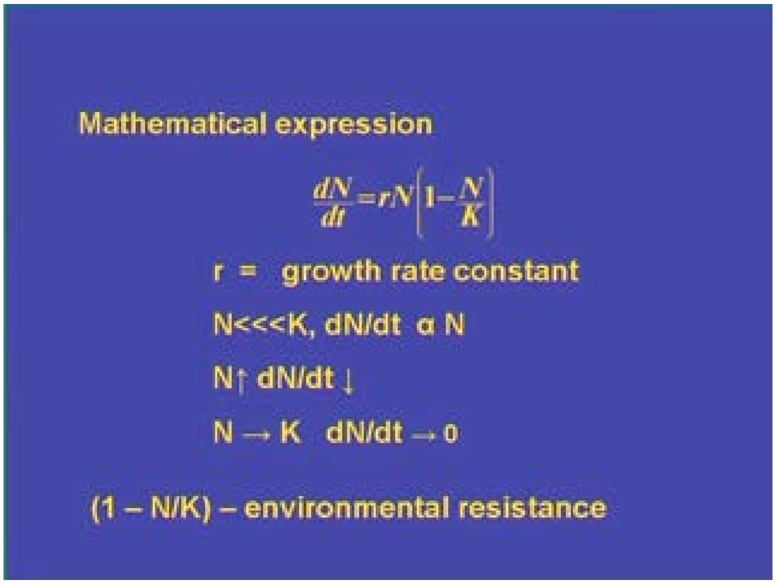

Mathematical expression

$$\frac{dN}{dt}=rN\left(1-\frac{N}{K}\right)$$

r = growth rate constant

$N \lll K$, $dN/dt \; \alpha \; N$

$N\uparrow \; dN/dt \downarrow$

$N \rightarrow K \quad dN/dt \rightarrow 0$

$(1 - N/K)$ – environmental resistance

We will see the equation; dN by dt is equal to r into N into 1 minus N by K where dN by dt is the rate of change of population and N is the population and k is the carrying capacity and r represents the growth rate constant. In this equation we will see what happened to this dN by dt with respect to N. When N is very very less compared to k value the dN by dt will be proportional to N. So, what is happening? In the term 1 minus N by K we can see that if N value is very small that N by K value itself will become almost negligible so your equation dN by dt will be equal to r into N or the rate of change of population will be proportional to N. As N increases what will happen, dN by dt will be decreasing the reason is, that 1 minus N by K that term value will be decreasing and when N tends to K that means when N is almost equal to the carrying capacity of the system dN by dt will be tending to 0 or there will not be any growth or net rate of change of population will be almost 0. So in this equation this 1 minus N by K term is very very important that is nothing but the environmental resistance.

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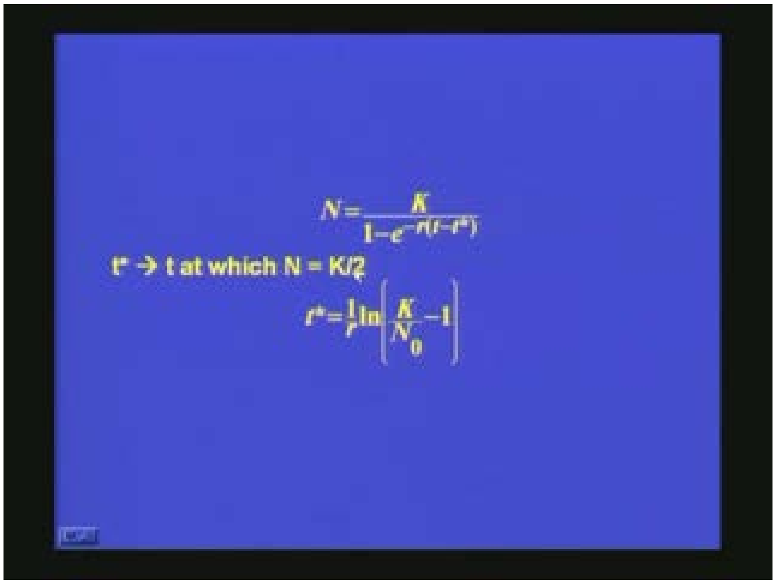

$$N=\frac{K}{1-e^{-r(t-t^*)}}$$

$t^* \rightarrow$ t at which $N = K/2$

$$t^*=\frac{1}{r}\ln\left(\frac{K}{N_0}-1\right)$$

Now we will see; we have the equation for the population increase or rate of change of population so how can we find out the population at any time t. What we have to do we have to integrate the above expression so you will be getting an expression like this; N is equal to k by 1 minus e raised to minus r into t minus t star. And we have also seen that this t star is nothing but the t at which N is equal to K by 2 or the population which is equivalent to half of the carrying capacity.

We can write another expression for this t star, it is a function of r, this is your exponential growth rate and K is the carrying capacity of the system and N 0 is nothing but initial population of the system. So, if you know these parameters then we can find out what is t star. The t star is nothing but 1 by r ln K by N 0 minus 1. So t star we will know and we know K and we know r then we can find out what is the population at any time t. Here the unknown is only t and we want to know at that time what is the population so we can put the t according to our convenience and get the population corresponding to that one. This is the way we can use this logistic curve for predicting the population.

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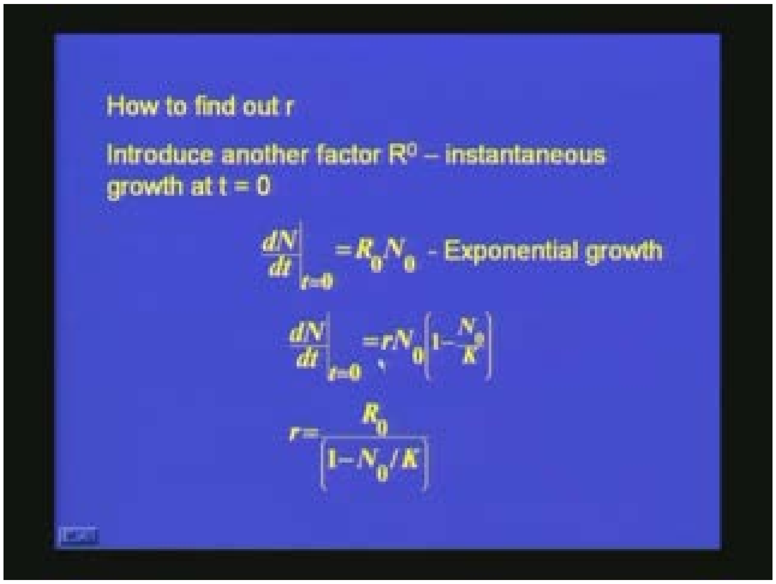

How to find out r

Introduce another factor R^0 – instantaneous growth at t = 0

$$\left.\frac{dN}{dt}\right|_{t=0} = R_0 N_0 \text{ - Exponential growth}$$

$$\left.\frac{dN}{dt}\right|_{t=0} = rN_0\left(1-\frac{N_0}{K}\right)$$

$$r = \frac{R_0}{\left(1-N_0/K\right)}$$

Now we will find out how we can find out this r because it is an exponential growth rate and we have seen that r is not a constant it will keep on changing, it will be increasing then it will be decreasing, it is a function of N. So, in order to find out r what we have to do is introduce another factor R 0 so this R 0 is nothing but the instantaneous growth at t is equal to 0. Once again we are introducing another factor R 0 this R 0 is nothing but the instantaneous growth at t is equal to 0.

So we can write dN by dt that is rate of change of population at time t is equal to 0 that is equal to R 0 into N 0 because N 0 is the initial population and R 0 is the instantaneous growth rate at t is equal to 0. So the rate of change of population is nothing but R 0 into N 0 and this represents the exponential growth.

We have also seen that dN by dt equal to R into N into 1 minus N by k, this one we have see earlier. N is the population at any time. So if you put t is equal to 0 definitely your N will be changing to N 0. This we can write like this; dN by dt at t is equal to 0 equal to r into N 0 into 1 minus N 0 by K. We know that dN by dt at t…… this is also dN by dt at t is equal to 0 and this is also dN by dt at t is equal to 0 so these two terms are same so we can equate these two terms so from this one we can find out r is equal to R 0 divided by 1 minus N 0 by K where R 0 is the instantaneous growth rate and N 0 is the population at t is equal to 0 and k is the carrying capacity of the system. So if you can find out r then we can find out what is the population at any time and what is the time required to reach the half carrying capacity etc.

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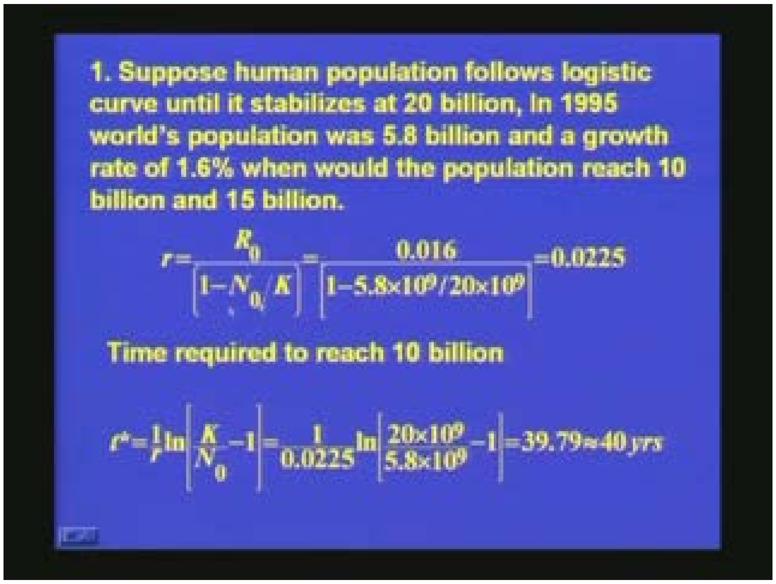

1. Suppose human population follows logistic curve until it stabilizes at 20 billion, In 1995 world's population was 5.8 billion and a growth rate of 1.6% when would the population reach 10 billion and 15 billion.

$$r = \frac{R_0}{\left[1 - N_0/K\right]} = \frac{0.016}{\left[1 - 5.8\times10^9/20\times10^9\right]} = 0.0225$$

Time required to reach 10 billion

$$t^* = \frac{1}{r}\ln\left|\frac{K}{N_0} - 1\right| = \frac{1}{0.0225}\ln\left|\frac{20\times10^9}{5.8\times10^9} - 1\right| = 39.79 \approx 40\,yrs$$

This is a simple problem. We will see how to solve it. This is just an example. suppose human population follows logistic curve until it stabilizes at 20 billion, in 1995 world's population was around 5.8 billion and a growth rate of 1.6 percentage when would the population reach 10 billion and 15 billion.

First what we have to do, we have to find out what is the exponential growth rate r. We have seen that the formula we can use, that is R 0 divided by 1 minus N 0 by K and we know what R 0 is, it is given as 1.6 percentage so we can put it as 0.016 and that divided by 1 minus N 0, at a time t is equal to 0 it is 5.8 billion divided by and carrying capacity of the system is 20 billion so we will be getting r as 0.0225. Now we have to see what is the time required to reach 10 billion. Because your carrying capacity is 20 billion so K by 2 is nothing but 20 by 2 that is 10 billion that is time t star. t star is nothing but the time required for the population to reach half the saturation value.

So t star is nothing but 1 by r into ln K by N 0 minus 1. We have seen the formula earlier so we know all the values so you substitute it and we will be getting around 40 years. So, if you want to reach the t star we have to wait 40 years.

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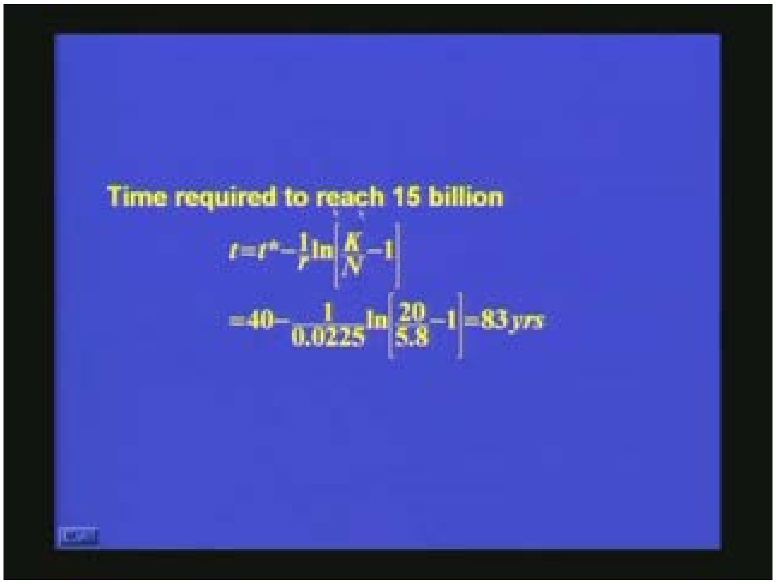

Time required to reach 15 billion

$$t = t^* - \frac{1}{r}\ln\left[\frac{K}{N} - 1\right]$$

$$= 40 - \frac{1}{0.0225}\ln\left[\frac{20}{5.8} - 1\right] = 83\,yrs$$

So once we get the t star we want to find out what is the time required to reach 15 billion so we can use this formula; t is equal to t star minus 1 by r into ln K by N minus 1 so we can see that if you want to reach 15 billion it takes around 83 years. This is just an example. We can use the same concept to predict the population we required at any time. Usually it is the design period whenever we talk about the water supply systems or waste water treatment systems.

Now we will talk about another term whenever we talk about the logistic curve. This term is also very important. This is the maximum sustainable yield. What does it mean the maximum sustainable yield? It is the maximum rate at which individual can be removed without reducing the population size.

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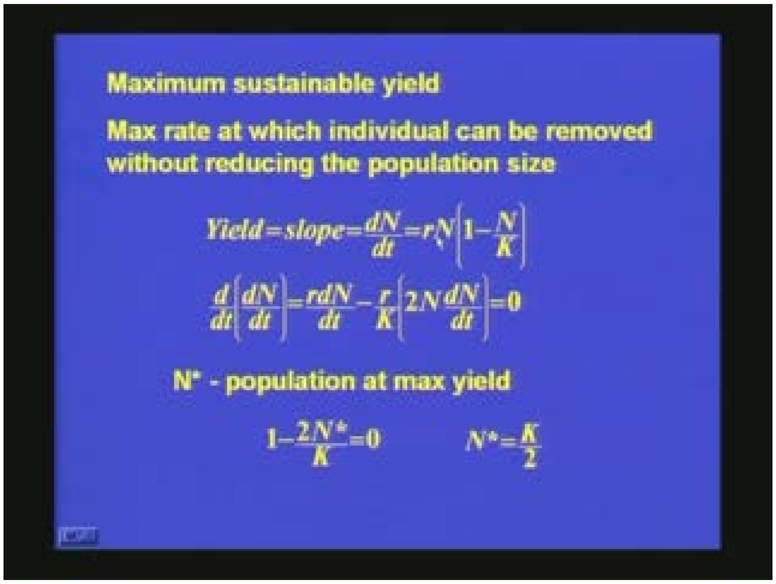

Maximum sustainable yield

Max rate at which individual can be removed without reducing the population size

$$Yield = slope = \frac{dN}{dt} = rN\left(1-\frac{N}{K}\right)$$

$$\frac{d}{dt}\left(\frac{dN}{dt}\right) = \frac{rdN}{dt} - \frac{r}{K}\left(2N\frac{dN}{dt}\right) = 0$$

N* - population at max yield

$$1-\frac{2N^*}{K}=0 \qquad N^*=\frac{K}{2}$$

The maximum rate at which individual can be removed without reducing the population size. That means your rate of population growth should not be changing. That is the maximum sustainable yield. Yield is nothing but the slope and we have seen that slope is nothing but dN by dt and dN by dt can be exposed in this term; r into N into 1 minus N by K and this is the environmental resistance term. And the maximum rate at which individual can be removed means the slope should not be changing. So the point if you want to find out then what we have to do, we have to find out the rate of change of this slope and equate it to zero. So d by dt of dN by dt we have to find out. That means d by dt of r N into 1 minus N by K we can find out so you will be getting it like this; r into dN by dt minus r by k into 2 N into dN by dt that is equal to 0. And N star is the population at maximum yield so from this one we can find out 1 minus 2 N star by k is equal to 0 or N star is equal to K by 2.

So, if you want to remove the population or the population at maximum yield is nothing but N is equal to K by 2 that means this is the point where you can get maximum population yield.

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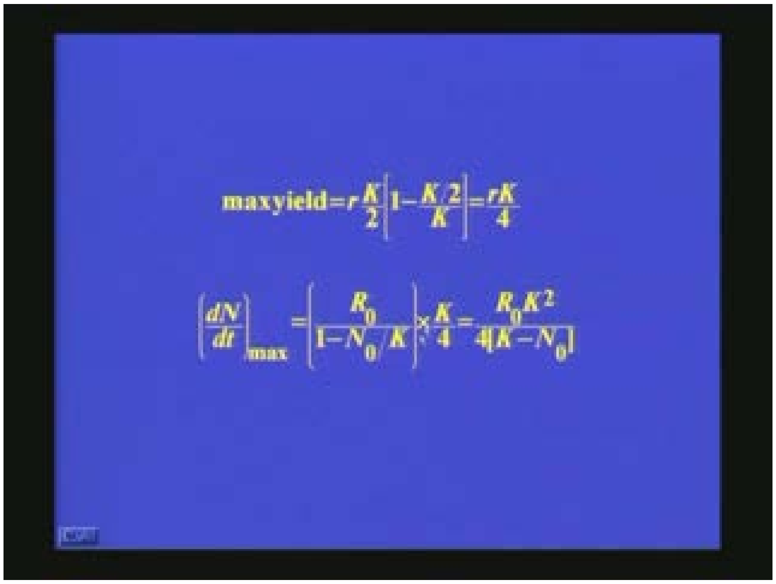

$$\text{maxyield} = r\frac{K}{2}\left[1 - \frac{K/2}{K}\right] = \frac{rK}{4}$$

$$\left(\frac{dN}{dt}\right)_{\max} = \left(\frac{R_0}{1 - N_0/K}\right) \times \frac{K}{4} = \frac{R_0 K^2}{4[K - N_0]}$$

And if we want to find out what is the maximum yield it is nothing but r into K by 2 into 1 minus K by 2 by K that is equal to r K by 4 or the dN by dt max that means the maximum population growth rate that is equal to R 0 into 1 minus N 0 by K into K by 4 because r is nothing R 0 by 1 minus N 0 by K into K by 4 then we will be getting R 0 into K star divided by four into K minus N 0 so this is the maximum population growth rate we can get when we follow the logistic curve. So till now we were discussing about various population forecasting methods and we have seen in detail what are all the advantages and disadvantages of each method and when we can go for each and every method.

We have also discussed in detail what is the most scientific way of predicting the population and that is nothing but the logistic curve or logistic growth method because that will be taking care of the environmental resistance the crowding effect the resource crunch etc so that is the most scientific way. So now, we have we have already discussed the area for the treatment plant and we have also discussed about the design period and we have seen how to forecast the population. So we know where to put up the treatment plant and how much time it has to serve the area and what is the number of population we have to serve.

Now, the next important thing is the water demand. What is the water demand per person, per day and what are all the other auxiliary water requirements so that we can find out what is the total quantity of water that needs to be treated.

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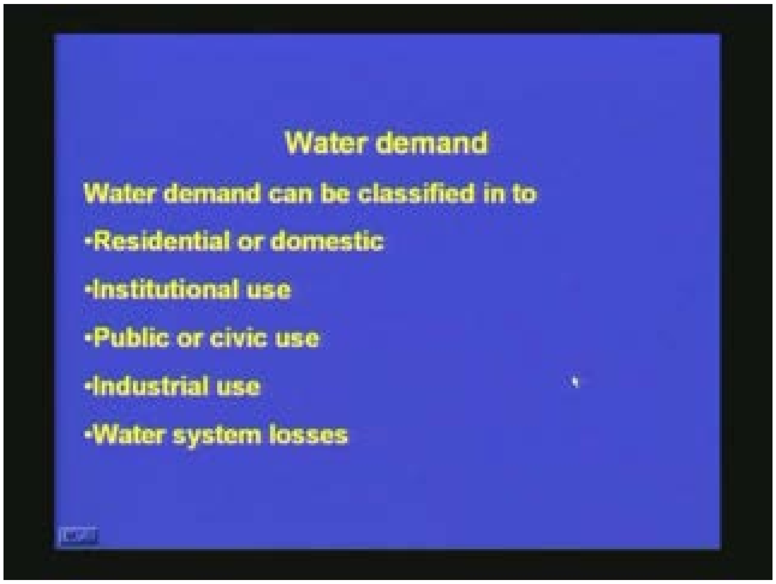

Water demand

Water demand can be classified in to

- Residential or domestic
- Institutional use
- Public or civic use
- Industrial use
- Water system losses

The water demand can be classified into various categories. Those are; residential or domestic and second one is institutional use, public or civic use, industrial use and water system losses. So whenever we talk about quantity we have to take into account all these parameters or all these heads separately and add it up then you will be getting what is the total water demand in a particular area. We will see one by one in detail.

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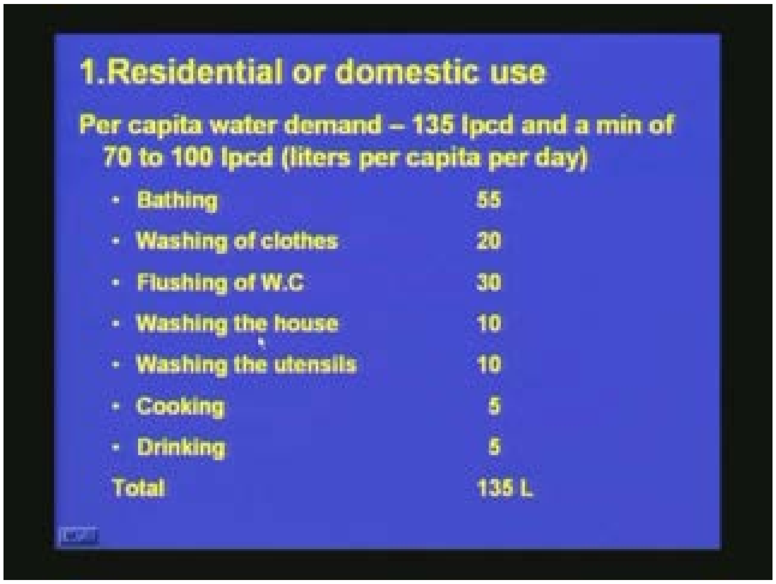

1.Residential or domestic use

Per capita water demand – 135 lpcd and a min of 70 to 100 lpcd (liters per capita per day)

• Bathing	55
• Washing of clothes	20
• Flushing of W.C	30
• Washing the house	10
• Washing the utensils	10
• Cooking	5
• Drinking	5
Total	135 L

The most important water demand is the residential or domestic use. So, according to the standards, the per capita water demand in Indian condition is 135 liters per capita per day. That means we are bound to supply 135 liters per capita per day for the proper living of human beings and if water scarcity is there a minimum of 70 to 100 liters per capita per day should be supplied. So now we will see how these 135 liters per capita per day is coming as the residential or domestic requirement.

If you want to divide the water consumption we can again divide it into many categories. It has been observed that for bathing an average person consumes 55 liters of water per day and for washing of clothes it is around 20 liters per day and flushing of WC it is around 30 liters and washing the house it comes around 10 liters and washing the utensils it is 10 liters and cooking 5 liters and drinking purpose we are using only 5 liters.

So whenever we talk about the quality these two (Refer Slide Time: 32:25) requires the maximum quality or the water quality should be very very good for cooking and drinking purpose and for the other things we can go for somewhat okay type of water. So if you add up all these things we can get a total water requirement of 135 liters. This is the water to be supplied for a person per day. But if water scarcity is there we have to supply at least 70 to 100 liters per capita per day. Whatever we have seen earlier is only for human use but in domestic use the consumption of water for domestic animals and live stock also should be taken into account.

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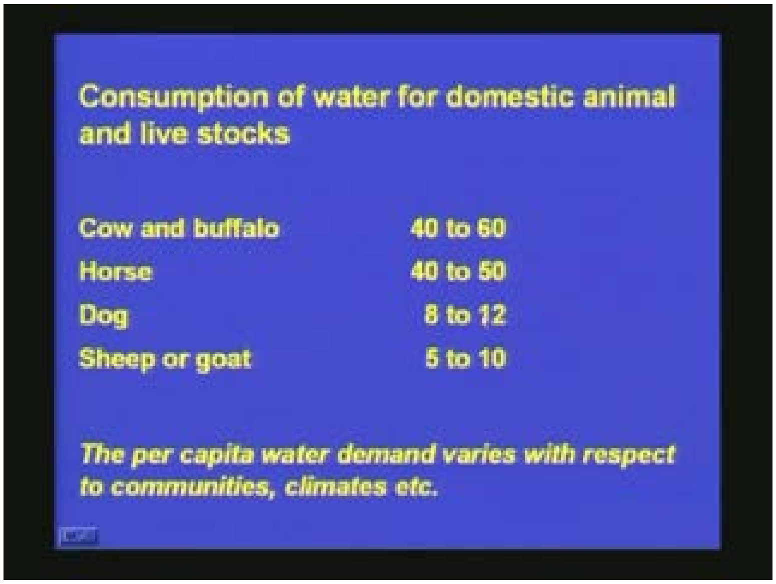

Consumption of water for domestic animal and live stocks

Cow and buffalo	40 to 60
Horse	40 to 50
Dog	8 to 12
Sheep or goat	5 to 10

The per capita water demand varies with respect to communities, climates etc.

So if we talk about this one; cows and buffaloes, if they are having……. so it will be consuming around 40 to 60 liters of water per day and horse 40 to 50 liters and dogs around 8 to 12 liters and sheep or goat around 5 to 10 liters. So this also we have to include depending upon the area whether they have the domestic animals and live stocks with human beings. If that is there, then we have to take into account this is this also.

And once again, the per capita water demand varies with respect to the communities, climate etc. This is very very important. Don’t assume that the water consumption of a place is constant or at different places if we consider it may not be a constant because it varies depending upon the communities and the climatic conditions. For example, if it is winter season definitely the water consumption will be much less compared to summer season. And talking about the communities, if it is a well established community or a posh area the water requirement will be very very high so they will be using the water for lawn watering, car washing etc so the water consumption will be relatively very very high whereas in poor communities the water consumption will be less. These factors also we have to take into account when we talk about the water demand.

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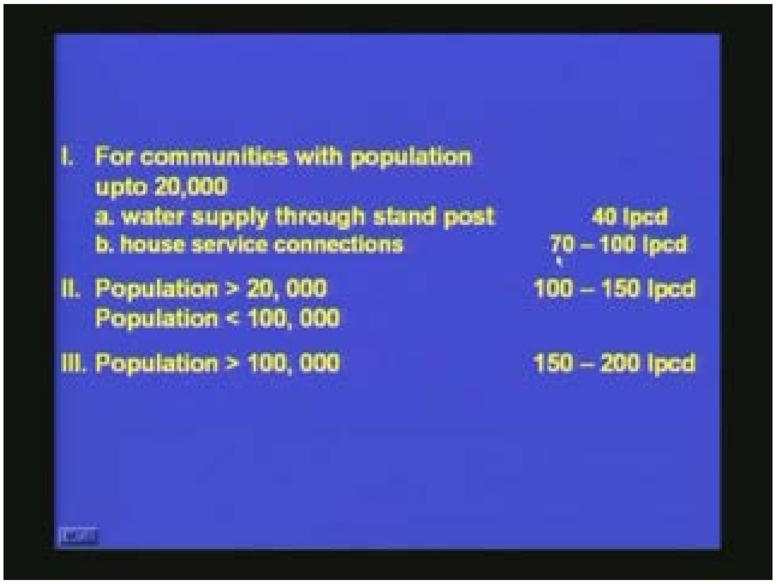

I. For communities with population upto 20,000	
a. water supply through stand post	40 lpcd
b. house service connections	70 – 100 lpcd
II. Population > 20, 000 Population < 100, 000	100 – 150 lpcd
III. Population > 100, 000	150 – 200 lpcd

Again the population is also a deciding factor about the water demand. For communities with population up to 20000 that means it is a very small community, if they don't have pipe water supply, if they are collecting the water through stand post then the water consumption will be very less, it will be only 40 liters per capita per day. The reason is they have to carry the water from a distant place and bring it and use it so definitely the water consumption will be less.

But if you have a small community but house service connections are there definitely the water use will be increasing, it will go up to 70 to 100 liters per capita per day. This is also very important for us to know how the water supply scheme in that community is. Apart from the population the water supply scheme is also important. And if the population size is more than 20000 and less than 1 lakh then the water consumption is around 100 to 150 liters per capita per day and if population is above 1 lakh the water consumption is increasing, it will be 150 to 200 liters per capita per day. The reason is there will be more community activities, recreational facilities etc so that requires more and more water that's why as the population increases the water demand of that community also will be increasing drastically. Hence, climatic conditions, community nature and community population all these parameters influence the water demand.

Till now we were discussing about the water demand in domestic sector or residential area. Now we will see what are all the water demand in institutional or what is the water demand coming under institutional use. That means any institute whichever is using water is coming under this category. That means the water consumption in hospitals, hotels, boarding schools, restaurants etc are coming under this category.

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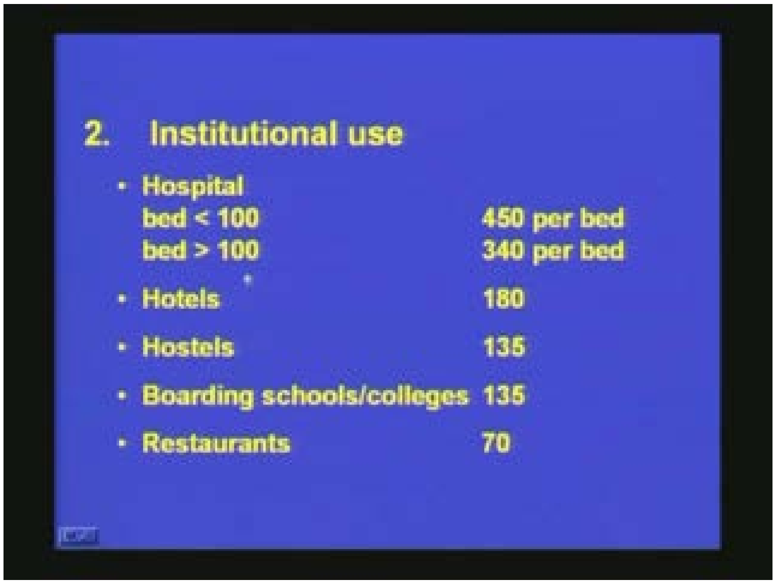

2. Institutional use

• Hospital	
bed < 100	450 per bed
bed > 100	340 per bed
• Hotels	180
• Hostels	135
• Boarding schools/colleges	135
• Restaurants	70

There are some standards available. For a hospital if the bed number is less than 100 the per capita water demand is 450 per bed. But if the number of beds are more then the per capita water demand is coming down, it is only around 340 liters per bed. And for hotels it is around 180 liters per capita and hostels it is 135 liters per capita per day and boarding schools and colleges it is 135 liters per capita per day and restaurants it is 70. That is the institutional use. Again, if you talk about airports and sea ports it is around 70 per person who is using the facility and day schools and colleges also it is around 45 and offices 45, cinema and concert calls halls 15 liters per person. So we have the standard. So we know how many institutions are present in that area of interest then we can find out what is the total water demand coming under institutional use.

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2. Institutional use

• Airports & sea ports	70
• Day schools and colleges	45
• Offices	45
• Cinema, concert hall	15

Now we will see what are all the water demand coming under public or civic use. What is meant by this public or civic use? This is the water consumption for the public or for the civic purpose. That includes; road washing, public park, sanitation, fire fighting etc because in big cities etc we have to maintain the roads properly. So, for road washing the water consumption is around 5 liters per capita per day. That means if you want to account for the public or civic use we have to add another 5 liters for road washing and for sanitation it is around 3 to 5 liters. Here, sanitation means public sanitary facilities whatever is provided. So, depending upon the population we have to provide 3 to 5 liters per capita per day.

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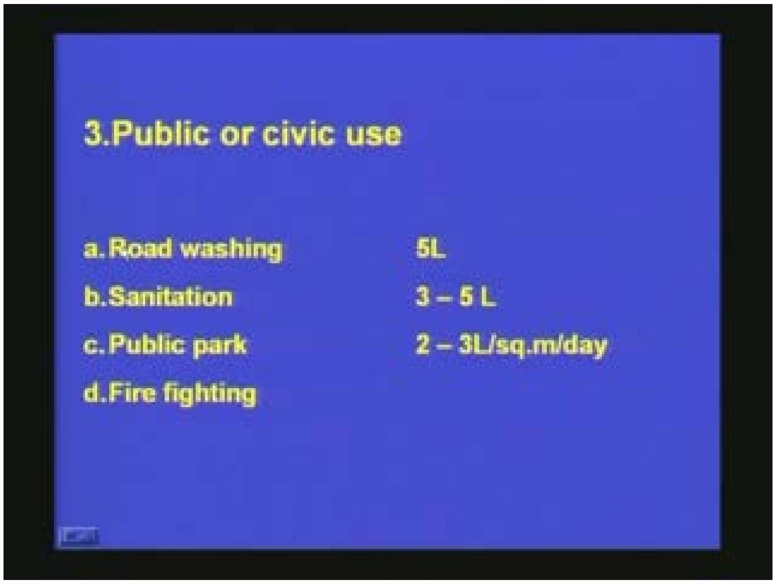

3.Public or civic use

a. Road washing	5L
b. Sanitation	3 – 5 L
c. Public park	2 – 3L/sq.m/day
d. Fire fighting	

And, public parks also need water for watering the lawns and the plants so the water requirement for this purpose is around 2 to 3 liters per square meter per day. So you will know the total area available for then we can find out what is the total water requirement for watering the park.

The next one is fire fighting. This is very very important because we have to have enough provision for fire fighting requirement. Now we will see in detail how can we find out what is the water requirement for this fire fighting or how can we find out the water requirement for fire fighting.

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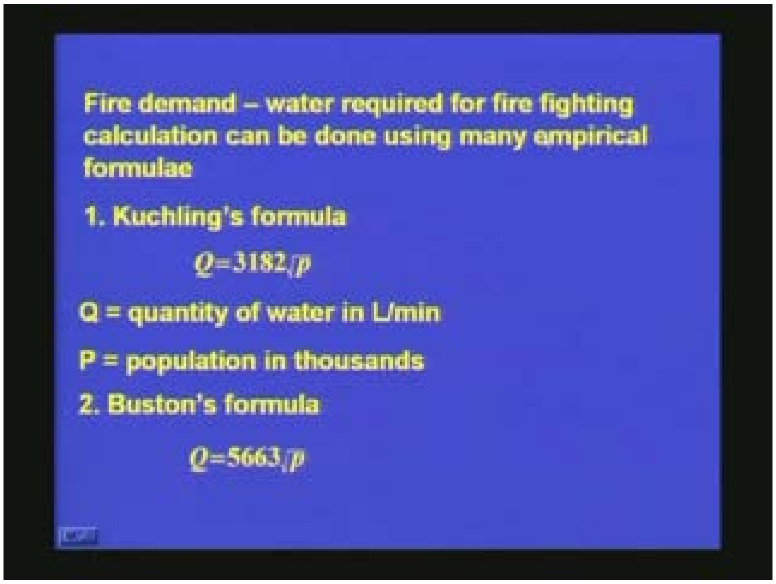

Fire demand – water required for fire fighting calculation can be done using many empirical formulae

1. Kuchling's formula

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

Q = quantity of water in L/min

P = population in thousands

2. Buston's formula

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

Fire demand - the water required for fire fighting, this calculation can be done using many empirical formula. There is no theoretical approach; everything is based upon empirical approach. There are many empirical formulas available for finding out the fire demand. Because what is happening is, the water consumed for fire fighting will be very less if you compare for the entire water requirement or water usage for the year, but why we have to provide the provision for fire demand is this; when there is fire we have to have enough water available for a short period under very high pressure then only we can fight the fire, that is the most important thing whenever we talk about the fire demand.

How can we find out the fire demand?
This is one of the empirical formula which is Kuchling's formula. Here Q is equal to 3182 root p. So Q is nothing but a quantity of water in liters per minute and p is population in thousands. We know what is the population in that area so we can put that one here in thousands and you will be getting the Q that is the water requirement for fire fighting in liters per minute so you have to provide that much of water for fire demand. And another formula is Buston's formula. He has given this formula; Q is equal to 5663 p. Again p is the population in thousands and q is the quantity of water in liters per minute.

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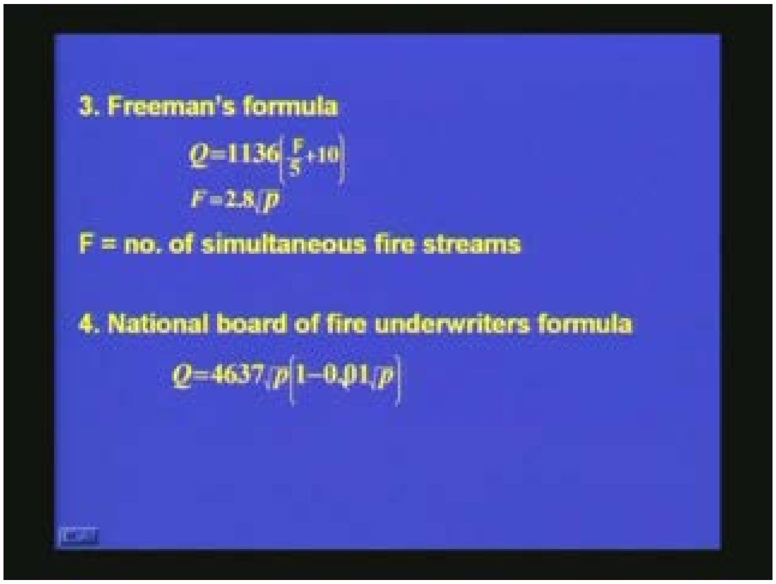

3. Freeman's formula

$$Q=1136\left(\frac{F}{5}+10\right)$$

$$F=2.8\sqrt{p}$$

F = no. of simultaneous fire streams

4. National board of fire underwriters formula

$$Q=4637\sqrt{p}\left(1-0.01\sqrt{p}\right)$$

Another one is Freeman's formula. Here Q is equal to 1136 F by 5 plus 10 and F is 2.8 into root p where F is the number of simultaneous fire streams required. And another empirical formula used for fire fighting is national board of fire underwriters formula. Here the formula is like this; Q is equal to 4637 root p into 1 minus 0.01 root p. This is one of the most commonly used empirical formula to find out the fire demand. The most important thing is most of the fire demand formula are empirical and it is a function of population. The basic assumption is, as the population is increasing the chances of fire occurrence will be more so definitely the fire demand also will be more so we can find out the fire demand based upon any of this empirical formula and provide provision for that one in the water supply system.

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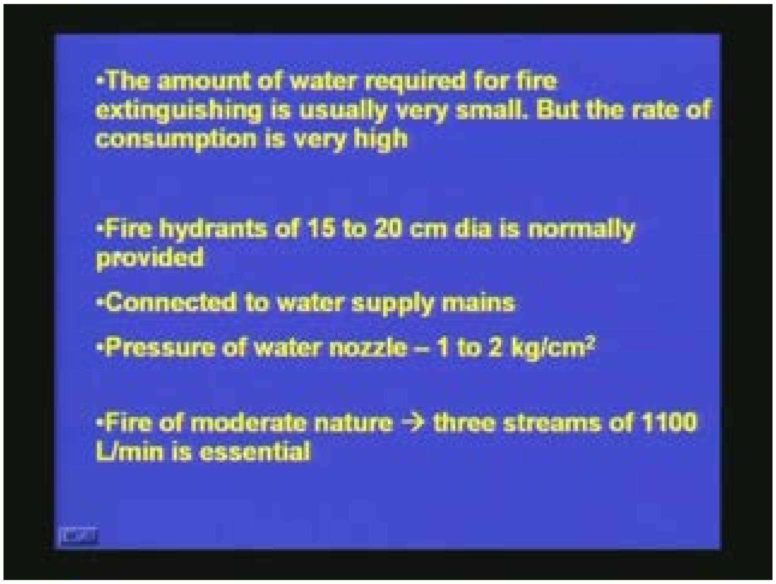

- The amount of water required for fire extinguishing is usually very small. But the rate of consumption is very high
- Fire hydrants of 15 to 20 cm dia is normally provided
- Connected to water supply mains
- Pressure of water nozzle – 1 to 2 kg/cm^2
- Fire of moderate nature → three streams of 1100 L/min is essential

This I have already discussed. The amount of water required for fire extinguishing is usually very small because the fire occurrence is very less. But the rate of consumption of water is very high that is why we have to always provide the fire demand. And the fire hydrants of 15 to 20 centimeter diameter is normally provided and these fire hydrants are usually connected to water supply mains and not the branch pipes. Usually the fire hydrants are connected to the water supply mains so that we can get the required amount of water under high pressure.

And pressure of water nozzle required for extinguishing the fire is around 1 to 2 kilogram per centimeter squared. So you can imagine what is the pressure under which the water is coming out of the nozzle in case of fire fighting. And if you have a fire of moderate nature a three streams of 1100 liters per minute of water is essential. This is very very important. If you want to extinguish a moderate fire we need three streams of around 1100 liters per minute and this will be going for an hour or two so we can imagine what is the amount of water required for the fire fighting. That’s why we have to consider this fire demand whenever we go for the water quantity estimation.

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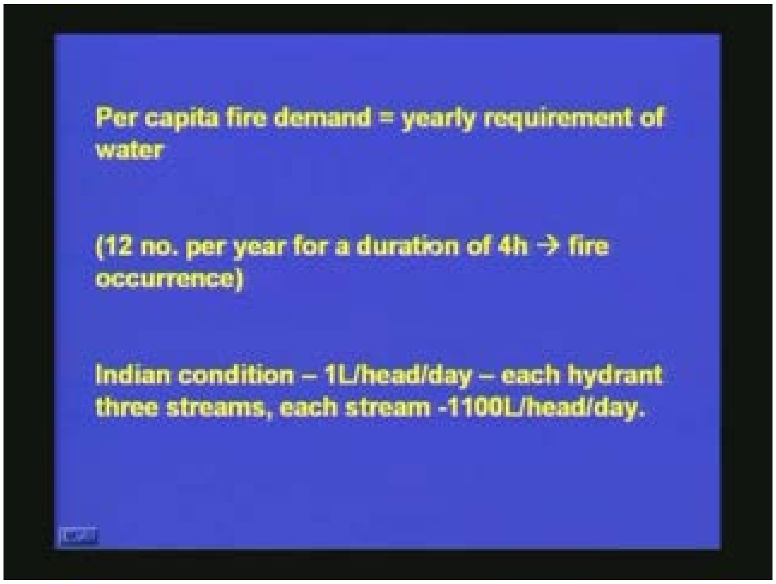

Per capita fire demand = yearly requirement of water

(12 no. per year for a duration of 4h → fire occurrence)

Indian condition – 1L/head/day – each hydrant three streams, each stream -1100L/head/day.

And usually the per capita fire demand is calculated based upon the yearly requirement of water. Because we know that what is the early requirement of water and we know what is the total population in that area so based upon that one we can find out what is the per capita fire demand. And usually we assume that twelve numbers per year for duration of 4 hours, this is the usual fire occurrence. That means in a year around 12 fire incidents will be occurring and the average duration of the fire may be around 4 hours so based upon that one we can find out what is the fire demand and we can convert it into per capita fire demand.

And in Indian conditions 1 liter per head per day is what we usually provide for fire demand because the population is very high compared to other countries so this is the per capita fire demand and each hydrant will be having three streams and each stream will be able to deliver 1100 liters per head 1100 liters per head per day or 1100 liters per minute this will be the water fluoride in each hydrant.

Now we will see the fourth one that is nothing but the industrial use. This is also very very important because in a locality there will be residential zone, institutional zone, then commercial zone, then you will be having industrial zone so each and every industry will be requiring water in most of the cases and the water requirement will be varying depending upon the process and product and the raw material. So depending upon the industry we have to supply the water.

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4. Industrial use

Type of industry

20-25% per capita demand for industrial use

So, how can we find out that one? This will be very difficult. so what usually we do is, we calculate the quantity around 20 to 25 percentage of the per capita demand assumed as the industrial use for that area because the industries will be varying and some industry will be consuming more water and some industry will be consuming less water. So on an average 20 to 25 percentage of the per capita water demand is left for the industrial use that is the usual calculation we do to find out the industrial water use.

Now we will see, we have seen that we have to calculate what is the water quantity required for residential, industrial, institutional zones etc but there will be water losses from the system.

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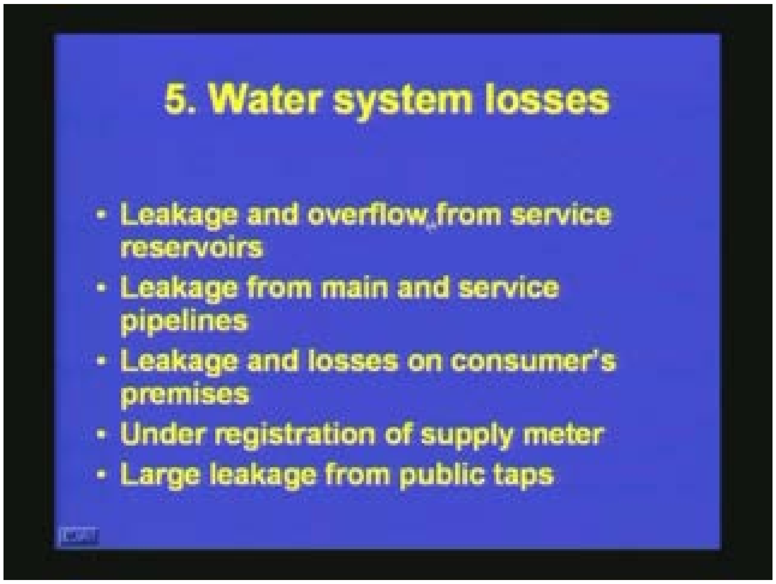

5. Water system losses

- Leakage and overflow from service reservoirs
- Leakage from main and service pipelines
- Leakage and losses on consumer's premises
- Under registration of supply meter
- Large leakage from public taps

So, whenever we talk about the water quantity we have to account for the losses also. So how can we account for the water losses? For that one we have to know what all are the water losses first. What are these water losses? It can be leakage and overflow from service reservoirs, that will be coming under quantity because the total quantity will be measured from here itself, then leakage from main and service pipelines is another loss, then leakage and losses on consumer's premises and under registration of supply meter. That means if the water meter is not reading properly and if it is under reading then definitely it is a loss for the water supply system. Then we have large leakage from public taps. This is a very common phenomena especially in our country. These are some of the losses.

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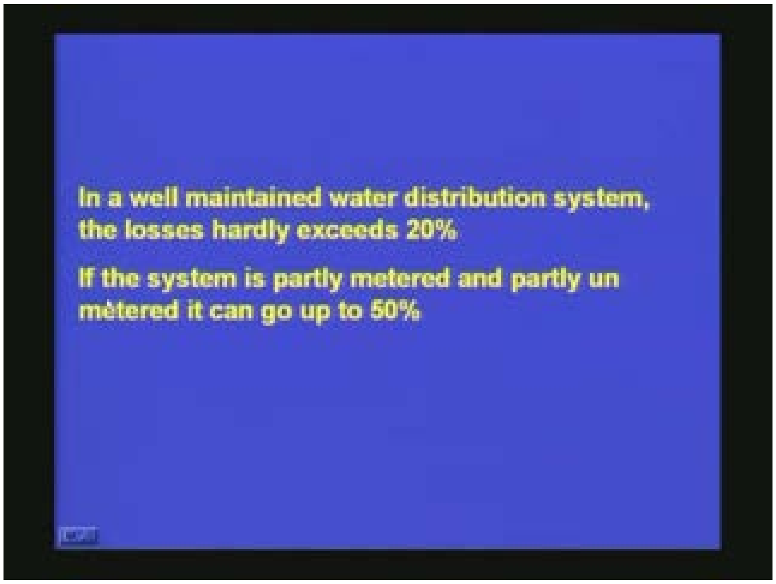

In a well maintained water distribution system, the losses hardly exceeds 20%

If the system is partly metered and partly un mėtered it can go up to 50%

And in a well maintained water distribution system the losses hardly exceeds 20 percentage. There will be losses, we cannot avoid completely the losses, there will be some sort of losses. But in well maintained water distribution system the loss is less than 20 percentage of the total water quantity. But if a system is partly metered and partly unmetered it can go up to 50 percentage because if the water is not metered people will be having the tendency to use more and more water so definitely that will be increasing the water loss. Any water which is going unmeasured is also coming under water losses so the water losses will be increasing. Now we will see what all are the other factors that affect the rate of demand.

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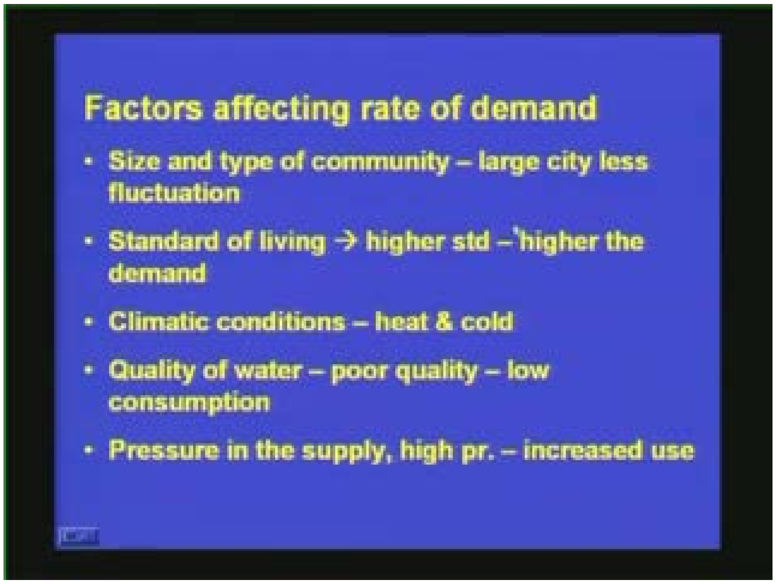

Factors affecting rate of demand

- Size and type of community – large city less fluctuation
- Standard of living → higher std – higher the demand
- Climatic conditions – heat & cold
- Quality of water – poor quality – low consumption
- Pressure in the supply, high pr. – increased use

As I have already mentioned the water demand is not a constant it will be varying with respect to the communities, it will be varying with respect to the population and it will be varying with respect to climate. So we will see in detail what all are the other factors which affect the water demand. Those are the size and type of the community. For example, in a large city the water demand the fluctuations will be less. This is very very important. If you have a small city the water demand fluctuations will be very very high but in a large city the fluctuations will be less and standard of living is another important factor.

If the standard of living of people is high then definitely the water demand will be high, the reason is, they will be using water for many other purposes like; lawn watering, car washing, etc or recreational purposes etc so as based upon the standard of living the water demand also will be increasing.

Another one is climatic conditions. This we don't have to explain at all. At hot climate the water demand will be very very high and in cold climate the water demand will be coming down drastically. And another parameter which decides the water quality is the quality of the water, water demand is the quality of water. If we are supplying poor quality of water definitely the consumption of water will be low and if you supply good quality of water the water consumption will be increasing.

Another one is pressure in the water supply system. If you have a high pressure in the water supply system increased water use will be there. And the next one is system of supply. If you go for intermediate supply then definitely people have a tendency to conserve water so the water consumption will be less or water demand will be less compared to a continuous water supply system.

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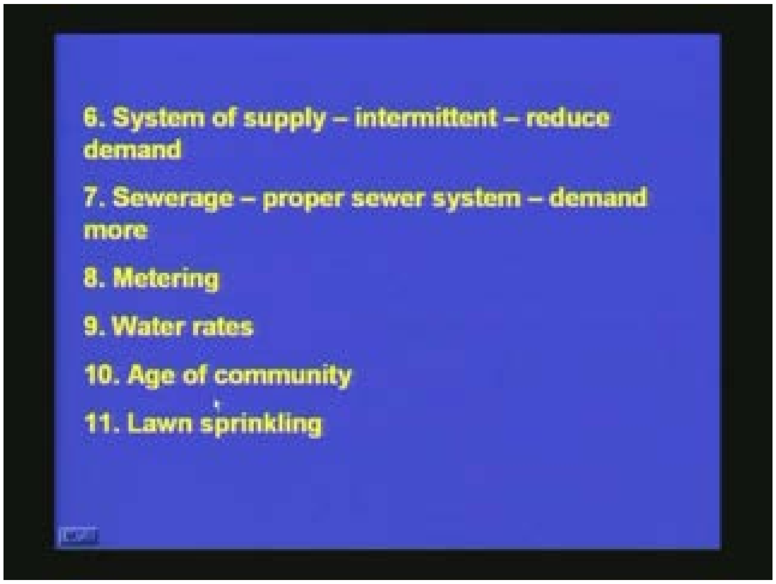

6. System of supply – intermittent – reduce demand
7. Sewerage – proper sewer system – demand more
8. Metering
9. Water rates
10. Age of community
11. Lawn sprinkling

Another one is proper sewerage. If you have a proper sewerage system the water demand will be more and if the sewerage system is not proper the water consumption will be less. Another one is metering. If you have proper metering it will be less and their existing rates, then age of the community and lawn sprinkling etc are the factors affecting the water demand.

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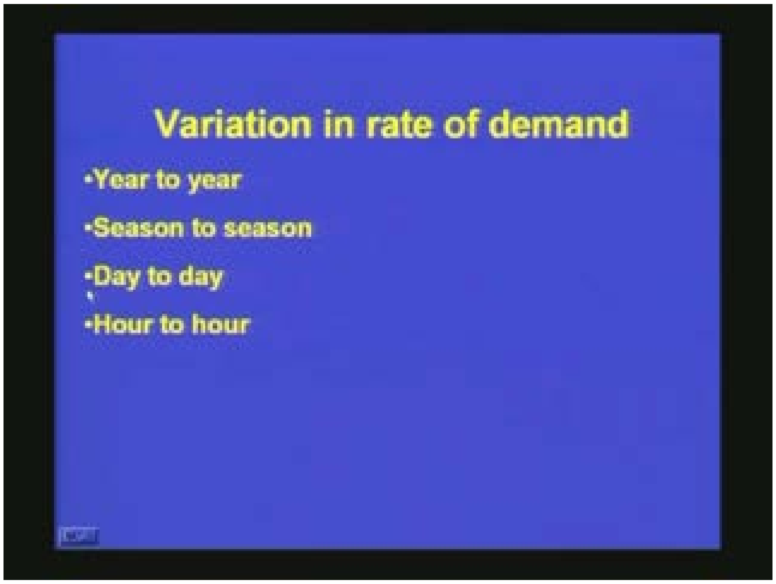

Variation in rate of demand

- Year to year
- Season to season
- Day to day
- Hour to hour

Now we will see whether the water demand is constant. It is not constant, it will be varying with respect to year and it will be varying season to season, it will be varying day to day and it will be varying hour to hour. This is very very important whenever we talk about the water treatment plant design or wastewater treatment plant design. For which one we have to design, whether we have to design for the average flow, whether we have to design for the maximum flow etc. We will see how the variation is. It is reported that the maximum seasonal consumption is around 130 percentage of annual average daily rate of demand. So if you take the average yearly rate and the maximum seasonal consumption is around 130 percentage of the annual average daily rate of demand and maximum monthly consumption is around 140 percentage of the annual average daily rate of demand.

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1. max. seasonal consumption – 130% of annual average daily rate of demand
2. Maximum monthly consumption - 140% of annual average daily rate of demand
3. Max daily consumption – 180% of annual average daily rate of demand
4. Max hourly consumption – 150% of average for the day

These are important. Maximum seasonal variation is 130 percentage of annual average daily rate. Maximum monthly consumption is 140 percentage of annual average daily rate of demand and maximum daily consumption is around 180 percentage of annual average daily rate of demand and maximum hourly consumption is around 150 percentage of average for the day. So it is varying so much; seasonal, monthly, daily and hourly variation you can see, it is 1.3 times, 1.4 times, 1.8 times and 1.5 times.

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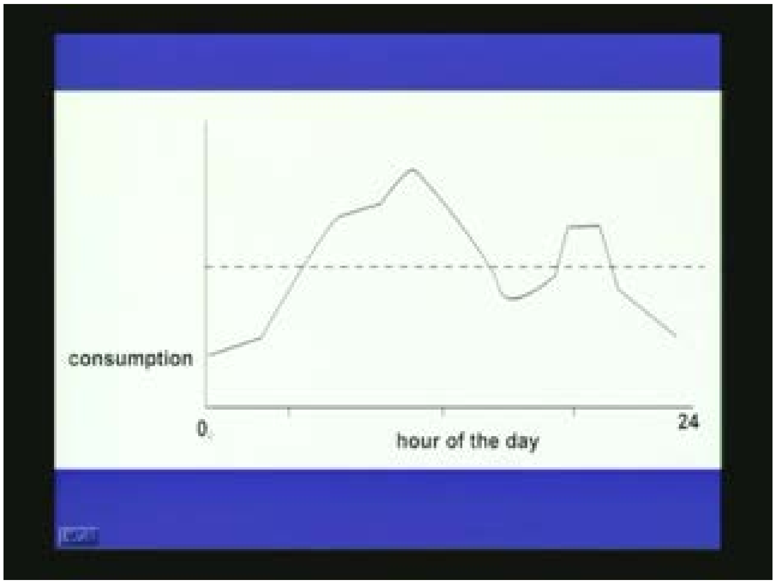

And if you see in a day how the water consumption varies, this is the consumption rate and this is the hour of the day. So we start from the midnight, we know that in the midnight the water consumption will be very very less and around 5'o clock the water consumption will be increasing and it will be peaking like this (Refer Slide Time: 53:38) around 11'o clock and it will be coming down again around 3 or 4'o clock, again it will be increasing in the evening time around 6'o clock, it will be going up and at 8, 9 and again it will be coming down. Therefore, this is the average daily water demand and this is the maximum hourly demand. So when we design the water treatment systems how can we find out. In water treatment systems many facilities are there. Filters and pumps are design for 1.5 times average daily demand. And distribution mains are designed for the maximum hourly demand. That means 1.8 to 1.5 that means 2.7 times the average daily demand.

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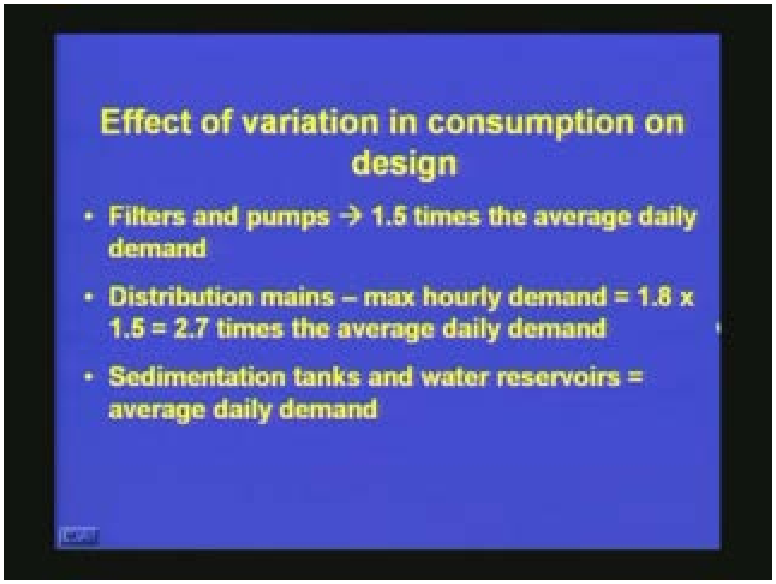

Effect of variation in consumption on design

- Filters and pumps → 1.5 times the average daily demand
- Distribution mains – max hourly demand = 1.8 x 1.5 = 2.7 times the average daily demand
- Sedimentation tanks and water reservoirs = average daily demand

This 1.8 is coming from the maximum daily demand and 1.5 is coming from the maximum hourly demand so with these two we will be getting 2.7 times. The distribution mains are designed for the maximum hourly demand and sedimentation tanks and water reservoirs are designed for average daily demand. So, for different design purposes we use different flow rates so this is very very important. Anyway you will be seeing this one in detail when we talk about the design.

Now we will see what all are the things we have seen today. We have discussed in detail what all are the various methods of population forecasting and we have seen that logistic method is the most scientific way of forecasting the population. Then we have also discussed in detail what all are the various water demands. So, if we want to find out the quantity we should note the population and the water demand per capita per day.

And the water demand can be classified into various categories, those are; residential purposes, institutional purposes, public or civic purposes and industrial purposes. And in domestic purposes we have seen that we are bound to supply 135 liters per capita per day water for a person. But if the water scarcity exists at least a minimum of 70 to 100 liters per capita per day supply is essential. And we have seen how to find out the fire demand and why we should give the fire demand provision in water supply system. It is because we need a huge quantity of water in a short period of time that is the important factor of this fire demand. Usually we convert the total fire demand of a year to in terms of population equivalence and we provide that one.

We have seen also how to find out the industrial use and we have also discussed in detail what are all the various water losses. And towards the end we discussed about how the water demand is varying with respect to season, year, month, day and hour. So various water treatment facilities are designed based upon these flow fluctuations so the pumping mains are all designed for the maximum hourly flow whereas the treatment plants are designed for the average daily flow.