Water and Wastewater Engineering
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Water Distribution Networks
Lecture # 37

Today we will talk about the distribution of water. A water distribution network consists of pipes with appurtenances and it transports water from the treatment plant to the consumers tap. It includes storage, balancing reservoirs and service reservoirs.

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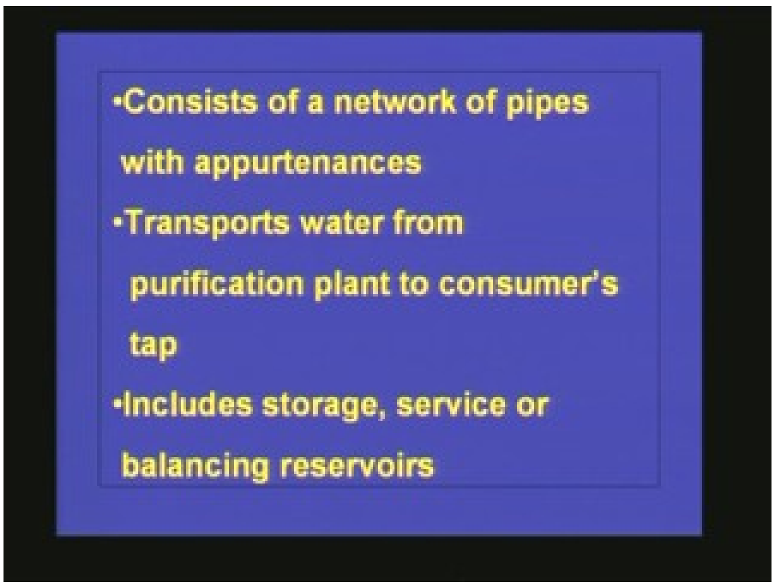

It is basically designed to adequately supply the amount of water for domestic purposes, commercial purposes, industrial purposes and fire fighting purposes and the adequacy of the design is checked by seeing whether we have enough pressure in the pipeline or not.

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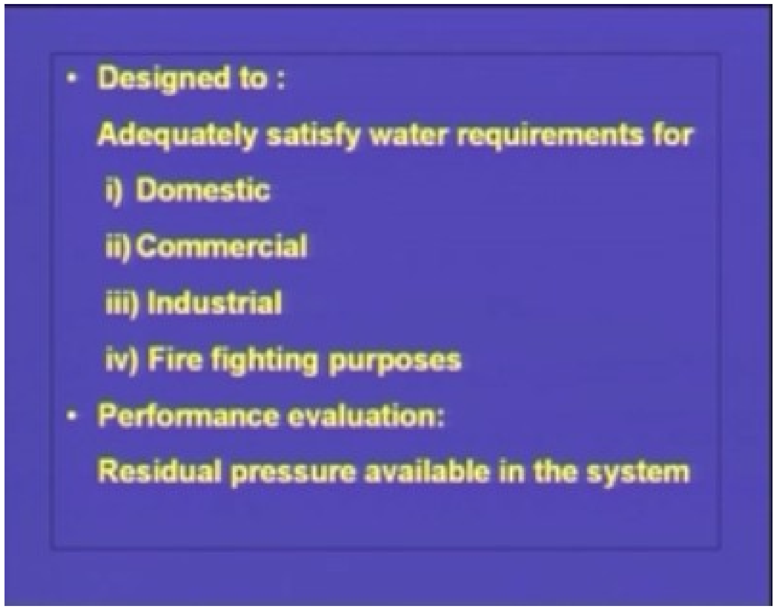

A good distribution system should supply water at consumer's tap with reasonable amount of pressure, it should meet the fire demand and it should maintain the water quality.

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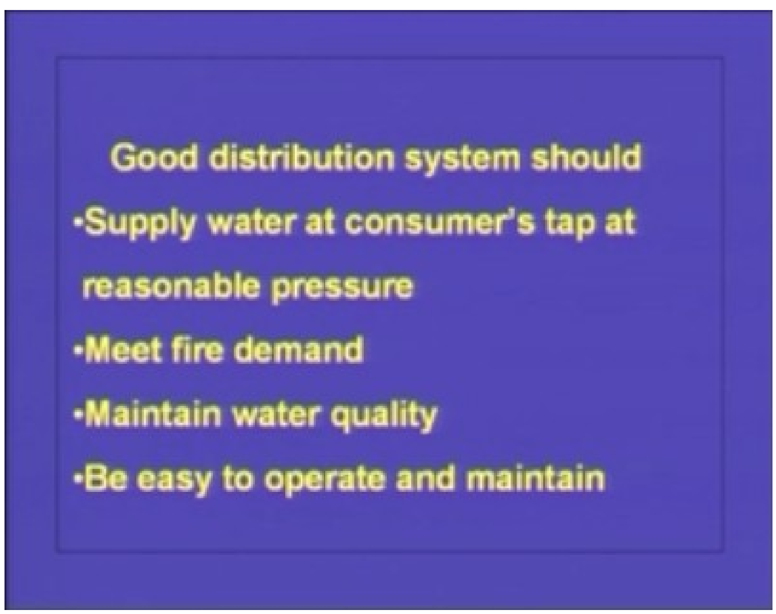

When we supply water to the consumers from the treatment plant we add chlorine at the treatment plant but the residual chlorine at the tap level is more important for the health of the consumers. So whether in between what is happening to the water quality is also very important. Water distribution networks should also not have many leaks and then the wastewater from the ground should not enter into the water distribution network.

Now we have to design a water distribution network such that the water quality is maintained very well. A water distribution network should also be easy to operate and maintain. It should not be very difficult to operate these water distribution networks and when we maintain these networks it should not cause much of a disruption to traffic. A good distribution system should also be reliable.

What we mean by reliability is, let’s say one or two pipes are breaking down in the system because of that breakage some of the consumers may not be able to get water for long periods of time. That kind of a water distribution system we say is unreliable. So the supply should be there even when some breakage is there in the system so it should be reliable.

As I have already mentioned whenever there is a breakage to the water distribution network and we go in and repair that it should not cause any disruption to the traffic. And one of the most important things in the design of water distribution networks is the initial cost that is the capital cost then we also have the operation cost. Particularly if you have a pump scheme then we spend lot of power in operating these pumps and the pumping cost and of course the maintenance cost. Hence, all these three costs namely the capital costs, the operating costs and the maintenance costs that should be minimal then we say that it is a very economical design.

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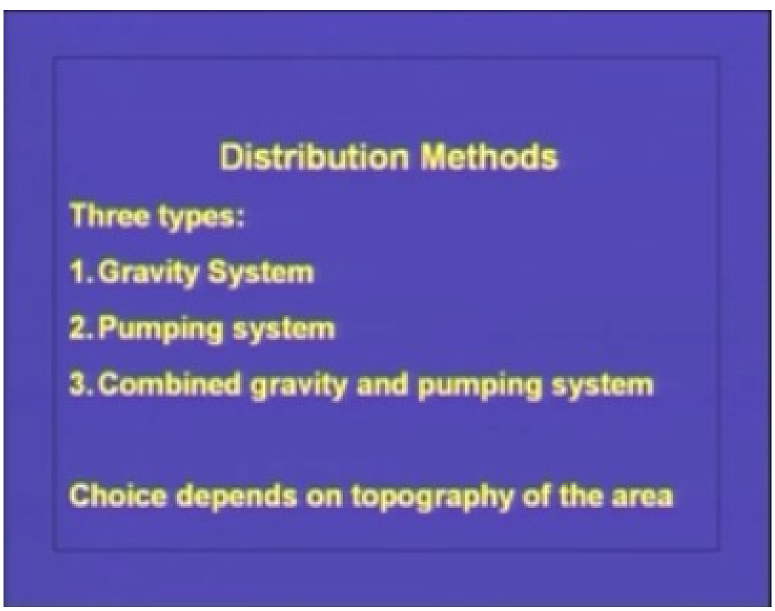

Then there are three types of distribution, water distribution systems. They are gravity system, pumping system and gravity cum pumping or a combined system. Now the choice of these systems depends upon the topography of the area. We look at these systems in detail now.

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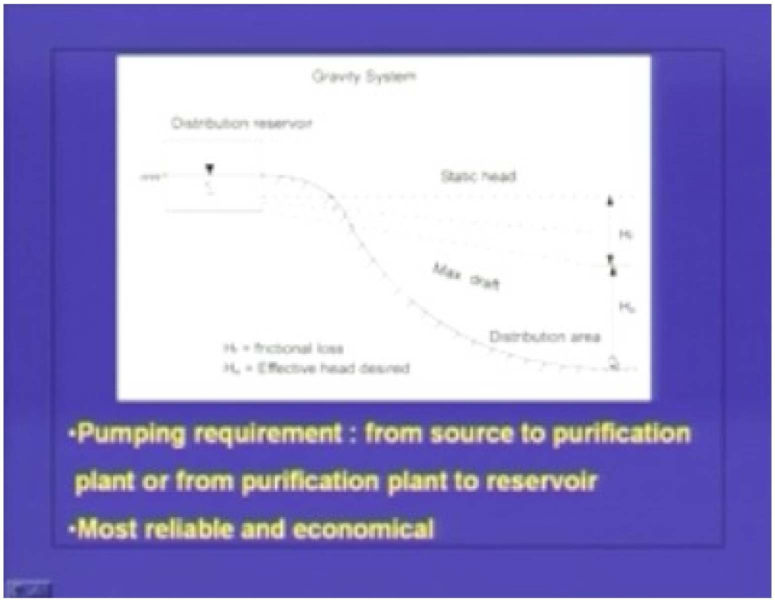

What you see here is gravity system, here is the distribution reservoir. Although I have not shown the treatment plant the treatment plant also could be very close to the distribution reservoir at a very high level and your distribution area is at a lower level like here, this is the distribution area (Refer Slide Time: 4:49) which is at a lower level and this is the distribution reservoir is at a higher level and all the water flows to the distribution area by gravity. As it flows by gravity in the distribution system you have lot of energy loss so if you plot your energy grade line or the hydraulic grade line the hydraulic grade line will be drooping. The Hf here shows what is the friction loss and He is the piezometric head and tail end of the system and this residual effect you have (Refer Slide Time: 5:20) should be more than what is desired.

What are the problems and what are the advantages of a gravity system?
First of all there may be some pumping required even in the gravity system. particularly if the source is at a lower level you may have to pump water from the source to either the treatment plant or if the treatment plant is also close to the source then from the treatment plant to the distribution reservoir. Now this kind of a system is very very reliable and it is very economical because there is no operating cost here. There are no pumps and we are not expending any energy and water flows only by gravity from the distribution reservoir to the distribution area.

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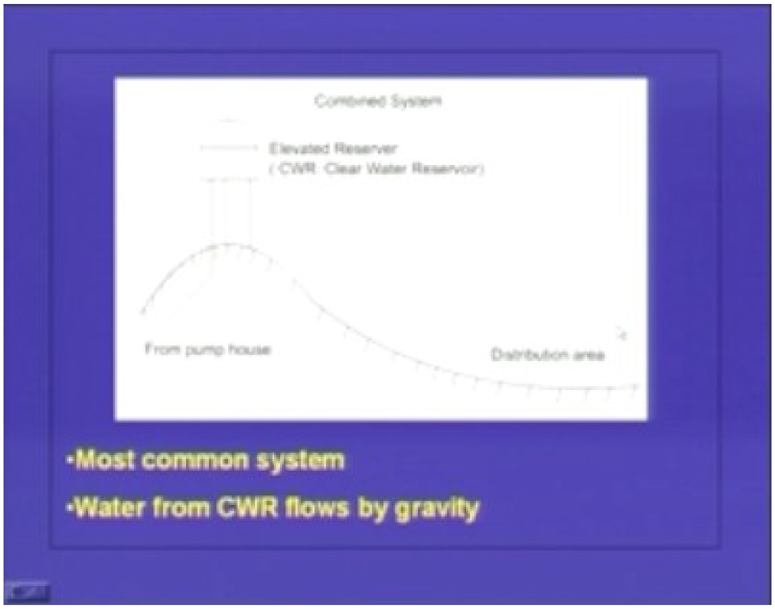

Next we have a combined system. In a combined system what we do is there is a pump house which pumps water from the treatment plant to an elevated reservoir or a clear water reservoir which is at a slightly higher elevation. So there is a pumping which is taking place from the treatment plant to the elevated reservoir and from the elevated reservoir the water flows to the distribution area by gravity.

This is the most common kind of a system which we have in urban areas. In a pure pumping system we put a pumping plant and the treatment plant very close to the source. There may be a dual pumping necessary here that's one stage of pumping from the source to the treatment plant and another pumping from the treatment plant directly into the distribution system. Here the water is pumped directly into the distribution system and what you see here (Refer Slide Time: 7:03) is a pump and pressure head and then in the distribution system you have the drooping energy grade line or the hydraulic grade line.

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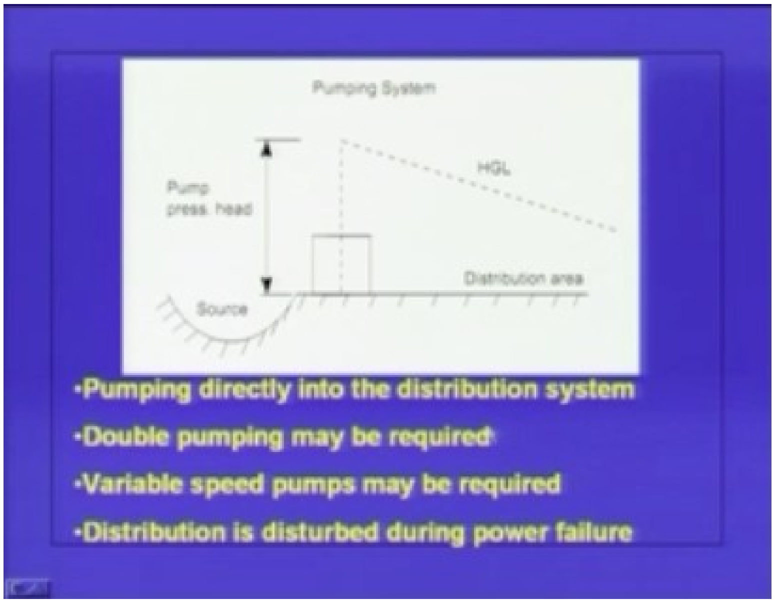

Now whatever is the elevation or the energy grade line or the hydraulic grade line at the tail end of this distribution area it should be more than adequate. Now the problem with pumping systems is you are pumping water directly into the distribution system so if there is a power failure to the pumps then the whole distribution comes to a standstill and the consumers will not get their water.

Another thing is there is variability in the demand. Always in a distribution system there is variability in the demand and that demand has to be met by variable operation. We have to choose the speed of the pump accordingly so we may need variable speed pumps for that purpose. This is the disadvantage of a pumping system.

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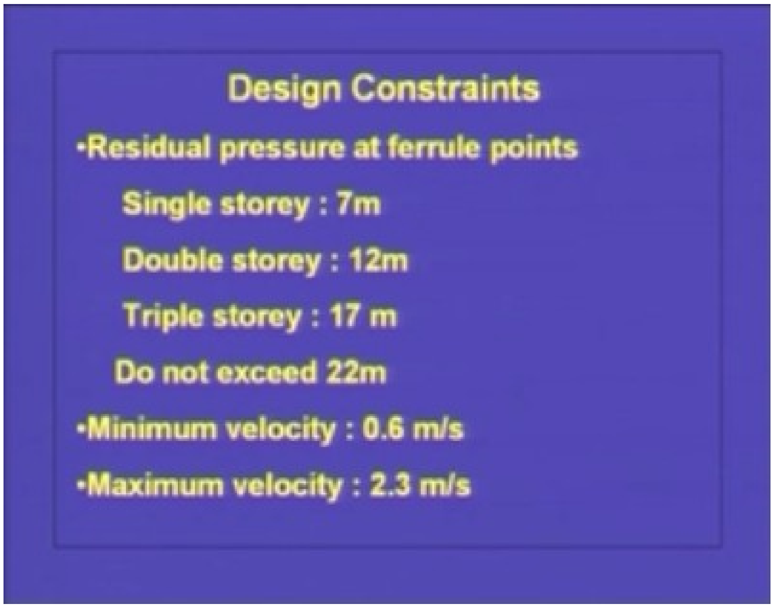

What are the design constraints?
Whenever we are designing a water distribution network there are certain constraints that our design has to meet. Our object is of course to see that whatever we have designed the capital cost plus operation cost plus maintenance cost should be minimal that is our design objective but there are design constraints. Design constraints are basically to see whether our system is performing properly or not like at the ferrule level.

A ferrule is a connection from the main system or your water distribution system to the individual buildings or individual houses that's what we call it a ferrule. And at the ferrule point you need to have certain amount of residual pressure so there is a constraint on that. If you are supplying water to a single storey building at the ferrule point you need to have a minimum of 7 m of head. If it is a double storey building you should have a minimum of 12 m and if you have a triple storey building you should have a minimum of 17 m of residual head at the ferrule point. At no time at the ferrule point the residual pressure head should not be more than 22 m, we do not design for that.

Let us say if you have a very high raised building and you are supplying water through your system then what you have to do is you have to ask those people to have a sump or whatever and then you supply water to that sump not to the overhead tank of their building because you cannot cross this twenty two meters limit and they can put a pump and from their sump they can take it to their overhead tank. Otherwise if the pressure is not building enough as you desire then you may have to use a booster pump in such locations.

Again there is another constraint in terms of the flow velocities. You have a minimum flow velocity that is to see that like there is no suspended matter which settles down. If the velocity in the pipeline is very low then the suspended matter may settle down and the water pipelines may get choked. Not only that if the velocity is not high then the water quality also gets deteriorated. You should not have any stagnant water in this distribution system so you need to maintain a minimum velocity of 0.6 m per second. Similarly there is a constraint on the maximum velocity. The constraint of maximum velocity is 2.3 meters per second. We cannot have any velocities anywhere in the system which is greater than 2.3 m per second this is because of the transients.

If the transients get created in your system that is if the velocity changes by one unit then there is a corresponding change in the pressure which is going to be very high so your initial velocities itself you should not have very very high velocities so you need to have a maximum constraint on the velocity which is around 2.3 m per second as per the Indian standards.

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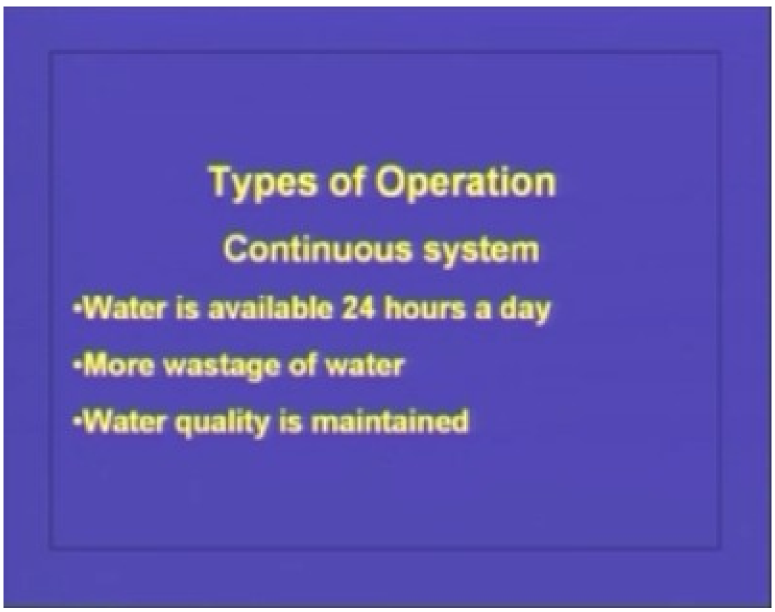

Then in a water distribution system you have two different types of operations.
They are continuous systems and intermittent systems. In a continuous system the water is available twenty four hours a day. Now that is the one which all the consumers would love to have. If we have enough water that we can supply then we can supply at the enough pressure the desired pressure. But then that kind of a system is going to be leading to lot of wastage of water. First of all if the people know that the water is being supplied twenty four hours a day then they tend to waste water in the houses or in the buildings. Not only that if you are supplying water twenty four hours a day let's say there is some leakage in the pipeline and if you are supplying twenty four hours a day then the amount of water that goes out of this particular leak will also be very high so there is more wastage of water in an continuous system. But one advantage of a continuous system is you can easily maintain the water quality in the distribution system.

We go for intermittent system of operation particularly when you cannot supply water to all the localities in the municipality at the desired pressure and sometimes enough quantity of water may not be available. Intermittent system is basically the water you are supplying only at fixed hours in a day.

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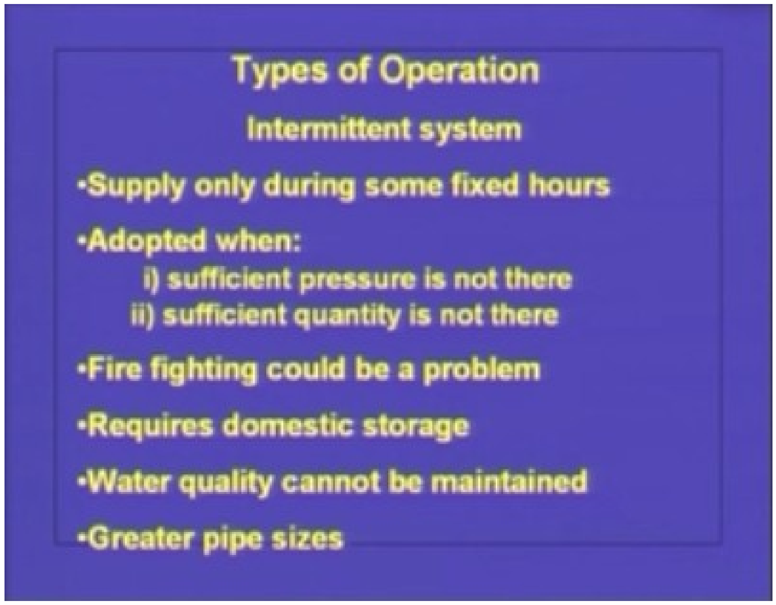

There are some problems with this intermittent systems. It is because your fire fighting cannot be met adequately. Let's say you are not supplying water through your distribution system and then suddenly the fire breaks out now that time we cannot draw water from your distribution system. Then it also requires some amount of domestic storage because you are supplying water only during few hours but then you need water throughout the day. So, at the domestic level you need storage. And because it is operating for only few hours a day the water quality cannot be maintained adequately in an intermittent system if you are not careful.

Another important thing is in an intermittent system you may have used greater sizes of pipes because the whole day's quantity or the demand is met only during few hours of the day or let's say eighty percent of the demand is met only three hours of the day that means the discharge or the flow rate through all these pipes will be very high. So, to carry the particular discharge you need to have larger sizes of pipes so that may be very uneconomical.

Again in any water distribution network we not only have the pipes but we also have reservoirs. There are two types of reservoirs; one is the storage reservoir and the other one is a distribution reservoir. A storage reservoir basically is meant to store the filtered water that is coming from the treatment plant. We may operate the distribution network only for some few hours but then you need to store the water to meet the demand for twenty hours a day. That means the capacity of the storage tank is normally we take about fourteen to sixteen hours of daily average flow then we also have distribution reservoirs. The distribution reservoirs are meant to meet fluctuating demands, they are also meant for equalizing operating pressures.

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First of all in any distribution network the flow rates in the system are going to vary even on hourly basis or on minute basis sometimes. So we have to be able to absorb these variations in the demand that is coming from the distribution system by putting a distribution reservoir.

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If we don’t have these distribution reservoirs then we may have to have variable speed pumps. That means we cannot operate the pumps at a uniform speed. So if you don’t have a variable speed of pumps then it’s going to have an effect on the pump life and the pump efficiency. What we do is when we have a distribution reservoir the pump will be operating at a constant speed and we will be taking that entire intake but then the distribution system itself may not be requiring all this water that the pump is giving. So, if the pumping rate is more than your demand then the water will be stored in the distribution reservoir and may be at a later stage your pump may be giving certain discharge but your demand is very high. If the demand is higher than the pump discharge that is coming out then you take that extra water from the distribution reservoirs. Therefore, in that way we can operate the pumps at a uniform speed.

Now what happens with this is it will actually reduce the sizes of your pipes, it will reduce the sizes of your pumps, it will also reduce the sizes of appurtenances and all those things. So because of this reduction in the sizes it also can reduce the size of your treatment plant and because of this reduction in size you can achieve economy.

Distribution reservoirs can also store water for emergency purposes and in fact can be used to maintain almost an approximate uniform pressure throughout your distribution system, this we will see later.

Now there are two types of reservoirs like surface reservoirs and elevated reservoirs. The surface reservoirs are typically made of masonry or concrete but when you construct these surface reservoirs you have to line them up so that there is no leakage from the surface reservoirs so appropriate liners should be used for this purpose. Again for the surface reservoirs we also have to compartmentalize I mean we divide the whole surface reservoir into several compartments and these compartments, let’s say I have two compartments one compartment I can dry it up and then I can use it for maintenance whereas the other compartment can be used for storing the water and then supplied to the distribution system.

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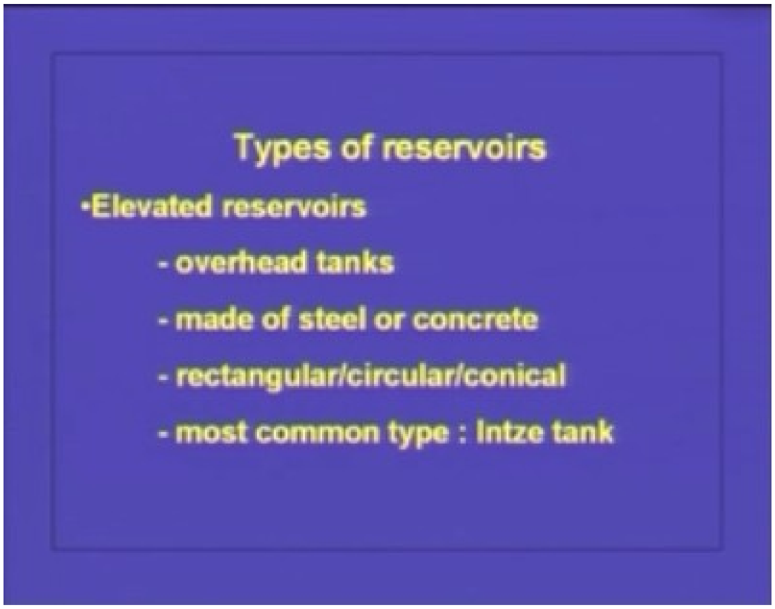

The surface reservoirs you have to locate it at very high points in that particular area so the water can go from the surface reservoir to the distribution area by gravity.

We also have the elevated reservoirs. These elevated reservoirs are the ones we normally see in any urban area or what we call as overhead tanks. These overhead tanks in the earlier days were made of steel. In fact most of the railways whenever they have these overhead tanks they are all made of steel or older ones but the current trend is to make these elevated reservoirs using concrete. This you would have seen when you would have traveled in trains. These elevated reservoirs can also come in different shapes and sizes like rectangular shape can be used, circular shape can be used and conical shape can be used and so on and forth and the most common type of an elevated reservoir is the Intze tank.

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Now the location of these distribution reservoirs depends upon the topography of the area and how well you want to maintain your pressures, how uniformly you want to maintain the pressure. They are typically located centrally so that any farthest from that distribution reservoir is more or less, let's say I have a point here, this is of equal distance from this distribution reservoir, another point is here and this is also almost at the same distance from the distribution reservoir so that way the head loss here will be almost equal to the head loss here so the pressure here and the pressure here may be maintained more or less same. Again the central location of the distribution reservoirs basically is meant to reduce the frictional losses.

The distribution reservoir capacity depends upon how much you want to equalize your pressure and the flow rates and how much of storage you want to provide for service during the breakdown and then how much of storage you want to provide for fire fighting. The breakdown reserve is typically taken as 25% of total storage if repairs last only for few hours. Let's say if the repairs are going to last for lot more hours then you need to have much more storage for supplying water during the breakdown.

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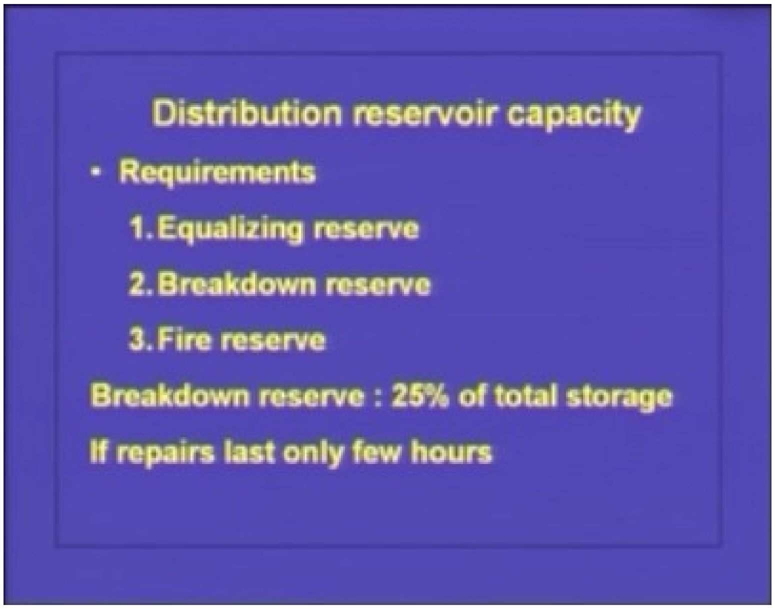

Distribution reservoir capacity for equalizing:
This figure you see here is what we call a mass curve analysis. In a mass curve analysis the time of the day is plotted on the x axis and the accumulated flow in millions of liters is plotted on the y axis. When I say accumulated flow what I mean is cumulative flow, if you look at this curve here this curve that I am showing this one (Refer Slide Time: 19:59) is also denoted here as cumulative demand curve.

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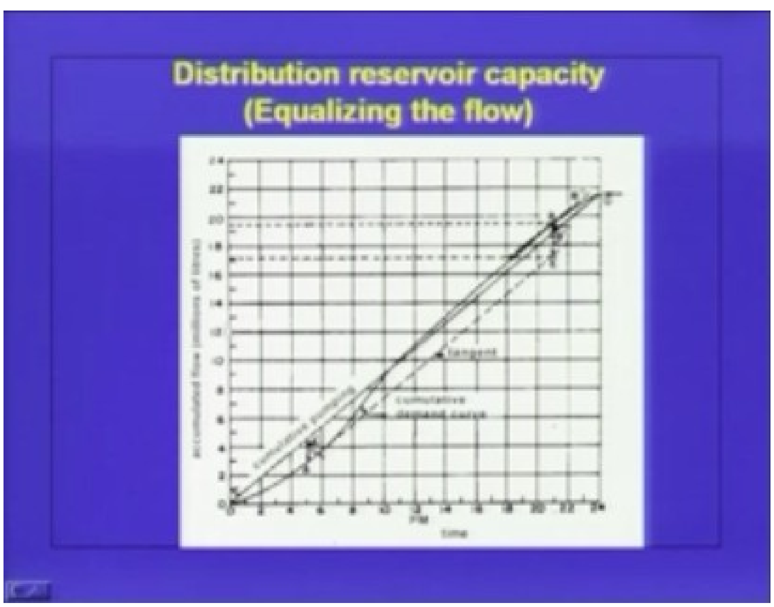

Let's say you start the day at zero hours and as it proceeds you add up all the demand as the time progresses and you plot that cumulative demand curve. And if you are having twenty four hours of continuous pumping you need to meet this total demand which is at this point, this is the total demand in the day that I have to meet by pumping uniformly for twenty four hours so if I join this point and the point over here (Refer Slide Time: 20:30) that will give you the cumulative pumping.

Now if you look at this point here that A and A prime the A and A prime tells you at this particular point than the total pumping up till this point is much more than the total demand that needed to be met during that time so the pumping rate is more than what we needed in the distribution system so this extra water needs to be stored and where will we store this, we will store this in distribution reservoir.

How did I get this A? I got this A by basically drawing a tangent to my cumulative demand curve and that line should be parallel to this cumulative pumping curve.
the tangent this line here the dotted line that should be tangent to the cumulative demand curve at the same time it should be parallel to the cumulative pumping curve and I see what is the difference between this value and this value and that is what is needed here, this AA prime is what I need to store during those periods when my pumping rate is more than my demand.

If you look in this location here again I have a tangent BB prime which is tangent to the cumulative demand curve at the same time it is also parallel to cumulative pumping curve. Now at this stage what kind of a situation we have? My demand is more than my pumping rate. That means because my pumping rate is less than the demand I have to meet that extra demand by depleting from the storage and that is the water I am going to get from the distribution reservoir. This particular intercept here the bb prime is what is required to take it out from my distribution reservoir. So the total capacity of the distribution reservoir is equal to BB prime plus AA prime or the distance between this BB prime the tangent to the demand curve at this location and the tangent to the demand curve at this location. This is how I will find out the capacity of the distribution reservoir.

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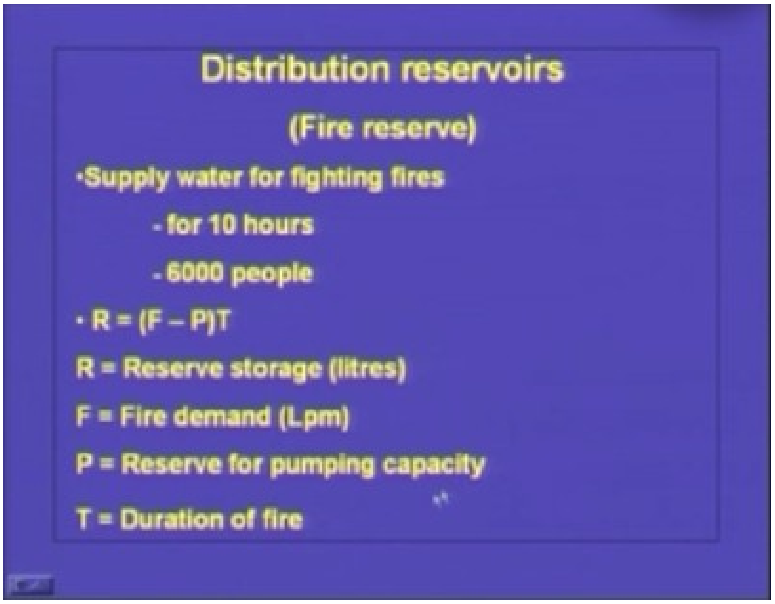

Now the distribution reservoirs are also used for storing water for fire fighting purposes. The supply water for fire fighting purposes is normally based upon how long the fire is going to last and under what kind of development I mean how many people are going to get affected by this particular fire.

Typically we calculate the amount of water that is required to fight a fire which is going to last for ten hours and in an area where six thousand people are living. You can also find out the capacity for fire fighting and that I have to include in my distribution reservoir using this equation R is equal to (F minus P) T where R is the reservoir storage in liters that I have to allocate for fire fighting and then F is equal to fire demand in liters per minute and P is the reserve per pumping capacity. Sometimes I can meet this fire demand by increasing the pump capacity itself rather than taking it from the distribution reservoir that’s why I have this F minus P so P is a reserve for pumping capacity and T is equal to duration of fire in minutes.

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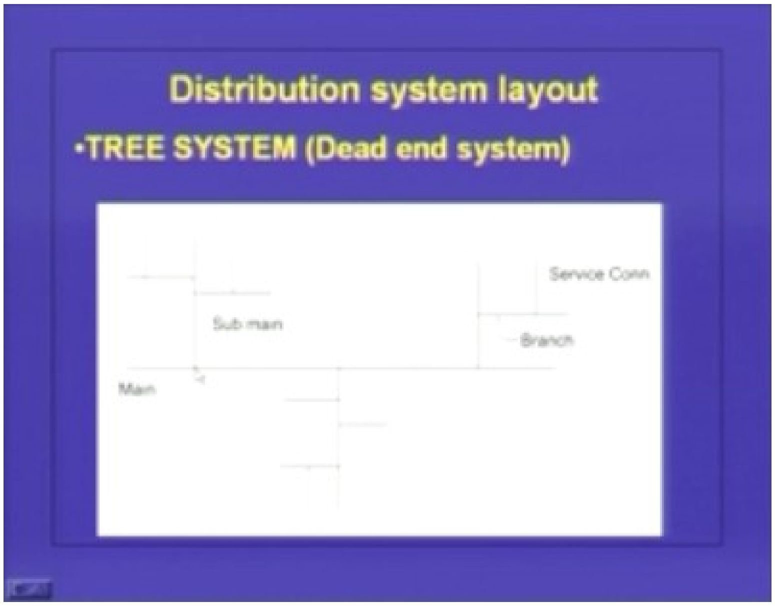

The other important thing about the distribution systems is the layout. Layout of a distribution system is very very important in ensuring reliable water supply and also for designing a very economical system. There are four typical layouts we adopt for distribution systems layout. The first one is a tree system or a dead end system.

In a tree system you have a main line which is coming from the treatment plant or a distribution reservoir and then this main line branches off into several submains. There is one submain here, there is one submain here and there is one submain here (Refer Slide Time: 24:52) and from the submain we branch off into what we call branches like I have a branch here, I have a branch here, one branch, a branch here and a branch here and from the branch it gets divided into what we call a service connection. In this tree system the water always flows in one direction. Like here the water is flowing in this direction, the water is flowing in this direction, water is flowing in this direction and I have dead ends at the ends of the system that is why it is also called a dead end system.

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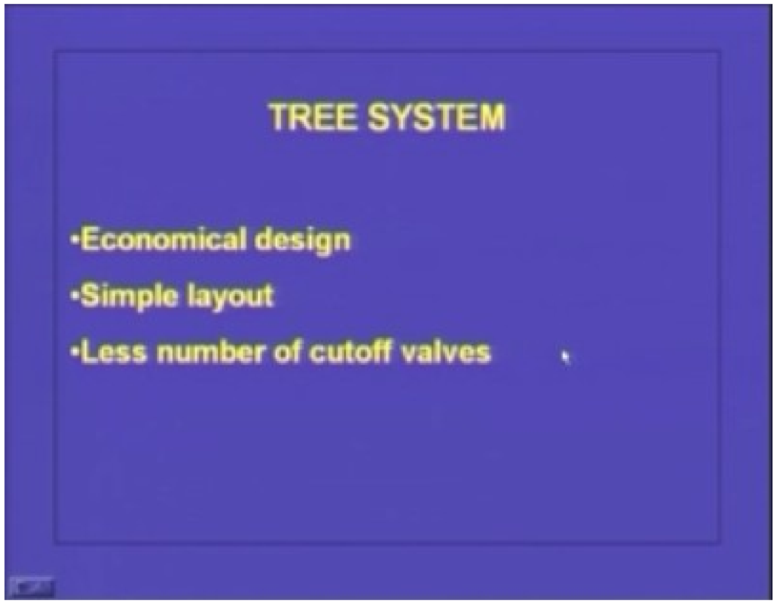

Let's see what are the advantages and disadvantages of a tree system. A tree system is very economical to design. That is because in a tree system you have the capacity of the pipes the size of the pipes keeps getting reduced as I go to the downstream side because only the main will have to carry all the water and the end of the system don't have to carry much water. So the sizes of the pipes get reduced as I go into the downstream direction in a tree system so it is very economical to design.

It always leads to a simple layout. You just follow the roads and the things like that so you have a very very simple layout. Again whenever I have a system like this (Refer Slide Time: 26:16) I need to have what we call cutoff valves or isolation valves. That means when I want to maintain this particular part of the system I need to have a cutoff valve which will cut off that particular part from the main distribution line. So, in a tree type system as I have shown a figure here I need a cut off valve here, I need a cut off valve here, I need a cut off valve here, I need a cut off valve here like that. So if you look at this configuration the number of cutoff valves in a tree type system will be very very less, that is another advantage. Another advantage is not an advantage in terms of layout or anything like that but it is very simple to analyze.

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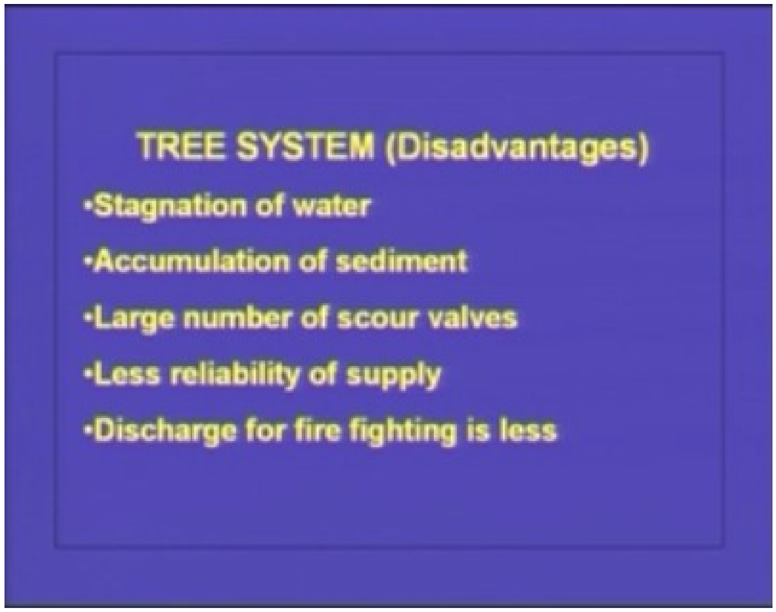

The disadvantages of a tree type system are you have pockets in the system. There are some areas where water will be very stagnant. Stagnant water can deteriorate the quality of water so we should avoid that. It is not as much possible to avoid this stagnation of water as it is for other types of the system. Now, because the stagnation pools are there it will also accumulate some sediment. If some suspended matter or sediment is there they also get accumulated.

Now a large number of scour valves are required to scour this particular sediment out of the system so that way although we are economizing in terms of not having many cutoff valves we are going to spend more money in terms of having more scour valves and if you look at the layout here let us say this particular line here breaks. If the line here breaks then this area, this area (Refer Slide Time: 28:08) and all the areas that I am showing here will not be getting the water. So that way you don’t have much reliability of water supply in case of breakdowns if you go for a tree type of a system. The other disadvantage is discharge for fire fighting could be less in the tail end areas if you go for a tree type of a system.

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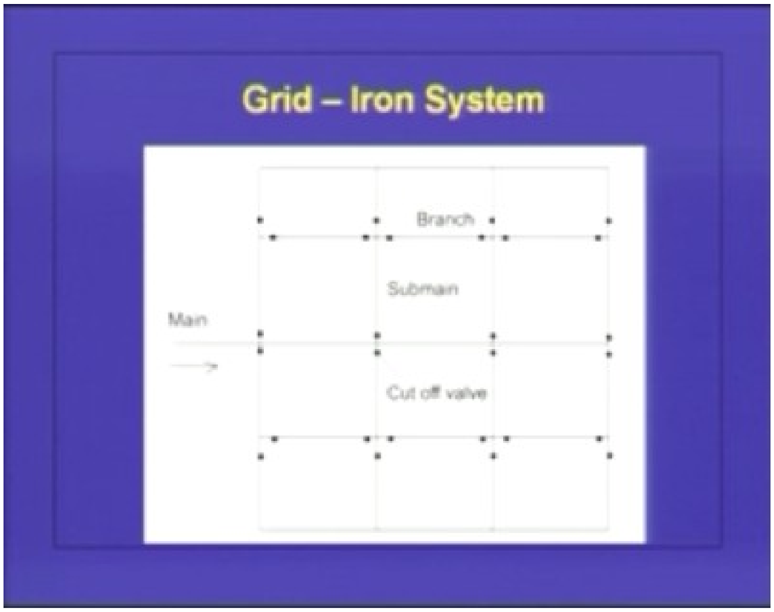

The other type of a system is what we call a grid iron system. in the grid iron system you have a main and this main gets branched off into submains here like there is a submain here and a submain here, a submain here, and the submain gets branched off into a branch line and you have so many of these cutoff valves to isolate any of the pipe for maintenance purposes or when a repair is required and so on and so forth.

If you look at the grid iron system as compared to a tree system let us say I have this area. If in this area (Refer Slide Time: 29:09) the water can come along this route or along this route or along this route so even if one of the pipeline breaks or two of the pipeline breaks I will still be able to supply water to a particular area so the reliability is already built into the system, the reliability in terms of being able to supply water during the breakdown. Not only that but you will also be able to maintain the pressures in a much better fashion as compared to a tree type of a system, this is the advantage of a grid iron system.

There are no stagnation points in grid iron system and because of that the number of scour valves will be less and as I already mentioned there is more reliable water supply. The disadvantage is large number of cutoff valves. I don't think that is really a disadvantage in terms of, may be for a very very large system the number of cutoff valves will be very high and things like that but one should not worry about that.

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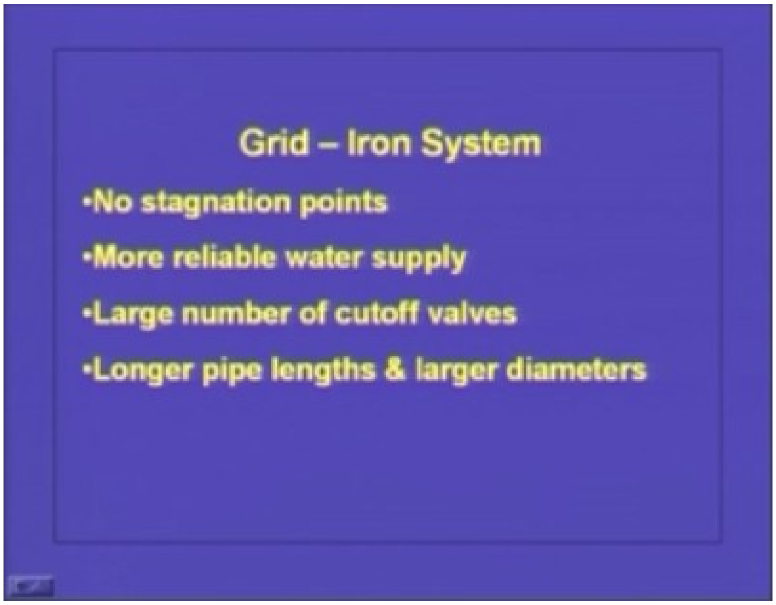

The other main disadvantage of a grid iron system is, if you look at the figure you compare the grid iron system I am showing here (Refer Slide Time: 29:35) with the tree type of a system that I am showing now between these two systems which one will have longer lengths of pipes. It is obvious that grid iron system will have longer lengths of the pipes and not only that but it will also have large diameter of pipes.

Let's say for example a demand here is being met through this pipeline as well as this pipeline or may be this pipeline, this pipeline and this pipeline, the demand here is being shared by several pipelines so this pipeline which is supplying the demand here as well as which is catering to the demand here it may have to carry more amount of water so the size of the pipeline also will be larger. Typically the sizes of the pipelines will be larger in a grid iron system compared to a tree type of a system.

The third type of a layout is your ring system. The advantages and disadvantages of a ring system compared to a tree type system are exactly similar to what we have for a grid iron system except there is only a difference in terms of the layout.

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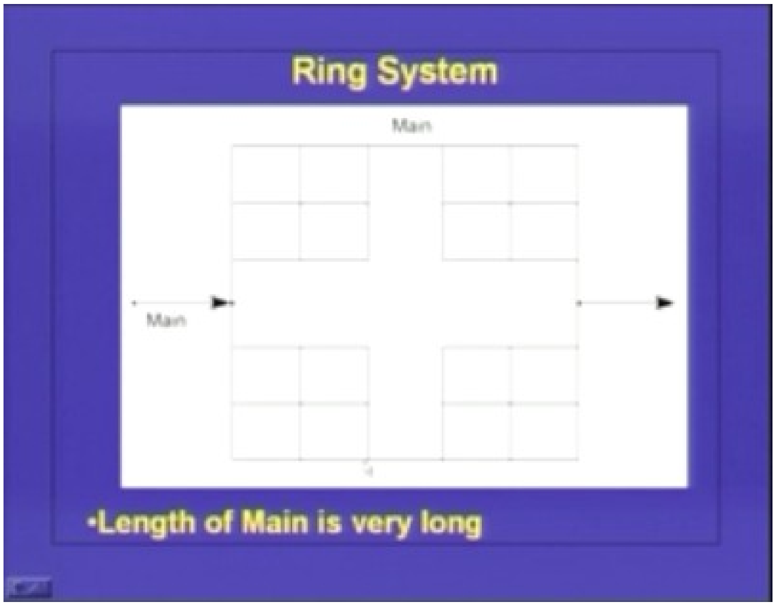

Here I have a main which branches off into two mains like in a circular fashion and then joins here and again it goes off and within this particular ring I will have my submains, branches and service connections like there is a submain here and there is a submain here, there is a submain here and there is a submain here (Refer Slide Time: 30:35) so this is what we call a ring system. with the ring system what happens is because this main line is going to be of a larger diameter pipeline the pressure drop from here to here will be much less. You know that the pressure drop is inversely proportional to the fifth power of diameter. So, if the diameter is large then the pressure drop will be less. Therefore the lengths of the mains are very long in the ring system as you can see in this particular figure.

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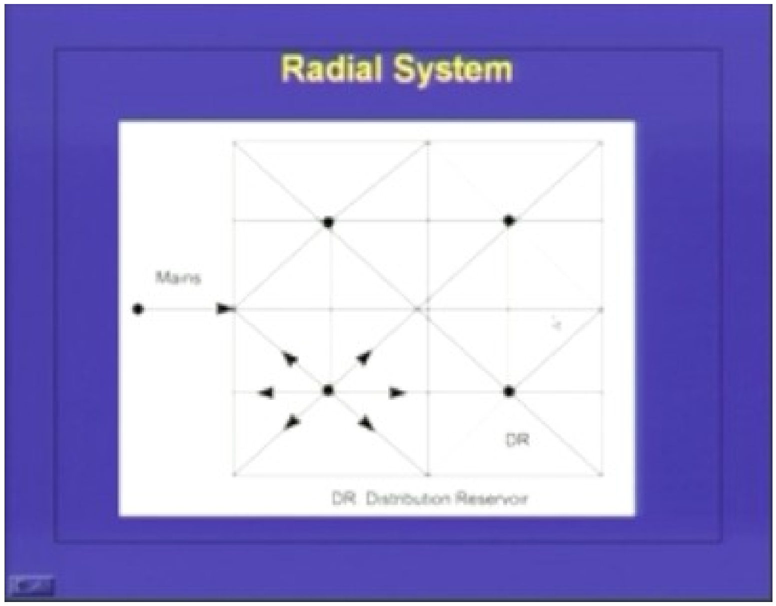

The last type of system I want to show you is the radial system. In the radial system the main will come here and it will be connected to the four distribution reservoirs that I am showing here. There is a distribution reservoir here, there is a distribution reservoir here, there is a distribution reservoir here and there is a distribution reservoir here. So this main will be primarily supplying water to the distribution reservoirs and from each distribution reservoir the water will be flowing along the radial, the pipe is laid out in a radial fashion in that particular area where you are supplying the water like I am showing here (Refer Slide Time: 33:02). Similarly this one will supply to this particular area. So in this way it will happen. Also because these distribution reservoirs can be elevated the reservoir will be able to maintain the pressures much more uniformly in a radial system.

Now what are the design steps that I have to take for designing a water distribution network. This is very very important. First thing you need to do for designing a distribution network is you have to conduct surveys. After conducting the surveys like topographical survey, geographical survey and survey for laying out the street lines like roads and whatever utilities you may have like electrical lines so for all that you need to conduct surveys. After conducting the survey you come and then fix the alignment of raising main.

Let’s say you have a distribution reservoir or a storage reservoir then you have a raising main from your treatment plant to that particular reservoir. So, if you fix the alignment for the raising main you locate the reservoirs depending upon the topography and for that you need the topographical map of the area. so you have to have the topographical map of the area also and then you also have to have a detailed map of the town which is showing all the roads other utilities that are going along the roadside like drainage pipelines, electrical contours and so on and so forth now those things again should be shown according to the cross sections of the streets etc as to where exactly these lines are there.

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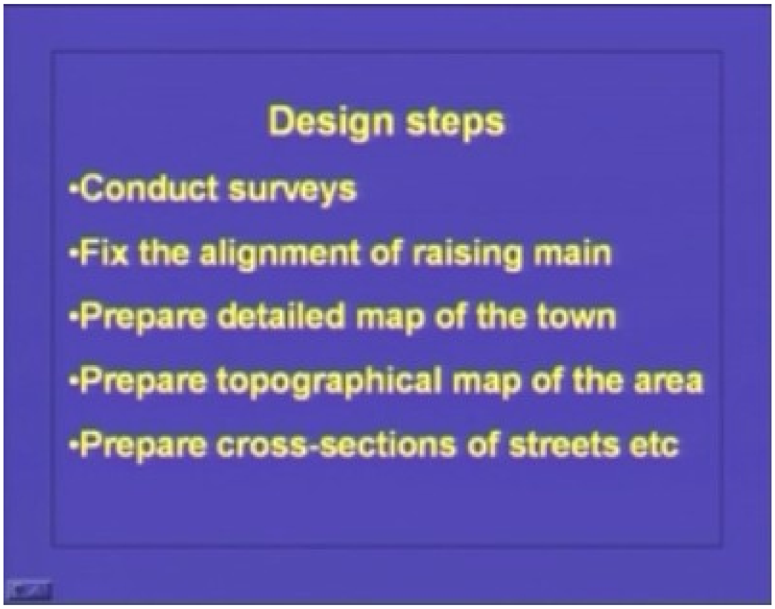

After getting all this information, in fact the current practice is you can use a Geographical Information System GIS package or whatever for collating all this information into a GIS information system. The next thing is you make a tentative layout, mark a tentative layout of a pipeline. Then after marking the tentative layout of the pipeline depending upon to which area you want to supply the water you show the positions of the reservoirs, valves and other appurtenances.

From the maps and the way the pipelines are laid and the areas to which these pipelines are supplying the water go to those areas conduct the population survey other census survey or from the census data you will be able to get what is the population that is being served by each pipeline.

If you know what is the population being served and then you also know how much water you have to supply depending upon the demand let’s say 100 LPCD or 150 LPCD and so on so forth you will be able to find out what would be the carrying capacity or what should be the carrying capacity of each of these pipelines or what should be the demand at each of the nodes in the net block. That you can get from the population density and the area that you have.

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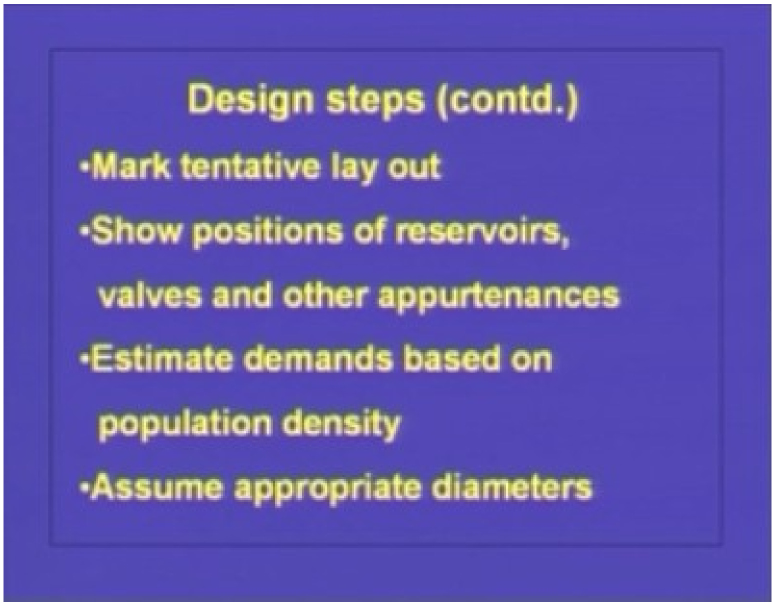

What you need to do is you need to assume appropriate diameters for these pipelines and after that you have to analyze the system. At this stage what we have is we have the network, we have the connectivity of these pipelines and we also have their lengths, the diameters we would have chosen the material for the pipeline like asbestos, cement pipelines or concrete pipelines or galvanized iron pipelines or plastic pipelines or whatever depending upon the material you know what is the resistance to the flow of these particular pipelines. We have all these data so we can check for pressures in the system at different locations by analyzing the system. When you are checking for the pressures or when you are analyzing the distribution system you will also be getting the flow rate in each of these pipelines then you can check for whether the assumed diameters or the assumed system is able to meet all the constraints.

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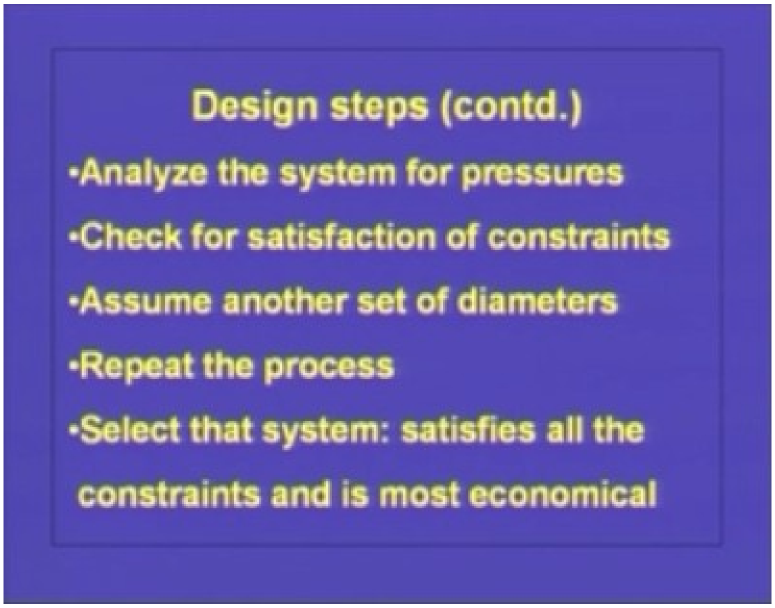

I have already mentioned to you what are the constraints. Let's say the pressure at any ferrule point should be greater than seven meters if it is serving a single storey building or the velocity should be greater than point six meters per second or the velocity should be less than two point three meters per second and so on and so forth. So you check whether these constraints are being met or not. Once these constraints are met that means you have chosen a plausible system which can serve your purpose but then you don't stop at this stage you assume another set of diameters. Once you assume another set of diameters you go and then do this analysis all over again and see whether it is meeting your constraints or not.

Let us say this is not meeting your constraints. That means in this particular set of diameters or what we call the decision variables in our design should be thrown out. You choose another set of diameter and then do the analysis. Now, after doing this you repeat this procedure for several of these alternative set of diameters that you have chosen. Let's say you have chosen some twenty of them and out of twenty twelve are meeting your constraints and eight are not meeting your constraints you throw these eight alternatives out which are not meeting the constraints you choose the other twelve so out of this other twelve you see which one is giving you the least cost because you know the lengths and you know the diameter, you know the material so you will be able to find out what is the cost of your system in terms of the capital cost. You also see, if it's a gravity system then you will not have much operating costs coming into the picture so you take this capital cost and see out of these twelve design alternatives that you have which is giving you the minimum cost and you choose that one.

Now if you do this and if you take a very very large system let's say you have 500 loads and then 600 pipelines so to know how many alternatives that you can do and what is the amount of time you are going to take for analyzing this you cannot do hand calculations and you have to use the software packages and many of the software packages are readily available these days like for example you can use what we call KY pipe, this is a software package developed by the Kentucky University that you can use, this is commercially available in the market and there is two levels of doing this. One is the simulations what we call the analysis of the system. You can do this analysis but then when I say you choose twelve alternatives or twenty alternatives where do I stop, do I stop at hundred alternatives or do I go for six hundred alternatives because let's say if I have 600 pipes and then each pipe can take four or five different values of the commercially available diameters then you see how many alternatives that you can have so that kind of a design the design that gives you the least cost cannot be done by hand calculations so you need to have what we call optimization subroutines for doing this.

There are methods which are available for doing this and that is beyond the level of this particular course. You can learn that in an advanced course on how to do the optimal design of a water distribution network. Before I go to the water distribution network analysis I want to tell you one more thing. Here I talked only about the diameters like I said select the systems that satisfies all the constraints and is most economical. Here I have not talked about the design of the layout itself. at a outer level there could be many many layouts which are possible, which can supply the water and which is reliable then which layout would you choose, so that is the outer loop in your design procedure.

Let's say first you choose a particular layout and for that particular layout you choose what are the most economical diameters you can get then you change the layout and again for the second alternative layout again you choose the optimal diameters that are possible. Like this you can have an outer loop for designing the layout itself. While doing that layout design you also have to talk to field engineers to see what kind of a field constraint that may come in. you may go and then give a particular route but then the field engineer may go in and say that it is not possible for me to acquire land for laying this pipeline or if I try to lay this pipeline these are the problems I am going to have. So you have to incorporate those kinds of constraints also while doing the design of the water distribution networks.

Now let's talk about this distribution network analysis. What is this distribution network analysis, what is the definition of the problem?

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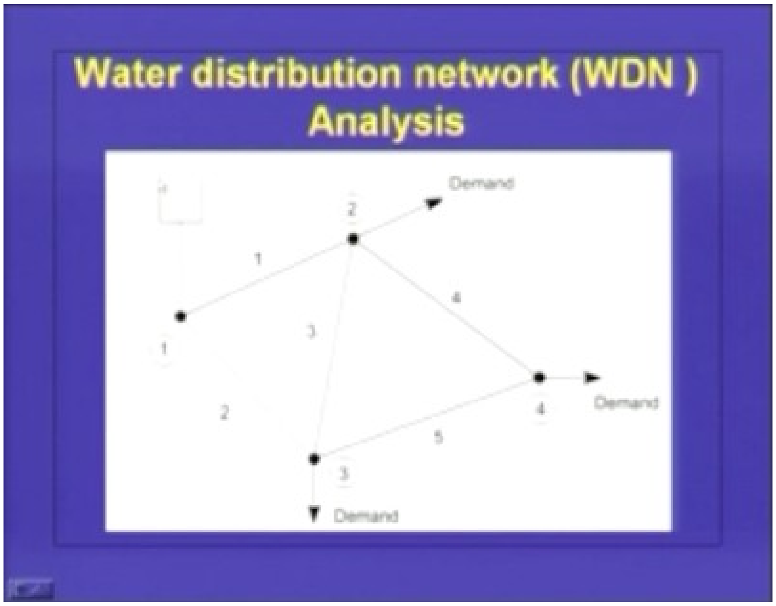

I give a very simple problem here. I have a network of five pipes and I have nodes one two three and four. When I say demand here that means from node 4 there will be a system that is going in a local level system which is going to draw water from this major system to meet the demand here. So if this node 4 is catering to certain number of people depending upon that population and the supply rate let's say 100 LPCD or 150 liters per capita per day or whatever I will be able to find out what is the demand. So in the network here I have already given you what is the configuration of the thing.

I have given you the layout and I will give you what is the demand here, what is the demand here and what is the demand here (Refer Slide Time: 42:55) and this particular network is being served by a distribution reservoir here. I will also tell you what is the water level in the distribution reservoir. So, given the water level in the distribution reservoir the demands and the pipelines and the lengths of the pipelines and the diameters of the pipelines the question is what would be the piezometric head at node 3, node 4 and node 2 and what is the flow rate in pipe 4, pipe 3, pipe 1, pipe 2 etc. That means I have to find out the discharges in all the pipes and the pressures or the piezometric heads at all the nodes.

Please note the piezometric head at node 1 is known because this node 1 is connected to a distribution reservoir. If I know what is the water level in the distribution reservoir then I would know what is the piezometric head. So piezometric head at 1 is known but 2 and 3 and 4 is what I am trying to find out. Once I do this analysis then I will be able to go and see whether the pressure here at node 2 is more than what I require and whether the velocity in pipe 3 is more than 0.6 meters per second and less than 2.3 m per second etc so that way the analysis is very important.

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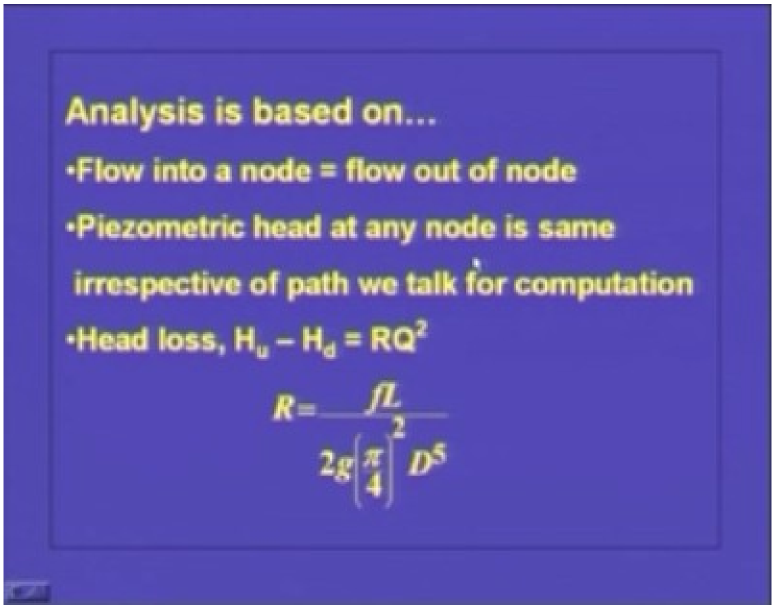

This analysis is based on three basic principles. One is flow into a node is equal to flow out of a node. like if you take node 2 the flow rate let's say is coming into node through pipe 1 so flow rate at pipe 1 should be equal to let's say the flow is going out of the node 2 towards the node 3 so that is flow out and similarly flow is going from two to four so that's also an outflow. So Q1 the discharge in one should be equal to discharge in three plus discharge in four plus the demand. So the flow in should be equal to flow out that is one principle.

Then piezometric head at any node is same irrespective of path we take for computation. That means let's say I have node 4, I know the piezometric head at one, piezometric head at three is equal to piezometric head at one minus the loss in pipe 2 then loss in pipe 5 will give me piezometric head at four. Similarly the piezometric head at four can also be determined through the other route. That is piezometric head at one minus loss in pipe 1 minus loss in pipe 4 is equal to piezometric head at 4. So irrespective of which path I take, I take this path or this path or I can go in this path (Refer Slide Time: 45:43) so whichever path I take the piezometric head at four should be the same that is the second principle.

The third principle is the head loss in any particular pipeline is equal to RQ square where Q is the flow rate, Hu is the head piezometric head at the upstream end and Hd is the piezometric head at the downstream end, R is the resistance factor. If I am using the Darsey Weisbach equation for calculating the head loss then R is equal to fL by 2 g pi by 4 square D to the power of 5 where D is the diameter of the pipeline and L is the length of the pipeline and f is the Darsey Weisbach friction factor. I can also use other equations for finding out this resistance.

What are the methods of analysis in terms of the formulation?
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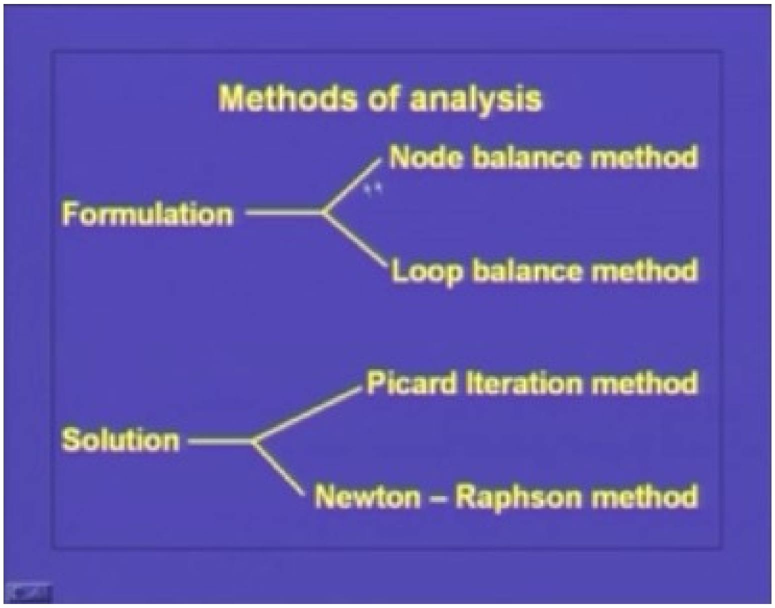

These principles can be used to formulate the problem. So the formulation could be as I mentioned node balance method or it could be a loop balance method. Then this formulation means I will formulate a set of mathematical equations which describe the flow process in this network that is the formulation. Once I get this set of mathematical equations then I should have how to solve these mathematical equations, there are several ways of solving these mathematical equations. As you see a little later these set of mathematical equations will be a set of non linear algebraic equations. So I have to have a method for simultaneously solving this set of non linear algebraic equations and that can be done through two methods that is what I call the solution. It is either Picard iteration method or Newton-Raphson method.

In this particular lecture we only talk about the formulation. Now, referring to the figure the demand at each node is known. R for each pipe is known because I know the length, I know the diameter and I know the material of the pipe so I know the resistance factor for each pipe and I also know the piezometric head at node 1 because the piezometric head at node 1 is related to what is the water level in the reservoir so H one is also known.

What are the unknowns? I need to know what is the flow rate in each pipe that is Q and piezometric heads H_2, H_3 and H_4.

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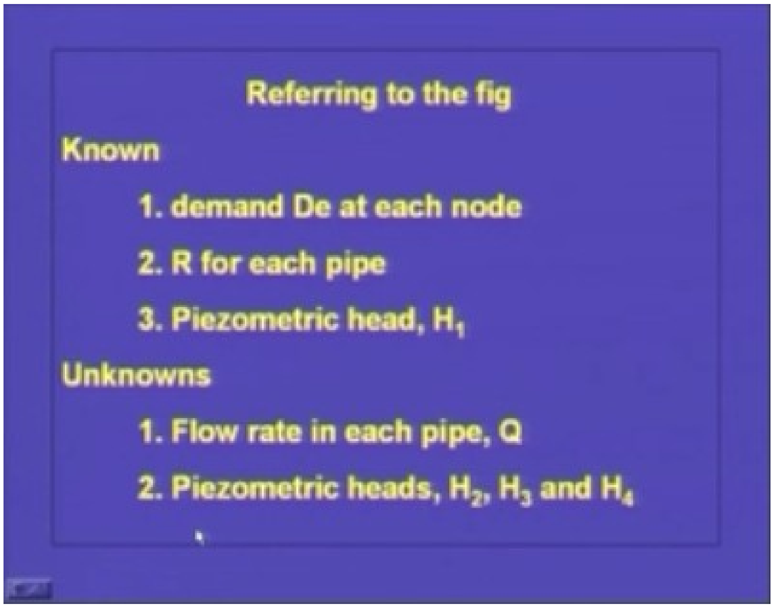

You look at this figure H_2 H_3 and H_4 (Refer Slide Time: 48:05) H_3 and H_4 I need to find out, Q_1 Q_2 and Q_3 Q_4 and Q_5 also I need to find out. Now how do I formulate this? There are eight unknowns and we require eight equations. In fact as I go through this I will show you how to reduce this number of equations, you may not require all the eight equations. We first write a flow balance equation at node 2. When I write the flow balance equation at node 2 looking at the figure I can say that Q_1 that is the inflow minus Q_3 that is the outflow at node 2 minus Q_4 that is the outflow at node 2 to us for and the demand at node 2 that is D_{e2} so they should balance out.

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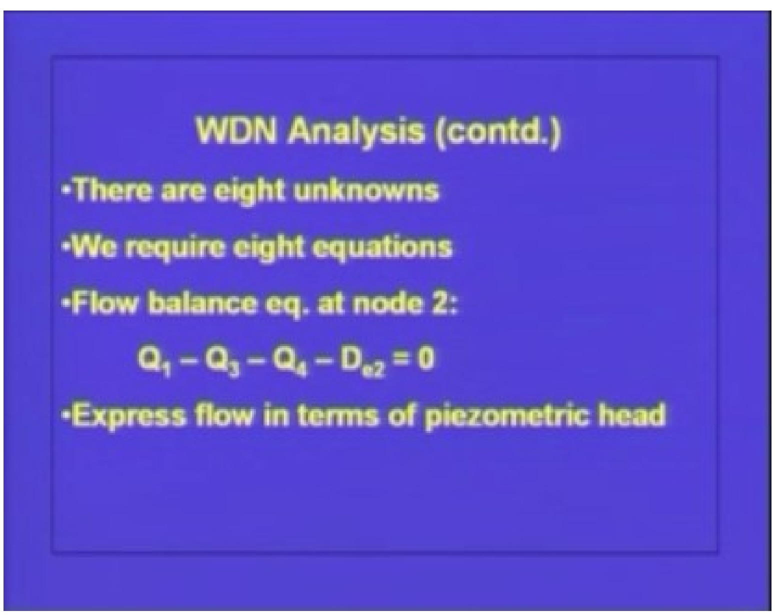

Now, to get the flow rate of Q_1 here it depends upon head at one and head at 2. So Q_1 can be written in terms of H_1 minus H_2 divided R_1 square root. Again Q_1 depends upon head at 1 and head at 2. So Q_1 square will be H_1 minus H_2 so Q_1 is equal to H_1 minus H_2 by R_1 square root.

Now in the WDN analysis I get this equation for the flow balance at any node like H_1 minus H_2 by R_1 square root, H_2 minus H_3 by R_3 square root, H_2 minus H_4 by R_4 square root minus D_{e2} is equal to 0 that is the nodal balance equation at node 2. Similarly, I can write nodal balance equations at other node, node 3 and node 4. Now I have three equations. In these three equations R_1 R_3 and R_4 D_{e2} D_{e3} D_{e4} R_3 R_4 here all these things are known and H_1 is also known and the only unknowns are H_2 H_3 and H_4. So I have three equations and I have three unknowns. So these three equations and three unknowns can be solved for simultaneously.

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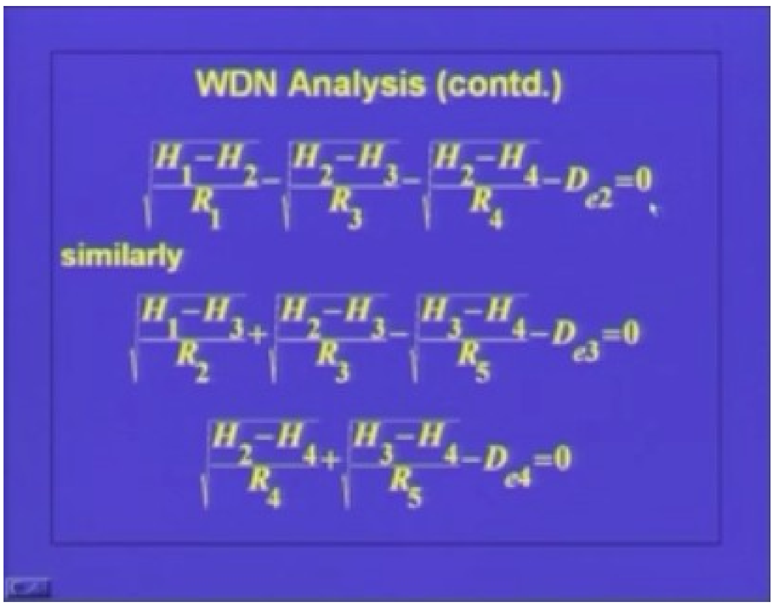

Therefore, depending upon the number of nodes I have and depending upon the number of reservoirs I have, that means the number of reservoirs I have means you know the reservoir water level so if I know the reservoir water level the node connected to that reservoir will know what is the head at that node. So the number of equations depends upon the number of nodes I have in the system minus whatever the number of reservoirs I have.

Let's say in this particular case (Refer Slide Time: 50:52) I have four nodes and one reservoir so the number of equations that come is three equations in three unknowns and these three equations can be solved for H_2 H_3 and H_4. Once I solve for H_2 H_3 and H_4 I go back to my resistance equation.

Thus in any pipeline I know the flow rate is proportional to what is the head at the upstream node. So, for any particular pipe I know what the upstream node is and what the downstream node is. If I know what is the upstream node and what is the downstream node I will be able to find out what is the flow rate in that particular pipe because I know what is the length and what is the diameter so this is what I will use for basically analyzing the network.

Now this I have already told you that I have three equations I use for an appropriate numerical method.

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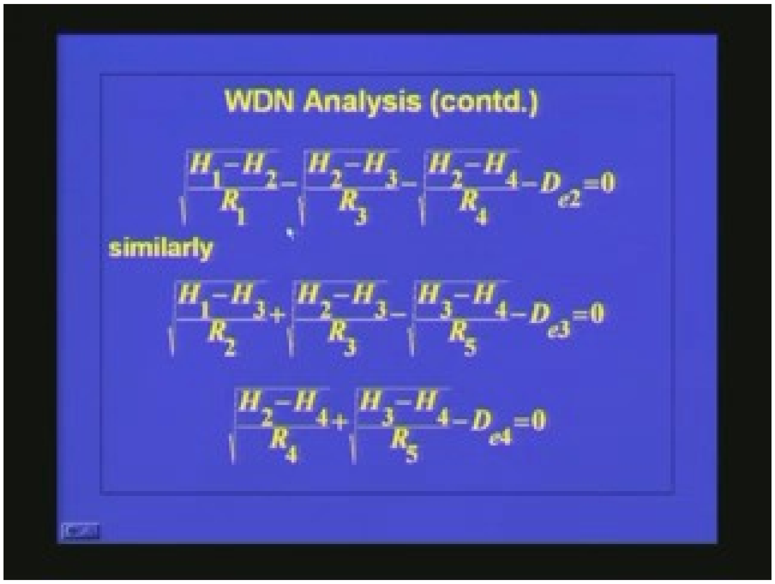

As you can see these equations here are non linear equations, they are algebraic but they are non linear equations. Now when you want to solve this system of non linear equations there are many numerical methods which are possible. One is the trial and error method. I will assume what is H_2 and what is H_3 and try to get what is H_4 here and I will substitute what is H_4 here and assume value of H_3 here and get a better value of H_2. I can keep doing this trial and error procedure and iterative procedure. Once I do this eventually as the iterations proceed I may have stable values of this H_2 H_3 and H_4 and I say that the system has conversed. This is an iterative what we call numerical method.

However, one has to be very careful while solving these equations these numerical methods. You may start with assumed values of these unknowns H_2 H_3 and H_4 then as your iterations proceed you may never be converging to certain definite values of H_2 and H_3 or the correct values of H_2 and H_3 and H_4. In that case we say that numerical method is diverging. So you have to choose a proper numerical method for solving the system of equations. There are several methods for doing this. As I mentioned we have the Picard iteration method and Newton-Raphson iteration method. Now Picard iteration method is lot more stable than Newton-Raphson method but that also one cannot say. Some methods which are very stable for certain systems may not be very stable for other systems that are why people keep working very much into finding out more and more numerical methods for solving these equations. Anyway we can solve this system of equations by anyway of these methods and then we can get the solution. Now in the way we formulated here that can be extended if valves are present or if pumps are present and it is also not very difficult to put all these things in a computer code.

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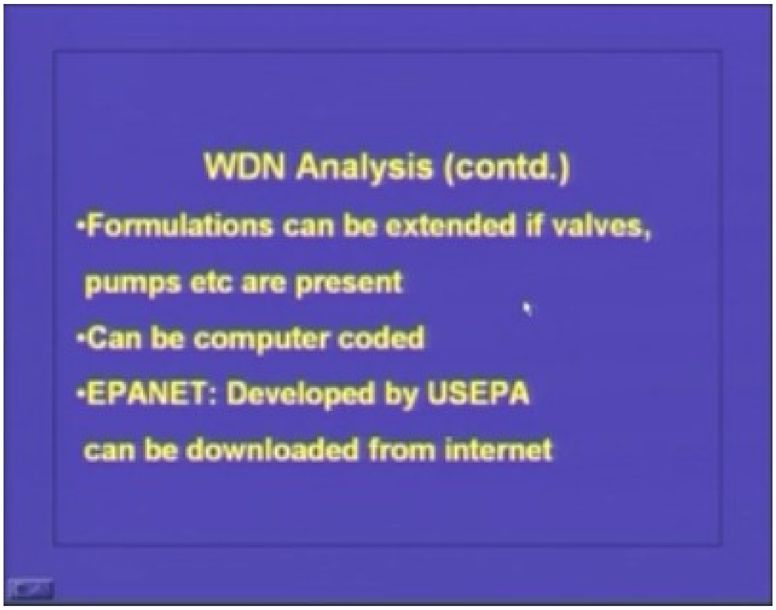

I have already told you about a computer code developed by University of Kentucky called KY pipe. But you also have computer course developed by other agencies like EPANET that is developed by United States Environment Production Agency. This particular program is available on the internet one can easily download this particular thing in the internet and one can use it for solution purposes, in fact you can do it yourselves, you can download it from the internet and it is very easy and you will see how the input should be given then the network program will make the analysis and will give you the results.

This EPANET will also actually track the chlorine concentration in a network. If you give what is the chlorine concentration or what is the chlorine dosage at the treatment plant it will also tell what will be chlorine concentration at different points in the network and you can compare that with whatever the standards you may have and see whether the water quality is maintained properly or not.

In this particular lecture I just want to summarize; I gave an overview of what is the water distribution network and what are the different criteria or the constraints that a good design should meet. I talked about what are the different layouts for the water distribution network and we also discussed about the distribution reservoirs, how to find out what is the capacity of the distribution reservoir, we looked at different layouts for the water distribution network then we looked at the design steps, what are the steps we should follow designing these networks and how to analyze a given distribution network.

Let us say somebody comes and then gives you that these are lengths, these are the diameters these are the networks so can you tell me what are the pressures at different locations, what are the flow rates, can you analyze this network then tell me whether it is meeting all my constraints or not. You will be able to do through water distribution network analysis, we have also seen this. I mentioned about Newton-raphson method,
I also mentioned about other numerical methods like Picard method, I leave it as an exercise. Basically you can go in deep a little bit to know more about these things and in the next lecture probably we will go and look at aspects of drainage networks.