Civil Engineering

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Lecture No. # 27

In today's class, we will discuss about reservoirs. When we say reservoirs, the purpose may be many folds. It may be used for flood control.

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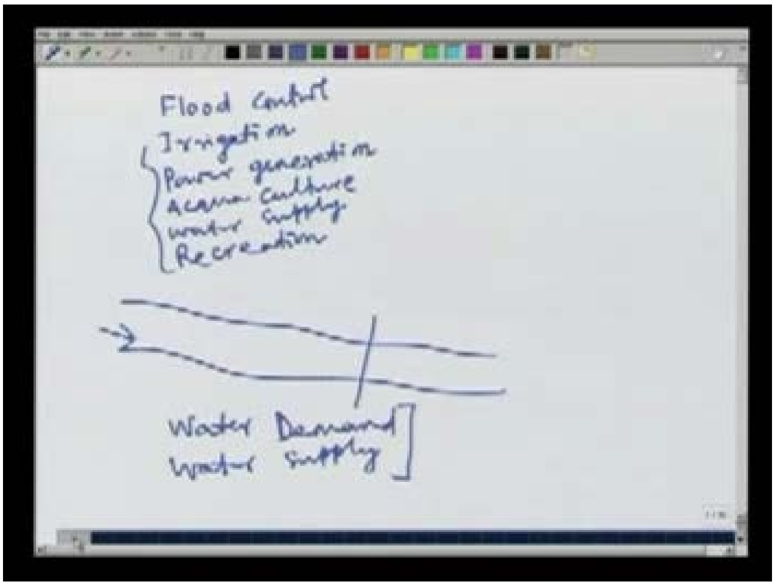

It may be used for irrigation, power generation, pisciculture or aquaculture, drinking water supply, can be sometimes used for recreation. We should remember that why we may build a reservoir due to one or more than one these reasons. Suppose the channel is flowing with water, we should know what the inflow is to the system and then accordingly we can design the reservoir based on our requirements. When we say requirement, we can call it demand sometimes. Based on the two terms, one is the demand the other is the supply we will design the reservoir.

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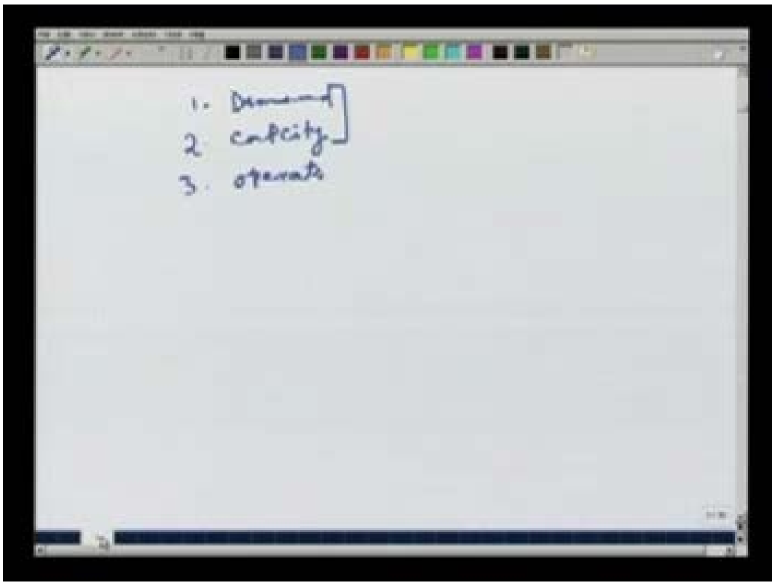

When we say reservoir, our purpose is basically three folds. One is to calculate what the demand is. What is the reservoir capacity and then how we should operate the reservoir?
We shall discuss about these two and we will solve some problems.

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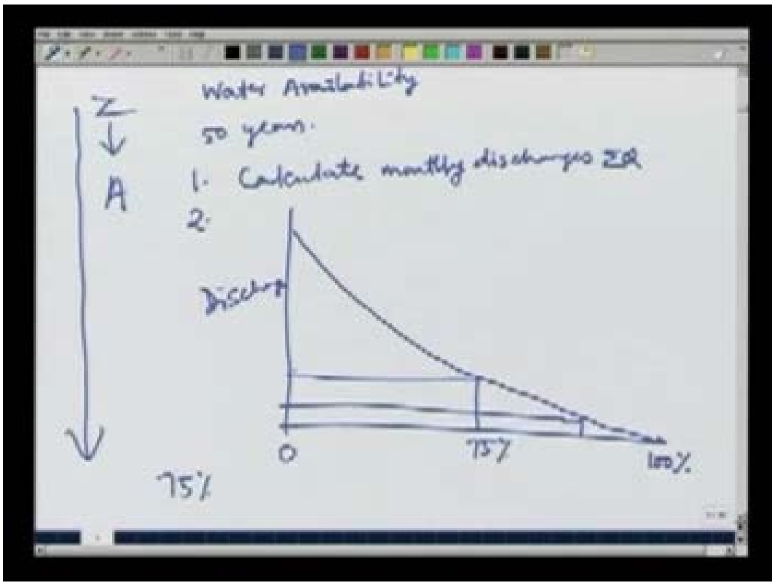

There is something called the water availability. What is water availability? Suppose I have the data for 50 years, let us analyze the daily discharges for a stream for 50 years. What I should do is accumulate these values per month or calculate monthly discharges. You sum the daily discharge values for the whole month. Now you get 12 values for a year. For 50 years, you get 50 multiplied by 12, that many values. Suppose I want to know the water availability so I can plot here, 0 percent. This is 100 percent and this is discharge and the series I get, I can write them in descending order. Means, the highest should be at the top. You can say Z to A. When I plot these values something like this, the highest value I should assign is 0 percent and to the lowest value, I should assign is 100 percent. It means 100 percent of the times; this discharge is available to me. Suppose I want to find out what is 75 percent dependable flow is, then here this is 75 percent. Suppose I want to know what 90 percent is, then I go here and find out the discharge. This is 90 percent dependable flow (Refer Slide Time: 05:13). This is 75 percent dependable flow.

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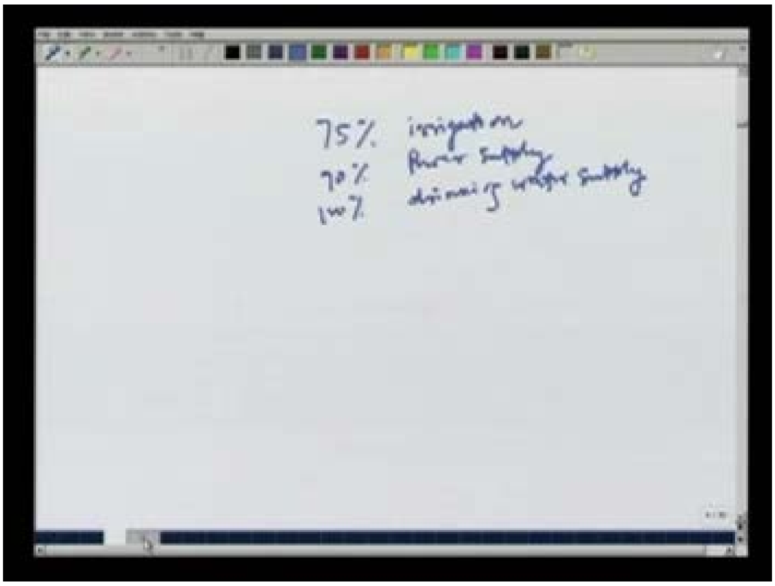

A thumb rule for deciding the reservoir is generally 75 percent dependable flow is used for irrigation and 90 percent dependable flow is used for power supply and 100 percent dependable flow is used for drinking water supply. Now let us go to the next thing to decide how I can find out the reservoir capacity. As I said earlier, we need to know what the demand or what is the water requirement is. The purpose can be many. For whatever is the purpose, depending on that, the requirement of water and the supply of water will be.

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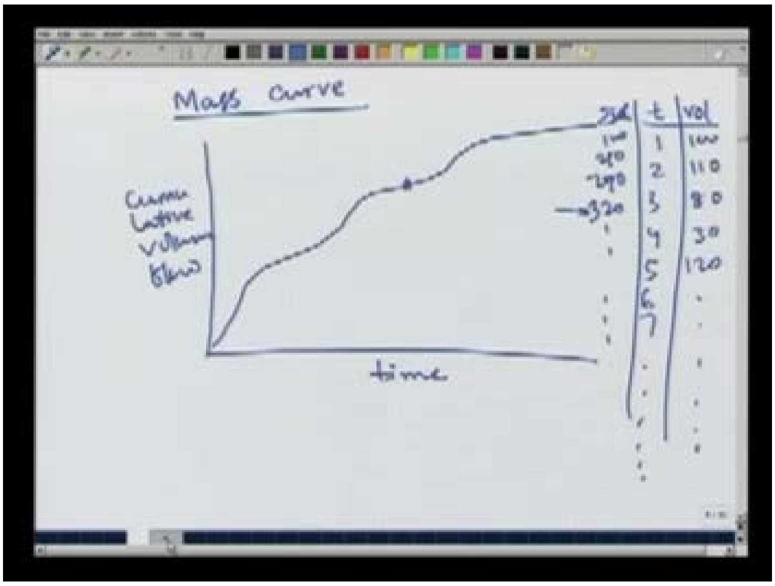

Now I will introduce you two terms, one is the mass curve and later I shall tell you about the differential mass curve. Let us see what mass curve is. In mass curve I plot here time and in the other axis, I plot cumulative volume. It means the curve will look like this because this is a cumulative volume. A value let us say here (Refer Slide Time: 07:12), cannot be less than its previous value because what is cumulative is, if I have a series, suppose this is t everyday or at monthly or yearly values and I have here the flow volume. Suppose this is time period 1, 2, 3, 4 like this and here I have let us say 100, 110, 80, 30 maybe 120 like this, then this cumulative volume will be 100 and then I keep on adding these numbers. That means 210 then 80, which is 290 then 30, 320 etc. Subsequent values are in this series. A value cannot be less than the previous values. This is called the mass curve. So for the stream under consideration for which we are trying to design the reservoir, we need to find out the mass curve of supply.

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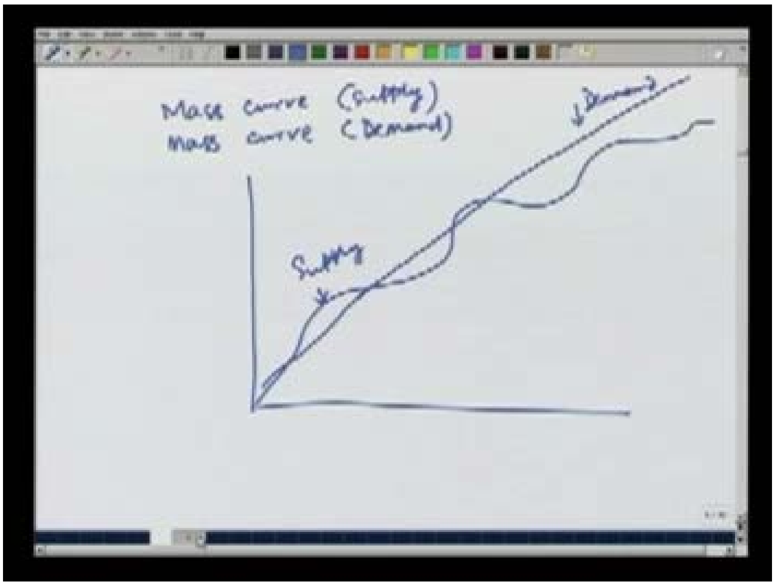

We find out, we calculate from the given data mass curve, the supply and remember this is mass curve for flow volume. We also need to prepare mass curve for demand and on the same plot, we try to see these two curves. Let us say supply is like this and demand is let us say like this. In this case, this is supply and this is demand. Then we know that at this place supply is more than demand. Let me make another curve with dotted line so that it will be clearer.

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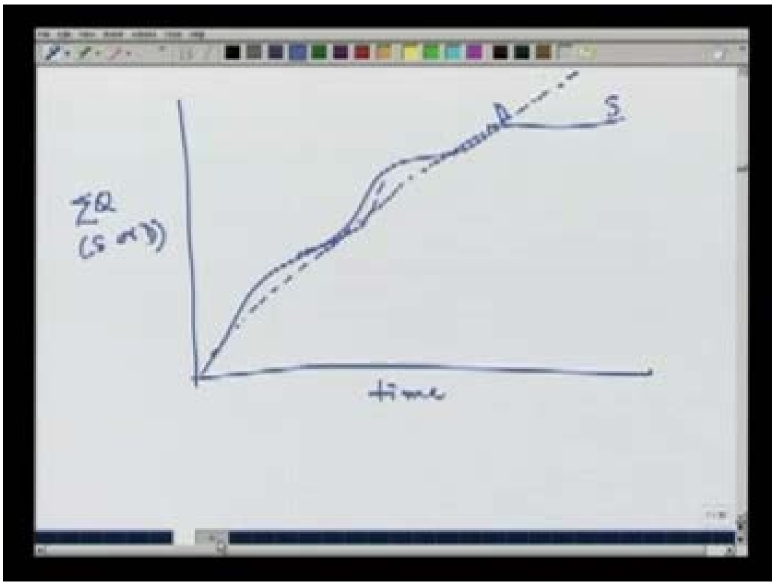

This is time this is mass curve or I can say Q, can be supply or demand. Let us say supply is through a solid line. So supply is like this. This is S and let us say demand is a dotted line. This is demand, so consider this portion from this to this. Let us say this supply curve is like this, so here supply is more than demand. We do not require the reservoir volume to store water because supply is already above demand. Consider this portion here, demand is more than the supply and we need some reservoir. We need some storage so that we can store the water and whenever required at this time, from this time onwards we can supply that water from the reservoir. This is the supply due to flow of the stream. But we should reserve water so that we can fulfill this demand.

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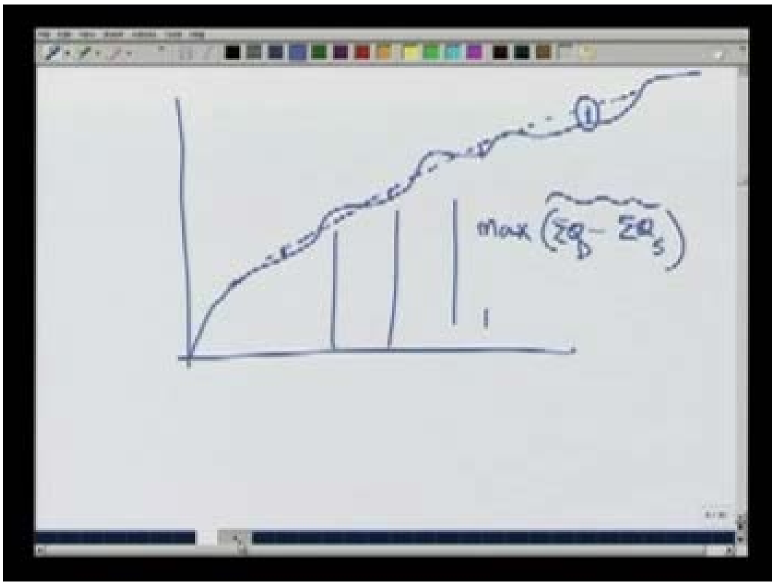

Let us see a systematic procedure to find out the reservoir capacity. First of all you prepare the mass curve for supply and then you prepare the demand curve. Let us say wherever demand is higher; you should concentrate on that location. For example here, demand is more I should find out the difference. Similarly here demand is more, I should find out what is the difference. Similarly here demand is more and I should find out what is the difference. Here demand is more I should find out what is the difference (Refer Slide Time: 12:27) and let us say we have 1, 2, 3, 4 volumes at 4 different places. The demand is higher than the supply and we need to know what the extra amount is. We should store to fulfill the demand. I should find out maximum of these differences. Let us say this is sigma Q demand – sigma Q supply. Wherever you consider these and wherever this value is maximum, that will be the reservoir capacity. This thing will be clearer when we solve one problem and let us go to the next thing.

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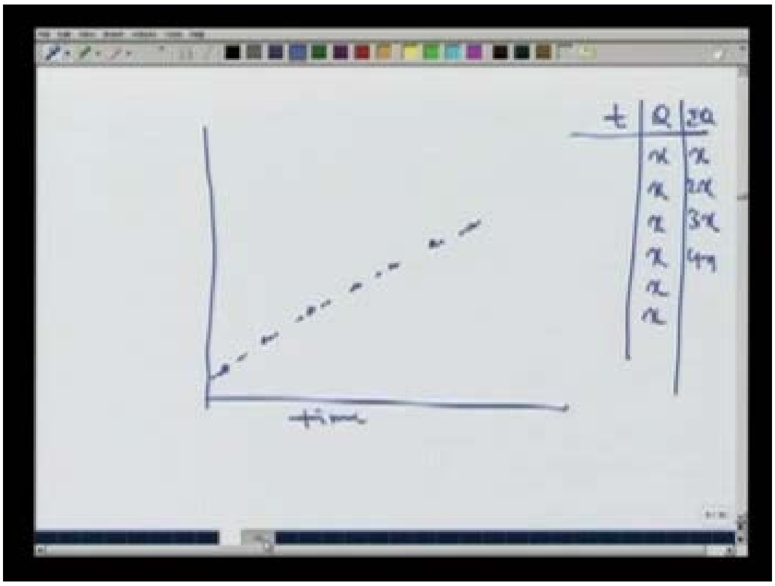

Just now I indicated that demand is through a constant curve like this. Do you think the demand will be constant? What does this mean? This means in time, this is time; let us say these are the values against each month. So for each month the demand is constant that is why this is a straight line with constant slope, because when I keep on adding, let us say this is x, x, x, x, x always. Then when I keep on adding, this will give me a straight line and with a constant slope. So sigma Q will be x, 2x, 3x, 4x and so on. We get a straight line. But do you think in reality this is the case?

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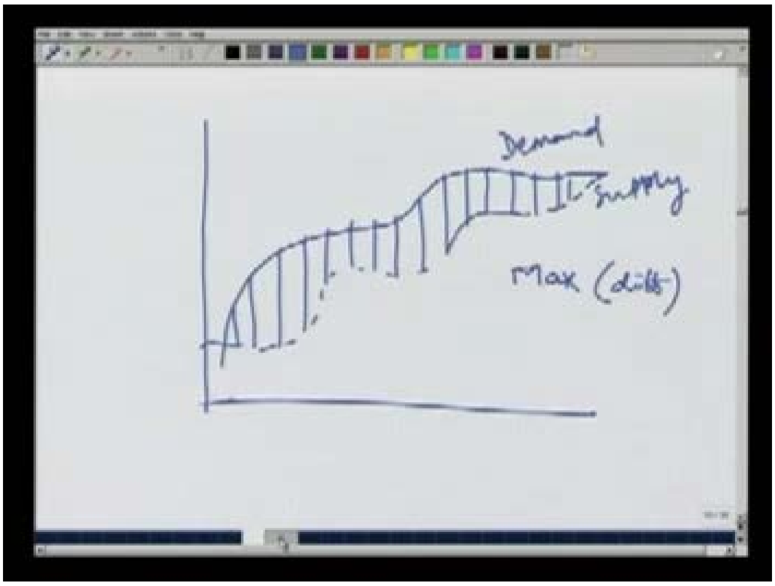

What we observe is the demand is also a variable in time. For example during summer we need more water. Similarly during winter we may need less water, so this demand will again be a variable thing. Let us say this is the variable demand, similarly this is the variable supply. This is supply. Then I should consider at different times what could be the difference and out of these differences I should accept for my design value or the reservoir capacity should be the maximum one. So I consider the maximum of these differences. Whether it is a constant demand curve or a variable demand curve, it does not matter. What we have to do is plot the mass curve both for the demand and the supply and try to see where the maximum difference is and based on that, we plot the maximum difference. We decide the reservoir capacity. I will move on to the next thing.

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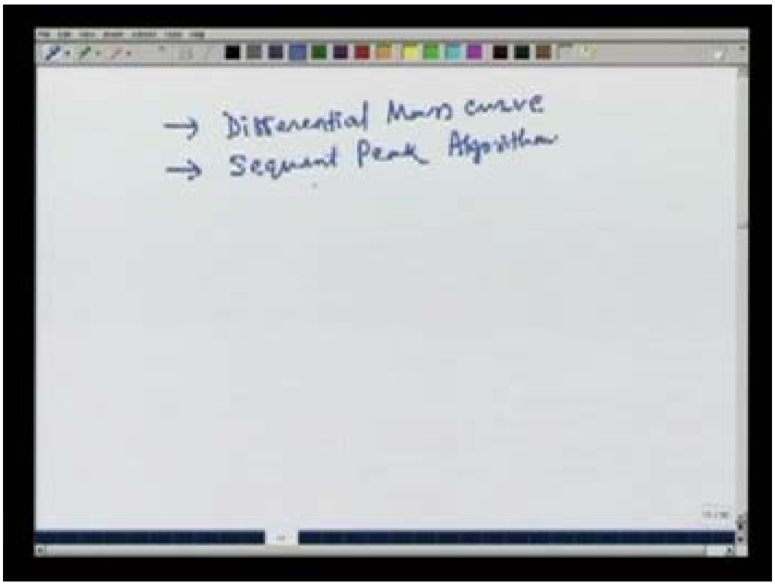

There is another technique to find out the reservoir capacity. It is called the differential mass curve. It is called the differential mass curve because we plotted the mass curve and then we find out the difference. This technique that I am going to describe is called the sequent peak algorithm. In this sequent peak algorithm, generally a computer programming is used and please remember that in order to design the reservoir, to arrive at a number for the reservoir capacity, what is done is, it not just 1 or 2 years generally, but we consider for the proposed site, we consider 40-50 years discharge value. When we consider such a long series, you know better to use a computer program. This sequent peak algorithm is a computer program. It is an algorithm which systematically calculates the reservoir capacity. Let us look into procedure in sequent peak algorithm.

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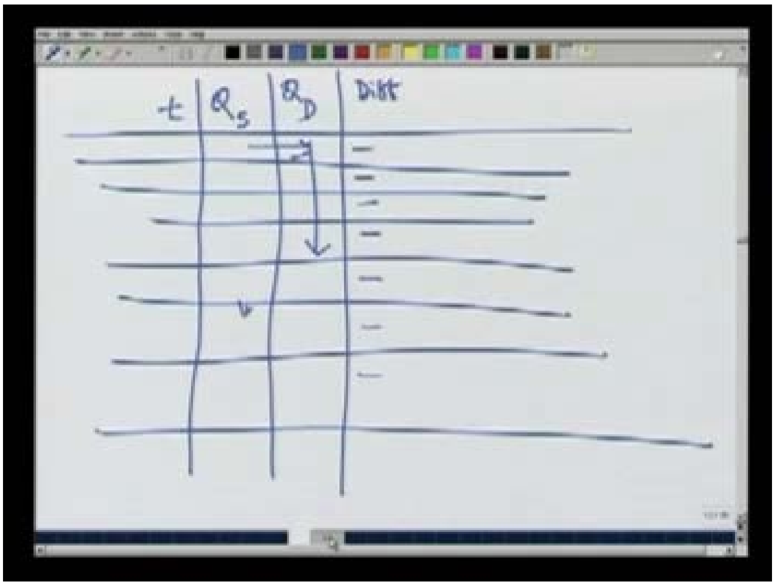

Let us say this is time and this is say supply and this is demand. What we do is in the previous method, in the differential mass curve first we find out the mass curve for this and then mass curve for this. We compare the mass curves then find out what the capacity is, but here what we do is first we find out the difference. We find out the difference and you can analyze the difference between these two columns. You get numbers here. Suppose this is supply, this is demand then you get a series.

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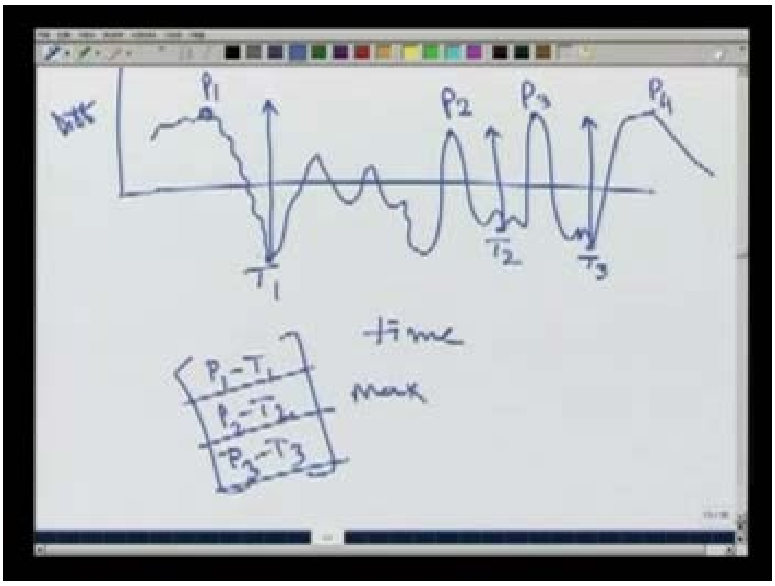

Some numbers will be positive, some numbers will be negative. You get a series like this. Remember if supply is more than demand, then supply minus demand will be positive. If supply is less, then supply minus demand will be negative. In sequent peak algorithm we try to find out the peaks. Suppose this is peaks remember, this is time and in y axis, I have the fourth column. In the previous table I showed this fourth column. This is time, this is supply, this is demand and this is the difference of these two. So this column is that difference. What

I do here is I consider the peak and then the next peak. Let us say that I neglect these two peaks because these values are less compared to this peak value because this is called a sequent peak algorithm. I have to search the next higher peak. Let us say this is another peak and if the series continue then I should find out where the peak is and remember I do not consider these peaks because they are less compared to this peak. So once I am here I should search for the next higher peak compared to this peak. In this particular figure I have 1, 2, 3, 4 peaks. In between the peaks, let us say this is peak 1, this is peak 2, this is peak 3, this is peak 4(Refer Slide Time: 21:22) and remember the decision how to find out the peaks. The peak has to be higher than these values and these two should not be considered because these are less compare to this. Here in between the two peaks, I should find out the minimum trough. Suppose the 1, 2, 3, 4 troughs are present, out of these 4 troughs I should decide the minimum one. Similarly in between these two peaks, there may be more than one trough on mini mass. I should find out the minimum one.

Similarly in between these two peaks, I have to find out whichever is the minimum value. Let us say this is T_1, this is T_2, and this is T_3. For calculating the reservoir capacity, what I should do is you just find out $P_1 – T_1$ for the difference between these 2. Similarly $P_2 – T_2$ and $P_3 – T_3$ and find out what is the maximum between these three. Do not forget that in reality, in the series, it may be a very long series and in the series, your computer program will do this operation. It will try to pick the numbers, the peaks and troughs and in between peaks and troughs, it will try to find out where the maximum difference is, depending on which the reservoir capacity will be decided. Now I will repeat once again. While calculating these differences you have to be slightly careful because this will be with a minus sign and this will be with a plus sign. When we say difference, basically we add these two magnitudes. This is the peak; this is the trough so we add these magnitudes to find out the reservoir capacity. These things will be clearer when we will solve some problems. So far we have discussed about the estimation of reservoir capacity and about three different things. One is the constant demand, the other is the variable demand and also we have discussed about the algorithm which is sequent peak. Also you should remember that conversely, one can do the problem, suppose a reservoir capacity is known, the reservoir volume is known, and then we can determine the volume. The requirement of water is the demand that needs to be fulfilled by these reservoirs. Can that be determined? Yes. So now we will see different problems. These concepts should be clearer.

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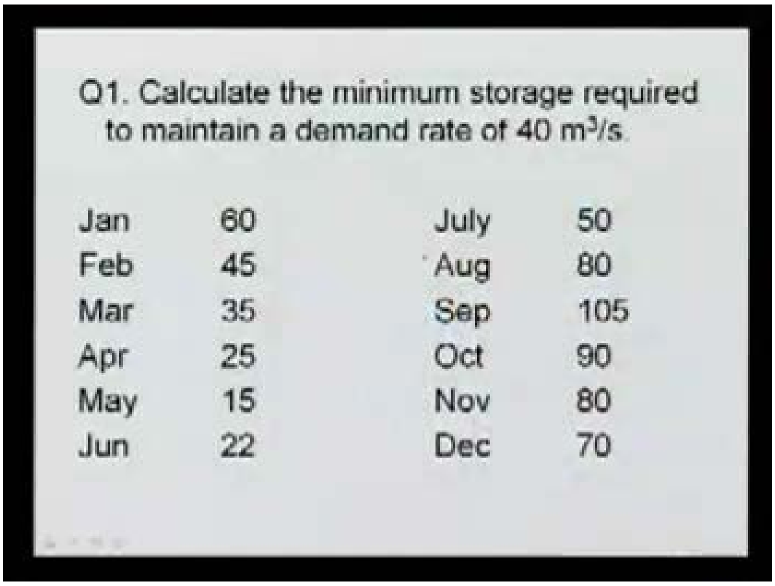

This is a problem one can calculate the minimum storage required to maintain a demand rate of 40 meter cube per second. These are the flows given for 12 different months. In January, it is 60 cumec. Please remember these two units cumec and metre cube per second are same. These are the numbers given for different inflows per year.

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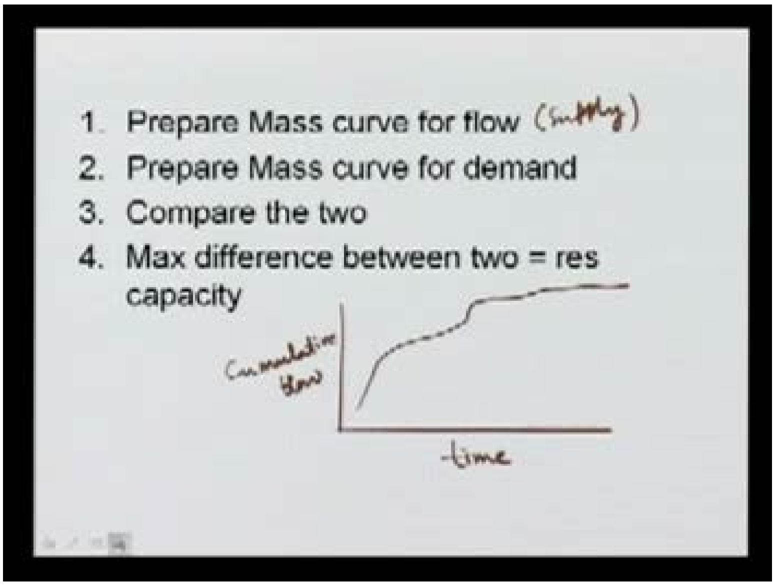

What we should do is we should first prepare the mass curve for flow. When I say flow it means this is the supply. Then I should prepare the mass curve for demand and I must compare these two to find out the difference, that is the reservoir capacity. Do not forget that mass curve is time. This is cumulative flow.

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Jan	60	1860	40	1240
Feb	45	1260	40	1120
Mar	35	1085	40	1240
Apr	25	750	40	1200
May	15	465	40	1240
Jun	22	660	40	1200
Jul	50	1550	40	1240
Aug	80	2480	40	1240
Sep	105	3150	40	1200
Oct	90	2790	40	1240
Nov	80	2400	40	1200
Dec	70	2170	40	1240

So here are the steps for different months. I have the supply. This number 60 indicates the average daily discharge. I should multiply 31 because January has 31 days. This is the monthly value. The 60 is the average daily discharge and for the month, this is the discharge you can say this is the supply. Similarly for other months, we have these Q max per metre cube per second as supply. Then this is the demand, this is a case of constant demand. The water required is 40 Q max. Again these are the daily values, so for respective months, I should find out the number, the monthly values. This is again in cumec. What needs to be done? I should prepare the mass curve. Remember these numbers are only for the month. So I must prepare the mass curve, only then I should compare the supply, the demand and the required reservoir capacity.

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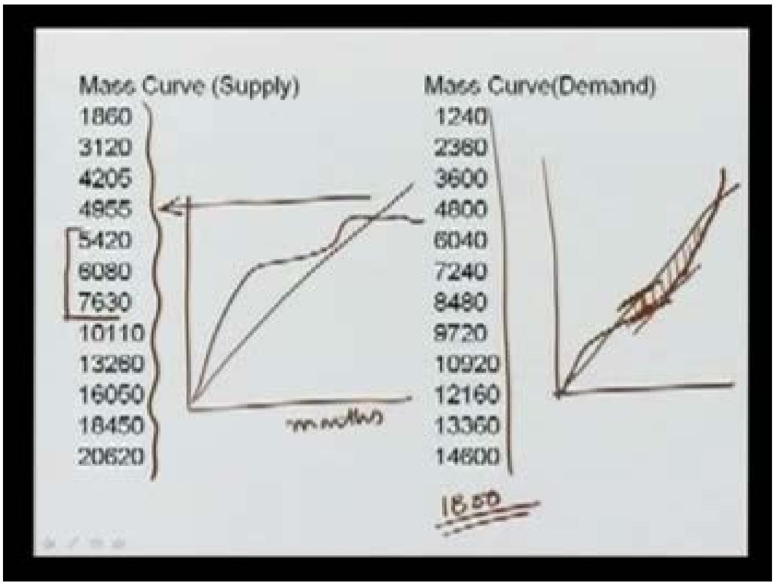

This is the mass curve for supply. Remember the previous numbers. What should I do? I should add the first number which will be 1860. I should add this to this and similarly I keep on adding. I get the cumulative curve which gives me the mass curve for supply. This is the mass curve for supply. In x axis, I will have the months here. I will have the months from January to December and in this axis I will have the supply. Whatever is the number, this will be the mass curve and similarly for demand I can get the mass curve by adding the previous column values. I must plot this and this. So here it will not be like this because the demand at some places will be more than the supply. Only then we require a reservoir. If the supply is higher than the demand, then there is no need for the reservoir. So let us say this is something like this then let me draw here one more figure. Let us say this is the demand because we have a constant demand. It will be with a constant slope and let us say the supply initially for example here 1860 is more than 1,240. Initially it is more but then gradually it will be less than that and then towards the end it is again more the supply is more. If you examine the critical months, it will be January, February, March. So look here supply is more compare to the demand but look at this. These 3 months are the dry seasons, and these 3 months are critical. We need a reservoir to cutter the requirement of water and these three periods will indicate what the required capacity is.

Suppose I find out the difference here, for example here the demand is 7240 and the supply is 6080, this is 1160, is required. Let us say this is one point and this is another, so my intention is to find out the difference between these two plots at different points and for that I should draw the tangents at different locations parallel to this line here. Depending on the maximum difference, from the demand we determine the capacity and if you do this graphically we will find out that this value will be slightly higher. Here the analytical number is 1160 but if you do it graphically, you may find it to be slightly higher. I believe the value will be around 1800 or 1900. It means the reservoir capacity will be that much. So what I have to do is, I plot this curve and take the difference and wherever the difference is maximum, I consider that to be the reservoir capacity. I think the case of constant demand is clear. Now let us see the second case.

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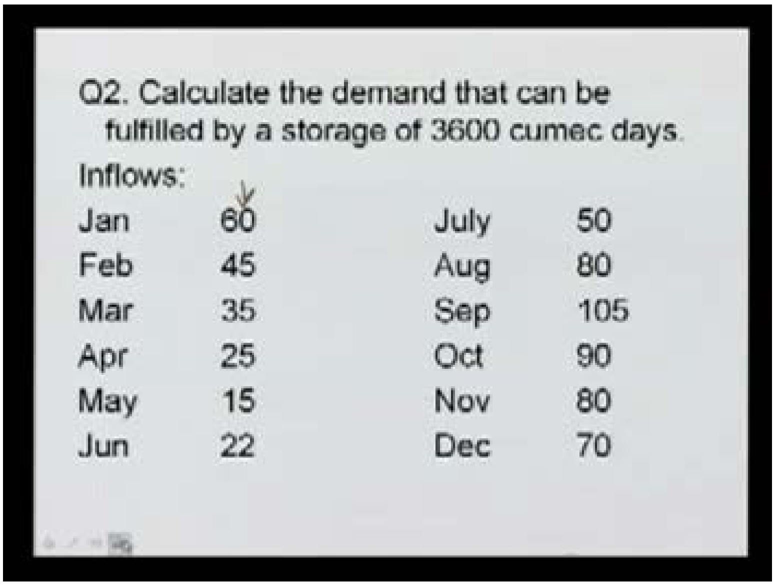

This case is to calculate the demand that can be fulfilled by storage of 3600 cumec days. This is the case of reverse problem. It means in the other problem demand was given and we have to find out the reservoir capacity.

Here reservoir capacity is given and we have to find out the demand. It can be satisfied through this reservoir. The exercise will be pretty similar. I will come back to this once again.

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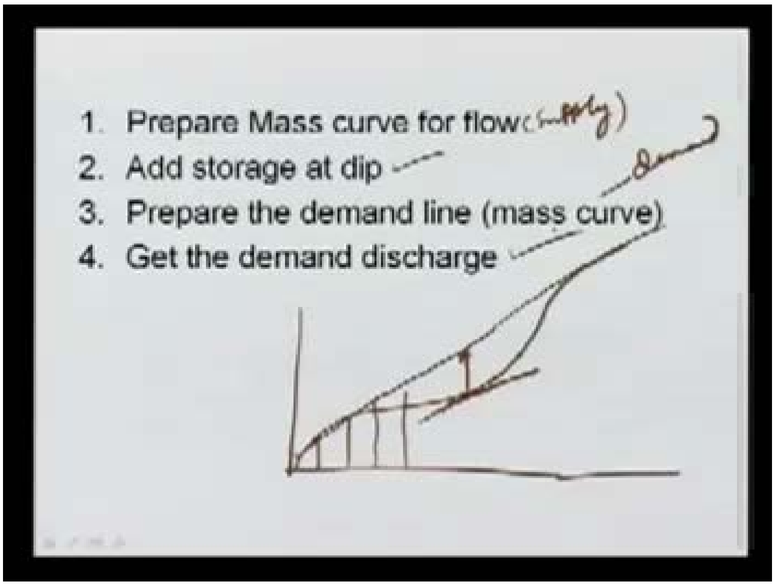

These are the inflow values so the procedure will be like this. I have to prepare the mass curve for the supply. This is supply. So prepare the mass curve for the supply and now you do not know the demand but you know the reservoir capacity. So what you have to do is you guess some lower values in the mass curve. Suppose this is the mass curve for the supply, then you can take this or this or this. You draw the tangents. Then let us say, my first guess value is this. I draw a tangent here. Then add storage I know this storage and the problem storage is given. So add the storage. Here through this you pass a line like this because you assume that the demand is still constant. This mass curve for demand will have a constant slope and if I get this line, what is to be done I know that this is the mass curve for demand. Once this curve is known I can easily find out the monthly values. For example here it will be with a constant value. You can deduct the previous month's value. For example here the monthly value will be this minus this. You get the demand discharge, monthly demand discharge. The objective is in this problem to solve the problem for the demand curve. We know the reservoir capacity and through this exercise, through this problem we can know the demand it can be fulfilled through this reservoir. Now let us see the next problem which will be on variable demand. Please remember that for the sake of explaining you I assume that the demand is constant. It need not be though. So let us see the next problem. This is for the previous problem.

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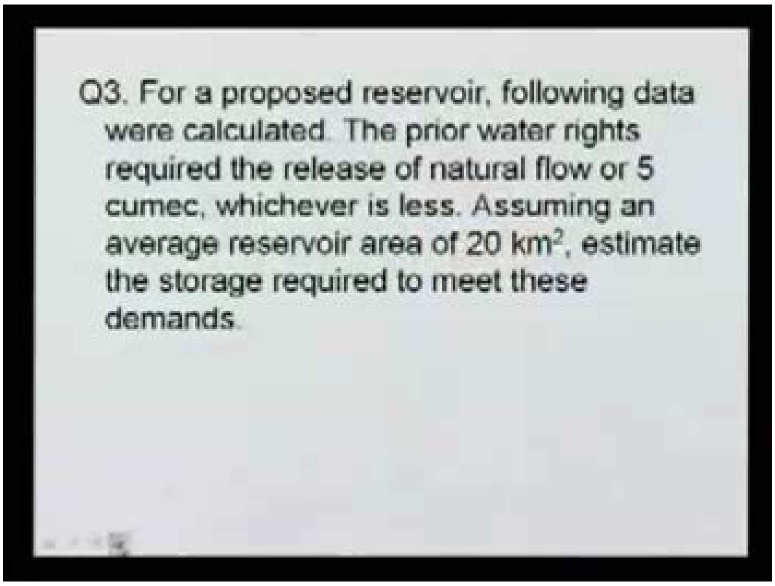

For a proposed reservoir the following data was calculated. Data will be given. Next, the prior water rights required the release of natural flow of or five cumec, whichever was less. This is important to understand sometimes, suppose you build a reservoir, but there might be some rulings. You have to maintain some flow. You cannot tap all the water. So here in this question, it is given that the release of natural flow of five cumec or whichever is less, have to be released for requirement. This, remember is not the demand. This is the water rights requirement. Then assuming an average reservoir area of 20 kilometer square, the reservoir area is given. Estimate the storage required to meet these demands. So let us see the data.

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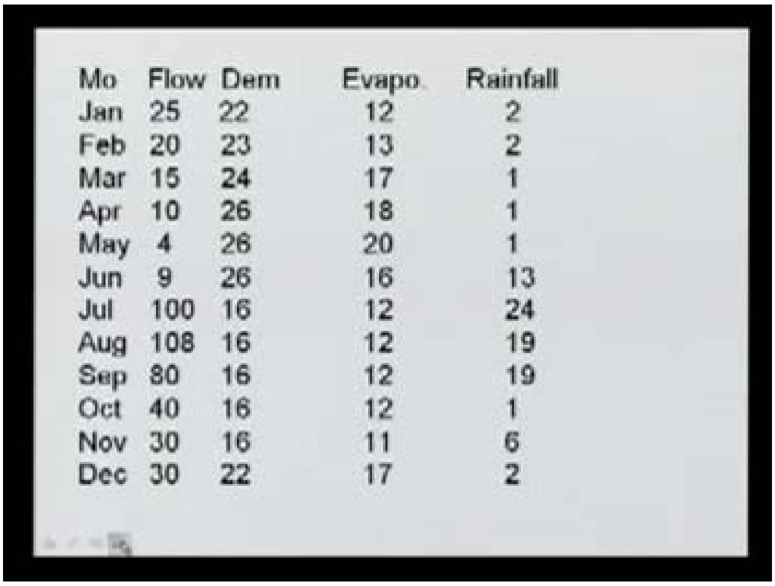

Mo	Flow	Dem	Evapo.	Rainfall
Jan	25	22	12	2
Feb	20	23	13	2
Mar	15	24	17	1
Apr	10	26	18	1
May	4	26	20	1
Jun	9	26	16	13
Jul	100	16	12	24
Aug	108	16	12	19
Sep	80	16	12	19
Oct	40	16	12	1
Nov	30	16	11	6
Dec	30	22	17	2

This is the data. These are months again the data is for one year. The second column is flow. Flow means flow in the stream and then this is the demand. This is the evaporation. Now when water flows, there will be some loss due to evaporation. This is evaporation and this is the rainfall. We have to be very careful because in this particular question, you know units are given here by mistake, so in the data you will be provided with units. For example rainfall may be in centimeter or in millimeter. Similarly evaporation will be in terms of some depth and flow will be in cumec and this demand will be again in cumec. These are the datas. What is the procedure we follow? We follow the same procedure.

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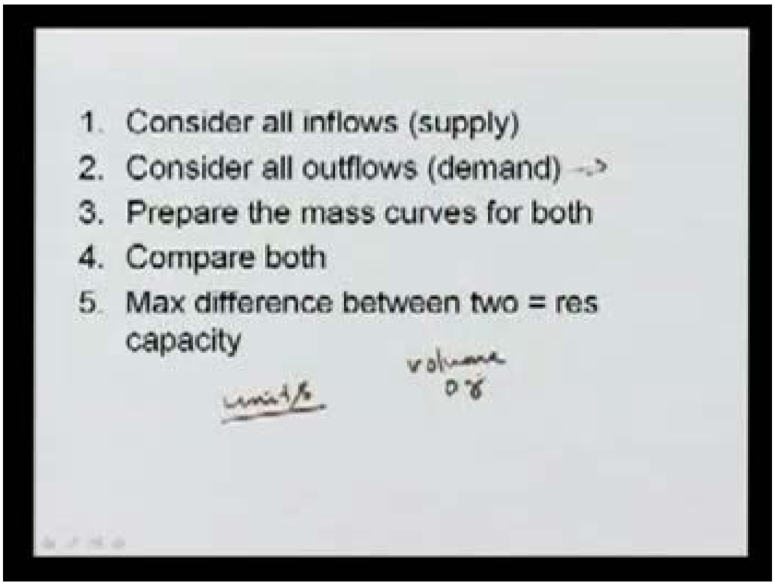

Consider all inflows and we call it a supply. For the given system you consider all the inflows and what will be the inflows. Let us see this will be inflow, this will be positive. This will also be because rainfall will add to the system so rainfall should be also considered as inflow to the system. Now let us see what the demands are. Consider all outflows because demand is something which we have to provide. The reservoir has to cutter so while calculating demand, we must consider this. This is the water required and also evaporation because this is a loss. For this system, this is a loss. So these two columns will give me the positive things. For the inflow to the system, these two columns will give me the negative things or loss or from the system. You now prepare the mass curves as usual that means in the x axis you take time or month. In y axis you take cumulative flow. Here there is a trick. You should be consistent as far as your units are concerned. Here I will give you the clue. The clue is either you use volume for all the components. For example rainfall, you should consider volume or you should consider the depth as the unit. You are free to use either volume or depth as the unit. While preparing the mass flow curve for the supply and for the demand you should be vigilant that your unit should be consistent.

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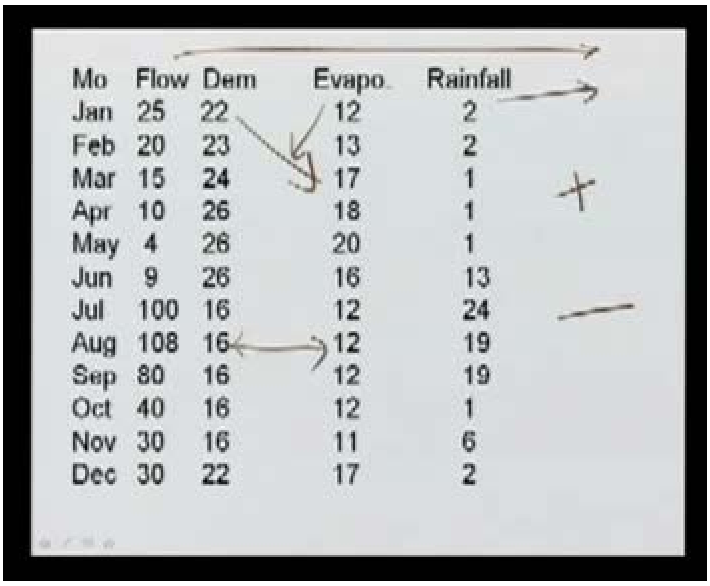

Mo	Flow	Dem	Evapo	Rainfall
Jan	25	22	12	2
Feb	20	23	13	2
Mar	15	24	17	1
Apr	10	26	18	1
May	4	26	20	1
Jun	9	26	16	13
Jul	100	16	12	24
Aug	108	16	12	19
Sep	80	16	12	19
Oct	40	16	12	1
Nov	30	16	11	6
Dec	30	22	17	2

If you are adding, for example here when you add flow, this is in cumec. This is in centimeters. You try to write in one unit. If you are using volume then to this depth, you multiply the reservoir area. You get the volume. Similarly, if you are interested in finding out the depth, for this flow when you divide by the area, these two steps are over and I also know how to prepare the mass curve. It is all same compared to both and as usual the maximum difference; the maximum difference between the supply and the demand curve will give us the reservoir capacity. The only difference in this problem is that the demand is not a straight line.

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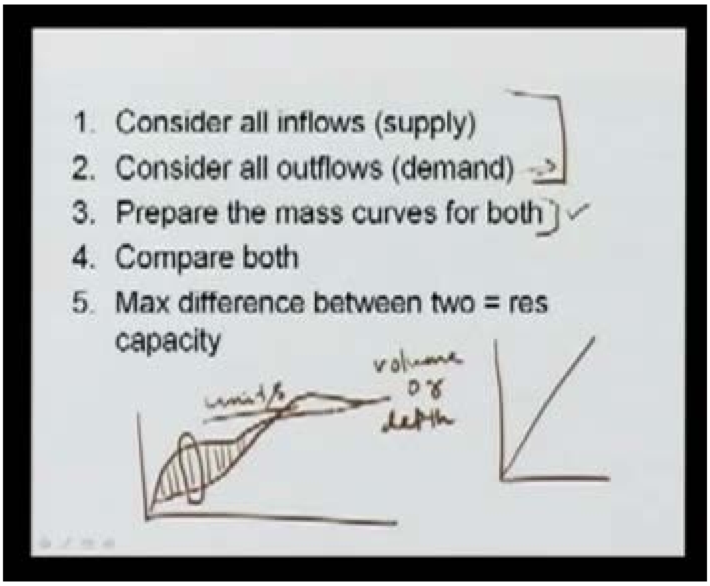

In the earlier programs demand was plotted like this because we assumed that the demand is constant but here, it will not be constant because of variable demands. It does not matter. You plot your supply and whatever the supply is, you plot the demand. Wherever it is maximum, you consider it at all places wherever it is maximum let us say at this place it is maximum.

That will be the reservoir capacity. I think this is clear. The example explains you how to take into account the variable demands. Let us see the next one which is on sequent peak algorithm.

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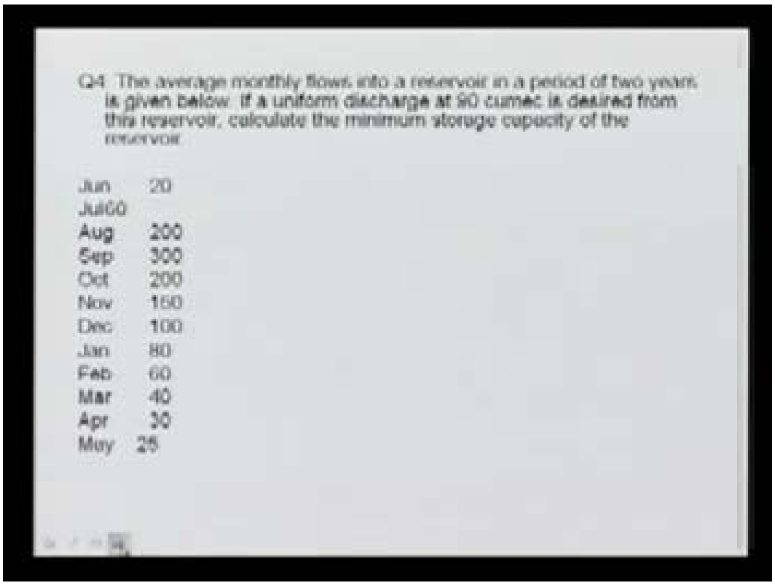

The average monthly flows in to a reservoir in a period of 2 years are given above. Please remember while you are planning for a reservoir, suppose you have been asked to design a reservoir, you have been asked to find out the reservoir capacity then the data should be for more than 10 years. Remember this, only for the sake of it; we plotted here the data for one year. But in reality you have to use more than 10 years data and again in sequent peak algorithm, it is very useful because you have a long series time data all right. This is the average monthly flows into a reservoir in a period of 2 years. It is given below. If uniform discharge at 90 cumec is desired from this reservoir, we calculate the minimum storage capacity of the reservoir. Again you have the demand which is constant and you can also solve this problem the way we did the first problem which is through differential mass curve but here we are trying to solve this problem through sequent peak algorithm. For June it is 20, July 60 and likewise we have here data for 1 year.

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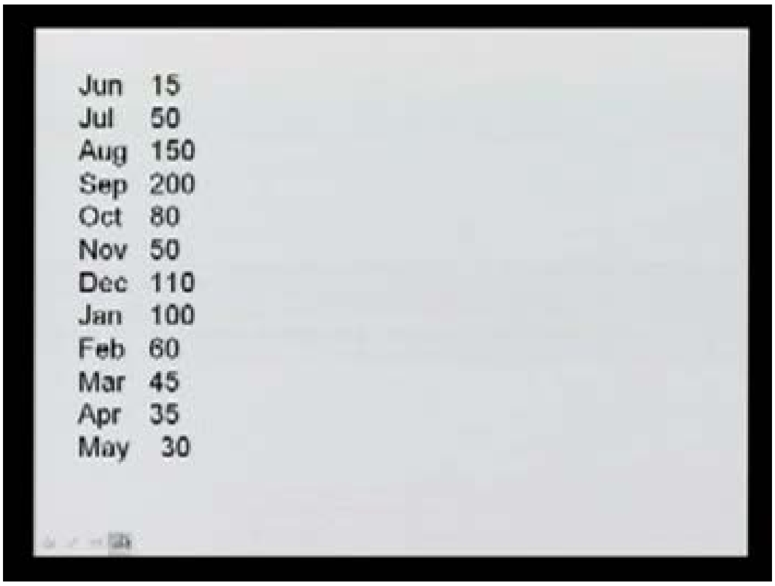

Next we have data for another one year, so what is to be done.

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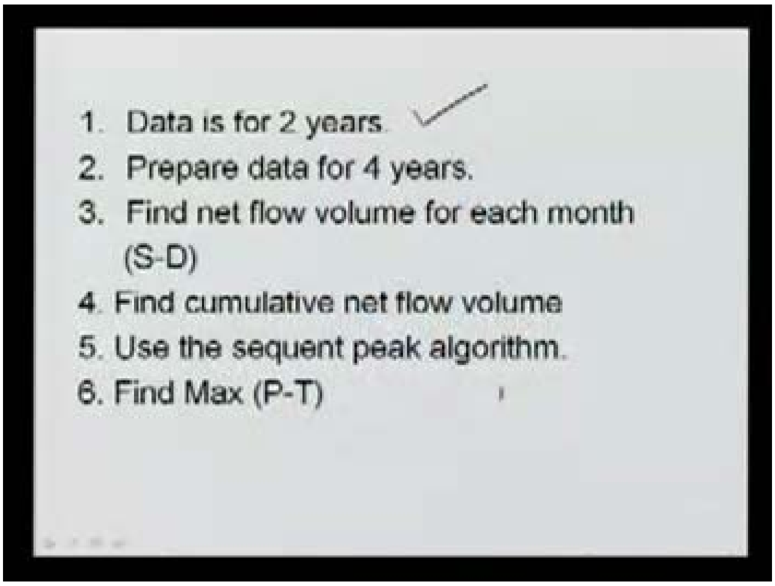

We have data for 2 years; the method says you if you are within the period's data prepare the data for two in periods. This is because we assume that the same flow will continue for the next two years. For example here we have data for 2 years and we must prepare data for 4 years. Then where from will we get the data for the next 2 years? The same data will be used for third and fourth year. Fourth year means we have 12 values. For the first year, twelve values, for second year and the third year, these values will be used and for the fourth year, these values will be used. Find net flow volume for each month. What you have to do is you do not have to prepare the mass curve. In the other method we have to prepare the mass curve. Suppose I have data for 24 months or may be 48 months. We use these 48 months to prepare the mass curve. Here we are not doing that, remember this. We use on monthly basis and we try to find out what the difference is. What we have to do is we are not preparing the mass curve but we will do it on monthly basis. We have to see the difference between supply and demand for each month. Means in the data sheet, we should consider row wise. So here we have the data for inflow and in the question, this is the 90 cumec for demand. We consider row vise and in a particular row we should see what the demand and the supply is and the difference. We have to prepare data this way.

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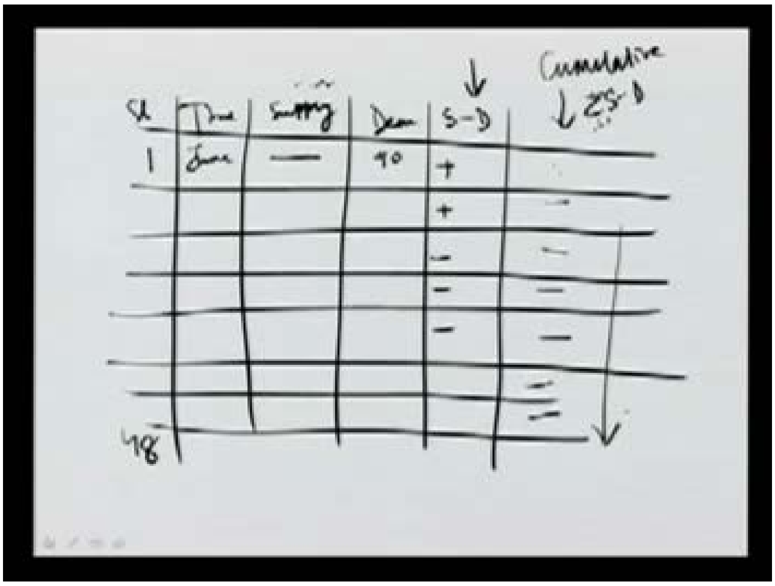

This may be serial number. This will be time and in our case it will be months and the data. For our case it is from June onwards and remember we have 48 values. This will be 1, this will be 48 and we have supply for each month. We have been given a number, so that the number has to be written here followed by the demand. Here you put 90 everywhere and then here you prepare S – D. This is supply; this is demand so you prepare supply – demand. Whenever it is rainy or in the so called non dry period, we will have to supply more than the demand. Therefore, the number that comes will be positive. Sometimes it may be negative. For each of these rows one has to find out the difference between these two and we should also remember the procedure we followed and what is the procedure? We find net flow volume. For each month and it is S – D.

In the computer program in fact you use the subscript i for this and this i is the index for the respective month and for the respective month you find out the difference. When I say difference, it may be positive or it may be negative S – D and then we find the cumulative net flow volume. Then in this column, you have to do something like a mass curve. In the earlier differential mass curve technique, what we did was preparing the mass curve here. After supply you prepare the mass curve for supply. After demand you prepare the mass curve for demand and then compare these two but here individually you prepare the difference between the 2 at each month. Then you prepare a cumulative series which means sigma S – D. So here there will be only one. Here it will be this plus this. Here it will be this plus this and we will get some numbers.

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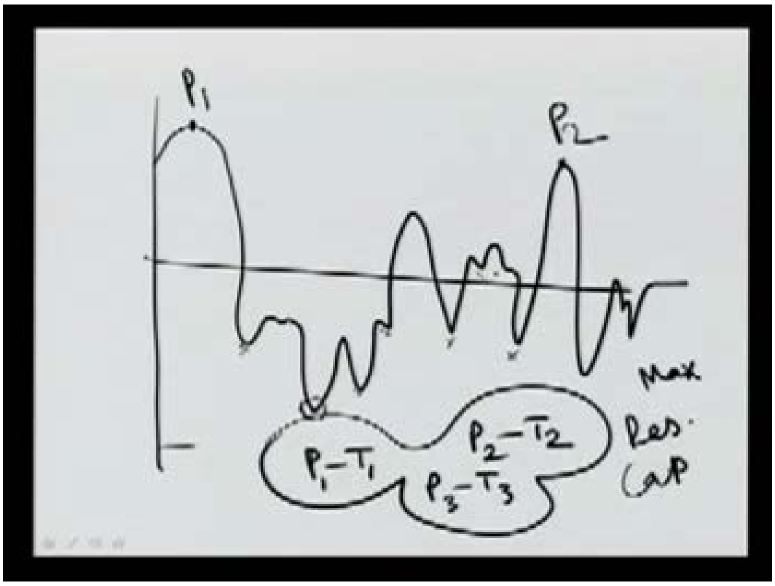

This will be treated to find out the peaks and the troughs and as we discussed. Now this is your first peak, you should see where the next higher peak is. This is a peak, this is a peak, this is a peak (Refer Slide Time: 50:27) but these peaks are lesser compared to this. But this might be higher than this so if this is peak 1, this is peak 2. Similarly in this series remember only this is an example and in this example we have 48 rows but in reality it will be more than that. You can guess if you have 50 years data, how big will the series be? The computer program will search and then you find out where the sequential peak is, that means one peak and the next peak should be higher than the first peak. Similarly you find out all the peaks and in between 2 peaks you will find the minimum of all the troughs. These are all the troughs. These 12 are also the troughs. But out of so many troughs, I will go for this one, because this is the minimum one. Then you decide P – T. If you have more than one peak, then corresponding troughs in the gap of two peaks, you find out the minimum troughs. Similarly between P_2 and P_3, there might be so many troughs and you decide to go for the minimum trough. So, $P_2 – T_2$, similarly $P_3 – T_3$ and you consider all these numbers and the maximum number will be your reservoir capacity.

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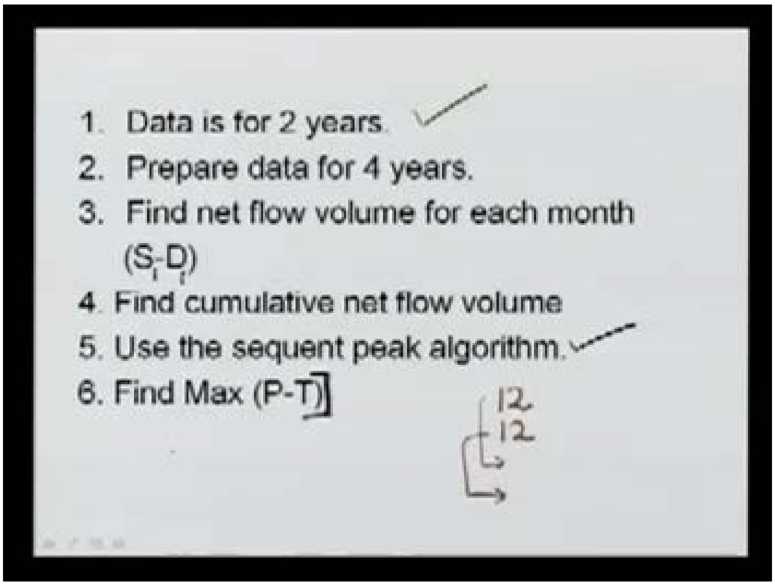

Once again I will repeat the procedure which says, use the sequent peak algorithm. It means to find out where P_1, P_2 or T_1, T_2, T_3 is and then find the maximum of all the P – T values. Out of all the P – T series, you find out the maximum one and the maximum value gives you the reservoir capacity. This is a sequent peak algorithm. This is more useful when we have a longer series and if you have lesser data then we may want to go for a differential mass curve. When we compare the results, they give more or less the same results. We should get same results. If one is using the differential mass curve and the other one is using the sequent peak algorithm, one should get the same results. But the sequent peak algorithm has lesser errors. So it is generally preferred. I think with the help of these four examples, the concept of estimating the reservoir capacity is clear and in the next lecture we will study the design of culvert.