Course Name: Watershed Hydrology

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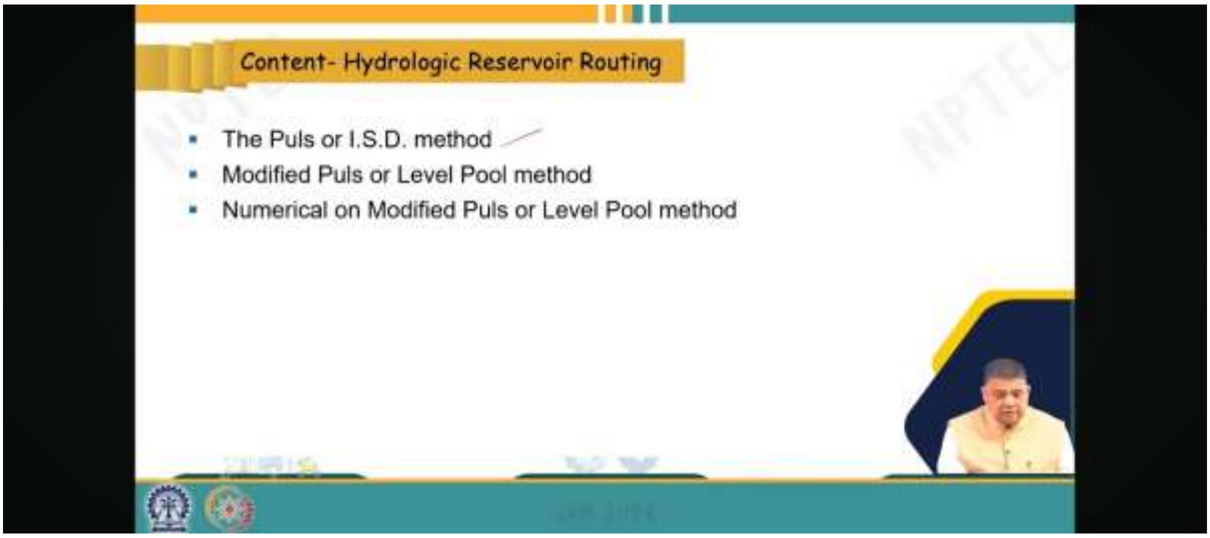
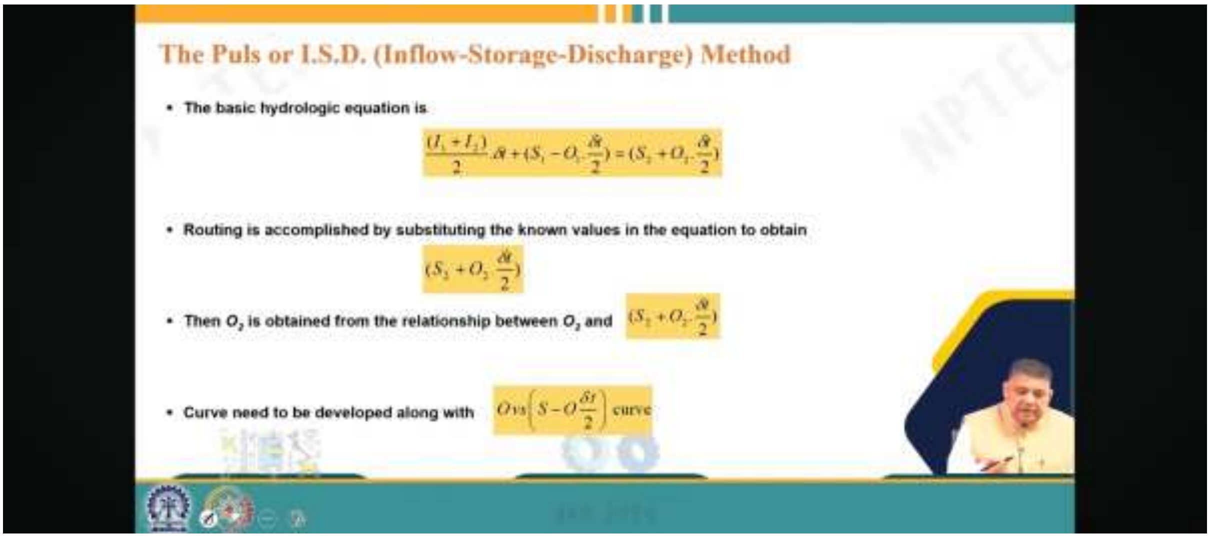
Week:10

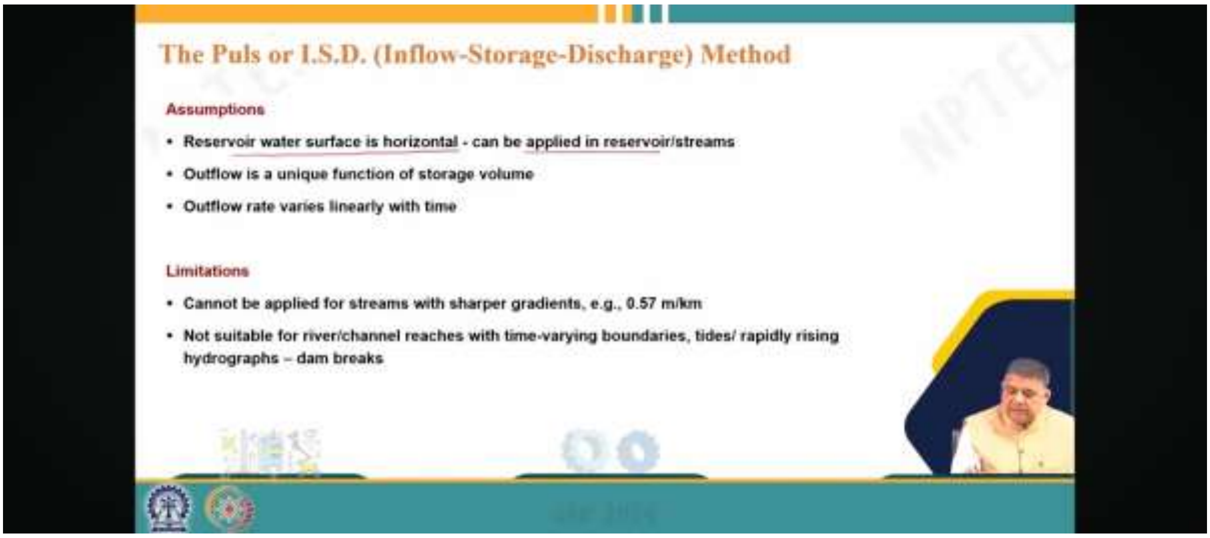
Lecture 47: Hydrologic Reservoir Routing



Hello friends, welcome back to this online certification course on Watershed Hydrology. I am Rajendra Singh, professor in the department of agriculture and food engineering at Indian Institute of Technology Kharagpur. We are in module 10; this is lecture number 2 and the topic is hydrologic reservoir routing. In this particular lecture, we will talk about the pulse or IST or inflow storage discharge method of hydrologic channel reservoir routing. Then we will talk about the modified pulse or level pool method, and then we will take on numerical on modified pulse or level pool method of handling the hydrologic reservoir routing. So, basically, the hydrologic reservoir routing we started in the previous lecture, and if you remember, we discussed the step-by-step method of hydrologic reservoir routing. Now, we take the next method which is called the pulse method or IST method, which stands for inflow storage discharge method. And the basic hydrologic equation which pulse method or as the method uses looks like this, slightly different than what we saw in the step-by-step method.



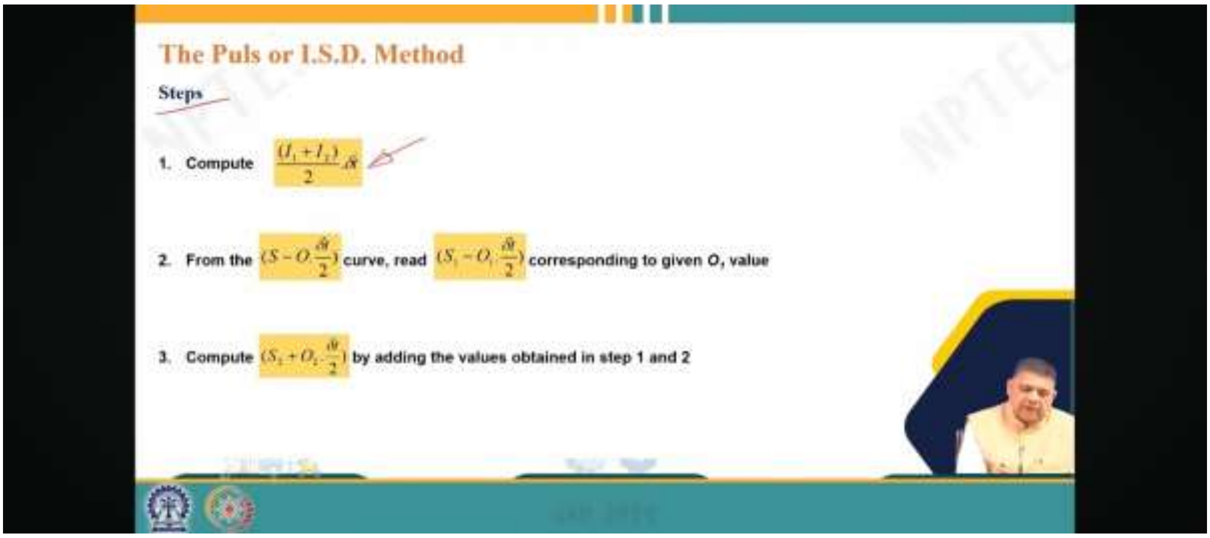
If you remember step-by-step method as $\frac{A_1 + I_2}{2\Delta T}$ like this we can write $\frac{O_1 + O_2}{2\Delta T}$ = $S_1 - S_2$. So, this was the form original mass balance equation form we saw, and this was also used in step-by-step method. But if you look it, the same equation is now written here. So, this component remains it is that inflow hydrograph which comes independently that remains as it is, but as far as inflow storage and outflow which are the dependent variables they are the suffixes 1 that is in the beginning of the time interval delta T they come on the left-hand side where in the suffixes 2 that is at the end of the time interval they move on the right-hand side.



So, basically it reads like $(I_1 + I_2)/2\Delta T + S_1 - O_1\,\Delta T/2 = S_2 + O_2\,\Delta T/2$. This is the form of equation which a pulse or ISD method uses. Routing is accomplished by substituting the known values in the equation to obtain $S_2+O_2\Delta T$, which is the right-hand side (RHS) of this equation. So, that means inflow plus outflow is known and initial time in values at the beginning of the interval we should know.

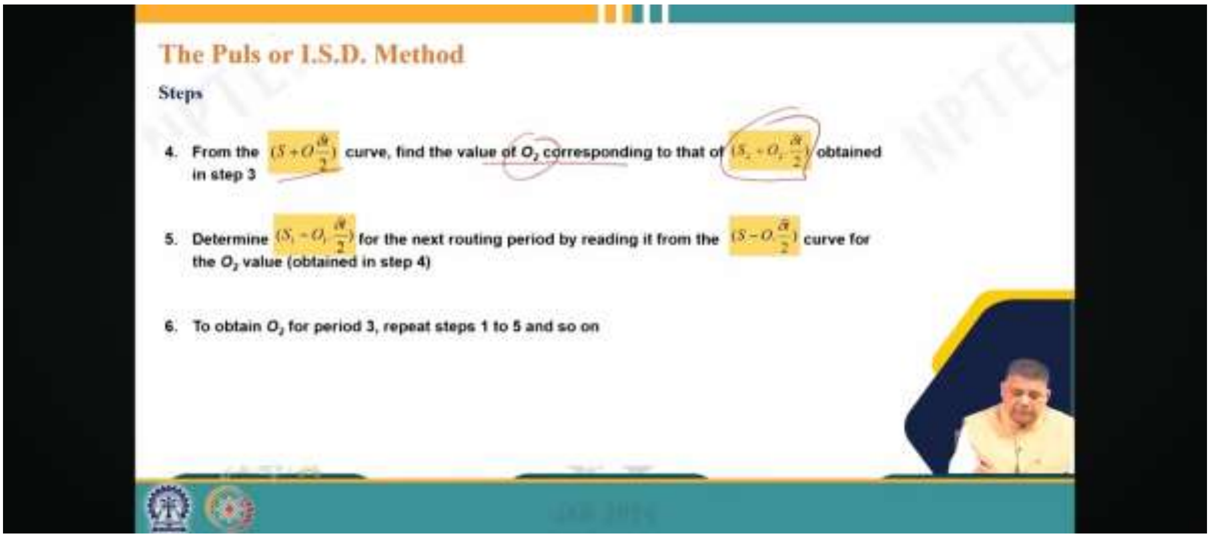
$O2O2$ is obtained from the relationship between O_2 and $S_2 + O_2\,\Delta T/2$ for the next step, and basically, we need to develop 2 curves here: O versus $S - O\Delta T/2$ and $S + O\,\Delta T/2S$. So, basically from the basic data as we said, that we require storage elevation and outflow elevation curves, an inflow hydrograph, and also the initial pre-flood level. These are the basic data which are required for reservoir routing, be it any method.

Basically, using that data, if you remember, in the step-by-step method, we simply developed 3 curves: inflow hydrograph, outflow hydrograph, outflow elevation, and storage elevation. But in this case, besides inflow hydrograph, we need to develop $S + O\Delta T/2$ curve and $S - O\Delta T/2$ curve. So, 2 curves we need to develop using S versus O versus outflow elevation because we have S versus elevation, O versus elevation. So, utilizing that, we have to develop these 2 curves in the particular method.



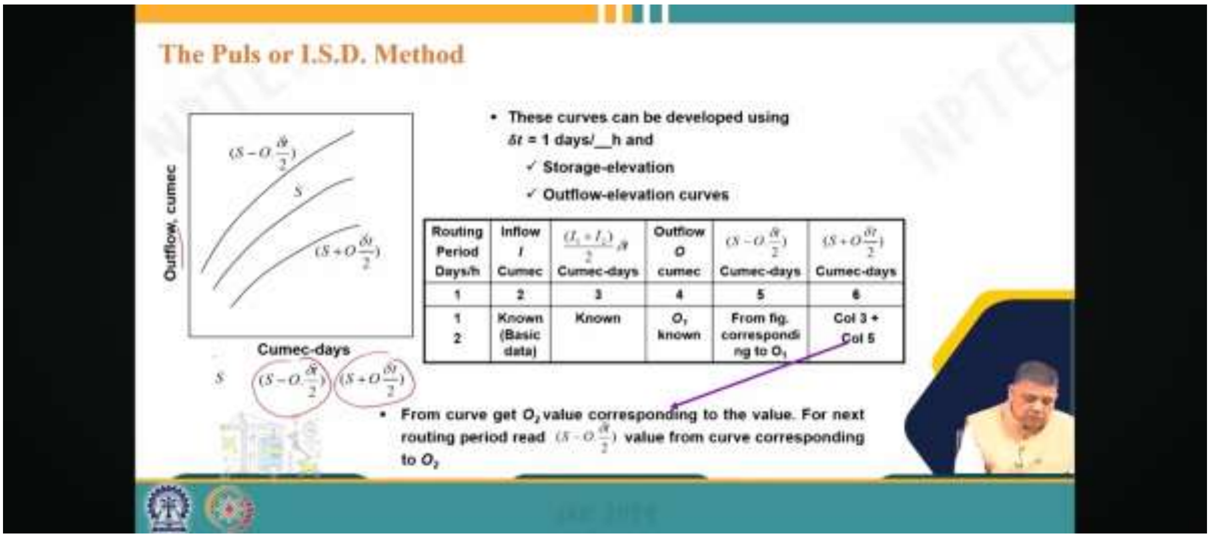
Certain assumptions behind this method are that reservoir water surface is horizontal, can be applied in reservoir streams.

So, that means, this assumption of a horizontal water surface in a reservoir is essential then outflow is a unique function of storage volume that we have already seen that we require the characteristic curves and outflow rate varies linearly with time. So, that means, that is a linear assumption we are making which is not really practical is not true. Then there are certain limitations also like it cannot be applied for streams with sharper gradients that is if gradient is more than 0.57 meter per kilometer then this method will fail and it is not suitable for river channel reaches with time-varying boundaries like tides, rapidly rising hydrographs, dam breaks, etcetera. So, sudden anything sudden if occurs in a stream then this method will not work.



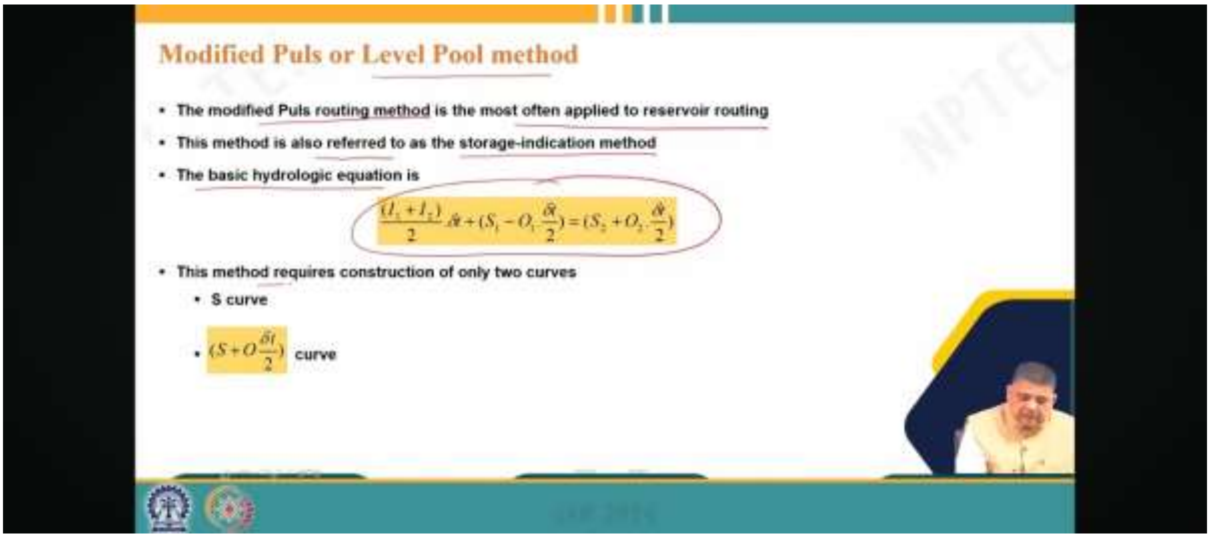
So, it only works for smooth flow conditions. Now, coming to methods of pulse or ISD method we first compute the $I_1 + I_2$ by 2 Δt. So, obviously, we know the inflow hydrograph and we choose Δt time intervals and then we compute this. Then from Os - O Δ 2 by curve we read S_1 - O_1 Δ2 by 2 corresponding to given O_1 value. Typically, the first value of outflow is known because the pre-flood elevation is known.

So, that means, we have pre-flood storage as well as pre-flood outflow, we know this value. So, O1 value is known. So, knowing O_1 we need to read SΔ1 + O_1 - O_1 + Δt by 2 values. As you remember these 2 form the left-hand side of equation. So, some of these will give us the S + O Δt by 2 that is S_2 + O_2 Δt by 2 that is at the end of the time interval.

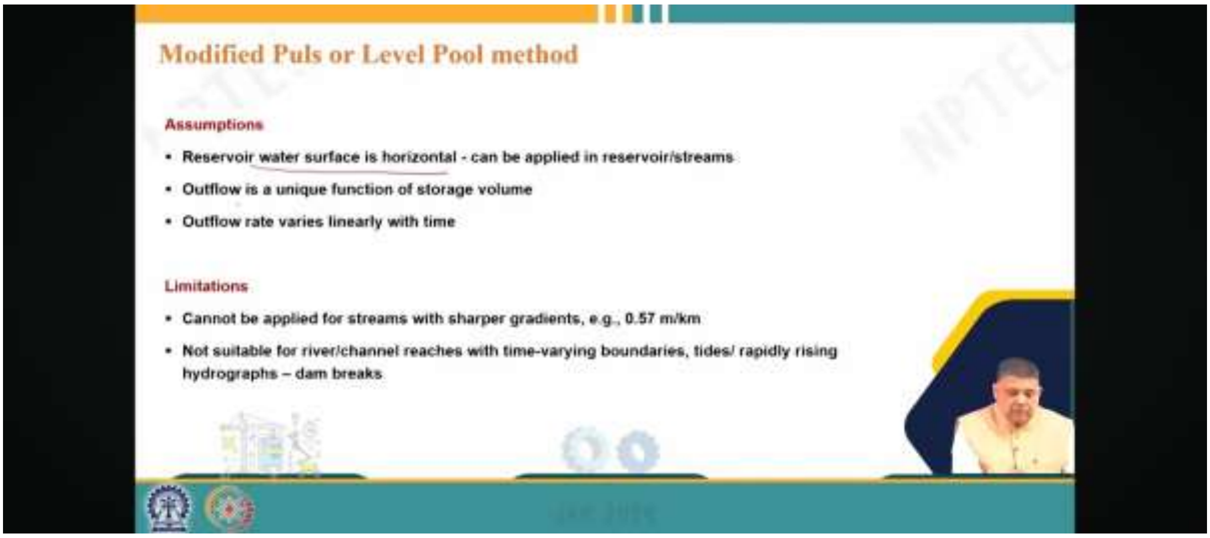


So, if we sum the values in step 1 and 2, we get this value. Then from S plus O delta 2 by 2 curve, we find the value of O_2 corresponding to the value we have calculated. So, we need to get O 2 value, and then once we know O_2 value for the next, that becomes O 1. Then we determine S 1 minus O 1 by Δ t 2 for corresponding to this O_2 and by reading from S curve. Then O_2 value is obtained, and they correspond to O 2 value. Then, of course, we continue this process. The sum of this plus inflow hydrograph will give S O_2 + O_2 by 2. Then we read another value, and so on. That is how this process gets repeated till we plot the outflow hydrograph till the routing is completed. These steps will also be clear when we take up an illustration or example. So, let's take an illustration, just a simple illustration. So, we need, as we discussed, to develop 2 additional curves here: S - O delta t by 2 and S + O + t by 2.

We already have S versus O curve because we know we have S versus elevation and we have outflow versus elevation; these 2 curves are available. So, using that outflow versus storage L curve, this curve is already known. So, now we need to develop these 2 curves, and for that, we obviously have to assume some value of delta t, and then, of course, we have to use the storage elevation outflow elevation curves. So, basically, once you have these values, S, O, and delta t, if it is known, then you can calculate S + O Δt by 2, S - O Δt by 2, and then you can develop this curve and plot. So, that is the requirement prerequisites before we enter the routing fridge.



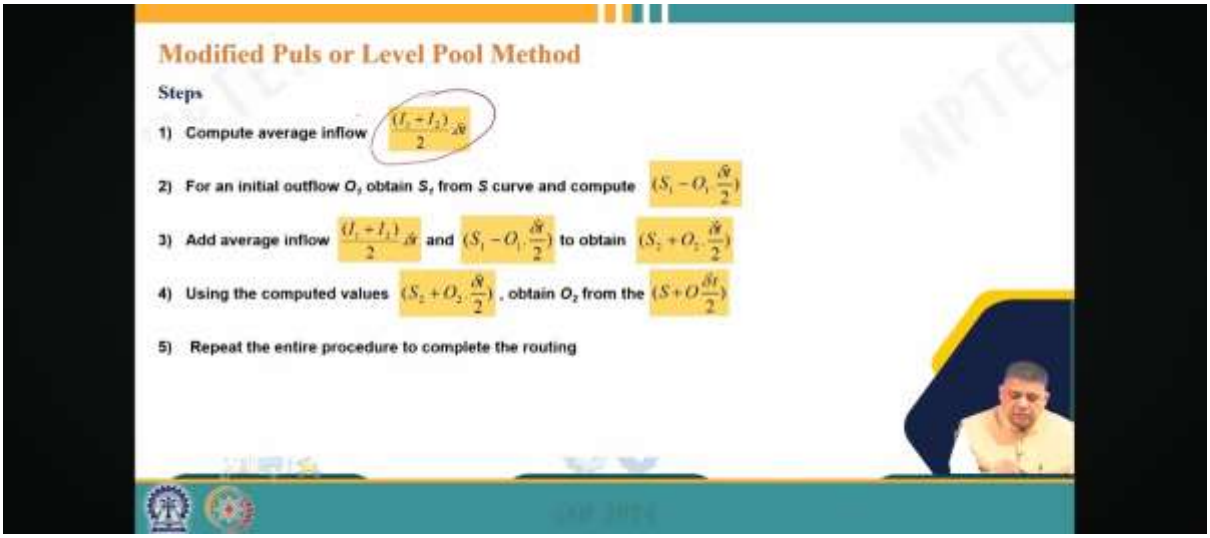
So, now, routing here routing period ah say days or hours. So, the first routing period. So, 1 2 3 and all these I value are known to us. So, that means, for every step $I_1 + I_2$ by 2 into Δt is known to us because we know the inflow hydrograph and we have assumed the delta t value. Now, coming to outflow the first value is known O_1 is known to us.



So, what we do is that ah from figure corresponding to O_1 we read S - O $\Delta 2$ value. So, suppose I have an O_1 value. So, O_1 is somewhere here let us say O_1. So, I will go and read this curve right and once I know this curve then the sum of ah this column 5 and sum of column 3 will give me S plus O delta 2 2 by 2 value. And once I know that from there here or here, I can read the O_2 value then O_2 this or suppose somewhere here O_2 value then I can these are this is just a hypothetical curve.

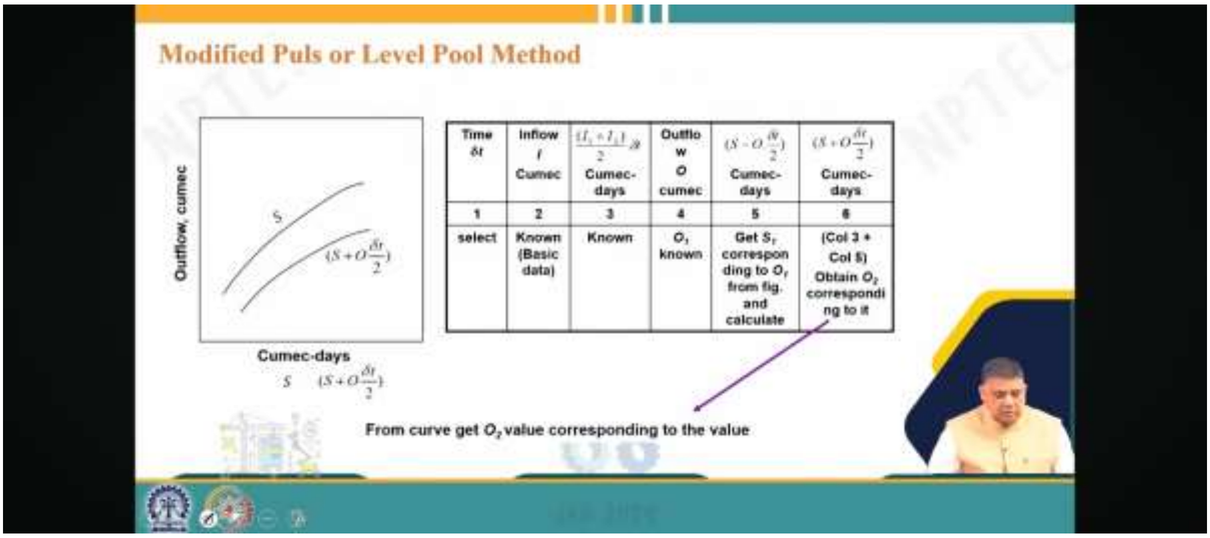
So, do not go by value. So, suppose I know here I can route this I can go to ah I can read this then sum and then on we can continue this process basically. So, the first value is known we need this curve to get this value sum of this and column 3 and column 5 will give S + O Δt value. Once I know S + O Δt value, I can read the outflow which is here and the form curve get O_2 value corresponding to value and the first routing period ah this value becomes this O_2 becomes O_1 and this becomes O_2 here becomes O_1 and then we read this value then sum of these two values of this and this process continues. And will a similar procedure will take we can take an example and it will be very clear to us.

Then we go to the modified pulse method. This modified pulse routing method is most often applied to reservoirs. It is also known as the lever plume method, one of the very popular methods used in flood routing or reservoir routing. It is also referred to by another name, storage as indication method. So, this has three different methods: modified pulse level, pool or storage indication method. So, all these methods mean the same thing. And the basic equation which is used here is the same as we use in the pulse method.



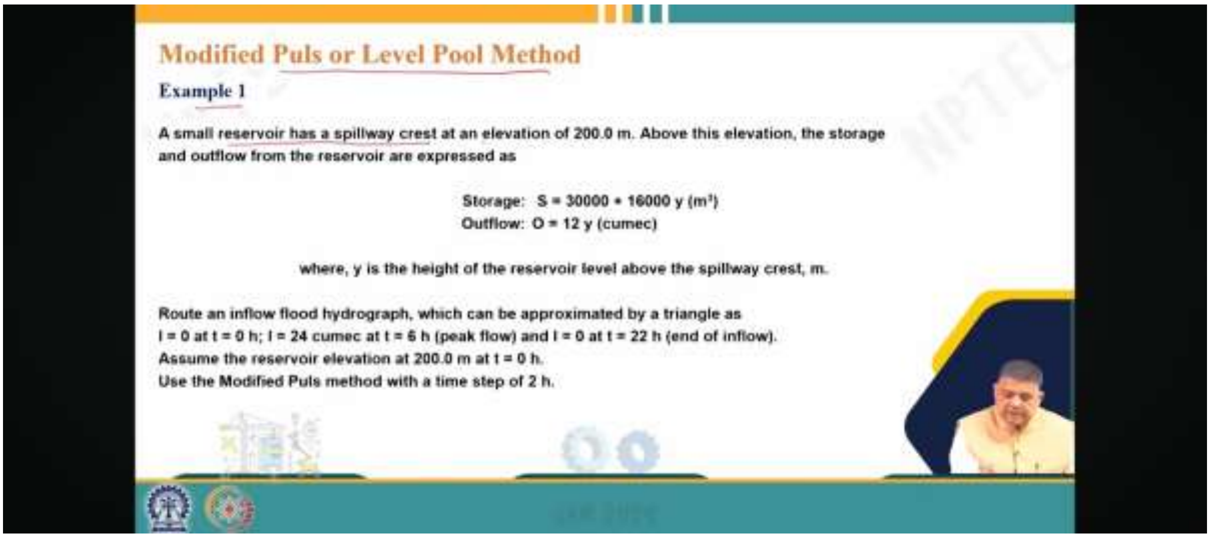
So, what is the modification? The modification is that this method requires the construction of only two curves: one is S curve, that is, S versus O, and the other one is O versus S plus O delta T by 2. So, remember in the pulse method, we developed three curves: S curve, S + O ΔT by 2 and S - O ΔT by 2. So, this flood curve is not developed in this particular method, and calculations are done using these two curves only. So, that is the modification in this method. So, assumptions remain more or less the same: that the reservoir water surface is horizontal, outflow is a unique function of outflow, and outflow rate varies linearly with time. Limitations also remain the same: that it cannot be applied for streams with sharper gradients and is not suitable for channel reaches with time-varying borders like tides or rapidly rising hydrographs, say in the case of dam breaks, etcetera.

So, that is the case we cannot use this method. And the steps remain more or less the same: that is, the $I_1 + I_2$ by 2 ΔT value is known, we know the initial values of O_1. So, obtain S_1 from the S curve. So, from here, from O versus S curve, we have two curves, remember O versus O S curve. So, once we know O_1, I can read S_1, and then I can compute this.

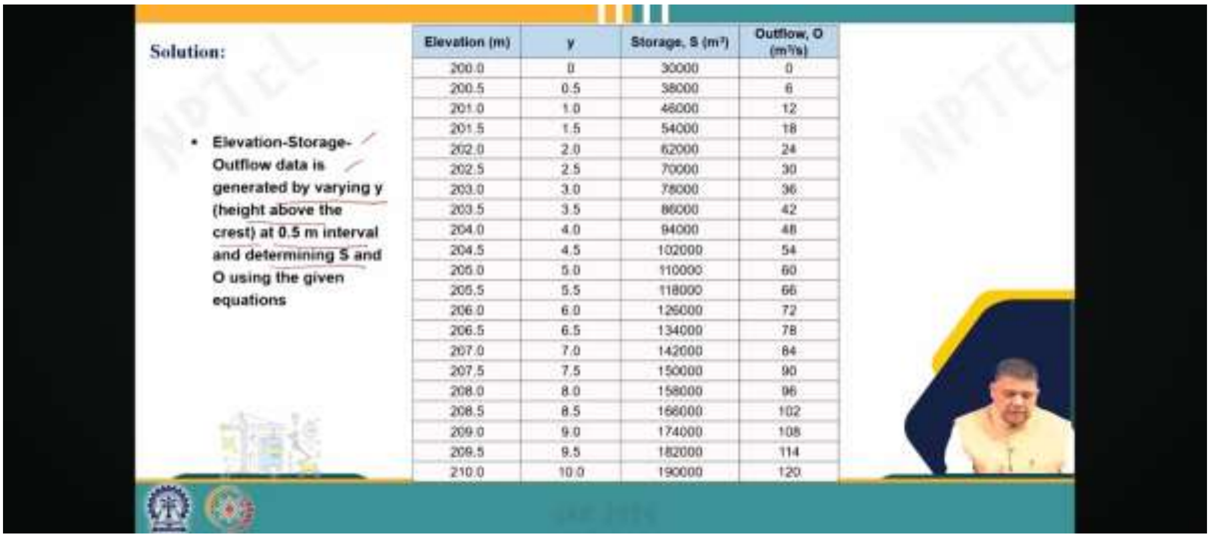


So, earlier we were reading this value. In pulse method, we are reading this value from the curve, but here we are computing this. So, that is the modification we do not develop this curve, but knowing O and knowing S we can compute this value. So, once we compute this value, we know this and this, that means left-hand side. So, we obtain the right-hand side from the right-hand side, we can correspond to this. We can write in O_2 and then once O_2 is known again I can get S value I can calculate S minus O_2 and then this process that procedure ah is till the complete repeated did the routing is accomplished. So, this is a modified pulse or method.

So, here we only develop two curves as you can see here. So, the time step is selected. This I this is known to us first value is known to us. So, get S_1 value. So, corresponding to O_1 we know we calculate S value we obtain here and this ah and then we calculate this. So, I know S I know ΔC.



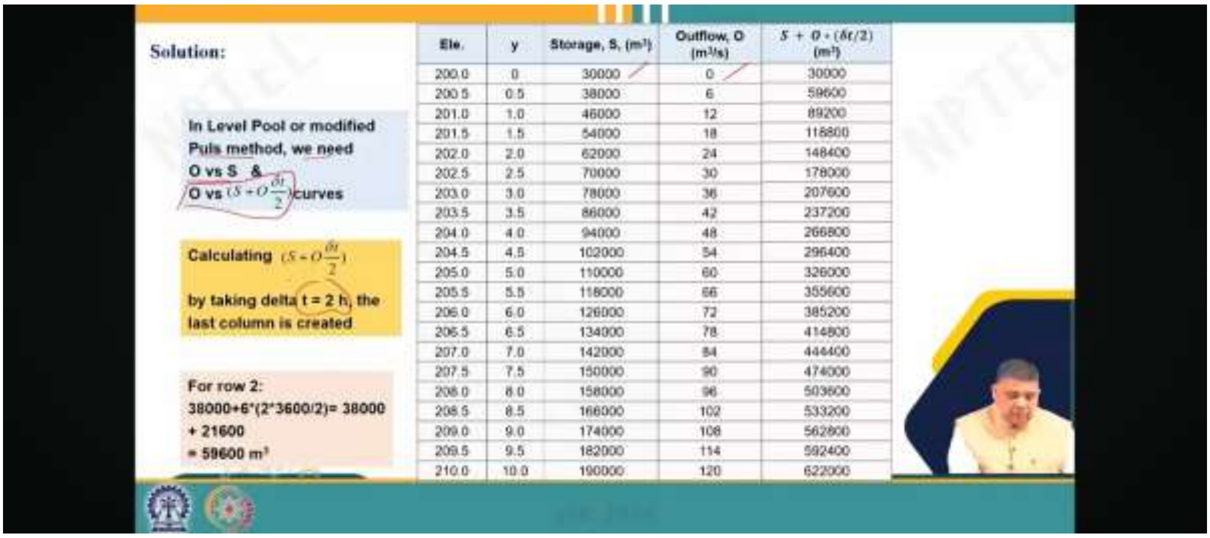
So, I can calculate ah this value and once I calculate this value this and this will give me column 6 column 3 plus 5 and then corresponding to this once I know S + O I do correspond to this I can find out the O_2 value which becomes ah the next step which becomes O_1 this O_2. So, he this becomes O_1 and this is how this process continues and then we finally plot the outflow hydrograph corresponding to the coming inflow. Let us take an example here and ah try to see. So, example 1 on modified pulse or level pull method a small reservoir has spillway crest at an elevation of 200 meters above this elevation the storage and outflow from the reservoir are expressed as storage that is storage is 30000 plus 16000 y in cubic meters and outflow is O equals to 12 y in cube x where I is the height of the reservoir level above the spillway crest which is the elevation of the crest is given. Route and inflow flood hydrograph which can be approximately by triangle edge I equal to 0 as t equal to 0 I equals to 24 q make at t equals to 6 hours that is a peak flow and I equal to 0 at t equal to 22 hours that is end flow and inflow.



Elevation (m)	y	Storage, S (m³)	Outflow, O (m³/s)
200.0	0	30000	0
200.5	0.5	38000	6
201.0	1.0	46000	12
201.5	1.5	54000	18
202.0	2.0	62000	24
202.5	2.5	70000	30
203.0	3.0	78000	36
203.5	3.5	86000	42
204.0	4.0	94000	48
204.5	4.5	102000	54
205.0	5.0	110000	60
205.5	5.5	118000	66
206.0	6.0	126000	72
206.5	6.5	134000	78
207.0	7.0	142000	84
207.5	7.5	150000	90
208.0	8.0	158000	96
208.5	8.5	166000	102
209.0	9.0	174000	108
209.5	9.5	182000	114
210.0	10.0	190000	120

Assume the reservoir elevation is 200 at time t equal to 0 hours. Use the modified pulse method with a time step of 2 hours. So, that means we have storage elevation outflow curve given, and of course, we also know the pre-flood pool level, this is given here, and we also have been given the delta t value. Most of the information is given for us to continue the routing. So, of course, we have elevation storage outflow data generated by varying y height above the crest in 0.5-meter intervals and determining S and O using the given equation.

So, we start with 200 y 0. Storage is from the equation we get, outflow from the equation we get, then we have a 0.5-meter length: 200.5, 201, 201.5, 202, and so on, we keep on changing the value.

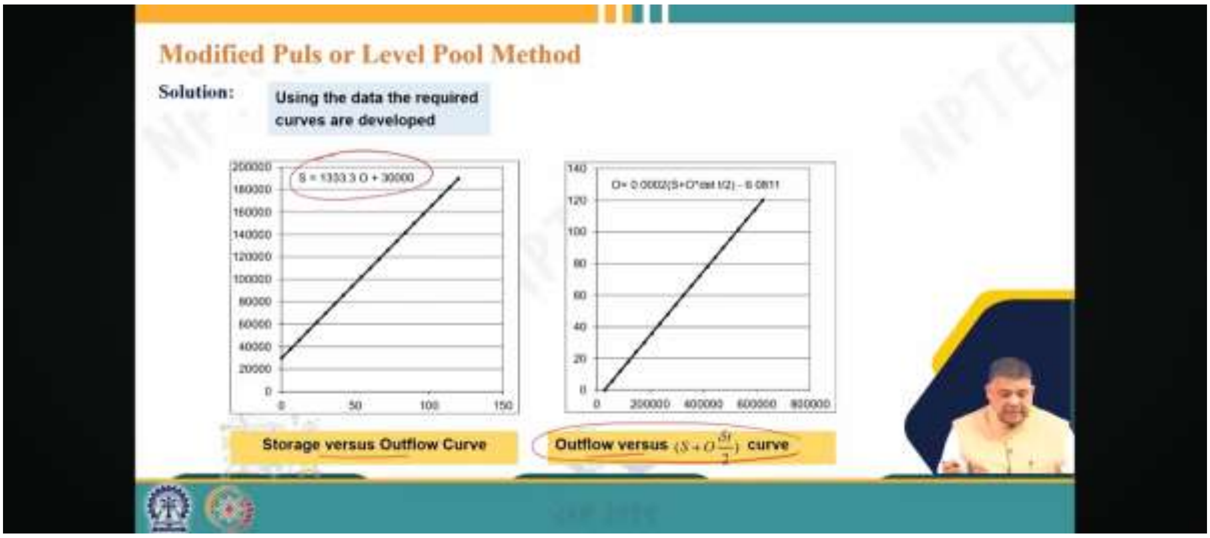


Ele.	y	Storage, S, (m³)	Outflow, O (m³/s)	$S + O\cdot(\delta t/2)$ (m³)
200.0	0	30000	0	30000
200.5	0.5	38000	6	59600
201.0	1.0	46000	12	89200
201.5	1.5	54000	18	118800
202.0	2.0	62000	24	148400
202.5	2.5	70000	30	178000
203.0	3.0	78000	36	207600
203.5	3.5	86000	42	237200
204.0	4.0	94000	48	266800
204.5	4.5	102000	54	296400
205.0	5.0	110000	60	326000
205.5	5.5	118000	66	355600
206.0	6.0	126000	72	385200
206.5	6.5	134000	78	414800
207.0	7.0	142000	84	444400
207.5	7.5	150000	90	474000
208.0	8.0	158000	96	503600
208.5	8.5	166000	102	533200
209.0	9.0	174000	108	562800
209.5	9.5	182000	114	592400
210.0	10.0	190000	120	622000

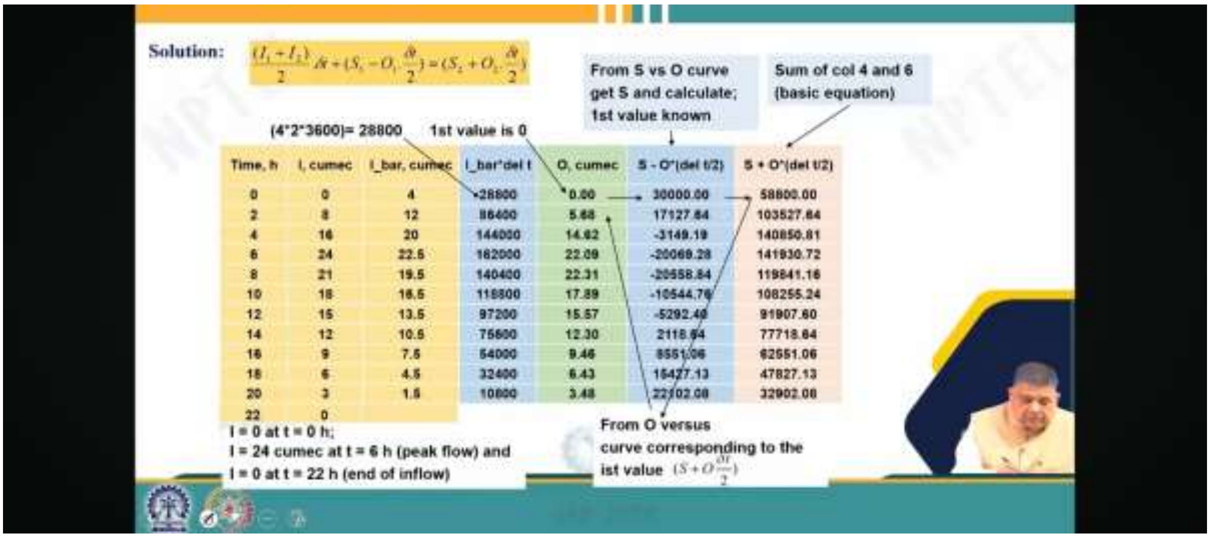
That means the value of y becomes 0.5, 1, 1.5, 2, 2.5 and so on, and then using the two relationships: 30000 plus 16000 y for storage and outflow is O equals to 12 y. So, using that, we can calculate this storage and outflow. Now in the lever pool method or modified pulse method, we need O versus S and O versus S plus O delta t, two curves, two curves are there.

So, obviously, the storage value is known to us outflow value is known to us already we calculated now we delta t also is given to us. So, we calculate S plus O delta t by 2 in this column. So, we know S we know O we know delta t we have taken. So, calculating the value. So, from here it will be 30000 no problem for row 2 that is this this value 59.

The calculations are shown here that is 38000 that is this value plus 6 that is ah that is the outflow value ah into 2 hours delta and then we delta 2-hour Δt is 2 then converting into seconds is 3600 multiplication and these two denominators is coming here. So, computing this we get 31000 plus 21600 the sum is 59600. So, this is value here. So, basically it is nothing, but simple calculation because we know S we know O we know delta t we can calculate and get this value. So, that is not a big calculation once we have this table pre-created for this particular problem then obviously, we can use the data we can plot the ah S versus outflow curve storage versus outflow and outflow versus ah versus O plus S plus O delta t by 2 curves.

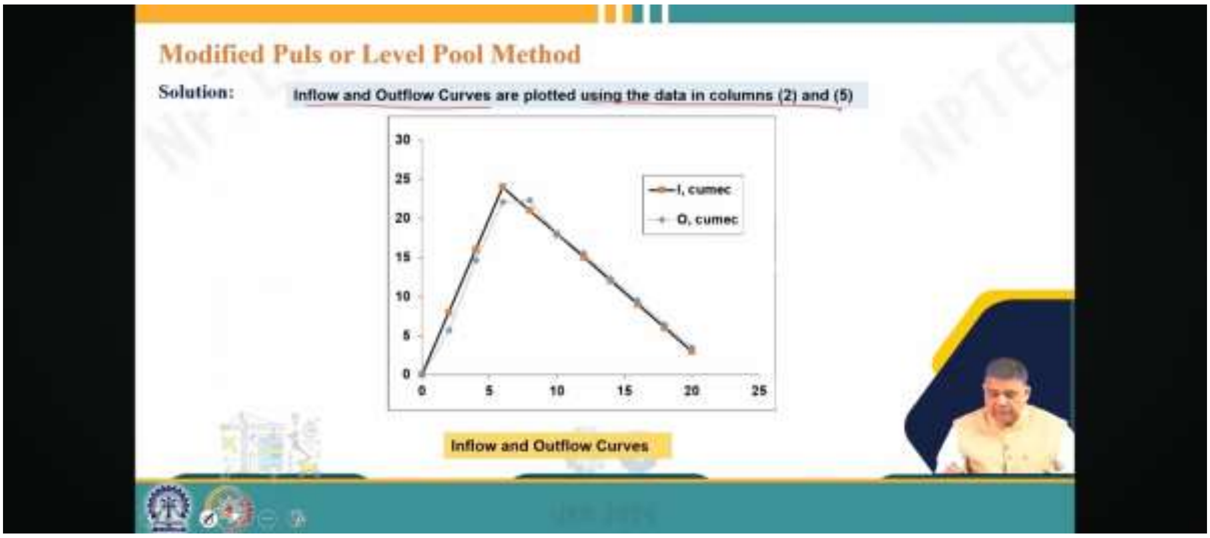


So, these two curves are there. So, I have developed a best fit line which is luckily comes out to be straight line not necessarily straight line, but this relationship because the relationships were given in such a way that we got the straight-line relationship for these curves also and these are the equations. So, now, I have flexibility that knowing O I can calculate use this equation to calculate S and also knowing ah S and O I can or O I can calculate the S + O Δt by 2 values also. So, using the because I have a relationship available with me otherwise, we can read the values from the curve that is not a problem. So, now, coming to routing table. So, this is the we have taken time 2 hours interval that is delta t as already mentioned the I values because we know that we have the triangular unit paragraph that I equal to 0 at 0 I equal to 24 at 6 hours.



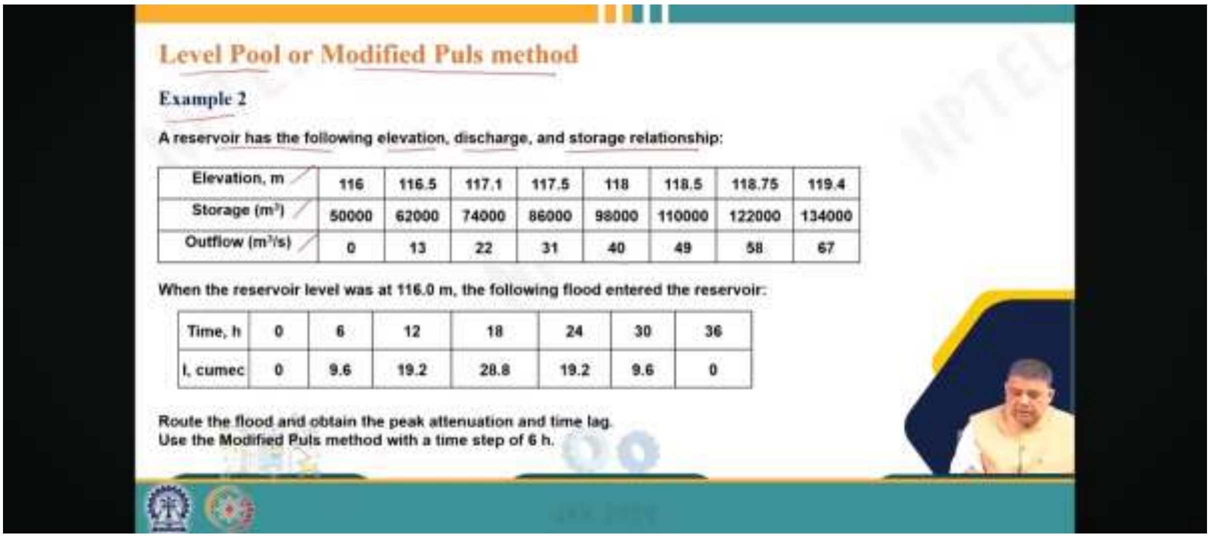
So, obviously, at 6 hours 24. So, obviously, at every hour 2 hours we know what the value is. So, at 8, 16, 24 then afterwards between 6 and 22 hours it becomes 0. So, we can find out the slope. So, 24 by 2 and then we can get the slope value.

So, it comes out with 21, 18, 15, 12, 9, 6, 3, 0. So, this is the inflow hydrograph and the I bar value that is I1 plus I2 by 2 that is 0 plus 8 is 4, 8 plus 16 is 12, 16 plus 24 is 20 and so on. So, I bar value we are calculating then of course, we have to calculate the I bar plus delta t that is this value that is here this column. So, this is I bar value already we have calculated delta t is 2 hours and of course, we have to convert into seconds. So, that is how we get 28800.



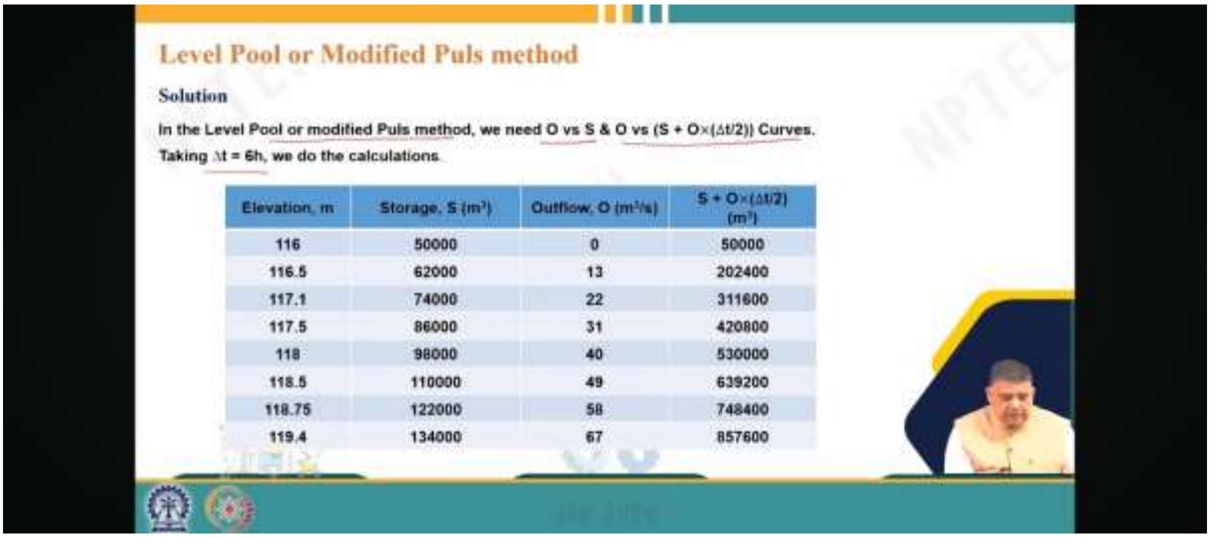
So, this is the value we get in cubic meters. So, because it is cubic and then we are multiplying with time. So, cubic meters we are getting this value. So, that value for different time we can calculate. Then the first value is 0 because from the beginning it is already mentioned that it is 0, and then from here once we know outflow equal to I can calculate this value from S versus O curve get S and calculate the first value. So, from O versus S curve I can get the value of S and then O .

So, this will remain 0. So, this comes out to be 30000 and this plus dill will give me the sum will be 58000 sum of column 4 and column 6 from the basic equation that is here will give me ah this value. Now, from this curve O versus corresponding O S plus O delta 2 curve I can get the outflow value which comes out to be 5.68 as I said that we can read the curve or we have the developed equation. So, I can find out the ah outflow value and once I have the outflow value then I can O plus S versus O curve I can get the value of storage and then I can calculate this and then sum of this and this will give me this then I can get a next value of outflow and so on so forth. So, I can keep on getting the values from here and ah thus I can ah complete the so here.



So, I can then finally, I can complete the routing and then I can plot inflow and outflow curves using the data in column 2 and 5 that is column 2 and 5 are 2 is ah this one that is inflow and then outflow is this one. So, inflow and outflow value I can plot and as you can see that ah inflow and outflow curves are plotted. So, as you can see that what is the attenuation and what is the time lag all those things can be found out once we have plotted the inflow and outflow curves. So, this is ah the ah that is what our interest is basically in this particular method. Now, we take another example on the same method is level pool or modified pulse method example 2 the Azure reservoir has the following elevation discharge and storage relationship.

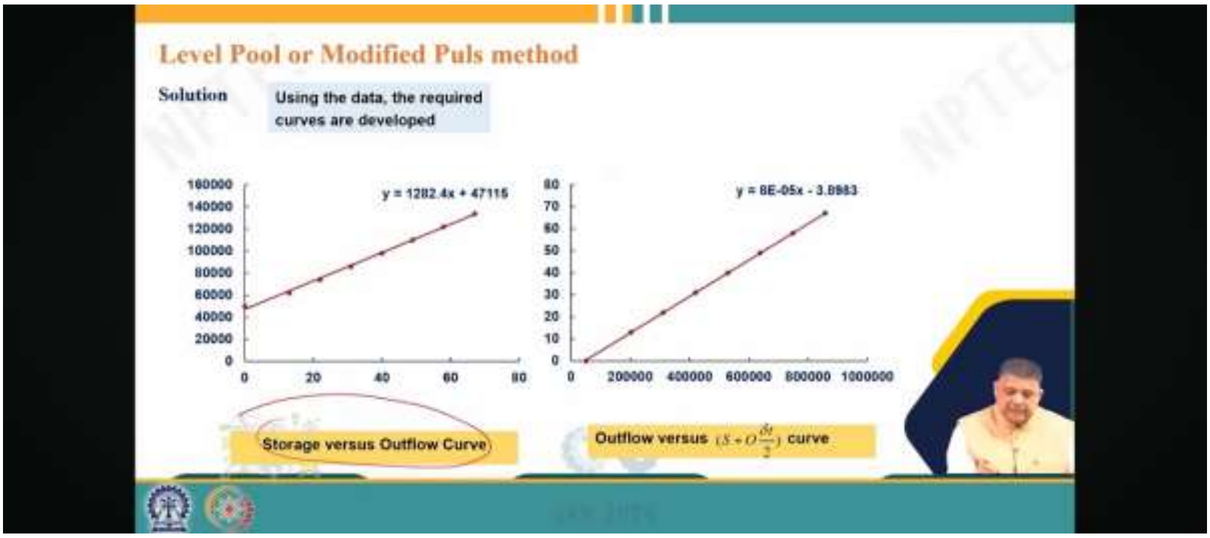
So, here we have elevation storage and outflow values are given here. So, elevation start from 116 goes up to 190.4 storage starts from 50000 and goes up to 134000 outflows 0 in the beginning it is 116-meter elevation and becomes 167 at highest elevation. When the reservoir level was 116 that means, in the beginning the following flood entered the reservoir.



So, that is the inflow hydrograph. So, at different 6-hour intervals we have inflow hydrograph coordinates, ordinates are given. Route the flood and obtain the peak attenuation and time lag using the modified pulse method with a time step of 6 hours. So, that means the method is specified and the time step is also specified in this problem. Otherwise also we would have taken 6 hours because the ordinates are given in 6-hour intervals.

So, we should not miss the peak. So, with that intention, we will continue with this. So, that we will not miss the peak or we will take the intermediate sub-values there is 3 hours can also be taken if you want a very final resolution routing. So, in the level pool method or modified pulse method we need o versus s and o versus s plus o delta t by 2 curves. Delta t is given as 6 hours. So, we need the calculations; elevation is given, storage is given, outflow is given, we need to calculate this value.

Initially, outflow is 0. So, at the initial elevation, s plus o delta t by 2 is also 0, but later on, we have different values and then we can calculate this value. Delta t is known to us and the only thing you have to remember is it is in cubic meter. So, you have to take care of the units, meter cube per second times second only will give you. So, obviously, delta t in hours. So, we have to multiply by second. So, that point has to be remembered, but otherwise calculations are pretty simple.

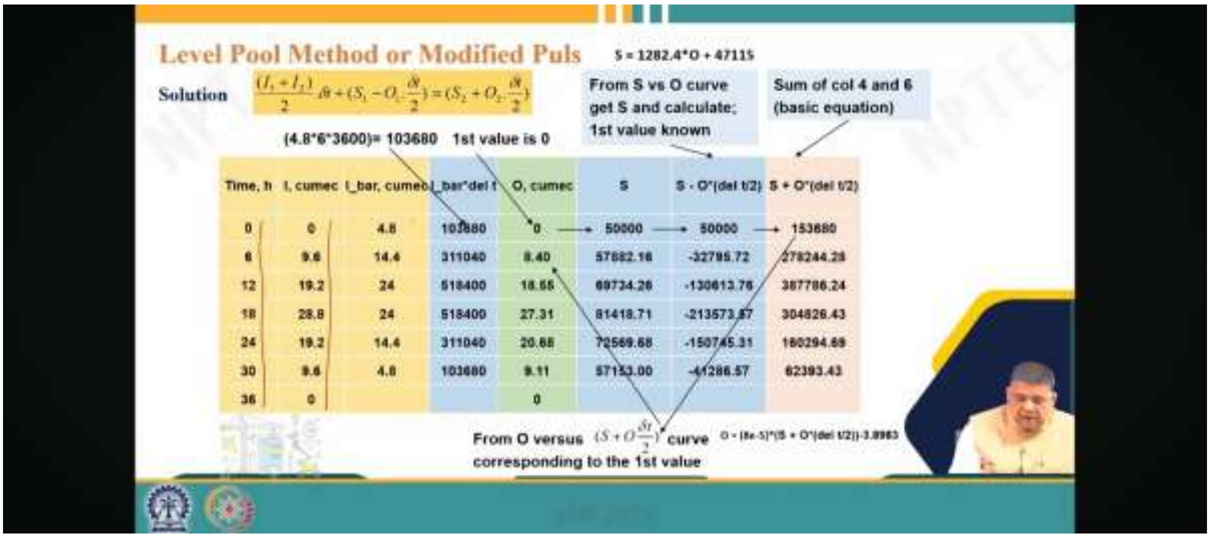


So, we have all the data available, and then we can use the data to develop the required curve. So, storage versus outflow curve, here also we are getting a straight-line relationship, and I have developed a straight-line relationship here. Then outflow versus s plus o Δt by 2 and I have also developed relationships here. So, I find if I have any particular value of x. This is a straight-line relationship. I can get the dependent variable value also straight away using the equation instead of reading the curve, and that flexibility is because I have used Excel for this particular purpose. Now coming to calculations, we can continue the calculation.

So, here the time 0 6 12 18 30 36 that is given, and inflow values are also given here. So, I bar we know I bar is nothing but the average of this, the average of this and the average of this.

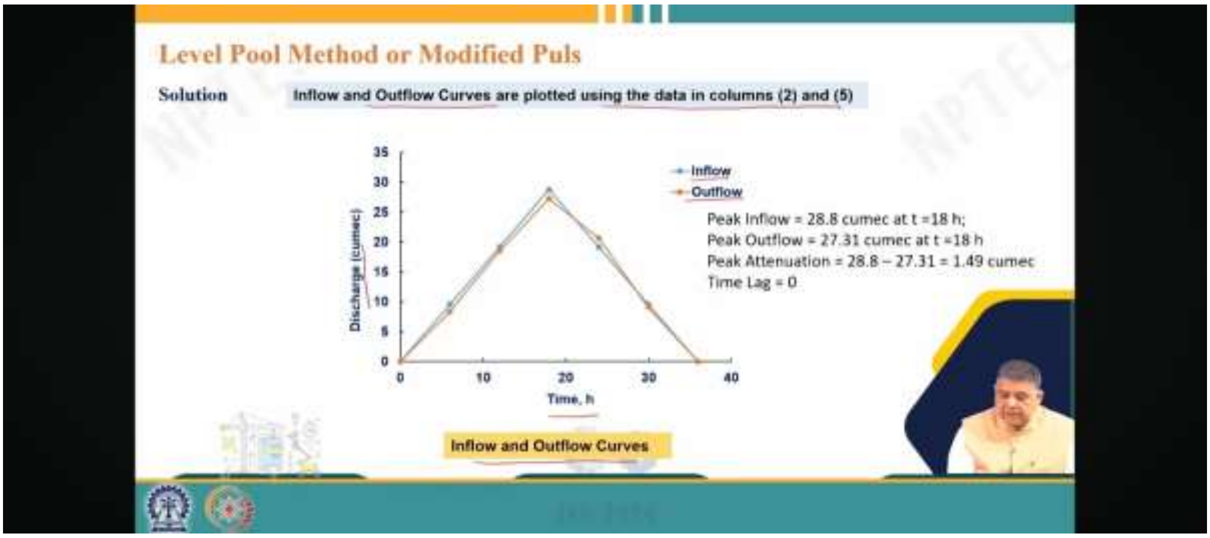
So, the average of the last 2 values is 4.8, 19.2 plus 9.6 is 14.4, and so on. This calculation is very simple, and then we want to calculate the I bar times delta t. So, I bar because I bar is I half we have already taken care of. So, this value is this column, and we have to multiply with delta t. Δt is 6 into 3600.

So, 4.86 into 3600 gives us a value of 13,680. This value is calculated here. So, this value we can easily calculate because we know I bar values and we know Δt value. So, we can calculate this irrespective. This is the inflow. Then the outflow, coming to outflow, the first value is given to us, that is O is first. O is known to us. Now, what we will do in this method from S versus O curve, we get S + S and calculate the first value.



So, S minus O Δt by 2. So, from O versus S curve we have to calculate ah this S or read this S and already we know that initially the ah the outflow was 0 and it was 50000. So, that is why ah S minus O delta t by 2 also remains 50000 because O is 0 so that means, this value we have calculated. Now, the sum of H bar left-hand side of the equation sums of ah this I bar delta t and S minus O delta t by 2 that will give us S plus O delta t by 2 that is this one. So, the sum of column 4 and 6 H bar basic equation will give us this particular column. So, this plus this is this now we use this particular value and use the O versus S plus O delta t by 2 curve we have already developed the relationship as I mentioned that is O is 8.8 E 5 S O plus delta t by 2 minus 3.8983 that is the equation ah we developed here you see here this equation. So, that equation we know. So, once I know S plus O delta t by 2 values, I can put this value in this equation and get the value of O and that value comes out to be 8.4 and this 8.4 is nothing, but the O value O_1 value for the next time step. So, corresponding to this O will go into the curve or use the relationship and get this storage value because we also have a storage versus outflow relationship developed. So, using this relationship we can calculate the storage value. So, once I know the storage I can calculate this value because I know S I know I have already chosen delta t value. So, this value I have to calculate outside and once I have calculated this sum of this and this that is $I_1 + I_2$ by 2 Δt and sum of plus S minus O Δt by 2 will give me right-hand side that is the sum of the value of S plus O delta t by 2 this value. Now, corresponding to this I will go once again into this relationship get the value of O which is 18.55 then from here, I will again read this I will calculate this sum of these and this will give me this I will again use this. So, this is an iterative procedure I can keep on doing right. So, unless and until the routing is completed, I can continue this process and then get all the values. So, my interest later on is in inflow and outflow inflow was already known to us the outflow value that is what we have calculated that is what we need to know and then I can plot inflow versus outflow.

So, inflow and outflow are plotted here. Inflow and outflow curves are plotted using the data in columns 2 and 5. This charge versus time, inflow and outflow curves are plotted; blue colour shows inflow, pink-orange colour shows outflow. The peak outflow is 28.8 cumec at t equals 18 hours, which we can read from the table. Also, the peak outflow is 27.31 cumec at t equals 18 hours. So, the peak attenuation that is the difference in the peaks is inflow minus outflow.



So, 28.8 - 27.31 comes out to be 1.49 cumec. Their peak attenuation is 1.49 cumec, but the time lag is 0 because both the peaks of inflow and outflow are occurring at the same time. And of course, it is happening because it is a mathematical problem. So, it is not really a practical problem. Typically, if it is a practical problem, then we know that this outflow will cross this inflow value and there will be not only attenuation but also a time lag between the two peaks. So, this will be the lag here, and this attenuation will be here. But this is a mathematical problem. So, we only got peak attenuation and no time lag. Typically, in a practical problem, we will get both lag and attenuation because that is the impact of reservoir on a flood entering the reservoir. That is what happens.

This is how we accomplish the reservoir routing. In the previous class, we saw a step-by-step method. In this method, we read two methods: a pulse method and a modified pulse method, and we solve the problems using the modified pulse method. But the pulse method also works in a similar fashion. The only thing we have to do is to develop another additional curve which we do calculations S - O ΔT by 2 calculations in this particular method.

So, with this we come to the end of this lecture and ah I hope ah you will practice the problems and you will get to understand the steps ah clearly, and in case of any doubt, please ah encourage questions. We will be happy to answer.

Thank you very much.