Course Name: Watershed Hydrology

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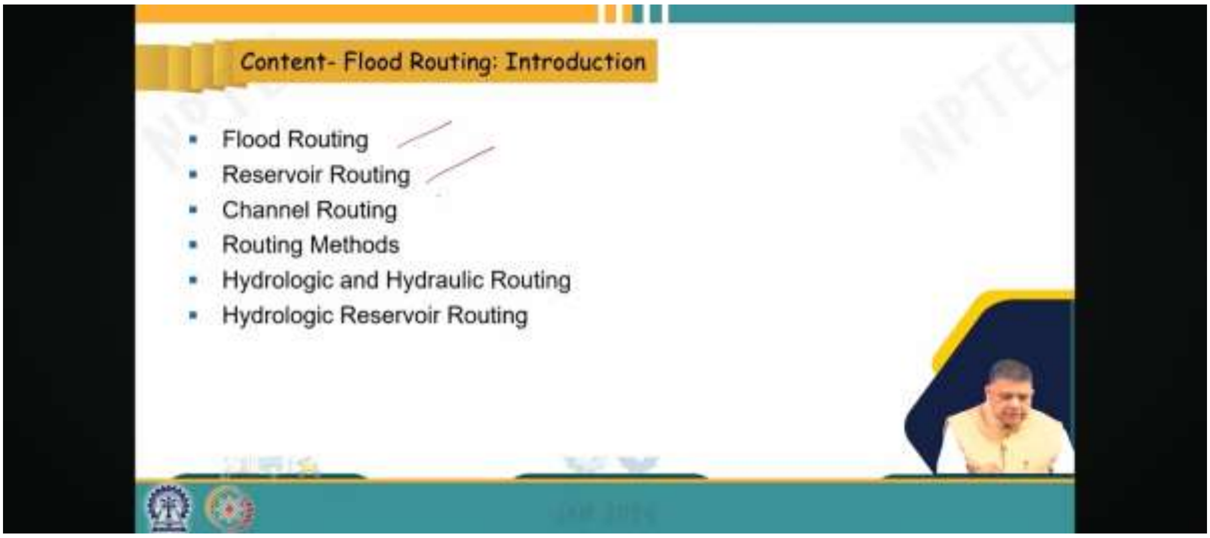
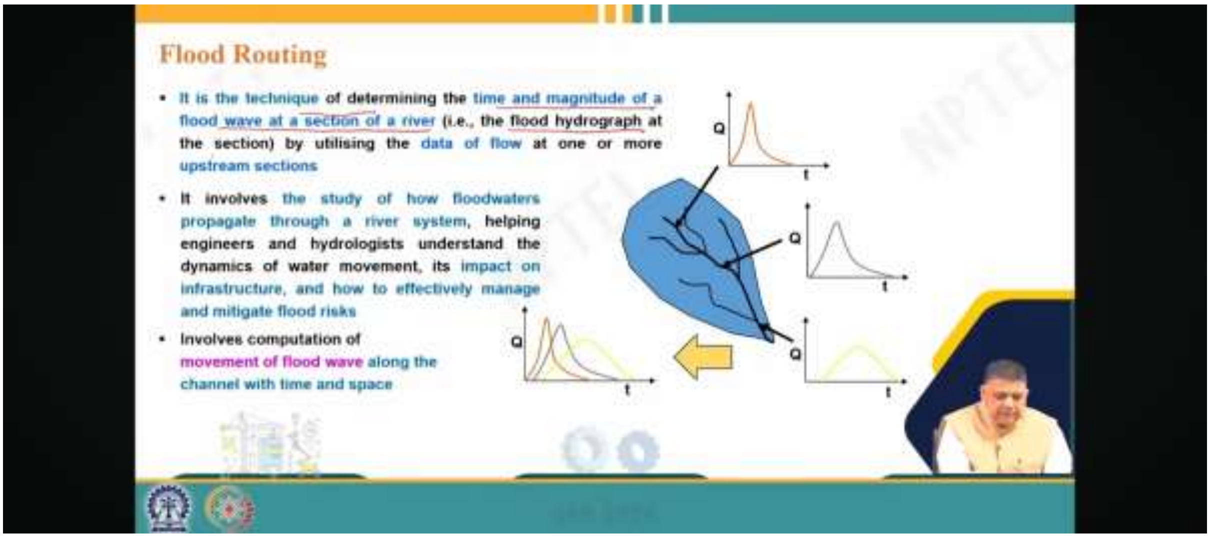
Week: 10

Lecture 46: Flood Routing: Introduction

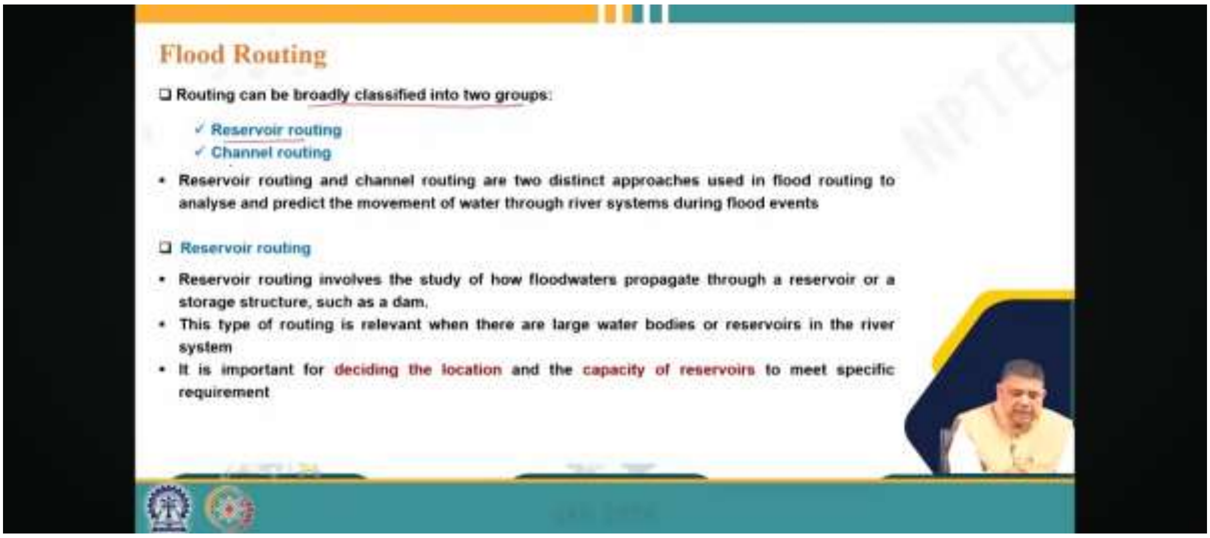
Hello friends, welcome back to this online certification course on flood and watershed hydrology. I am Rajendra Singh, professor in the Department of Agriculture and Food Engineering at the Indian Institute of Technology Kharagpur. We are beginning Module 10 today; this is Lecture number 1 on the topic of flood routing and we will be introducing the topic today. This lecture will include an introduction to flood routing, reservoir routing, and channel routing. We will introduce routing methods, talk about hydrologic and hydraulic routing, and lastly hydrologic reservoir routing.



Now, beginning with flood routing, it is the technique of determining the time and magnitude of a flood wave at the intersection of a river, basically the flood hydrograph at the section by utilizing the flow data at one or more upstream sections. So, basically, that means if we are interested in getting a flood hydrograph and the time and magnitude of fluid at a particular point, then if we utilize the data at any upstream point, for example, if we have a gaging site and a flood hydrograph available, then using this flood hydrograph, we can determine the shape and size of the hydrograph at this particular point, which is nothing but flood routing. That means determining the time and magnitude of a flood hydrograph at any desired section by utilizing the data of one or more upstream sections. So, there could be more than one upstream section and based on that, we can determine what will be happening to the hydrograph at this point and finally at the point of interest.

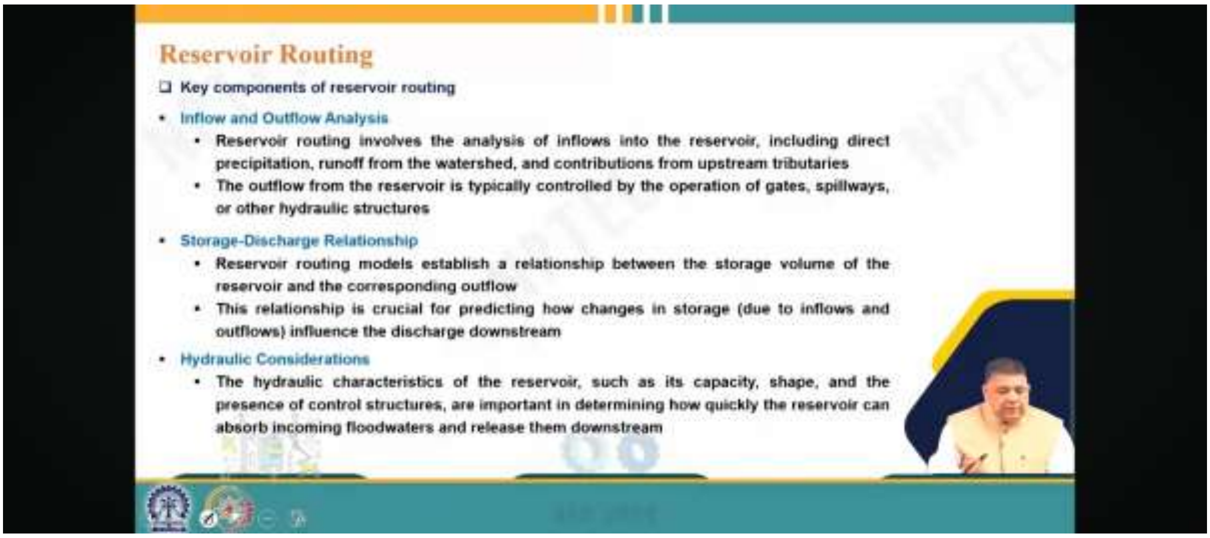


So, it involves the study of how flood waters propagate through a river system, helping engineers and hydrologists understand the dynamics of water movement, its impact on infrastructure, and how to effectively manage and mitigate flood risk. So, basically, if you know the flood hydrograph at any upstream section, then you can determine the shape and size of the hydrograph at this particular section. Let us say, for example, if you can find out at this particular section. Then basically, we know how the flood water is moving along this particular stream and of course, we can understand how water is moving, at what pace it is moving, how it is changing, how the velocity and depth of the hydrograph are changing, how the flow is changing and what will be its impact if there is any infrastructure, how it will be impacted, and obviously, it helps us in managing and mitigating flood risk if at all that is there. So, it basically involves computation of the movement of flood wave along the channel with time and space. That is how we study the movement of the flood water along the stream and that is how we come to know, with time and space, how the hydrograph will change. And of course, as you can see, we started here at this particular section with this, then when in the intermediate section, we got this hydrograph and at this point, we got a different hydrograph.

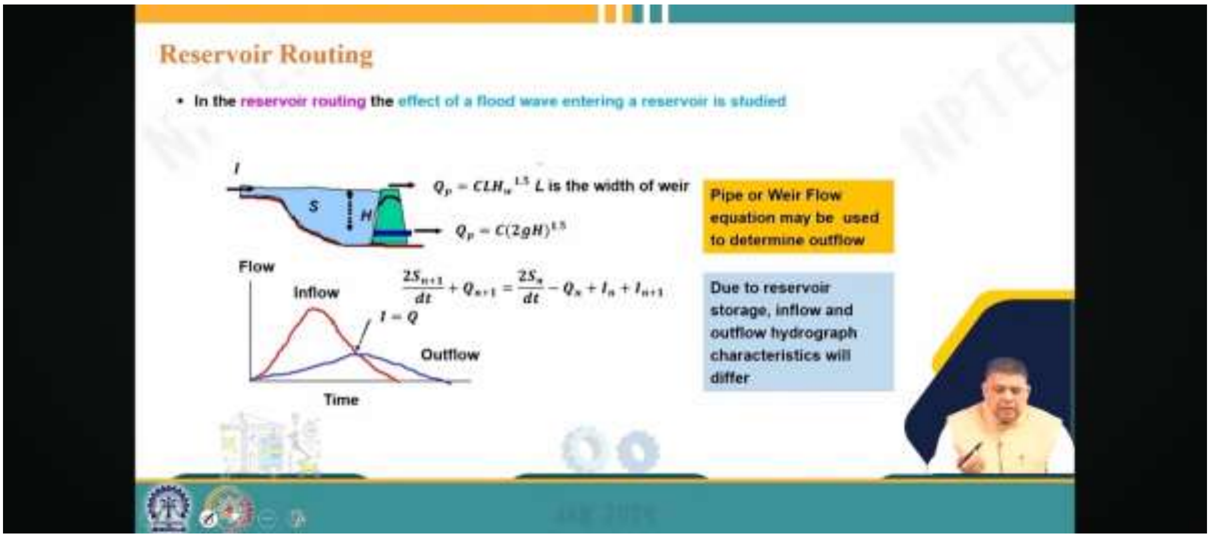


So, we really know how the peak is reduced and how much time lag there is in the peak hydrograph from the upstream section to the downstream section, and of course, we can also find out the knowing the cross-section, knowing the discharge we can also find what the velocity of fluid is in a particular section, that is what flood routing is all about. Now, routing can be broadly classified into two groups: reservoir routing and channel routing. So, reservoir routing and channel routing are two distinct approaches used in flood routing to analyse and predict the movement of water in the river system during flood events. So, basically, two different approaches can be adopted depending on what our interest is whether we have a reservoir or a storage structure like a reservoir then what will happen to that structure we can analyse or what will happen to the flow if only the stream is there how the flood hydrograph propagates or moves that could be another aspect. If we talk about reservoir routing, the first one then it involves the study of how flood waters propagate through a reservoir or a storage structure such as a dam.

So, that simply means that if flow is moving and if a reservoir is there then what will happen how what will the impact of this coming flood water which is coming from upstream how it will impact the reservoir or the dam that is what we analyse in reservoir routing. And this type of routing is relevant when there are large water bodies or reservoirs in the river system. So, if in a river system we have, for example, you have a large basin where you have a river stream coming, they are different root trees and then in between somewhere a dam is constructed. So, if a dam is constructed that means there will be a reservoir. So, obviously, if we know the flood hydrograph at this point and some flow flood wave of interest is coming then what will happen to the structure the reservoir or the dam that is what study is studies under reservoir routing.

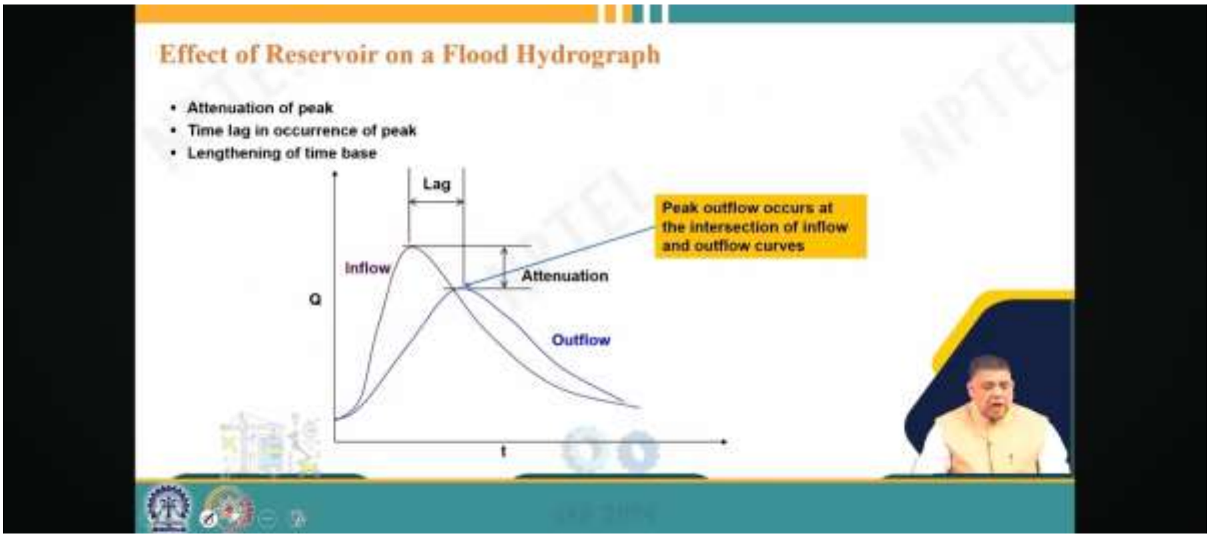


It is important for deciding the location and capacity of reservoirs to meet specific requirements. So, obviously, if you do not have a dam or reservoir and if you want to construct one, then obviously, this type of routing will help you find out what is the ideal location of the reserve dam or reservoir within the basin and what should be the capacity of the reservoir or what should be the height of the dam or what should be the capacity of the spillway through which the water will be released across the dam. So, all these decisions can be made and if already existing structure is there then what happens to the storage and outflow characteristics that are studied under reservoir routing. Now, if you talk about the reservoir routing itself within that, then there are certain key components of reservoir routing. That is one is the inflow and outflow analysis. So, reservoir routing involves the analysis of inflows into the reservoir including direct precipitation runoff from the watershed and contribution from upstream tributaries and the outflow from the reservoir is typically controlled by operation of gates or spillways or other hydraulic structures.



So, basically, obviously, as I said that if you have a dam constructed across a stream here and a reservoir is there then of course, this particular catchment will be having not only the flow from this stream but will also from the overland flow from these adjoining areas that will be contributing. So, that and of course, the direct rainfall if the reservoir capacity reservoir spread area water spread area is like that then of course, some rainfall will be falling directly on that surface. So, all these will constitute the inflow and of course, the outflow obviously is regulated through any such structure, a dam by there are gates or spillways through which these outflows are regulated. So, that is why you have a typical inflow and outflow analysis can be done. Then of course, there is a storage discharge relationship.

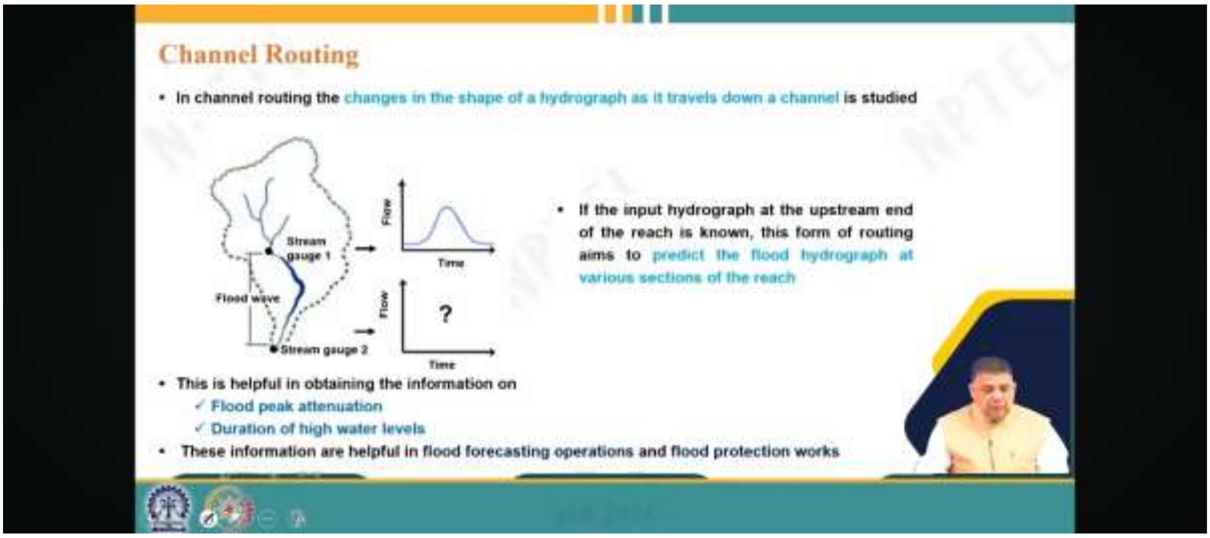
So, recharge reservoir routing models establish a relationship between the storage volume of the reservoir and the corresponding outflow, and this relationship is crucial for predicting how changes in the storage, inflows, and outflows influence the discharge downstream. So, obviously, if you have a discharge versus storage relationship, you know when inflow is coming, storage will be affected, and if your gates are being operated, outflow will be affected. So, obviously, there will be interrelations between storage and outflow, and that can be analysed through reservoir routing. Then there are certain hydraulic considerations, like the hydraulic characteristics of the reservoir such as the shape and the presence of control structures, that are important in determining how quickly the reservoir can absorb incoming floodwaters and release them downstream.



So, obviously, you have to know all the characteristics of the reservoir and also of the outflow structures which are there in order to be able to route the flow through this particular reservoir. Now, in the typical case, we have already discussed in reservoir routing, the effect of the flood wave entering a reservoir is studied. So, obviously, when the flood wave enters a reservoir, then of course, there are two things which are there; one is storage, of course, in the reservoir and, of course, the hydraulic head. And, of course, this hydraulic head is responsible for outflow through the downstream section, and that depends on whether a pipe or weir are there. Depending upon the nature of the structure, pipe or weir flow equations may be used to determine outflow. So, obviously, if a weir is there, then the equation could be like this, or if it is only a pipe, then the equation could be like this. So, depending upon what kind of structure you have, based on that, you can decide the, you can determine the outflow and of course, that will be governed by the elevation, the water surface elevation in the reservoir, and of course, the storage in the reservoir.

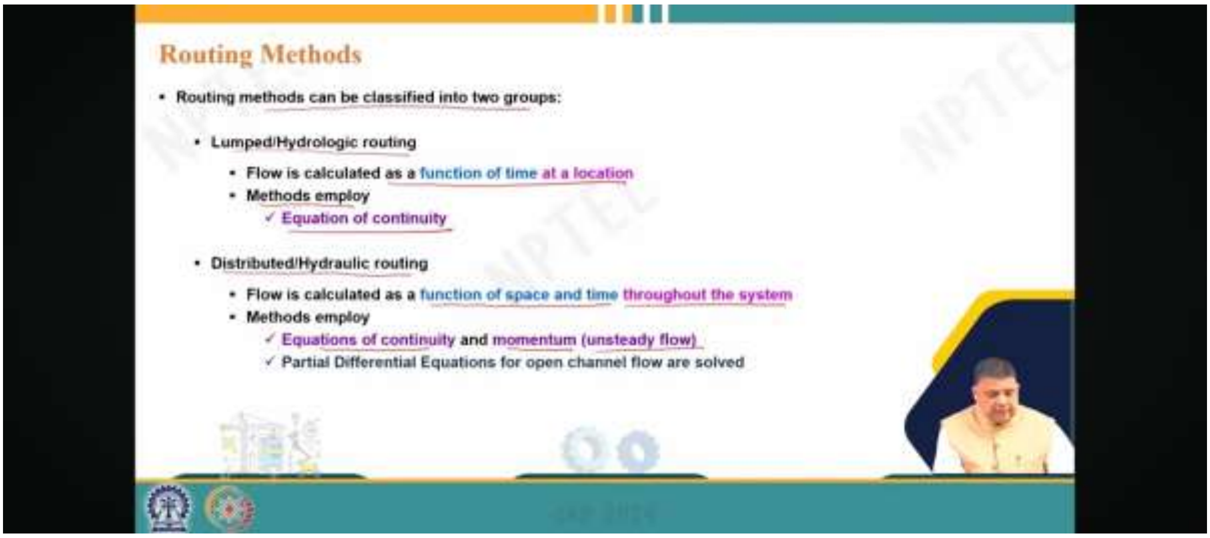
So, due to reservoir storage, inflow and outflow hydrograph characteristics will be first. So, obviously, when a typical hydrograph enters the. So, this is the inflow hydrograph, red colour. So, that when a typical hydrograph enters the reservoir because there is storage and there is control outflow. So, obviously, the outflow hydrograph, which is here, the outflow and blue colour, will be definitely different than the inflow hydrograph and all these are governed through the equations because you have inflow, outflow and storage change is also taking place.

So, obviously, depending upon the type of, I will discuss that type of routing. We have different kinds of formulation which you can use and of course at this particular junction where the inflow hydrograph and outflow hydrograph cross each other, at that point inflow is equal to outflow. So, this portion basically shows the storage and this portion shows the discharge from the storage. So, this is the changes. So, this is stored discharge from storage and this is the storage buildup because of inflow being higher than the outflow. Now, coming to the effect of the reservoir on a flood hydrograph, if we talk about the effect of flood on a flood hydrograph then there are three different things what could happen: one is attenuation of peak, then time lag in occurrence of peak and lengthening of the time base.



So, as you can see here, this is a typical inflow hydrograph, this is a typical hydrograph. So, obviously, the attenuation basically refers to the reduction in peak. So, the peak of the inflow hydrograph will be much larger than the peak of the outflow hydrograph. So, this reduction in peak is referred to as attenuation, that is, attenuation of peak. Then of course, the time there will be a time lag between the peak of inflow high blow because of the storage. So, that is referred to as lag, that is time lag in the occurrence of peak and of course, because of the slow nature of the release, the time base of the high flow outflow hydrograph will be much larger as compared to the inflow hydrograph.

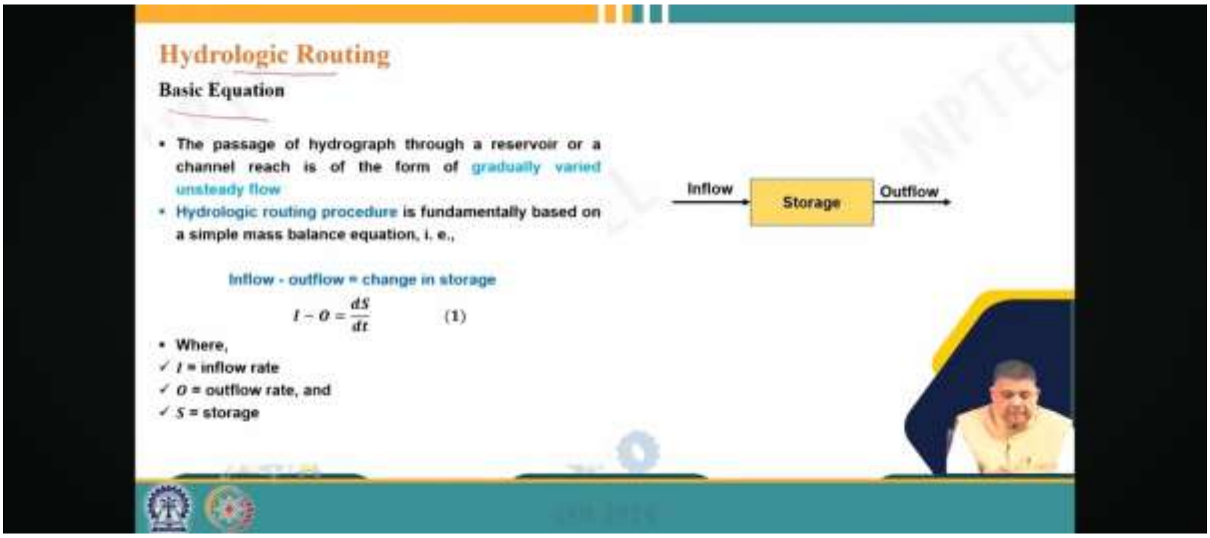
So, these are the three different impacts that happen. The peak gets attenuated; there is a lag in the peak occurrence of inflow and outflow; and the time base of the outflow hydrograph is larger than the inflow hydrograph. Now we come to channel routing. In channel routing, the changes in the shape of the hydrograph which travels down a channel are studied. So, of course, there is no reservoir here. Basically, as we defined in the case of flood routing, the same thing can be said about channel routing. That means if you have a particular point where you have a stream gauge with a flood hydrograph or known hydrograph.



Obviously, you route the flow and then it enters any other downstream stream gauge. What will happen to this hydrograph is what is studied in channel routing. So, if the input hydrograph at the upstream end of the reach is known, this form of routing aims to predict the flood hydrograph at various sections of the reach. Any section you are interested in, you can find out, and this is helpful in obtaining information on flood peak attenuation. Obviously, there will be changes in the peak, and you are interested in finding that, and of course, the duration of high-water levels. This is basically because this information is helpful in flood forecasting operations and flood protection work. So, obviously, if you know what peak of flood is likely to occur at a point of interest, then of course and how after how what is the time lag between the peak of inflow at this point and this point.

So, you know how much time after how much time a particular peak flow will be occurring at a point of interest and then accordingly ah the of course, you have the forecasting and then you can take up the flood protection works that is the channel routing. Now, we have discussed two types of routings that is ah reservoir routing and channel routing. Similarly, the routing methods can also be classified into two groups that is lumped or hydrologic routing and distributed or hydraulic routing and in the lumped or hydrologic routing flow is calculated as a function of time at a location and basically ah these methods employ equation of continuity. Wherein in the case of distributed hydraulic routing flow is calculated as a function of space and time throughout the system and methods imply equation of continuity and also momentum for unnecessary flow.

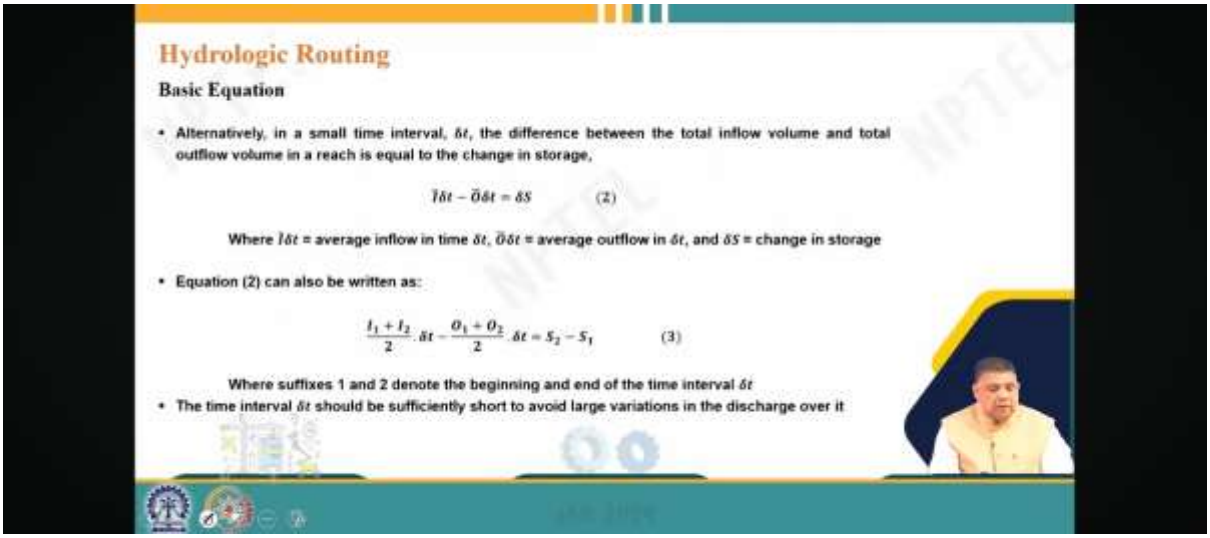
So, in this case basically in hydraulic routing partial different equations of the open channel flow are solved. So, the difference is that here only the location is important here it is space and time both are taken into account and in this case ah only the methods employ equation of continuity in this case methods employ both equation of continuity and momentum. Now, let us come to hydrologic routing and let us talk about the basic equation. The passage of hydrograph through a reservoir or a channel reach a form of gradually varied unsteady flow typically it is a gradually varied unsteady flow I am sure that you have read in hydraulic hydraulics of fluid mechanics these terminologies. So, hydraulic routing procedures is fundamentally based on a simple mass package when the equation of continuity which is nothing, but mass balance equation that is inflow minus outflow is change in storage.



So, you have inflow, you have outflow, and of course, in between, there is storage. So, inflow minus outflow is the change in storage. So,

$$I - O = \frac{dS}{dt}$$

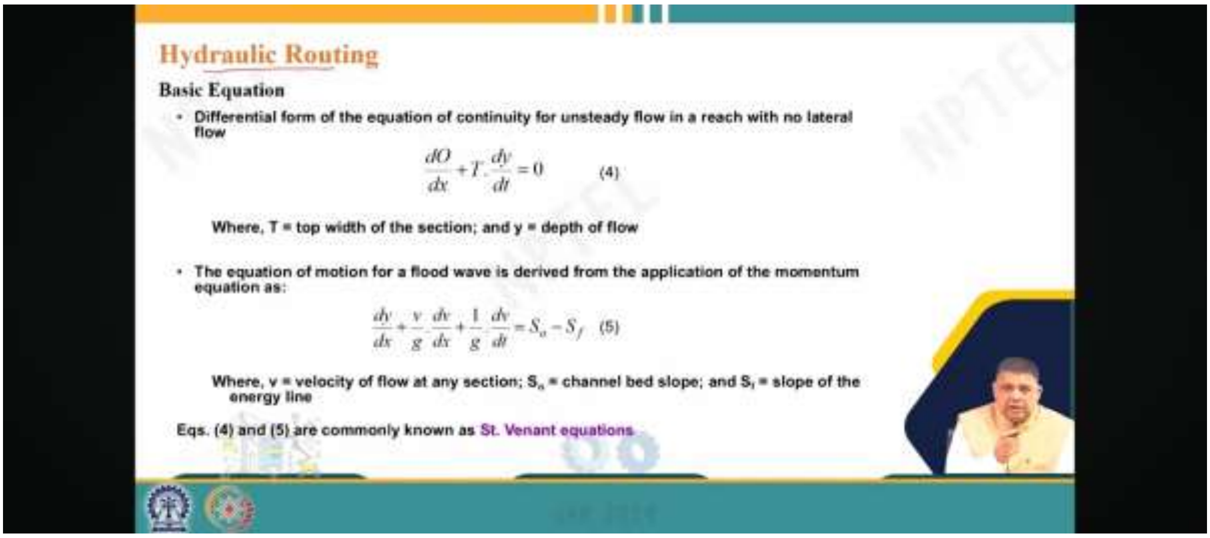
where II is the inflow rate, OO is the outflow rate, and SS is storage. So, over time, over which we are talking about the inflow and outflow rate, over which how the storage is changing, that is the simple mass balance equation. Alternatively, we can consider a small-time interval $\delta t\delta t$ and the difference between the total inflow volume and total outflow volume in the reach can be considered as equal to change in storage, that is $\bar{I}\delta t - \bar{O}\delta t = \delta S$ where $\bar{I}\delta t$ is the average inflow in the time δt, $\bar{O}\delta t$ is the average outflow in δt and δS is the change in storage.



So, now, we are bringing time also into the picture, and this equation number 2, and this equation can also be written as

$$\frac{I_1 + I_2}{\delta t}, \frac{I}{I_1 + I_2} \times \frac{\delta t}{2} - \frac{O_1 + O_2}{2} \times \delta t = S_2 - S_1$$

where suffixes 1 and 2 denote the beginning and end of the time interval δt. And, of course, the time interval δt should be sufficiently short to avoid large variations in discharge. So, basically, we have the same equation: mass balance, inflow minus outflow, it changes in storage, and the way we are representing it could be different. So, these are different ways through which we can express the same equation by what variables we are considering depending upon that. So, this is simple, the basic equation of hydrologic hydraulic routing.



On the other hand, if you consider the hydraulic routing, we already have seen that there is an equation of ah, the momentum equation also comes into picture along with the mass balance. So, in this case, the differential form of the equation of continuity for a steady use with no later inflow, ah, if you consider, is used. So,

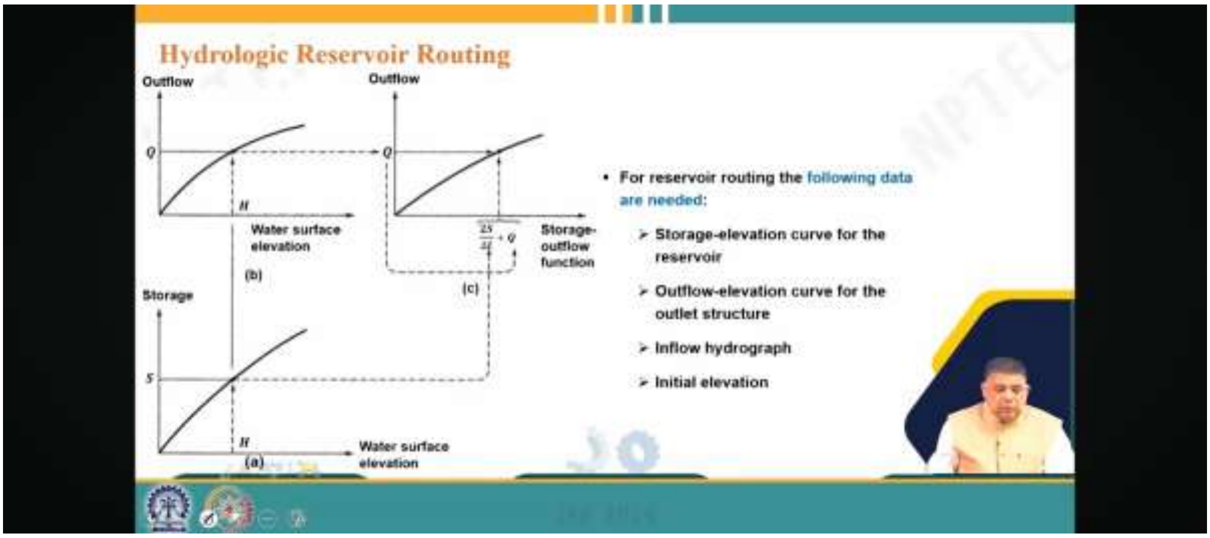
$$\frac{dO}{dt} + t\frac{dy}{dt} = 0$$

where tt is the top width of the section and yy is the depth of flow, and the equation of motion for a flood wave is derived from the expression of the momentum equation as we can write this is the equation of ah, the momentum equation, that is

$$\frac{dS}{dt} + \frac{v}{g}\frac{dS}{dt} + \frac{1}{g}\frac{dS}{dt} = S_0 - S_f$$

Whereas, v is the velocity of flow at any section, S_0 is the channel bed slope, S_f is the slope of the energy line, and these two equations, questions 4 and 5 taken together, they are commonly known as catenoid equations and they are very popular in hydraulics of fluid mechanics.

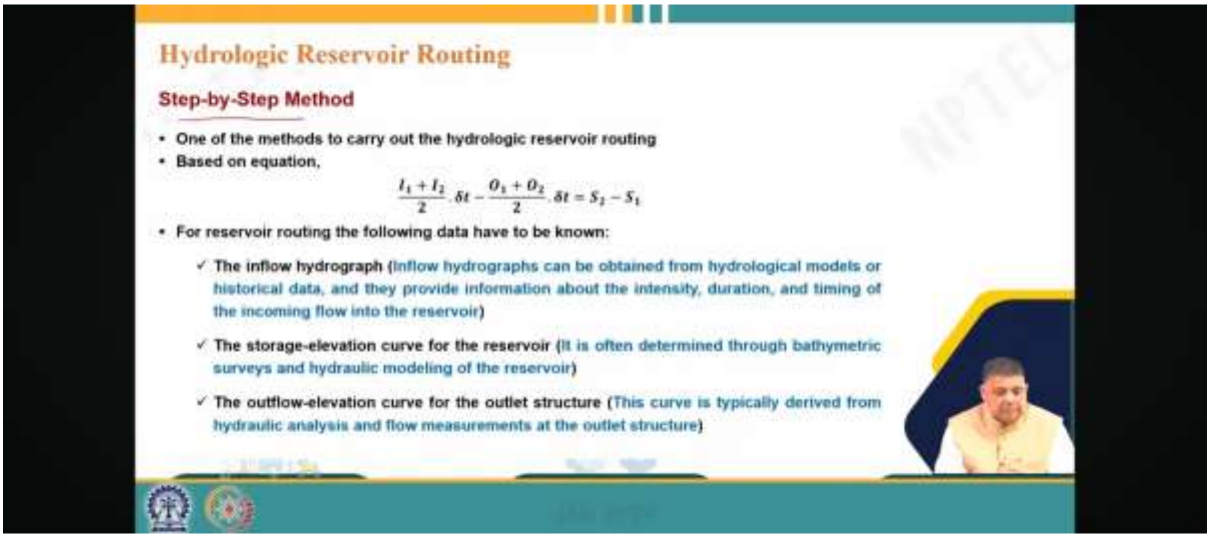
So, basically when we talk about the hydrologic routing the method of their use simple mass balance equation inflow minus outflow is for change storage wherein when we go to hydraulic routing, we use a differential form of the equation of continuity as well as equation of ah the momentum or momentum equation. Now, if you look at hydrologic reservoir routing. So, now, we are saying reservoir routing we studied earlier hydrologic and hydraulic routing we studied here now we are taking hydrologic routing ah reservoir routing together. So, we will be talking about hydrologic procedures for reservoir routing. So, basically for reservoir routing the following data are needed we need a storage elevation curve for the reservoir.



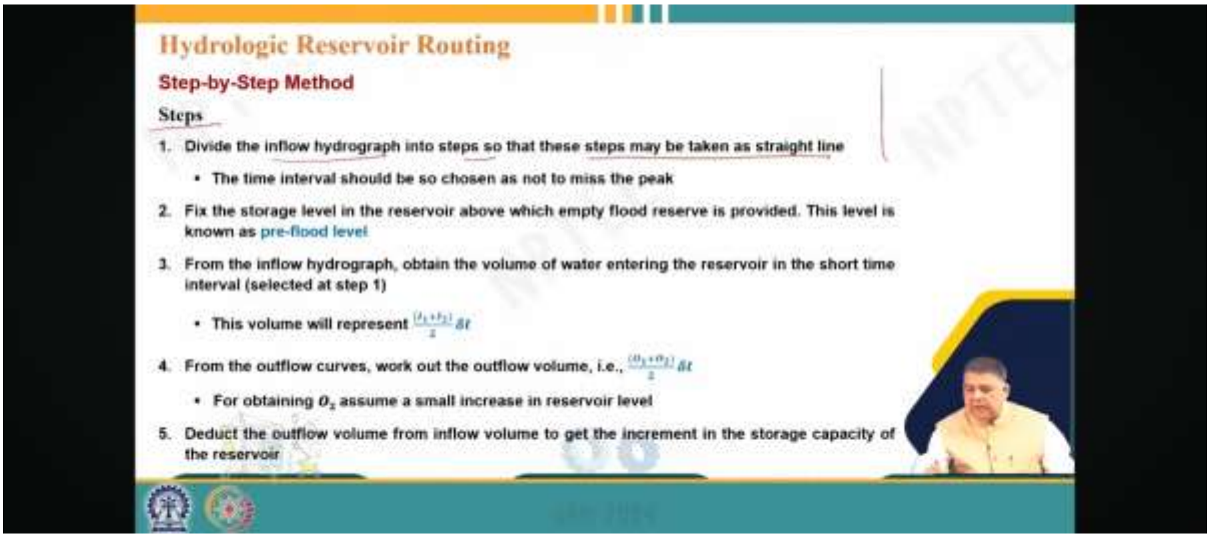
So, you have a storage elevation curve for the reservoir. You have storage here and elevation here. You need this storage relationship for the reservoir; we also need outflow elevation curve for the outlet structure. Outflow elevation curve, which is the outflow elevation curve for the storage structure, we also need. Basically, once we have outflow versus elevation and storage versus elevation.

Of course, we can also develop a relationship between storage versus outflow. S versus outflow relationship can also be developed. And this is one form of that relationship; it is a storage outflow function, a particular form where the form you are considering, that takes into account.

But it is possible because you have storage versus elevation, you know outflow versus elevation. So, you can always develop a relationship between storage and outflow. The third thing which we require, and basically just to mention, these two are called characteristics curve curves of the reservoir, and these curves are always available with the reservoir authority. So, for any given dam site or reservoir, you can get this from the reservoir officials.



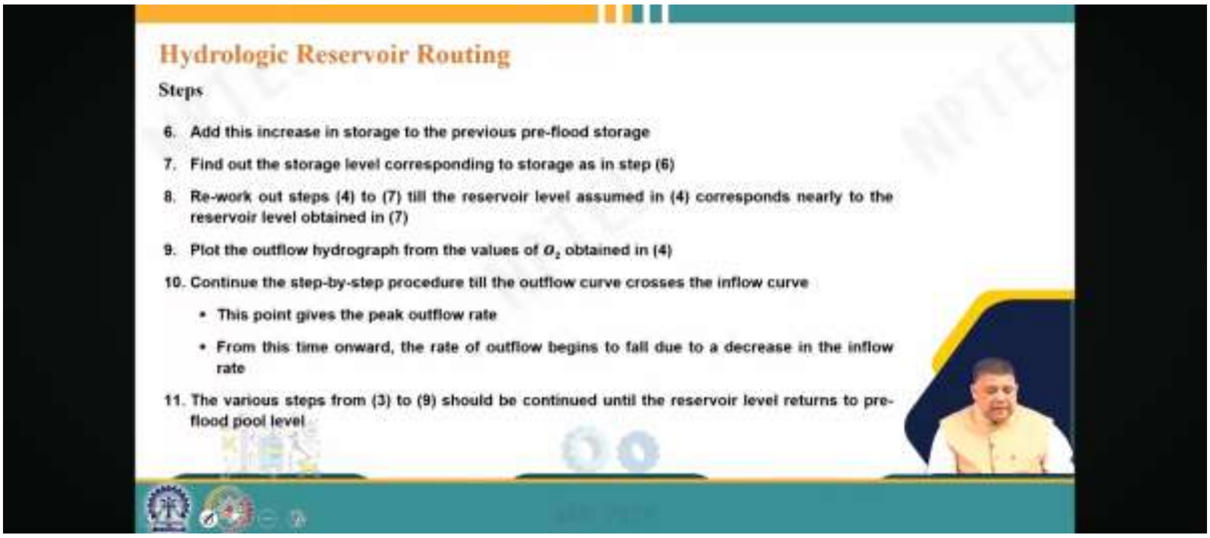
Then of course, you also need to know the inflow hydrograph, that is the hydrograph you want to route through the reservoir, and of course, the initial elevation. That means when this particular flow is likely to enter the reservoir, what is the initial condition in the reservoir, that is initial elevation. So, these things are required in a hydrological routing or reservoir routing. Now, we go step by step; that is one of the methods, a popular method of hydrological reservoir routing. So, it is one of the methods to carry out the hydrological reservoir routing, which is based on the equation in this particular form. So, all methods will be using the same equation, but in different forms maybe.



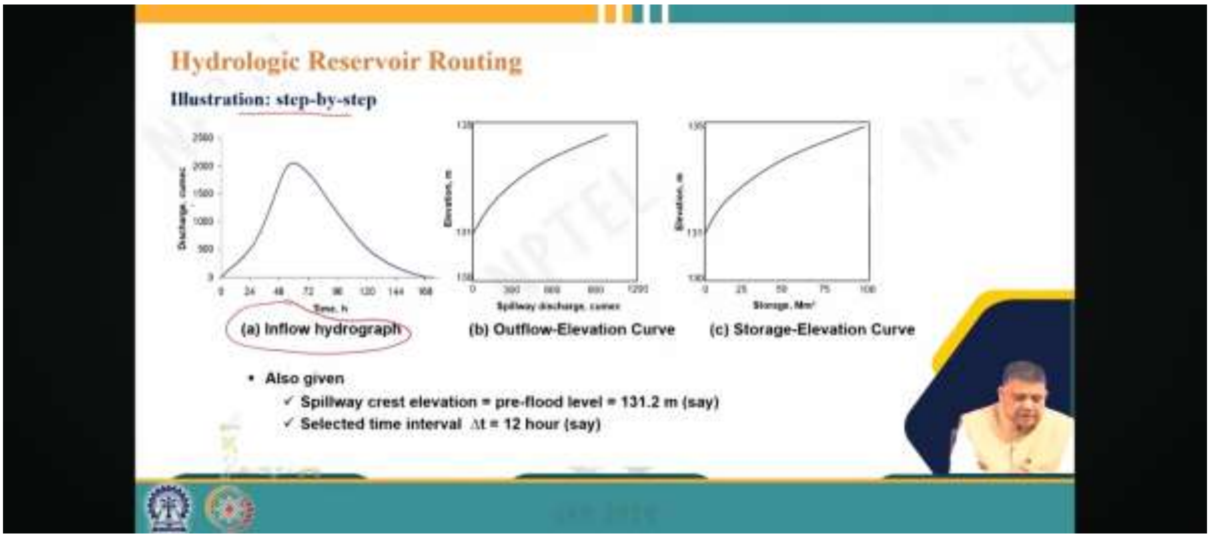
So, this uses the basic form and of course, we have already seen that for reservoir terminal quality data has to be known, that is the inflow hydrograph and the storage elevation curve of the reservoir and outflow elevation curve for the outlet structure. So, these things we have already discussed; these three are a must for carrying out the hydrological reservoir routing.

Now, coming to the steps of the method. So, here the inflow hydrograph is divided into steps so that these steps may be taken in a straight line.

So, basically, you have an inflow hydrograph and basically when we say we divide. So, obviously, we have to decide the delta t, and delta t should be sufficiently small so that we can have a piecewise linearization. We know that this curve is not linear, but we want to have a piecewise linearization, that is why this delta should be small, and also this delta should not miss the peak. Fix the storage level in the reservoir above which empty flood reserve is provided; this level is known as pre-flood level, that is the level when the flood is likely to occur. From the inflow hydrograph, obtain the volume of water entering the reservoir in the short time interval, that means this value.

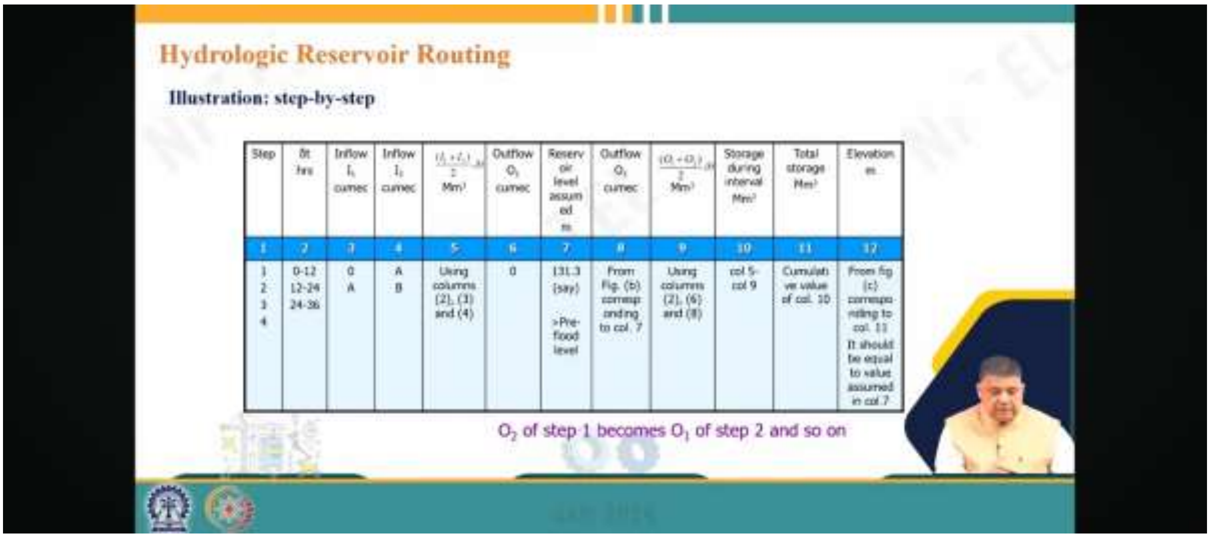


So, we know delta t we have chosen then we know I_1, I_2. So, we can find out the inflow volume then from the outflow curve, we need to work out the outflow volume, that is this one, the second part of the equation and of course, for obtaining O_2, we assume a small increase in the reservoir level. And then by deducting the outflow volume from the inflow volume, we get the increase in the reservoir capacity or the storage capacity of the reservoir. And of course, then if we add this increase in the storage to the previous flood flow structure, we know the cumulative storage. And then we can find out the storage level elevation corresponding to storage in step 1.



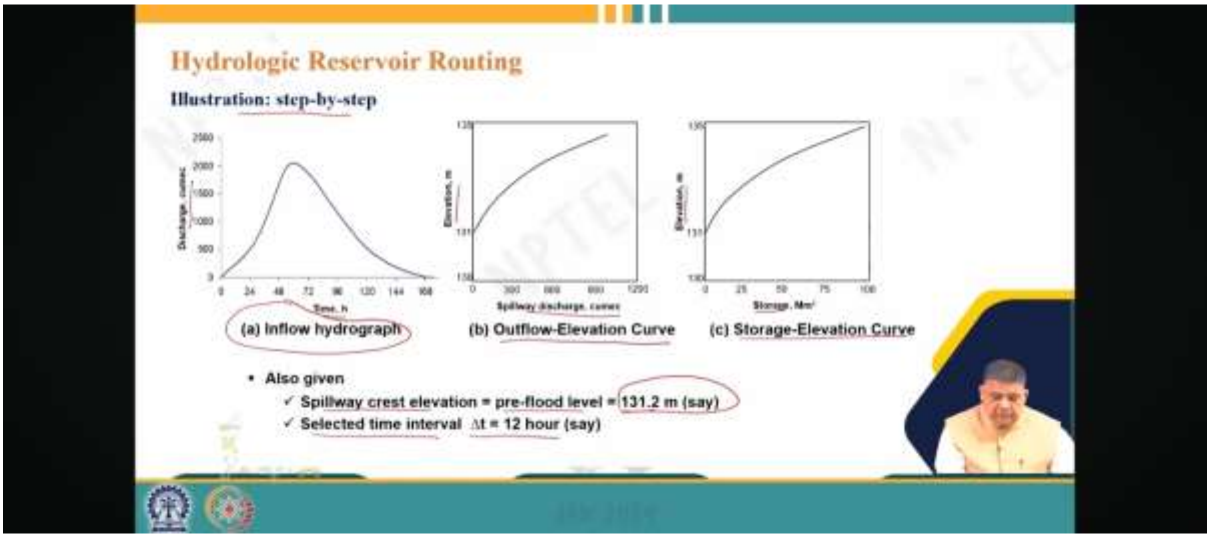
And then obviously, we have to carry out these steps in an iterative manner. We work out steps 4 to 7 until the reservoir assumed in 4 or corresponds nearly to a reservoir level. So, basically, then we will plot the hydrograph values obtained in step number 4; that is what we are doing. And then we will continue this step-by-step procedure till the outflow curve crosses the inflow curve, which gives us the peak outflow rate. From this time onwards, the rate of outflow begins to fall due to the increase in the inflow rate. Various steps from step 3 to 9 should be continued until the reservoir assumed to do flood flow level, actually, these are the steps.

But I think the procedure will be clearer when we discuss step by step through an example or through an illustration. So, let us take this illustration step by step method. As we said, we have an inflow hydrograph where discharge versus time is there. Then we have outflow, this spill word discharge versus elevation, which we are calling it outflow elevation curve. And we have storage versus elevation data, that is, storage and data.



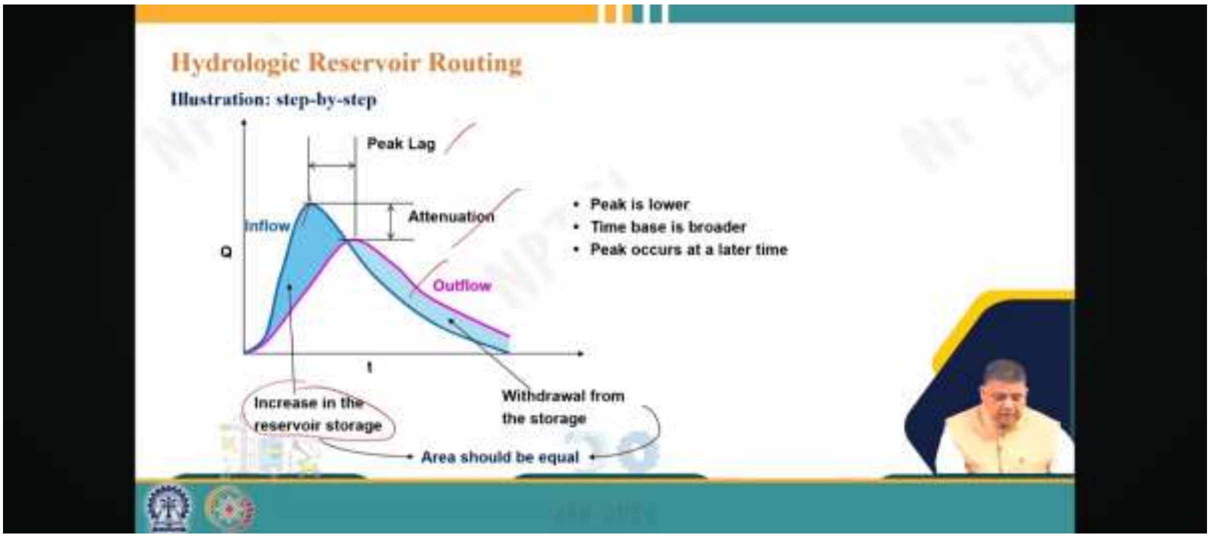
So, a, b, c are available with us. Also given is the spillway crest elevation or the pre-flood level at some elevation, 131.2 meters, let us say. And let us say that we selected a time interval, delta t, equal to 12 hours. Then we have to carry out this entire calculation in this table. So, here you have the different steps like step 1, 2, 3.

Then, ah, this is delta t hour. So, in step number 1, the time interval we have chosen is 0 to 12 hours. So, we will talk about 0 to 12. In step number 2, it is 12 to 24, 24 to 36 and so on. Now, inflow at 0 hour, we know. Then inflow I_1 at 1_2 hours, we will know the value, and similarly at 12 hours, a will come here and the new value at 24 hours will come, and so on. So, this is what that data is already available with us and that means, this $I_1 + I_2$ by $2\Delta t$, that is the inflow volume in million cubic meters, we can calculate using this ah column 2, 3 and 4.

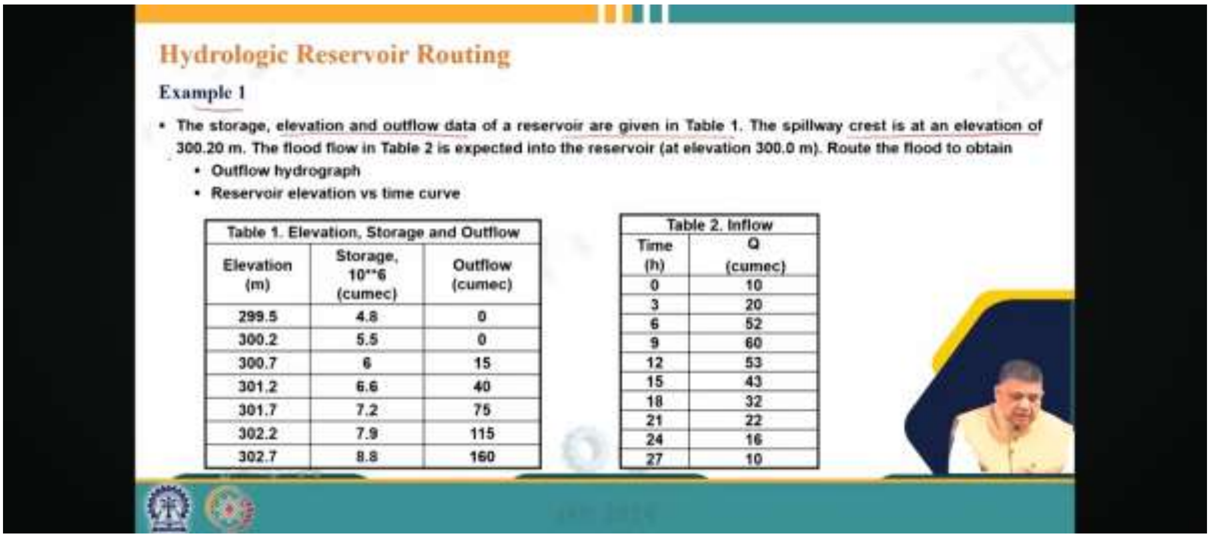


Now we come to outflow, outflow O_1. Ah, the first value will be known to us because ah we know where the elevation is, what is the elevation, that is, elevation is given as 131.2, and ah 131.2 elevation is 0. So, ah, I mean that will be known to us anyway. It is a pre-flood level. So, there is no outflow going at that particular point. Then we assume a certain reservoir level, say 131.3, which has to be greater than the pre-flood level, and it was 131.2. So, that is why we assume a slightly higher value.

Now, corresponding to this reservoir level from Figure B, that is the storage elevation outflow curve, we can find out the value of O_2. So, from this storage elevation curve, we can find out the value of outflow elevation curve, sorry, we can find out the value of O_2. So, this O_2 will be obtained corresponding to this elevation. So, once we know O_1 and O_2, we can calculate this, that means, the difference of **$I_1 + I_2 - 2\Delta t - O_1 + O_2$ by $2\Delta t$** will give us the change in storage during the interval, that is column 5 minus column 9 will give us the change in storage. And the total storage will be the cumulative value of column 10, basically, we will be in the beginning corresponding to 131.2, we know the storage and this change is coming. So, that is the cumulative value, and then subsequently column 10 cumulative values will come. And then from Figure C, corresponding to this value from the storage elevation curve, we will reach the elevation. Now this value should be equal to the value assumed in column 7. So, column 7 we started with a particular assumed value and then we are reading a final value. So, these two values should match. If they match then our step is complete, and that means, the $O2O2$ value which we obtained here, this O_2 value, this will make step 1 become O_1 of step 2 and so on.

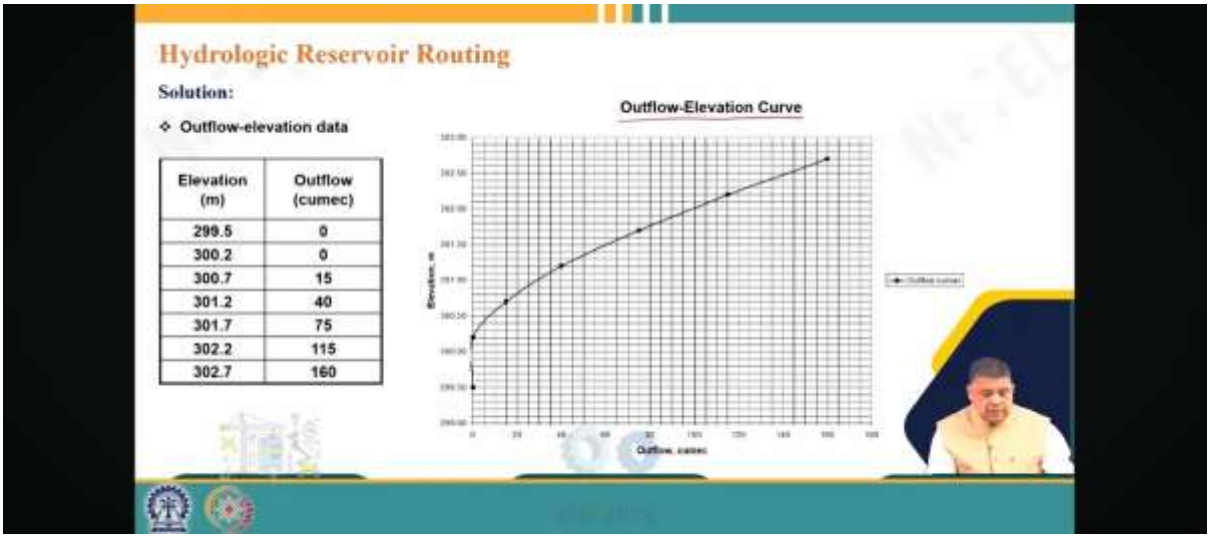


So, it is O1 of step 2 then we will assume another value here like this is say we have got another one we assume another value say 131.5 and then we continue this entire procedure and send this. So, this way step 2, step 3, and so on will continue and once we have completed this entire thing then obviously, we will plot the inflow and outflow and then we will find out the peak lag peak attenuation and the time base if it is. So, of course, already means this is an increase in the reservoir storage this portion withdrawal from the storage and typically this area will be equal because what is getting or at least or if there is a that that we have to see actually the time depending upon the time itself. So, of course, this is how the hydrologic routing is taken care of.



So, now, we take up an example the storage elevation and outflow data of a reservoir are given in table 1 the spillway crest is at an elevation of 100 meters the flood flow in table 2 is expected into the reservoir at elevation 300 to route the flood to obtain outflow hydrograph reservoir elevation versus time curve. So, we have this is a characteristic curve that elevation storage and outflow are available inflow hydrograph is available we say that these are required also the pre-flood pool elevation is given to us. So, based on this data using this data and taking a particular value of so, we can develop this storage elevation curve from the given outflow elevation curve inflow hydrograph we can plot.

So, this is a storage elevation curve this outflow elevation curve and this is the inflow hydrograph that I have used excel for plotting these graphs one can do manually also or any other software can be used for plotting. So, we have the initial data available with us we also know the pre-flood level that is 300 meters and we also know corresponding to the pre-flood level what is the storage that is 5.3 million cubic meters which we read from corresponding to 300 from the curve and we need to select delta t. So, let us say that we have selected delta t equal to 3 hours that is basically the time step we have been digitized given.

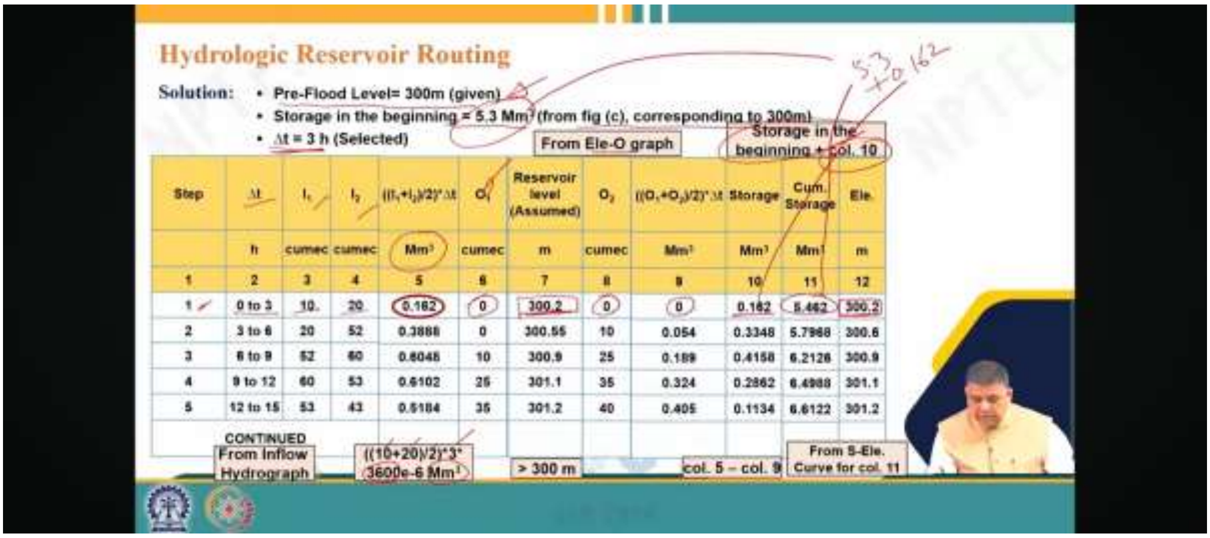


So, we can do anything. So, here that means, Δt step number 1 to 3 hours I 2 value we read from the inflow hydrograph and then we can calculate this,

$$\frac{\boldsymbol{O_1 + O_2}}{\boldsymbol{2}} \times \Delta \boldsymbol{t}.$$

$$= \frac{\boldsymbol{10+20}}{\boldsymbol{2}} \times \boldsymbol{3} \text{ hours}$$

So, then of course, you have 3600 seconds and of course, you want to produce in million cubic meters. So, it is basically the unit conversion. So, that is how you will get in million cubic meters. So, this is the inflow volume then you calculate, you come to the outflow side the first value of outflow is given because at 300 level there is no flow.

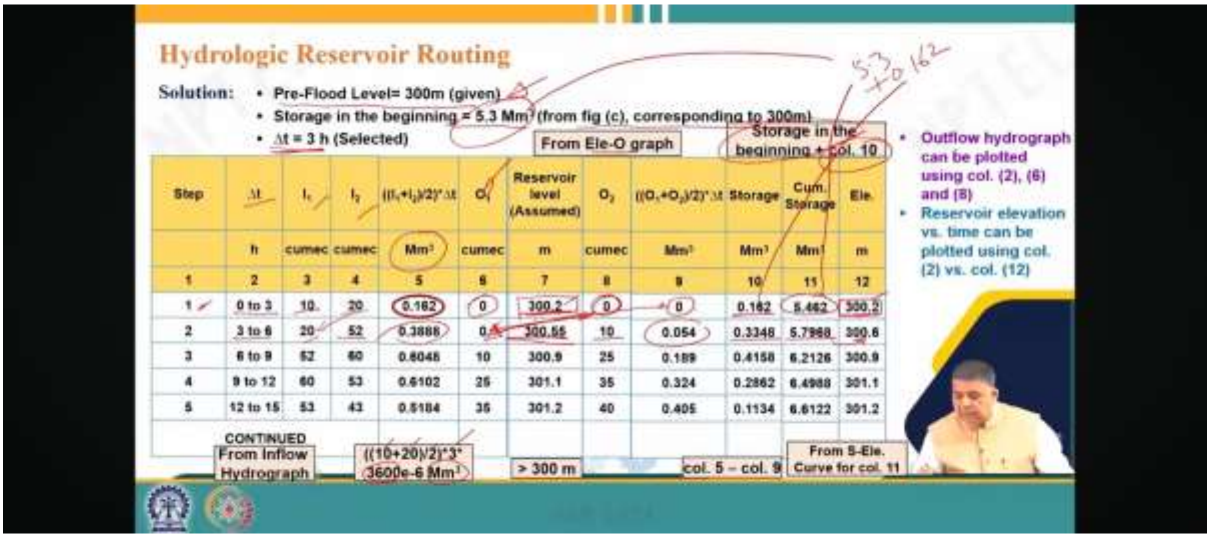


So, it is 0 now we assume a reservoir level. So, let us say we started with 300 here and we assume a bigger value that is 300.2. Now, from elevation outflow hydrograph corresponding to 300.2 we get value of 0 that we read from the curve basically. So, O 1 plus O 2 by 2 into delta t will remain 0 because O 1 is 0 O 2 is 0.

So, this value is 0 now that means, the storage is inflow minus outflow that is 0.162 that is during this particular storage where is the cumulative storage is this storage already there 5.3 here. So, this is nothing, but storage in the beginning plus storage in column 10.

So, we get 5.462 which is 5.3 from here and 0.162 from here. So, that is how we get this value cumulative storage and then corresponding to that we read the elevation that is from storage elevation curve we have to read the elevation and now we get a value of 300.2 which is same as the value which you assume that is column 7 and column 11 column 12. So, if these two values are same then our step is complete otherwise you have to go again you assume another value and continue in this step. So, you will continue step 1 till your reservoir level assumed and the reservoir level obtained in column 12 they match once they match then your step is complete step 1 is complete.

Now, we get into step number 2. So, step number 2 is time is 3 to 6. So, we know inflow this becomes here we get this value we calculate this value outflow is the first value here becomes the first value here. So, it is 0. So, that is why it is sorry I am sorry this will come here this outflow will come here. So, this is 0 here. So, that is why it is 0 here then again, we assume another value we read the outflow we get calculate the $\frac{O_1 + O_2}{2} \times \Delta t$ then inflow minus outflow gives us this change in storage during this particular step then cumulative value this plus this is this then corresponding to this we read the table if we get similar value then we say ok.



So, 300.55 we say ok then again, we continue this process until unless and until we our outflow hydrograph that means, we continue this and then we plot the outflow hydrograph using column 2 6 and 8 and reservoir elevation time can be plotted using column 2. So, column 2 and column 12 we can plot. So, this is how we will complete the step by hydrologic reservoir routing using step by step method. So, with this we come to end of this particular lecture we introduced flood routing we talked about the channel and reservoir routing we talked about hydraulic and hydrologic routing and we took a particular method step by step method of a hydrologic reservoir routing. Please give your feedback and also raise your questions or doubts we will be happy to answer in the forum.

Thank you very much.