Engineering Hydrology
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Module 5 - Lecture 67
Reservoir Routing

Hello all, welcome back. In the previous lecture we were discussing about flow routing. Flow routing is the technique by which we are determining the flow details, such as discharge and also the water surface elevation at the downstream location in the case of a channel or reservoir by making use of the known details at the upstream location.

We have discussed about two different methods of flow routing, that is hydraulic routing and hydrologic routing. In the case of hydraulic routing we are making use of both the continuity and momentum equations, that is mass conservation and momentum conservation techniques are utilized in the case of hydraulic routing. On the other hand, hydrologic routing is making use of only continuity equation, along with the continuity equation some storage function also will be utilized. So, from that itself it can be understood that hydrologic routing is a kind of lumped model, that is with respect to time, variation of discharge and water surface elevation can be determined by making use of hydrologic routing. But in the case of hydraulic routing we can determine the variations with respect to time as well as space, that is if you want to determine the spatio-temporal variation in the flow properties as the flood wave travels from the upstream to downstream we need to go for hydraulic routing. If we are making use of hydrologic routing techniques it will be giving only the details related to temporal variation, spatial variation cannot be estimated by using hydrologic routing and if the flood wave is traveling from upstream to downstream and it passes over a reservoir that is termed as reservoir routing and the study related to the movement of floodway from upstream to downstream is studied in the case of a channel it is termed as channel routing.

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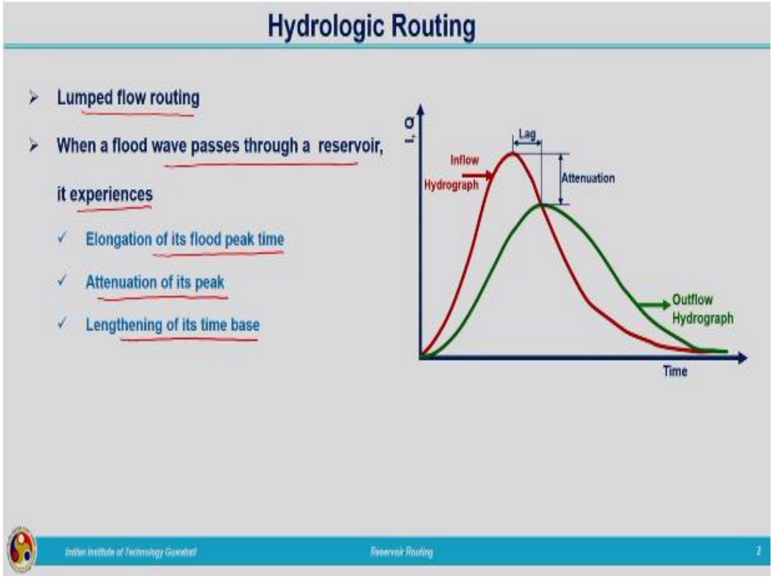

So, in today's lecture we are going to discuss about reservoir routing. So, hydrologic routing it is a kind of lumped flow routing. By making use of the upstream known data related to discharge or stream hydrograph, we will be finding out the flow hydrograph at a location downstream in the case of a reservoir and also a channel. So, in that case we are going to find out the variation with respect to time at a particular location. When a flood wave passes through a reservoir it experiences so many changes, that is in the previous lecture itself we have seen we cannot expect the same flow hydrograph at the downstream location as it traverses a distance from upstream to downstream, there are so many changes taking place in the case of a hydrograph, that is flow properties are getting changed.

With the help of a figure we can understand that this is the inflow hydrograph and the corresponding outflow hydrograph is represented by the green curve. As the flood wave travels from the upstream to downstream it experiences an elongation in its flood peak time, that is represented by lag and also you can observe that the peak is reduced that is termed as attenuation of its peak. When the flood wave travels from upstream to downstream there is a reduction in the peak of flow hydrograph takes place that is termed as attenuation, that is the reduction in the peak flow value. Now, as far as the time base is concerned and there is a lengthening of its time base also, compared to inflow hydrograph there is lengthening of the time base in the case of outflow hydrograph.

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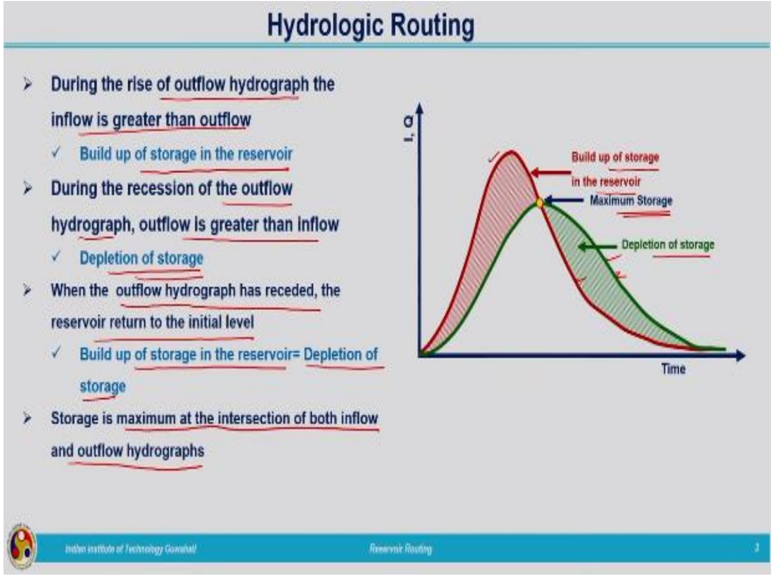

Now, you can observe that during the rise of outflow hydrograph the inflow is greater than the outflow. This is our inflow hydrograph and green curve is the outflow hydrograph, you can observe that the inflow is greater than that of the outflow hydrograph during the time of rising, that is when you compare the rising curve of both the inflow and outflow hydrograph, inflow hydrograph rising curve is higher than that of the outflow hydrograph, that is the outflow value is less than that of the inflow value as far as the rising limb is concerned. Where that much of deficiency is taken place in the Q value. Where this Q has gone? That is added to the storage, so that is termed as build-up of storage in the reservoir. All the flow which is represented by the inflow hydrograph is not represented by the outflow hydrograph during the same time, that we can understand by comparing the rising limb of both the hydrographs. So, that difference is added to the storage which is termed as the build-up of storage in the reservoir, that is represented by this red hatched area that is the build-up of storage in the reservoir.

Now, coming to the falling limb, during the recession of the outflow hydrograph, outflow is greater than inflow. Look at the figure you can see comparing this inflow and outflow hydrograph you can see outflow is more than that of the inflow. This is termed as the depletion of storage, that is marked by this green hatched region and this is the depletion of storage. When the outflow hydrograph has receded, the reservoir returned back to the initial level. Outflow hydrograph recession is taking place once it is receded reservoir level will be coming back to the initial level, so we can conclude that build-up of storage in the reservoir is equal to depletion of storage. So, you look at the figure these shaded areas, red region is representing the built up of storage in the reservoir and the green region is representing the depletion of storage. Once the reservoir level has reached to the initial level we can conclude that the built-up of storage is equal to the depletion of storage. So, you look at the figure you can see there is a meeting point of both the hydrographs, inflow hydrograph and outflow hydrograph are meeting at a particular point. Storage is maximum at the intersection of both inflow and outflow hydrograph, that particular point, meeting point of these two hydrographs is representing the maximum storage. We were making use of a particular term for the point which is representing maximum storage, that is nothing but the point of inflection. So that is represented by this point and it is the point corresponding to maximum storage, all the storage components in the catchment contributes to the flow. Once it reaches that maximum storage after that recession limb is starting and withdrawal from the storages will be taking place, that is represented by the depletion of storage.

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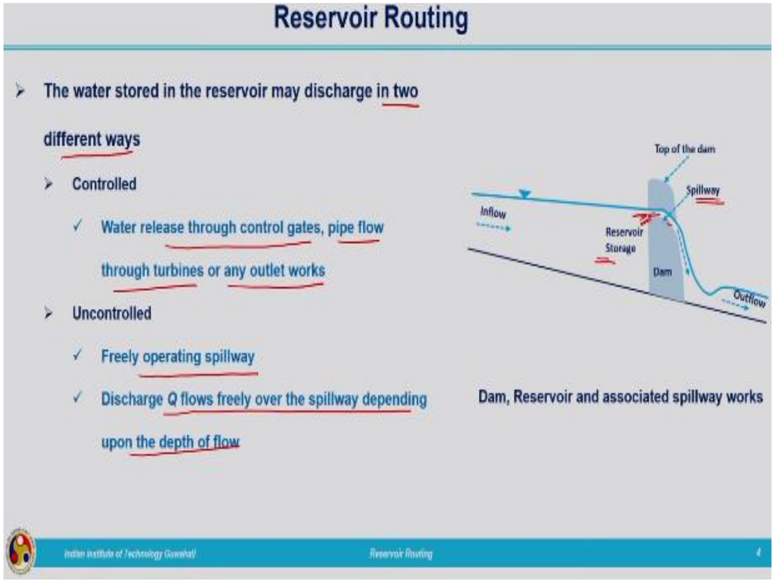

Now, we will move on to the topic of reservoir routing. The water stored in the reservoir may discharge in two different ways, that can be expressed by means of a figure. Here we are having a dam structure and this is the dam and this is representing the top of the dam and reservoir storage is coming in the upstream side of the dam and water flow is taking place above the reservoir. So, that part of the reservoir is having a hydraulic structure, spillway. Spillway is the structure which allows the smooth passage of the flow above the reservoir, that is how much water has to be released from the reservoir that is represented by means of the functioning of spillway. Spillway will be having different types of control structures provided depending on that we are having different types of spillway for controlling the water flow from the reservoir. So, the inflow is taking place from the upstream side and it is flowing above the spillway and outflow is obtained at the downstream end. So, this is the basic principle which is taking place in the case of a dam, dam will be having different hydraulic structures for controlling the flow. Spillway is one structure which allows the smooth flow of the water from the reservoir, so this spillway can be of control one or free flowing ones.

So, the outflow from the reservoir can be divided into two types that is first one is the controlled one, that is the water released through control gates or spillways such as pipe flow through turbines or any outlet works, because in the case of dams, spillways will be provided at this location or some other locations such as emergency spillways, so these spillways can act as a control structure which will allow the flow to get released in a controlled manner. Sometimes the spillways will not be having any control structure and it is the case with the free-flowing spillway. So, that is the case with the uncontrolled way of release of water that is freely operating spillway. In the case of controlled release here for the spillways some control structures will be present, so these control gates will be operating according to the requirement of the release. During the monsoon time the water level in the reservoir will be increasing beyond a certain level then these gates will be completely open, allow the water to discharge towards the downstream side. In the case of freely flowing spillways when it reaches that level, when it reaches this particular level water will start flowing freely. But in the case of spillways which are having controlled structures such as gates these gates have to be operated according to the water level. So, in the case of uncontrolled way of release discharge Q flows freely over the spillway depending upon the depth of flow. The flow that is the outflow from the reservoir depends on the water present in the reservoir. How much is the head which is causing the flow that depends on the water depth or water level in the reservoir.

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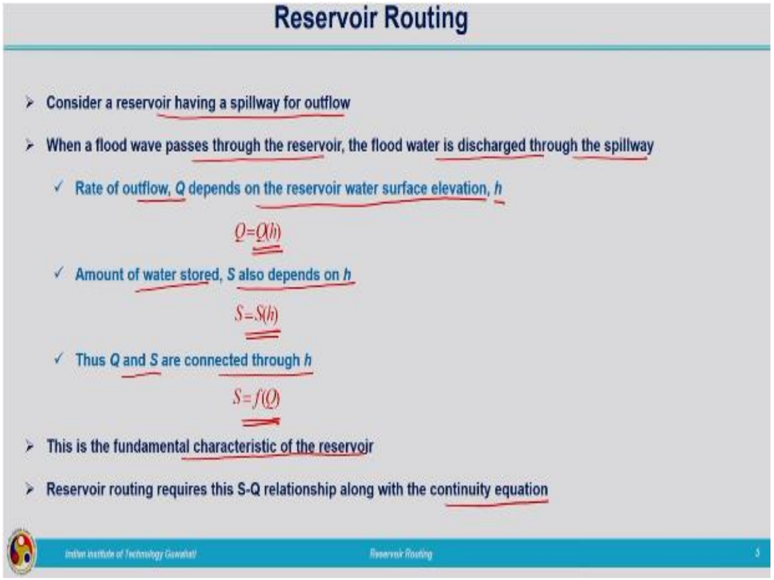

Now, consider a reservoir having a spillway for outflow. We are considering the reservoir with a spillway, that spillway may be freely flowing or maybe working based on the controlled principle. When a flood wave passes through the reservoir, the flood water is discharged through the spillway. The rate of outflow Q depends on the reservoir water surface elevation h. In the reservoir we are having certain level of water, so how much water is released over spillway depends on the head provided by the water present in the reservoir, so we can write Q as a

$$Q = Q(h)$$

Now, coming to the amount of water stored S is also a function of h. What is S? Storage in the reservoir. How much water is stored within the particular reservoir that also depends on h, as h is changing storage will be increasing or decreasing. So, we can write S is equal to

$$S = S(h)$$

Q is a function of water level and storage is also a function of water level. So, what we can conclude, we can conclude that S is a function of Q.

So, through these relationships Q and S are connected through h. So that can be written as

$$S = f(Q)$$

This is the fundamental characteristic of the reservoir which is utilized for carrying out the routing, reservoir routing along with the continuity equation and in the previous lecture we have seen that for carrying out hydrologic routing we need to have one more equation in addition to continuity equation. So, in the case of reservoir this is the relationship that is the relationship with the storage and the outflow is considered as the extra equation which is required for carrying out the reservoir routing.

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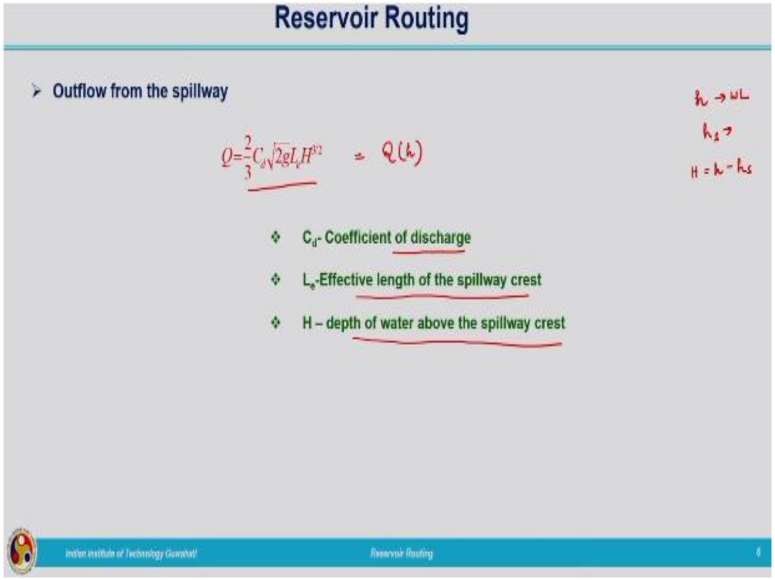

In the case of reservoirs with spillway, outflow from the spillway can be written as

$$Q = \frac{2}{3} C_d \sqrt{2g} L_e H^{3/2}$$

In this equation C_d is the coefficient of discharge, L_e is the effective length of the spillway crest, H is the depth of water above spillway crest, that is we are having the water level in the reservoir and spillway crest is there, so that is having certain level, then the difference between these two will be giving us capital H, that is if small h is the water level in the reservoir and small h_s is representing the level of that is the bottom level or the sill level of the spillway, then we can write

$$H = h - h_s$$

So, we can write this expression as *Q* as a function of *h* again, this again depends upon the water level in the reservoir, that is the capital *H*, that is the value of capital *H* is the difference between the water level in the reservoir and the level corresponding to the spillway sill. So, the outflow from the spillway is also a function of water level in the reservoir.

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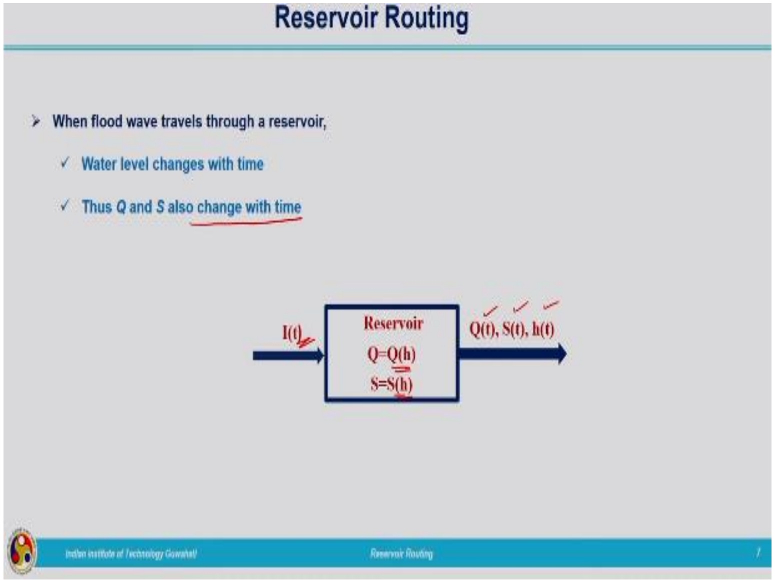

Now, when a flood wave travels through a reservoir water level changes with time i.e, as the time elapses there will be changes taking place in the water level. We have already observed that the storage is a function of water level, outflow is also a function of water level. This water level is a function of time, so indirectly we can tell that storage and outflow are also functions of time. *Q* and *S* are also function of time. Now, we can schematically represent the case with reservoir routing. Our system is reservoir, reservoir is acted upon by an inflow, this *I(t)* is represented by the inflow hydrograph, we already know the relationship *Q* as a function of *h* and storage as a function of *h* and by knowing these values and some initial conditions related to *Q* and *S* we can determine the values corresponding to *Q(t)*, *S(t)* and *h(t).* Outflow or the outputs in this hydrologic system is *Q(t)*, *h(t)*, *S(t)*, that is *Q*, *S* and *h* as function of time has to be determined by modelling this system. We are having the input as in flow hydrograph and some relationship related to reservoir storage properties. Along with that we are having some initial values corresponding to discharge outflow and the storage. So, before going to the technique related to reservoir routing, we need to have an understanding related to the *S* and *Q* relationships, that is the relationship between the storage and the outflow.

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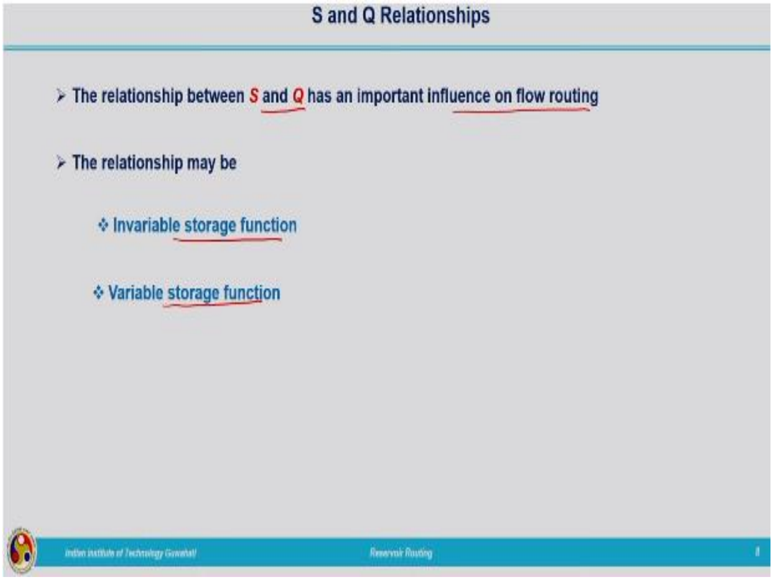

The relationship between *S* and *Q* has an important influence on flow routing, because that is the factor which is determining the extra condition required for solving the problem, that is along with the continuity equation we need to have this storage outflow relationship. The relationship may be invariable storage function or variable storage function. Two types of storage functions can be considered, one is termed as invariable storage function, second one is termed as variable storage function.

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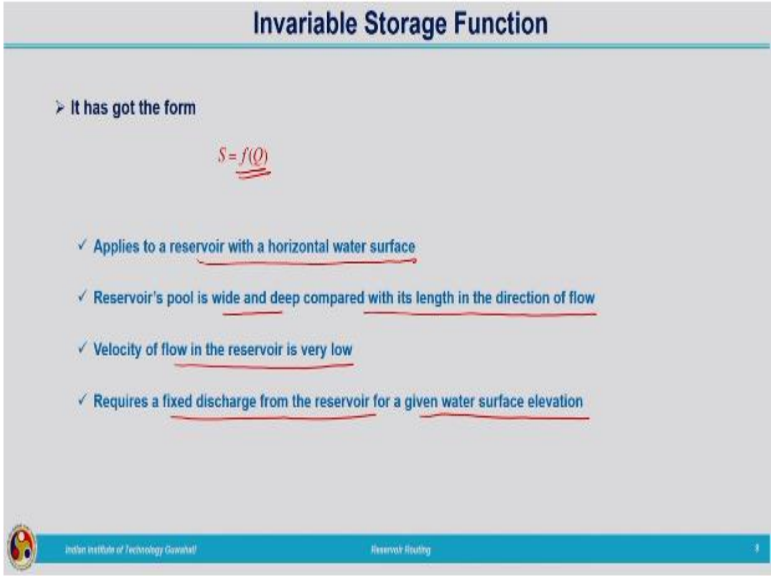

What are they? What is the difference between them? First one is the invariable storage function, it has got the form

$$S = f(Q)$$

This we have seen in the case of reservoir. Discharge or the outflow from the reservoir is a function of water depth in the reservoir and the storage in the reservoir is also a function of water depth in the reservoir. Since, these two are related to water level in the reservoir we can write this relationship that is S is a function of outflow discharge, that is $S = f(Q)$. There are certain conditions to be taken care while making use of this equation for flow routing. It applies to a reservoir with a horizontal water surface, we need to make sure that the reservoir is having a level water surface or horizontal water surface. Reservoir pool is wide and deep compared with its length in the direction of flow. You imagine the figure of the reservoir, in that we are having upstream channel and compared to the length of the upstream flow the width of the reservoir and the depth of the reservoir is high then only we can assume that there is a flat-water surface and also the velocity is very less. So, the reservoir's pool is considered to be wide and deep compared to the length in the direction of flow. Now, coming to the velocity. Velocity of flow in the reservoir is very, very low and it requires a fixed discharge from the reservoir for a given water surface elevation. For getting the water surface elevation it needs to have a fixed discharge. So, these are the conditions to be satisfied for making this assumption that is S is a function of Q, that is this is the case with invariable storage function.

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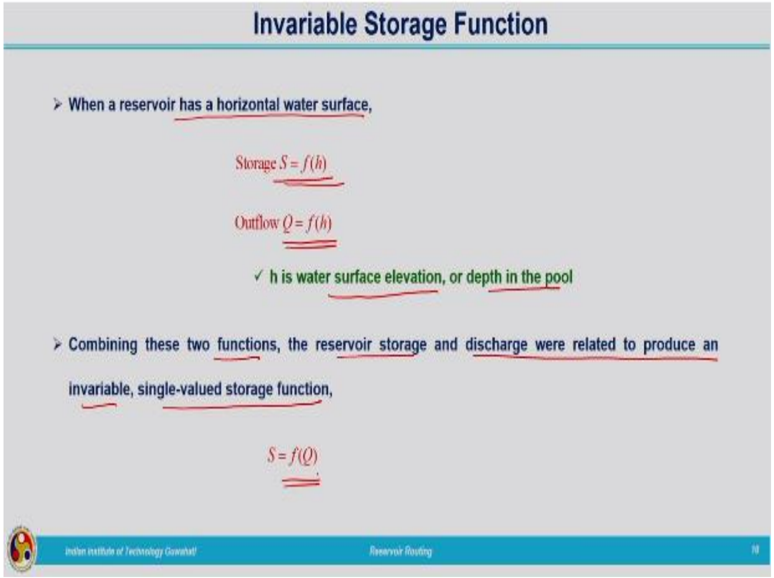

Now, when a reservoir has a horizontal water surface,

Storage $S = f(h)$

that is storage is a function of water surface elevation h. Also,

Outflow $Q = f(h)$

This we have already seen, h is nothing but the water surface elevation or depth in the pool. Combining these two functions the reservoir storage and discharge were related to produce an invariable single valued storage function, that is nothing but

$S = f(Q)$

That is in the case of invariable storage function we are writing the storage as a function of water level, outflow is also a function of water level, then we are relating the storage and outflow by making use of a function, that function is representing the invariable storage function.

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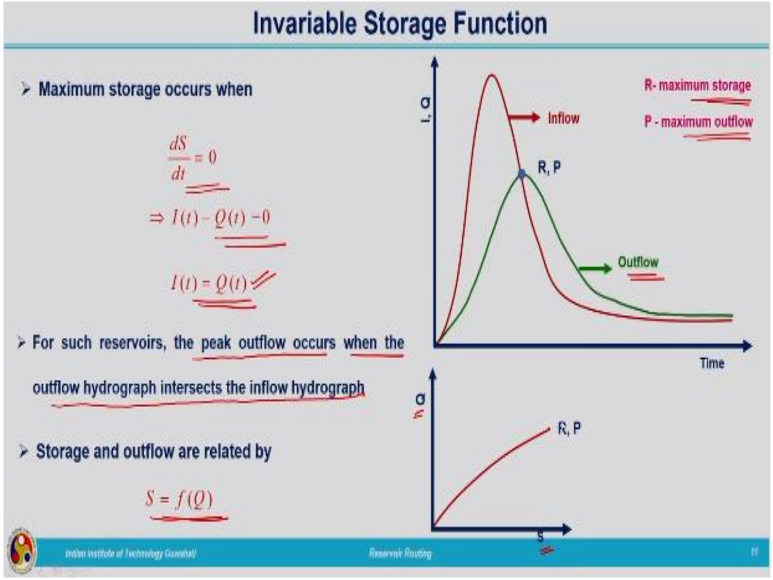

We can look into the properties of the invariable storage function with the help of the hydrographs, that is the inflow and outflow hydrograph, where the maximum storage will be occurring. Mathematically if we are representing, certain quantity is maximum means differential of that particular quantity will be equal to 0. So, here we are going to consider the case with the maximum storage. At the maximum storage,

$$\frac{dS}{dt} = 0$$

If we are differentiating the function related to storage it should be equal to 0 when it is maximum. If that is the case then,

$$I(t) - Q(t) = 0$$

i.e., what is $\frac{dS}{dt}$? $\frac{dS}{dt}$ is the difference between inflow and outflow, $\frac{dS}{dt} = 0$ that means $I(t) - Q(t) = 0$, that gives you a relationship as

$$I(t) = Q(t)$$

So, where this condition is coming in the figure, inflow is equal to outflow, that is at the meeting point of two hydrographs. So, for such reservoirs the peak outflow occurs when the outflow hydrograph intersects the inflow hydrograph, that we can conclude from this relationship $I(t) = Q(t)$. When we are observing the curves, we can understand that $I(t) = Q(t)$ at the meeting point of these two curves. So, that is represented by this point and we know what is the point representing the maximum storage, it is the point of inflection, that is represented by R and P. R is the maximum storage, nothing but our point of inflection it is the same as that of maximum outflow, from the outflow hydrograph we can understand that it is representing the point corresponding to maximum outflow.

Storage and outflow are related by the function $S = f(Q)$. We are not discussing about that particular function over here but we can understand that storage and outflow can be related to each other since both are functions of water depth in the reservoir and here the point of inflection is representing the maximum value corresponding to the outflow hydrograph, P corresponding to the outflow hydrograph. So, we can plot the storage and discharge relationship by means of a curve like this, Q along the y axis and S along the x axis that can be represented by means of a single curve. This is the invariable storage function; this particular point is representing the maximum storage and also maximum outflow.

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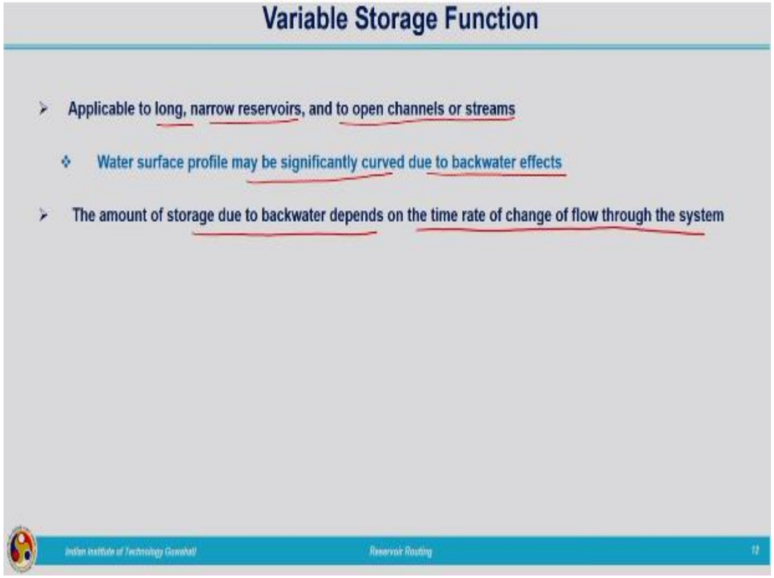

Now, coming to the variable storage function. Where it can be applied? In the previous case we have seen, in that case the length of the reach should be shorter compared to the width and depth of flow. Now, coming to the variable storage function, how it is different from the invariable storage function and we have seen that it can be applied to the case with the width and depth of the reservoir should be more compared to the length of the upstream reach we are considering, but that may not be always possible, that means we cannot make use of that formula representing the invariable storage function always. Sometimes the reach may be very narrow, in those cases we may have to go for the variable storage function. So, let us look into variable storage function, it is applicable to long narrow reservoirs, the width of the reservoir is less and in the case of open channels or streams. Open channels the length is too high, so in such cases we may not be able to make use of the storage function which is represented by the invariable storage function. Such cases the water surface profile may be significantly curved due to back water effects, if the length of the upstream reach is more, for example, in the case of a channel or in the case of reservoir itself the upstream length of the reach is very long there will be effects of back water flow because of that the water surface cannot be assumed as a levelled one or horizontal one, it can be represented by means of a curved water surface profile. The amount of storage due to back water depends on the time rate of change of flow through the system. So, this storage cannot be approximated as a function of outflow, this storage is depending on the time rate of change of flow through the system.

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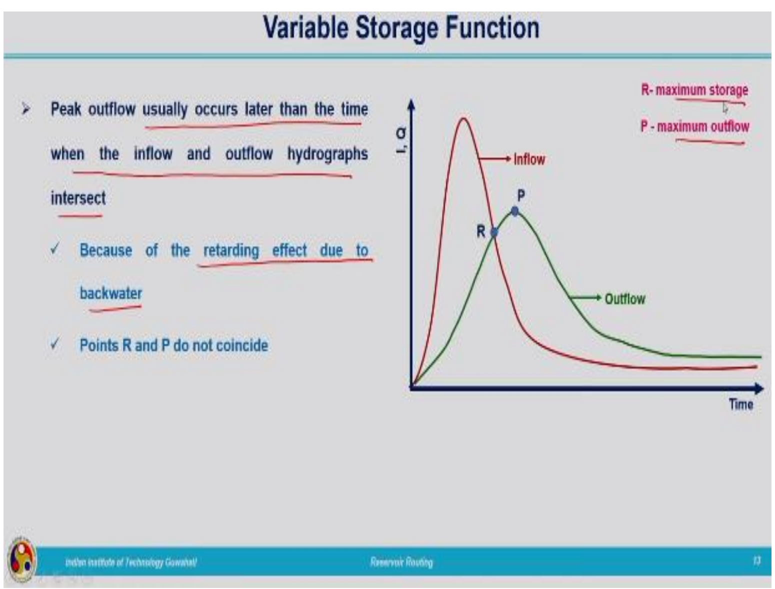

Now, in this case the peak flow usually occurs later than the time when the inflow and outflow hydrographs intersect. In the case of invariable storage function, we have seen from the figure itself we got a clear meeting point, that point was representing the maximum storage and also the peak outflow. But in this case invariable storage conditions it's not like that, both are different. This is because of the retarding effect due to the backwater, backwater will be causing a retarding effect because of that the maximum storage will not be coinciding with the peak of outflow hydrograph. So, if you are plotting it, it will be like this, we are having the inflow hydrograph, this is our outflow hydrograph, from the curve it is very clear that the points R and P do not coincide, R is coming here, R is representing the point of maximum storage and P is the peak of outflow hydrograph. So, here peak of outflow hydrograph and the point corresponding to maximum storage both are different, both are not coinciding, even though both the hydrographs are intersecting at a particular point that is representing the point of maximum storage, that is different from the peak flow of the outflow hydrograph. This is due to the retarding effect of the backwater. So, P is the maximum outflow and R is the maximum storage.

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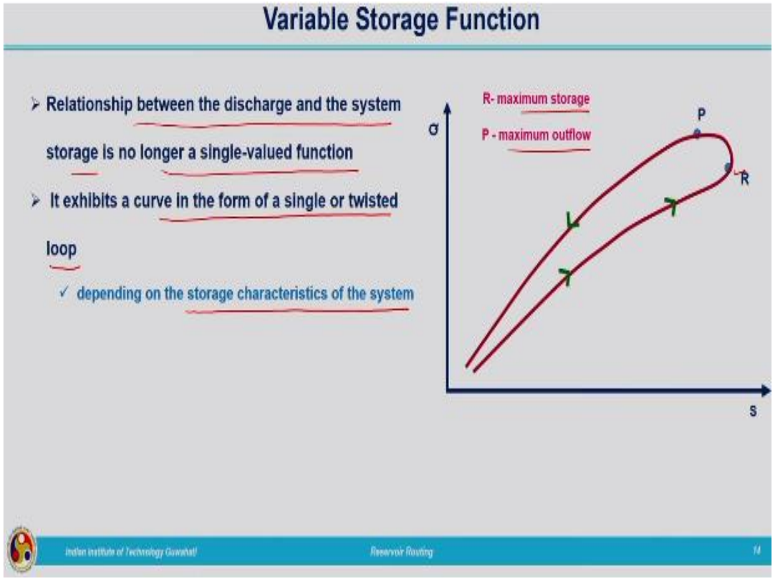

Actually, we want the relationship between the S and Q. Coming to the relationship between the discharge and the system storage is no longer a single valued function. We cannot represent the relationship between the storage and outflow by making use of a single valued function as we have taken in the case of invariable storage function, $S = f(Q)$. It exhibits a curve in the form of a single or twisted loop that depends on the storage characteristics of the system. It can be plotted by means of this curve, it is like a twisted loop. So, here in this case we can mark R that is the point corresponding to maximum storage at this particular point and the peak of outflow somewhere away from that, both are not coinciding each other. R is the maximum storage and P maximum outflow, both are not coinciding each other, both are representing different points that with the help of the hydrographs also we have understood.

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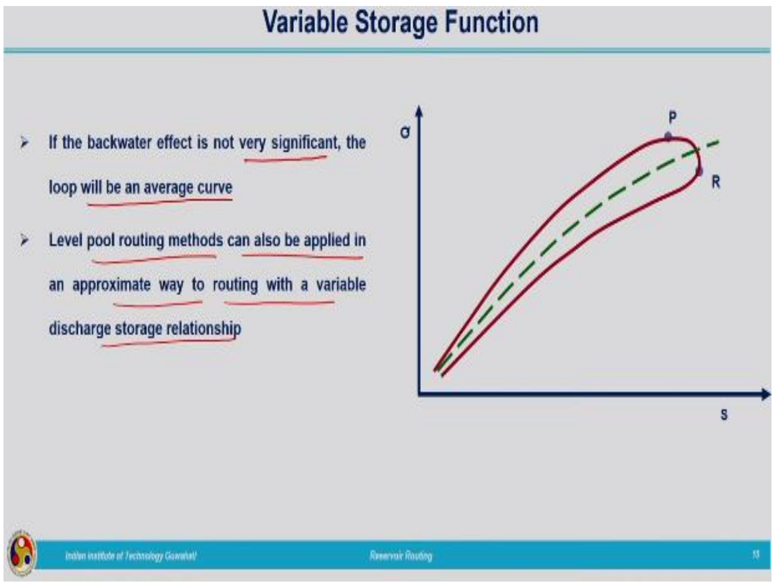

Sometimes it can happen in such a way that the effect of back water may not be that much significant and the loop can be averaged by means of an average curve. Instead of making use of the twisted loop we can average this thing, these two loops will be the ends of the loops will be coming closer and it can be averaged to get a single curve, that assumption can be made in the case of back water effect is very less, negligible backwater effect can be considered in such a way that it is representing an average storage discharge curve. So, it can be drawn like this, the storage discharge function can be represented by means of this average curve. In such cases level pool routing methods can also be applied. Level pool routing is the one in which we have assumed the invariable storage function and that can be applied in an approximate way to carry out the routing with a variable discharge storage relationship. Methodology will be similar to that of the level pool routing but the storage function we will be making use by making use of the average curve of this storage discharge function.

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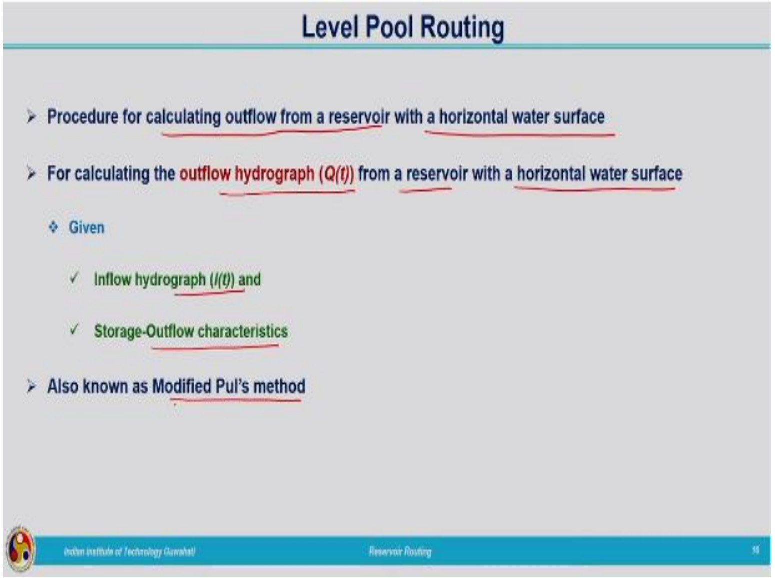

Now, we can move on to the reservoir routing. This technique is considering the water level to be horizontal, this is also termed as level pool routing. Another name which is used is the modified Pul’s method. So, level pool routing or the reservoir routing is the procedure for calculating outflow from a reservoir with a horizontal water surface. We are assuming a horizontal water surface in the case of a reservoir routing with this method, so that we can assume the storage discharge function as a single invariable storage function. For carrying out this level pool routing we need to have certain data, what are these input requirements. We need to have inflow hydrograph *I(t)* and storage discharge characteristics, that is storage outflow characteristics. This method is also termed as modified Pul’s method. This is a semi graphical method, that is level pool routing or modified Pul’s method is a semi graphical method.

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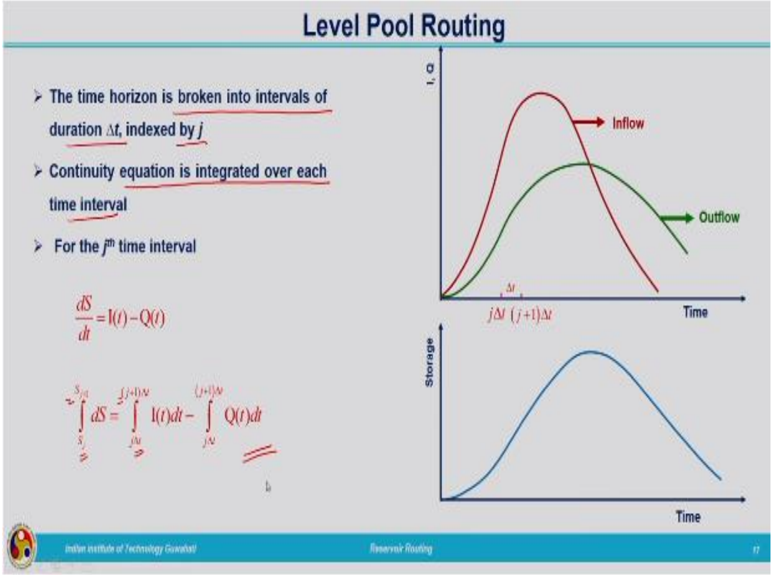

These graphs you already know, the upper ones are representing the inflow and outflow hydrographs and the lower one is representing the storage and time relationship. Storage versus time is also plotted. The time horizon is broken into intervals of duration Δt indexed by *j*, that is from the inflow hydrograph we can understand that it has got a certain time base or time is increasing, rising curve is occurring then peak has attained and then reducing, recession curve has started, finally the flow is reaching at 0 value. So, we know as the time elapses how the inflow variation is there, so that time is discretized into different time intervals Δt. So, we are going to represent it at the j^{th} index. So, at this particular point it is $j\Delta t$ and next point is $j+1\,\Delta t$. Between these two the time interval is Δt, Δt has to be small because here we are going to assume that is the continuity equation is integrated for each time interval. Each of this Δt we are going to integrate the continuity equation. So that is the principle which we are going to make use here. So, integrating continuity equation is equivalent to averaging out the values between these two time intervals if we are considering Δt to be very small, that is we are making an assumption that within this time interval the variation corresponding to discharge, storage and also inflow can be considered to be linear. So, for the j^{th} time interval $\frac{dS}{dt}$ we are having the expression time rate of change of storage is equal to $\mathrm{I}(t) - \mathrm{Q}(t)$ represented by our continuity equation. What we will be doing? We are going to integrate *dS*,

$dS = \mathrm{I}\,dt - \mathrm{Q}\,dt$

This equation we are going to integrate between the interval *j* and *j+1*, *j*Δ*t* and (*j+1)*Δ*t*. So, the storage varies from S_j to S_{j+1} and time varies from *j*Δ*t* and (*j+1)*Δ*t*. So, the integral equation can be represented by this equation

$$\int_{S_j}^{S_{j+1}} dS = \int_{j\Delta t}^{(j+1)\Delta t} \mathrm{I}(t)dt - \int_{j\Delta t}^{(j+1)\Delta t} \mathrm{Q}(t)dt$$

Here the interval Δ*t* as I have told it will be very short interval, so we will be assuming the linear variation as far as *Q*, *S* and *I* are concerned.

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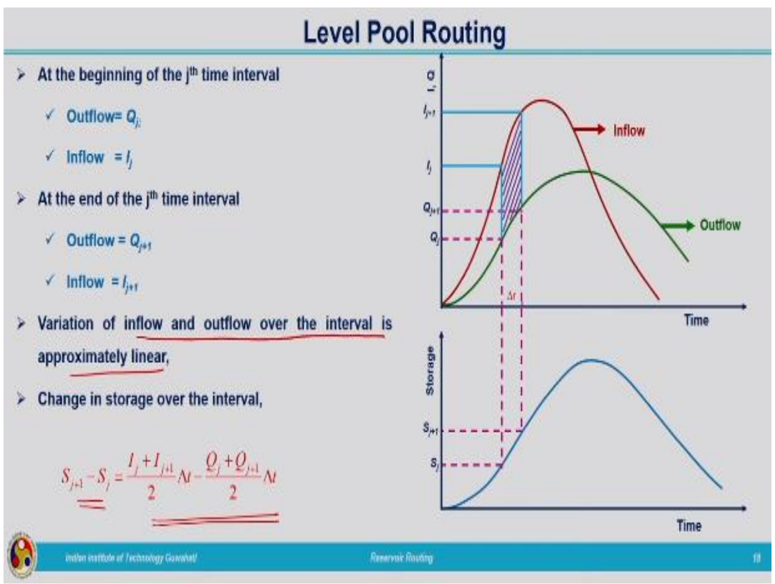

So, we will write the expression in that way. At the beginning of the j^{th} time interval outflow is Q_j, inflow is I_j. So that is marked over here, the outflow Q_j and inflow I_j. Now, the corresponding storage is marked by S_j and at the end of the j^{th} time interval or at the beginning of $(j+1)^{th}$ time interval, we can write outflow is equal to Q_{j+1} and inflow is equal to I_{j+1}, that can be marked like this Q_{j+1} and I_{j+1}, corresponding storage is S_{j+1}. So, these are the different terms which we are going to make use for converting the previous integral equation. So, the variation of inflow and outflow over the interval is approximately linear, so that we should be very careful while considering the Δt interval. If it is too large we cannot assume this linearity assumption. So, change in storage over this interval can be represented by this hatched area. So that can be represented by making use of our continuity equation, previous equation has been rewritten after averaging out different terms i.e.,

$$S_{j+1} - S_j = \frac{I_j + I_{j+1}}{2}\Delta t - \frac{Q_j + Q_{j+1}}{2}\Delta t$$

So, for making the calculation simpler we have averaged out the expression. So, the equation has taken this form, that is the inflows and outflows were averaged out and the difference between j^{th} and *(j+1)* nodes considered that is corresponding to Δt is considered that is representing the change in storage $S_{j+1} - S_j$. So, that is written over here by the above equation and you can see maximum storage is marked over here that is representing the point of inflection.

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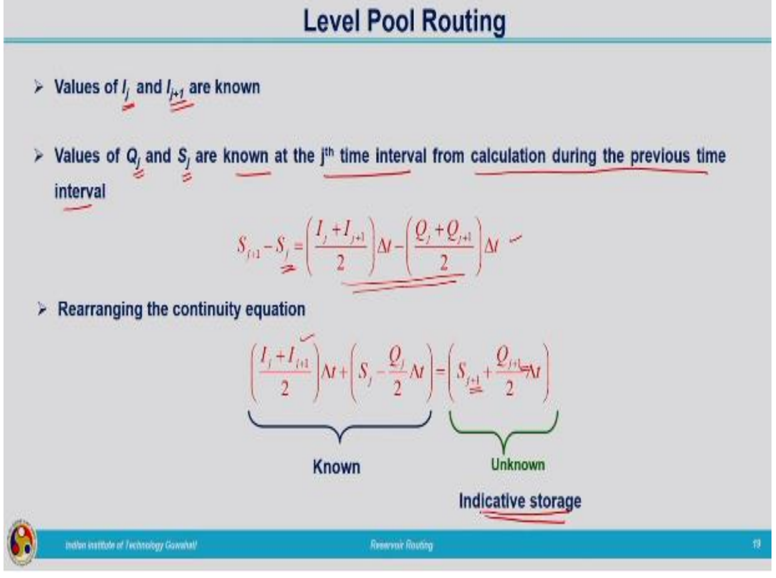

Now, values of I_j and I_{j+1} are known. While explaining the data requirements I have already told that we need to have the inflow hydrograph. For carrying out the hydrologic routing or the level pool routing some input data is required, in that we need to have the inflow hydrograph. So, corresponding to the values I_j and I_{j+1} it is already there with us. Values of Q_j and S_j are also known at the j^{th} time interval from calculation during the previous time interval. Forget about the

j^{th} time interval, at the beginning some initial conditions need to be provided. So, initially we are having the inflow hydrograph and the values corresponding to the outflow value and also storage is known to us. Initial conditions need to be provided along with the inflow hydrograph and in addition to that we need to have the storage discharge function. So, this is our relationship which we have seen in the previous slide. Difference in storage can be written by making use of this expression. This equation we are going to modify based on the data which we are having. We need to arrange this equation in such a way that known values to the one side of the equation and unknown values on the other side of the equation. So, we are going to rearrange this continuity equation

$$S_{j+1} - S_j = \left(\frac{I_j + I_{j+1}}{2} \right) \Delta t - \left(\frac{Q_j + Q_{j+1}}{2} \right) \Delta t$$

we are just rearranging this equation is equal to

$$\left(\frac{I_j + I_{j+1}}{2} \right) \Delta t + \left(S_j - \frac{Q_j}{2} \Delta t \right) = \left(S_{j+1} + \frac{Q_{j+1}}{2} \Delta t \right)$$

At the *(j+1)* node *S* and *Q* that is the storage and discharge are unknown values, initial condition only known to us, from the initial condition we can come to the next time levels. So, that is why known values are combined together and unknown values are kept together on the right-hand side.

So, these values on the left-hand side are known values and the right-hand side are unknown which needs to be calculated. So, the term $\left(S_{j+1} + \frac{Q_{j+1}}{2} \Delta t \right)$ is termed as indicative storage, which is unknown. Indicative storage which is unknown that needs to be calculated. But at the first-time step, at the beginning, beginning of the first time step these values are known to us, initial conditions are already provided.

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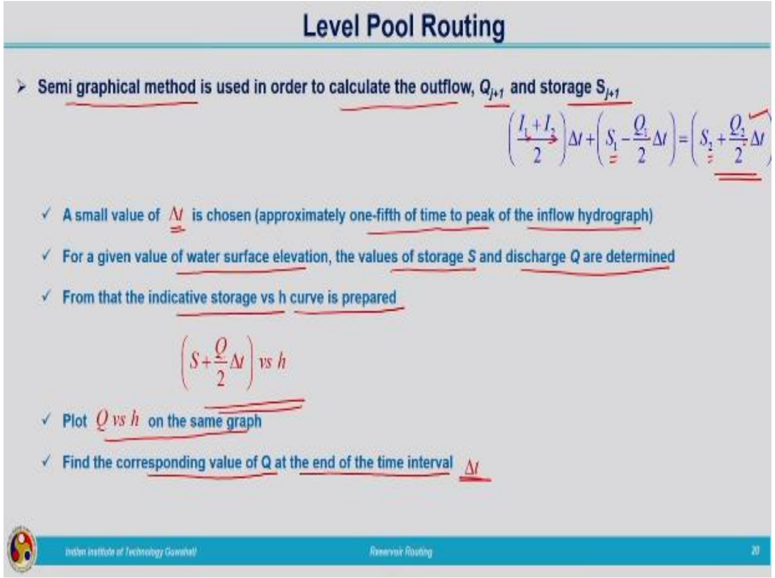

So, what we are going to do? We are going to make use of a semi graphical method in order to calculate the outflow Q_{j+1} and storage S_{j+1}. This is our equation just repeated from the previous slide,

$$\left(\frac{I_1+I_2}{2}\right)\Delta t+\left(S_1-\frac{Q_1}{2}\Delta t\right)=\left(S_2+\frac{Q_2}{2}\Delta t\right)$$

left hand side values are known to us and right-hand side values are unknown. Instead of I_j, I_{j+1} I have taken it for the beginning $\left(\frac{I_1+I_2}{2}\right)$, $\left(S_1-\frac{Q_1}{2}\right)$, $\left(S_2+\frac{Q_2}{2}\right)$. S_2 and Q_2 are unknown. Look at the equation I_1, I_2 known to as complete inflow hydrograph is there and S_1 and Q_1 corresponding to the initial condition storage and discharge is known to us. So, this left-hand side can be computed that is equal to the right-hand side represented by the indicative discharge. Now, a small value of Δt should be chosen. So, for calculating the left-hand side we need to have an assumption corresponding to Δt, that Δt should be taken in such a way that the linearity assumption should be valid between these nodal points. It can be approximately taken as one fifth of time to peak of the inflow hydrograph. Since inflow hydrograph is known to us, we know the time to peak of inflow hydrograph, based on that we will be calculating the one fifth of that value that can be considered as the Δt as an initial guess. For a given value of water surface elevation the values of storages and discharge Q are determined. We are already having the relationship between the storage and Q and the variation with respect to water surface elevation as far as S and Q are concerned, those are known to us from the previous records. So, from the known values of S versus h and Q versus h we can find out the relationship between S versus Q. So, from that the indicative storage versus h curve is prepared, that is indicative storage means what is there, indicative storage is the one which is represented by the right-hand side of this equation, $\left(S_2 + \frac{Q_2}{2}\Delta t\right)$. So that is calculated from the known values of S and Q, that is S versus h and Q versus h relationship is already there with us, based on that we can find out the value corresponding to the indicative discharge.

So, once the indicative discharge is calculated the curve corresponding to indicative discharge versus h is plotted, that is $\left(S + \frac{Q}{2}\Delta t\right)$versus h is plotted. Now, in the same plot we will be drawing Q versus h curve, discharge or outflow versus h which is given to us that also will be plotted in the same plot of indicative discharge versus water surface elevation. From that find the corresponding value of Q at the end of the time interval Δt. If I say like this you would not be able to understand anything we will discuss it with the help of different graphs.

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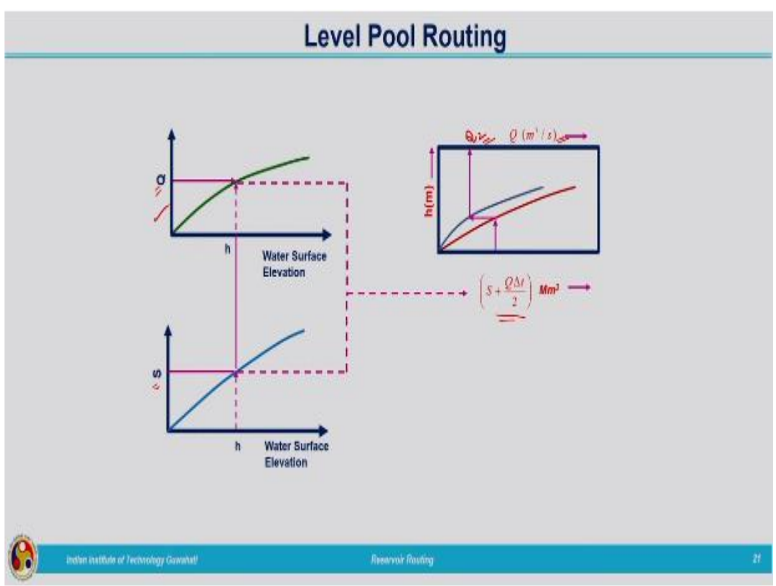

So, this graph that is the first graph is representing Q versus h that is the outflow versus elevation water surface elevation, water surface elevation along the x-axis and outflow along the y-axis and the graph below that is representing the storage versus h curve, that is storage along the y axis and water surface elevation along the x axis. Now, what we are going to do corresponding to particular h we will note down the storage. In the similar way corresponding to same h we will note down the value corresponding to Q. After that by making use of this S and Q value corresponding to single h, we will calculate the value corresponding to the indicative discharge $\left(S+\frac{Q}{2}\Delta t\right)$. S and Q corresponding to single h we have taken from the graphs, which are known to us and Δt we have assumed one fifth of the time to peak of the inflow hydrograph, from that we are calculating the indicative discharge. After that what we will do, as the next step we will plot another graph that is this $\left(S+\frac{Q}{2}\Delta t\right)$ in million-meter cube we will convert and that will be plotted along the x axis and y axis will plot water surface elevation. This graph can be completed because for different water surface elevation small h value we are having different Q values and different S values. Corresponding to each and every h value we will calculate the this $\left(S+\frac{Q}{2}\Delta t\right)$, that is the indicative discharge and indicative discharge versus h water surface elevation will be plotted like this and in the same curve we will plot the Q versus h, that is the same curve, this curve, Q versus h we will plot in this, that is Q will be plotted along the x axis and h along the y axis. So, we will get an approximate curve like this and initial value of $\left(S+\frac{Q}{2}\Delta t\right)$ is known to us, corresponding to that we will project it on to the h versus Q curve and it will represent the value corresponding to Q_2. So, now Q_2 value is known to us, Q_1 value from the initial condition we were having idea and now Q_2 is obtained from the indicative discharge curve. We have plotted the h versus indicative discharge and h versus Q which is already given to us in the same graph and from the initial value of indicative discharge we have found out the value corresponding to Q_2, that is the outflow corresponding to the end of the time interval Δt.

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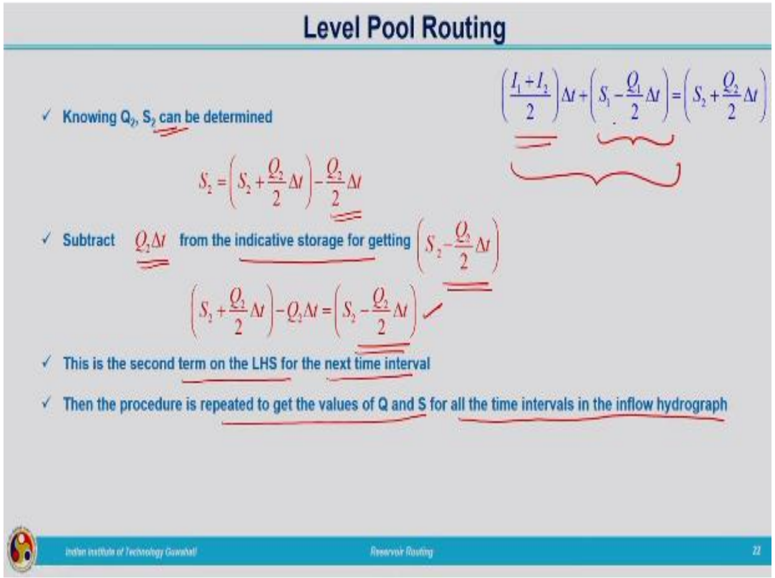

So, by knowing Q_2 we can determine S_2, that is we are going to make use of this equation,

$$\left(\frac{I_1+I_2}{2}\right)\Delta t+\left(S_1-\frac{Q_1}{2}\Delta t\right)=\left(S_2+\frac{Q_2}{2}\Delta t\right)$$

Here, we are having the indicative discharge S_2 is equal to

$$S_2=\left(S_2+\frac{Q_2}{2}\Delta t\right)-\frac{Q_2}{2}\Delta t$$

that is indicative discharge minus $\frac{Q_2}{2}\Delta t$ will be giving us the value corresponding to storage at the end of the time step. So, S_2 is obtained like that. Now what we will do we will subtract $Q_2\Delta t$ from the indicative storage for getting $\left(S_2-\frac{Q_2}{2}\Delta t\right)$ i.e.,

$$\left(S_2+\frac{Q_2}{2}\Delta t\right)-Q_2\Delta t=\left(S_2-\frac{Q_2}{2}\Delta t\right)$$

So, by subtracting $Q_2 \Delta t$ from the indicative storage we will get the value corresponding to $\left(S_2 - \frac{Q_2}{2}\Delta t\right)$. This is the second term on the LHS for the next time interval, that is $\left(S_2 - \frac{Q_2}{2}\Delta t\right)$ is calculated here, this is the second term on the equation. So, this second term is known to us $\left(\frac{I_1 + I_2}{2}\right)$ for all the time are known to us, so we are known with the left-hand side. Now, indicative discharge corresponding to the end of the time interval is known to us. So, the procedure which we have taken now will be repeated till the end of the inflow hydrograph ridges. So, this is the step that is it is a semi graphical technique we need to make use of the graphs given to us that is the relationship *S* versus *h* and *Q* versus *h* are known to us, from that we are finding out the value corresponding to indicative discharge and indicative discharge is plotted against the water depth and in the same plot we have plotted the discharge versus water depth. By making use of that graphical technique we will get the *Q* value corresponding to the end of that time step and after that following these steps we can proceed till the end of the inflow hydrograph.

So, the procedure is repeated to get the values of *Q* and *S* for all the time intervals in the inflow hydrograph. Thus by following these steps we can calculate the discharge hydrograph, that is the outflow hydrograph and storage versus time, that is for different time intervals we are calculating, so at a particular point by making use of the inflow hydrograph and the known relationships that is directly *Q* versus *S* relationship is not given to us, but we are having the relationship, how the storage is varying with respect to water surface elevation and also how the outflow is varying with respect to water surface elevation those are known values.

By making use of the inflow hydrograph and the known relationships of *S* versus *h* and *Q* versus *h*, we can calculate the indicative discharge and from that we are finding out the *Q* or the outflow corresponding to the end of the time step and steps which are explained over here can be continued to get the values corresponding to *S* and *Q* for different time intervals. This procedure will be repeating until the end of the inflow hydrograph, that way we can plot the outflow hydrograph and the storage corresponding to the location at the downstream point of the reservoir making use of the inflow data.

So, that much about level pool routing. Level pool routing is the same as that of modified Pul's method of reservoir routing. This is coming under the category of hydrologic routing. Do not get confused with the hydraulic routing. This is reservoir routing which we have explained is based on the hydrologic routing principle, so we have made use of only the continuity equation, we have not used the momentum equation here in this case. We have used the continuity equation along with some storage discharge relationship.

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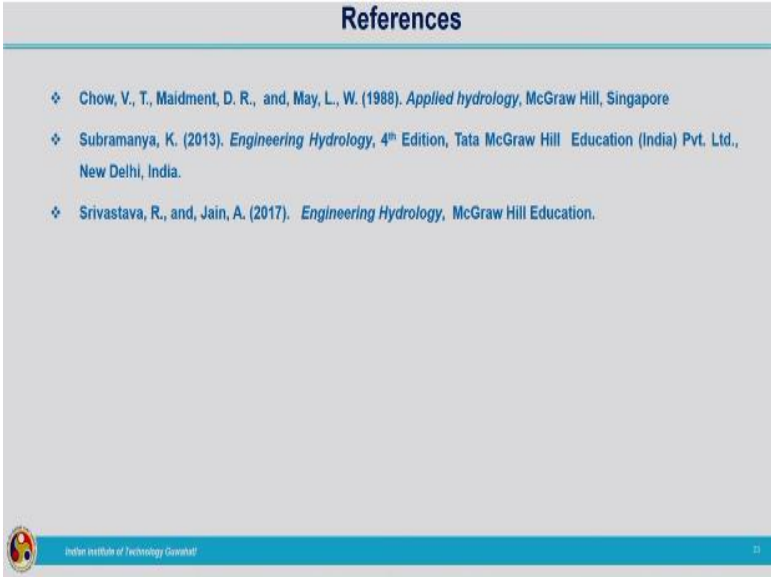

So, the references related to this topic are given over here. Here I am winding up this lecture. Thank you.