Course Name: Watershed Hydrology

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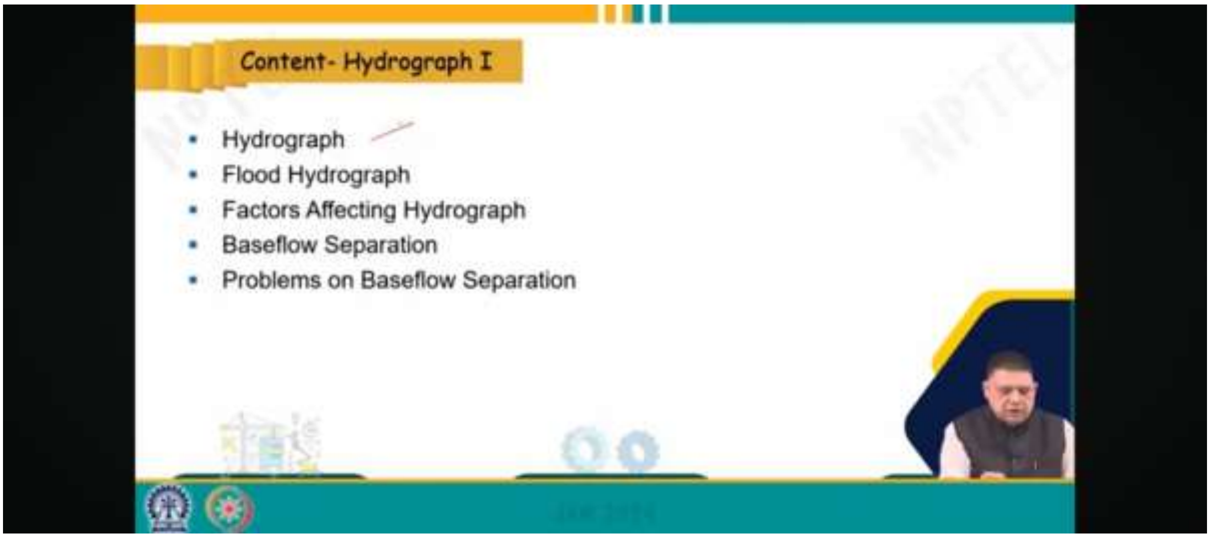
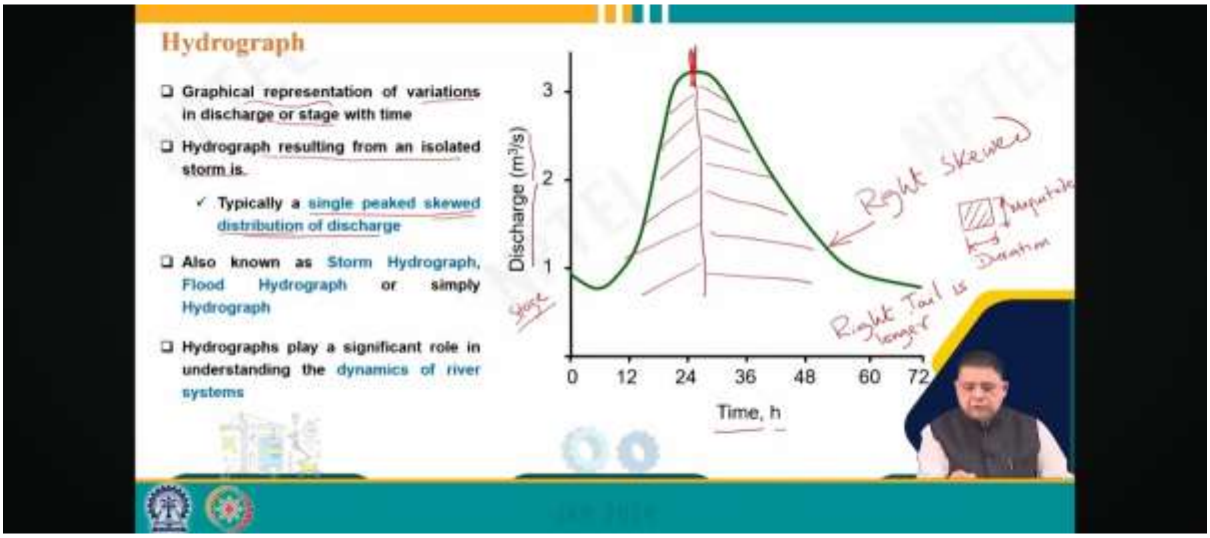
Week: 05

Lecture 21: Hydrograph I



Hello friends, welcome back to this online certification course on Watershed Hydrology. I am Rajendra Singh, a professor in the Department of Agriculture and Food Engineering at the Indian Institute of Technology Kharagpur. We are beginning Module 5 today; this is Lecture Number 1 and the topic is Hydrograph Part 1. In this lecture, we will introduce the hydrograph, then discuss the flood hydrograph, proceed to factors affecting the hydrograph and finally, delve into an important hydrological analysis called base flow separation. We will also work on a problem related to base flow separation.

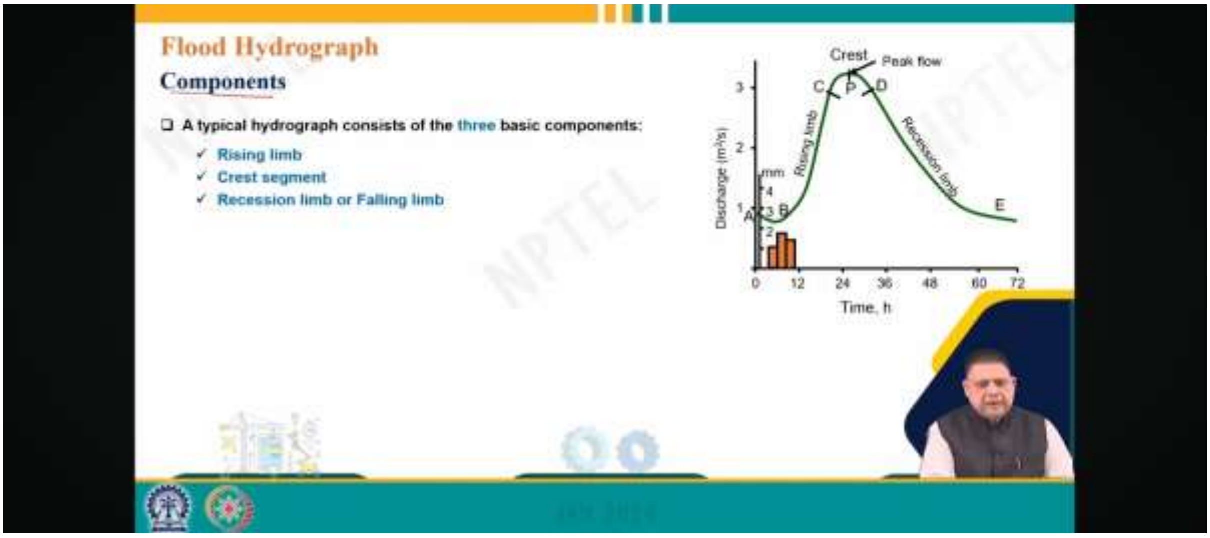


Now, coming to the hydrograph, it is the graphical representation of variations in discharge or stage with time. So, if we plot discharge in cubic meters per second against time in hours, or if we plot stage, as you saw, we have rating curves representing stage-discharge relationships. Thus, it could be stage or discharge, but mostly, it is discharge. Therefore, when we plot discharge against time, it is called a hydrograph, and a hydrograph resulting from an isolated storm typically exhibits a single-peaked skewed distribution of discharge. So, when we refer to an isolated storm, it means a storm of a certain duration and magnitude.

So, when we say isolated storm, that means it is a single spike of a certain duration and having a certain effective rainfall magnitude and of course, it is uniformly distributed over this particular time. So, if a hydrograph we take which results from an isolated storm, then it will have a single peak. Just a single peak will be there. Here you can see a single peak. If it is a complex storm, there might be more than one peak, but typically in an isolated storm, there will be a single peak and it is a skewed distribution. A skewed distribution, when we say that the area under the curve, if we draw a vertical line here, then if you take the left side and the right side, the area under the curve or the magnitude which is represented by the left-hand side and the right-hand side, they differ. So, this is a skewed distribution, not uniform, that the left side and the right side are not uniform and, in this case, it is basically a hydrograph that is right-skewed, that means its right tail is longer than the left tail. So, the right tail is longer.

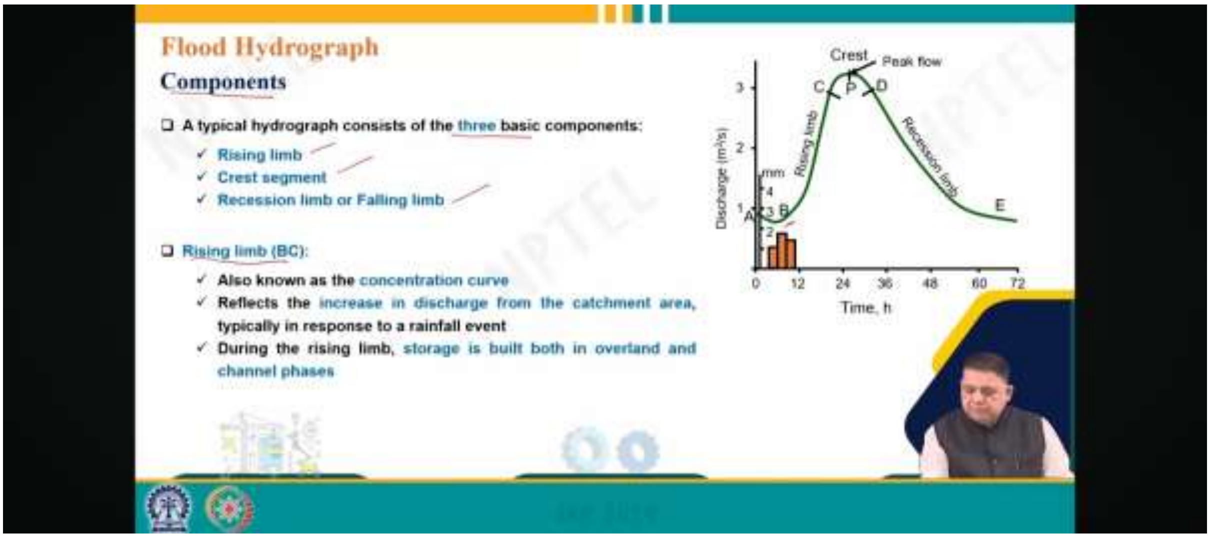
So, always when you draw a hydrograph, you have to keep in mind that its right tail is longer. Many times, what happens is that we discuss normal distribution also, where we said that its mean is here and the area on either side of the curve is the same. So, this is normal distribution because the area on either side, left side, right side, is the same. That is normal distribution and many times when students are asked to plot a hydrograph, they typically plot a normal distribution curve which is not correct. So, please do remember that when you draw a hydrograph, remember that it is a skewed distribution and that simply means its right tail is longer than the left tail and that is why then you will automatically get a proper shape. So, you have to remember this form.

A hydrograph is also known as a storm hydrograph, flood hydrograph or simply a hydrograph. So, when we say flood hydrograph, hydrograph or storm hydrograph, we mean the same thing: a discharge plotted against time. Hydrographs play a significant role in understanding the dynamics of river systems, which is quite obvious because we know that for any water resources management in a particular region for development, we do require the magnitude of water resources, which we have discussed several times. Basically, through hydrographs, we can find out how much water is available at a particular location in a stream, as well as its magnitude and timing. Accordingly, we can plan our activity. That is the importance of hydrograph.



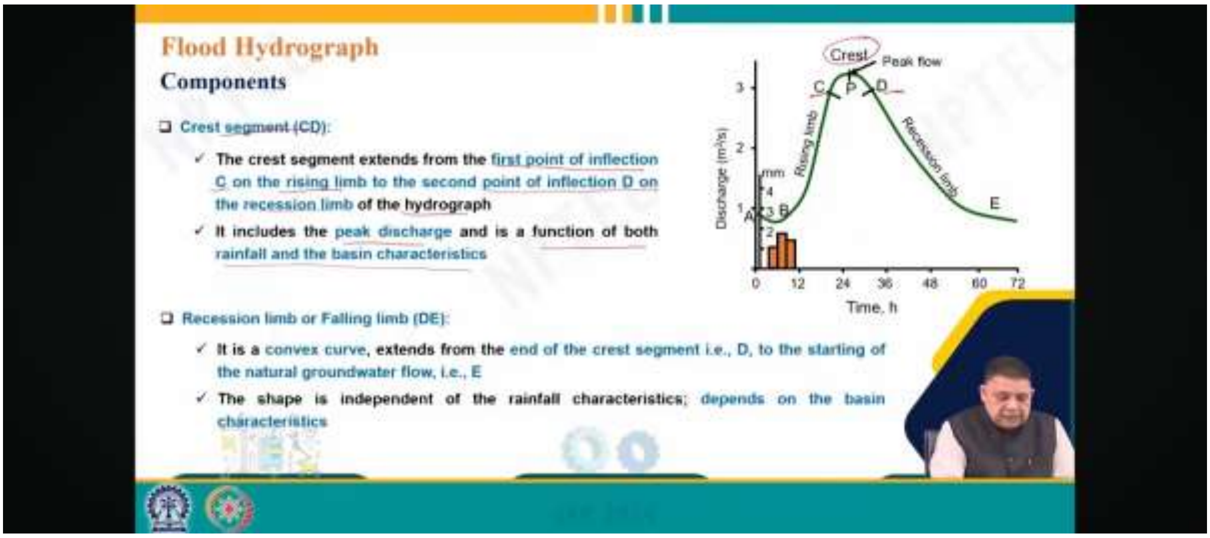
Now, if we talk about the components of a hydrograph, a typical hydrograph consists of three basic components: rising limb, crest segment and recession limb or falling limb.

As you can see here in this graph, we have the rising limb, we have the crest segment and we have the recession limb. If we take them one by one, starting with the rising limb, which starts from point B and ends at point C here, then this is the rising limb. You can see here that the high ERH, or effective rainfall hydrograph, is plotted, indicating the runoff generation and the consequent rise in water level or discharge. This part shows the increasing discharge with time. Point B represents the start point, and C is called the point of inflection. The rise continues after that point as well.

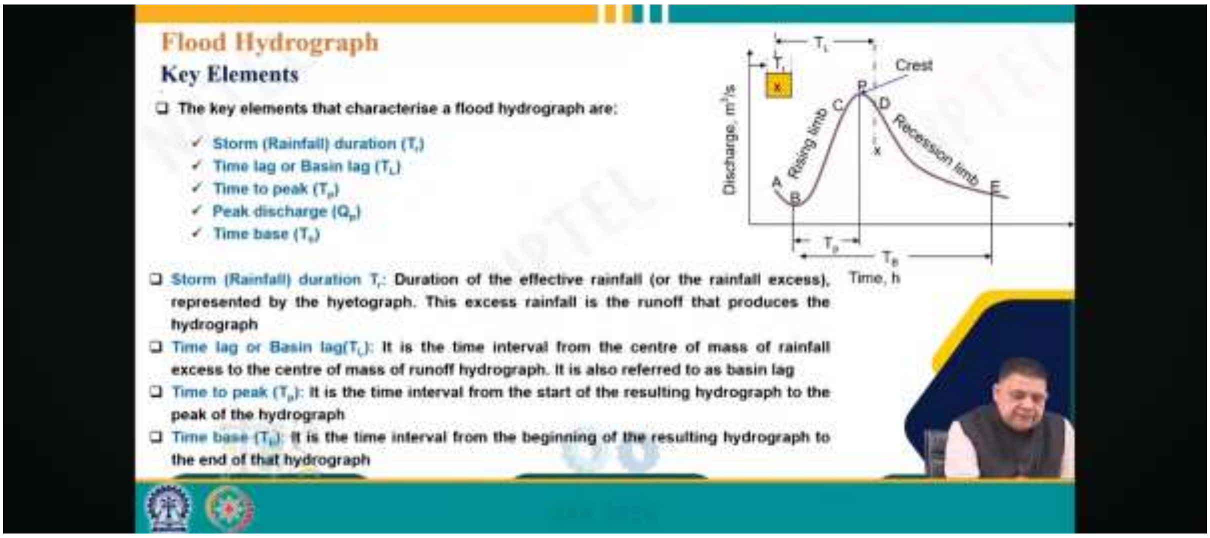


So, this part is called the rising limb. It is also called the concentration curve because the flow is actually getting concentrated in the basin. So, there is a concentration of flow and a rise or increase, which is why it is called a concentration curve. It reflects the increase in discharge from the catchment area typically in response to a rainfall event. So, as we have already discussed, whenever a rainfall event occurs, there will be abstractions. After abstractions, we have effective rainfall, and as a result of that, there will be overland flow and an increase in surface runoff. At the same time, the infiltrated water could flow either through subsurface flow or through groundwater, which also contributes to the stream. And of course, this discharge includes both surface and groundwater flow, a base flow, and during the rising limb, storage is built both in overland and channel phases.

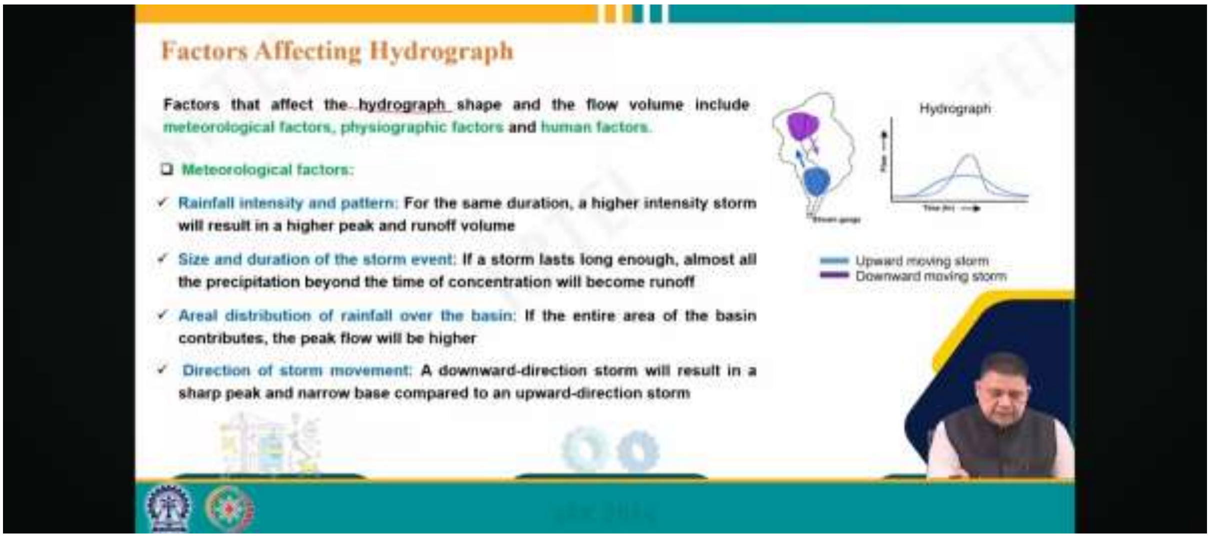
So, here, overland flow is taking place. Obviously, the flow depth increases. We discussed Hortonian overland flow; then as the flow reaches the outlet, its depth increases because of a larger area contributing, and also the channels which carry the flow will have a rising trend; they will also have higher flow leading to the stream. So, this is the rising limb. Then next comes the crest segment CD. It starts from here and ends here, and the crest segment extends from the first point of inflection C on the rising limb to the second point of inflection D on the recession limb of the hydrograph. As you can see, this crest segment starts from a point of inflection on the rising limb, which is shown here as C and a point of inflection on the recession limb, shown as point D.



Basically, when we say "point of inflection," that basically shows that the curve's slope changes drastically at that point. So, of course, you can see here, the slope will change; in this case, more flattening is taking place, more sharpening is taking place, and the segment's significance of this crest segment is that it includes the peak discharge and function of both rainfall and basin characteristics. In the previous case, especially, we saw it was only a factor of rainfall or the input, but in this case, it depends both on rainfall as well as basin characteristics because both sides are coming into picture here. So, between two points of inflection C and D, that is a crest segment, and its significance is that it keeps the crest or the peak discharge includes that. Then we have the third component, which is the recession limb or falling limb, which is a convex curve extending from the end of the crest segment D, that is where the peak crest segment ends, to the starting of the natural groundwater flow, that means, when this storm started, there was a certain flow in the stream, and because of this storm, the flow increased, and then, of course, there was a recession. And then, obviously, when the effect of this entire particular event goes off, then the water level will again reach its pre-rainfall event level, and that is the point we are calling E.



So, from D to E, if you join a line that represents the recession limb or falling limb, its shape is independent of rainfall characteristics; it depends on the basin characteristics. So, up to that point, basically, it's rising, and then rainfall stops. It is typically said that the inflection point on the recession limb is where the rainfall stops, and from there, you see that discharge decreases, indicating a withdrawal from the storage of the basin. That is recession. There is a withdrawal and that is why these characteristics are basically the basin characteristics which really impact the slope shape or slope of this curve, rather than the rainfall characteristics because rainfall has ceased already. So, its impact is no longer visible or valid on the recession limb. So, we have three important components: rising limb, crest segment and the recession limb.

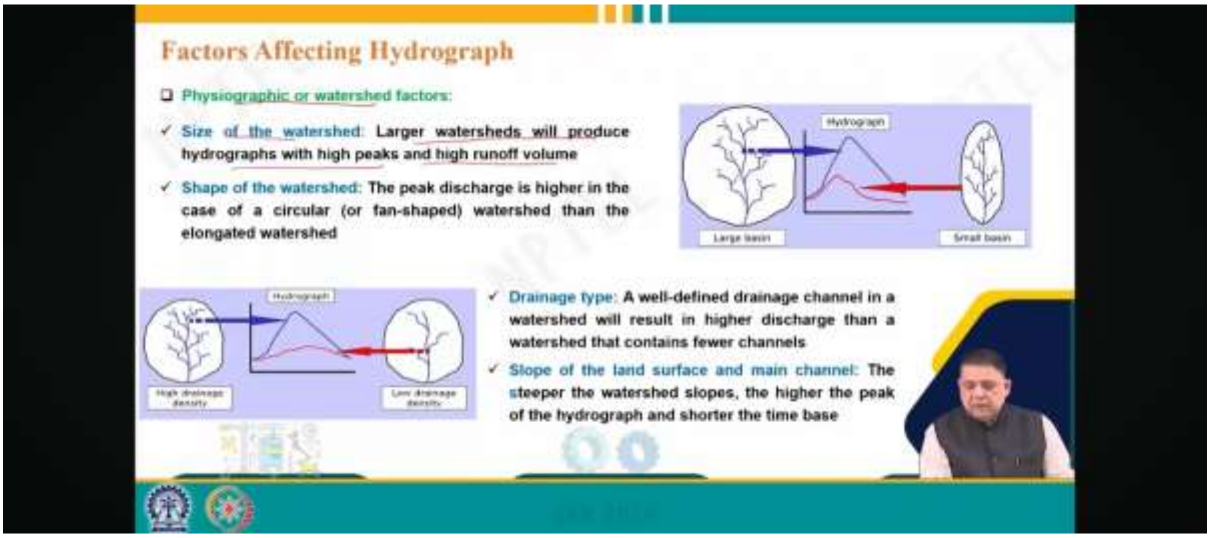


And if we come to key elements, the key elements that characterize a flood hydrographer, there are certain important features which we must understand and know, and these are storm duration TR, these are the symbols typically we use, time lag or basin lag time to peak TP, peak discharge QP, and time base, which is TV. So, as you can see here, storm rainfall duration TR. This is the storm rainfall being shown here through this rectangle where already I saw the origin, the time. This is the time scale. So, this TR, this is the time storm duration that is representing, and x is representing the magnitude of the storm. So, duration it is a duration of effective rainfall or the rainfall excess, which is represented by a hydrograph.

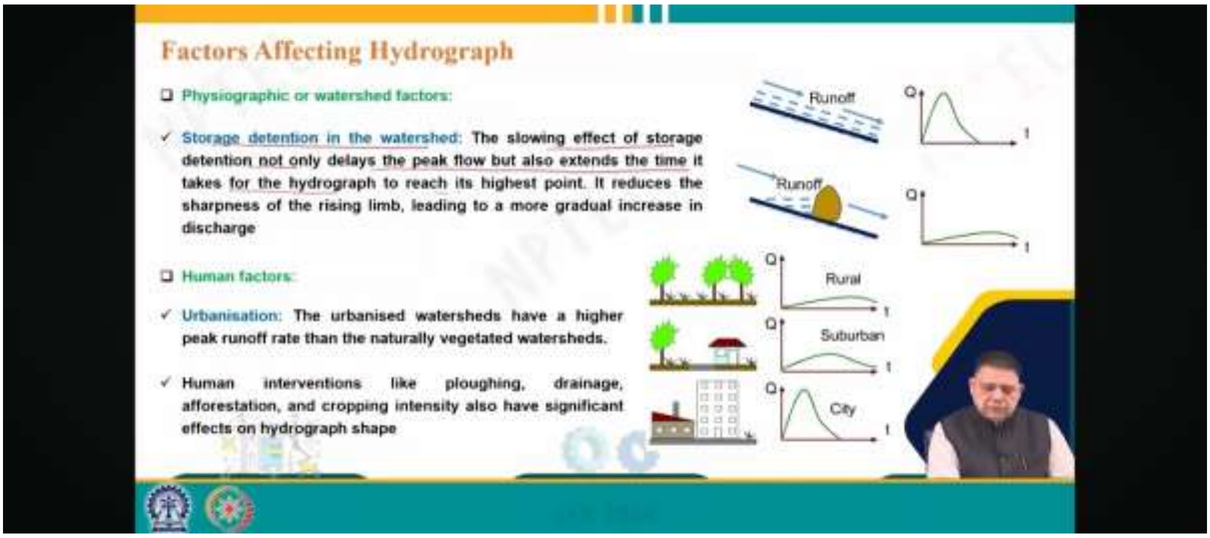
So, that is a hydrograph here, and this excess rainfall is the runoff that produces the hydrograph. So, this excess rainfall causes runoff, which basically produces this resulting hydrograph which we are seeing here. Then the second element is time lag or basin lag (TL), which is shown here as TL, and it is the time interval from the center of mass of rainfall excess to the center of mass of runoff hydrograph, and it is also referred to as basin lag. So, basically, because it is a rectangle, finding the center of mass, that is the central point, is not very difficult, but in the case of a hydrograph, because it is a skewed distribution.

So, obviously, we have to locate where the center of mass could be, and there are various ways it can be done mathematically; it can be done very easily. So, once you locate that, then the time interval between the input and the output, that is, input is the effective rainfall and output is the hydrograph. So, the time interval between these two is referred to as time lag or basin lag. Then third is time to peak time is travel from the start of the resulting hydrograph to the peak of the hydrograph. So, basically, here the hydrograph is starting and up to the peak, that is the time interval referred to as Tb.

Then there is a time base; it is a time interval from the beginning of resulting hydrograph to the end of that hydrographs and that is the point we said we discussed ah point E here. So, from point B to point E, the time interval that is referred to as time base ah of the hydrographs, and these are ah and of course, the Q_p or the peak discharge which is being represented by this vertical line, this is also very important. So, these are some important elements and many times you will sign find figures just representing these symbols. So, it is very important that you understand ah what these symbols represent and what they mean actually, so it is very important to remember. Then we can talk about the factors affecting ah runoff and the factors that affect the ah factor factors affecting hydrograph, and basically the factors affecting hydrograph are the factors affecting runoff which we have discussed earlier because of the simple reason that ah how the hydrograph is affected because of the ah external factors ah then that reflects on the hydrograph shape also.



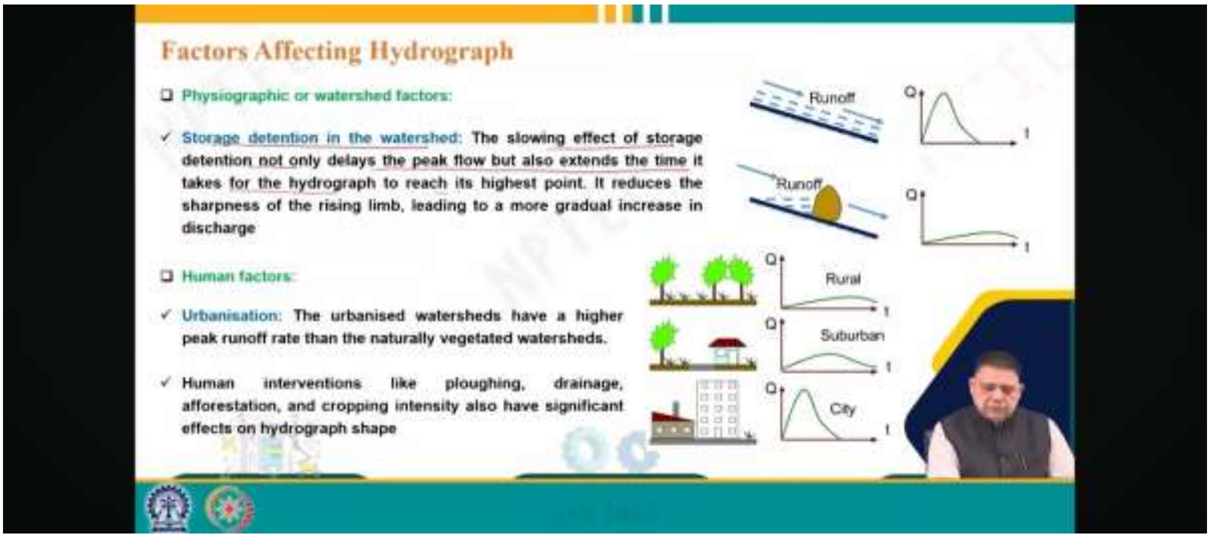
So, factors that affect the hydrograph shape and flow volume they include meteorological factors, physiographic factors and human factors, and already in detail, we have discussed this. So, meteorological factors that are important rainfall intensity and pattern size and duration of storm event, aerial distribution of rainfall, direction of storm. So, aerial distribution is important because if the entire area of the basin contributes the peak flow will be higher and direction of a storm event we already discussed that if a storm is moving upwards or towards downwards then it affects the runoff differently and that is how the hydrograph shape is also affected like a downward direction storm will result in a sharp peak and narrow base compared to an upward direction storm that these factors we have already discussed in detail while discussing the runoff.



Then a physiographic or watershed factors. So, size of the watershed if the larger watershed will produce hydrographs with high peak and high runoff volume which is quite obvious because ah if we if the same rainfall occurs on these two then obviously, because the contributing area is more.

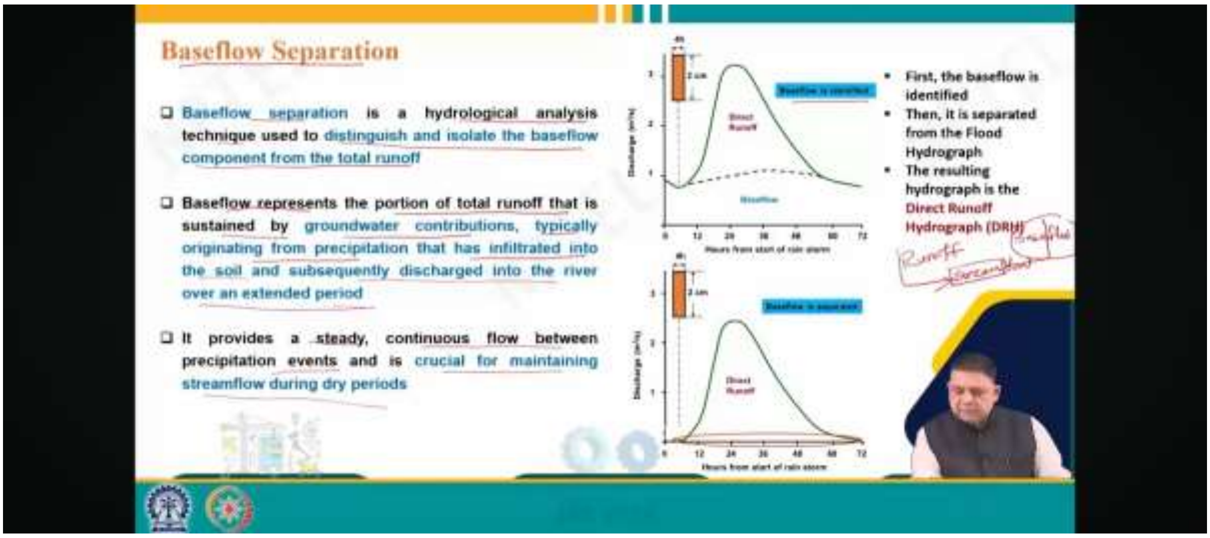
So, the peak will be high, and the magnitude will be high in total volume. Then, the shape of the watershed, the peak discharge is higher in the case of a circular or fan-shaped, as you can see here, this is a circular or fan-shaped than an elongated watershed. So, this is more of an elongated, more elongated is being shown here more in a better way. So, elongated watershed here, this is a longer elongated one. So, obviously, if it is circular or fan-shaped, then what happens is that because the time of concentration of the watershed, that is, we know that is where from the farthest point of the watershed water reaches the outlet and once it is a fan shape.

So, the time of travel from different parts of the watershed is more or less the same, and that is why water reaches the outlet at the same time, and that is why the flow peak is higher in the case of a circular or fan-shaped watershed. Then, drainage type, a well-defined drainage channel in a watershed will result in high discharge than a watershed that contains fewer channels, which is quite obvious because if the drainage channels are well-developed or well-defined, then they will carry the water quickly to the outlet, and the slope of the land surface and the main channel steeper, the watershed slope, higher the peak of the hydrograph, which is quite obvious because the flow velocity will be so, most of the water will be reaching almost at the same time, and that, but the time base will be of course, shorter because water will quickly go out of the basin if it is a slope land. Then, physiographic and watershed characteristic is still continuing that storage detention of the watershed. So, obviously, the slowing effect of storage detention not only delays the peak flow but also extends the time it takes the hydrograph to reach its highest point. So, obviously, if there are storage structures as you can see in here if there are storage structures and then water will be of course, most of the water will be stored and thus the water which will be reaching the outlet will be significantly impacted and it is compared to a watershed where there is no storage structure and the it will be quite a flat hydrograph maybe time base is longer.



Then there are certain human factors also that impact the shape of the hydrograph, and most importantly, its urbanization. So, if the urbanized watershed has a higher peak runoff rate than the naturally vegetated watershed. So, obviously, if it is a highly urbanized watershed then obviously, as we know that most of the land surface will be paved because of roads, buildings, and other constructions. So, because of that, most of the water will quickly flow out and that is why it will have a much higher peak compared to a suburban and it will be of course, compared to a rural it will be significantly higher. Then, other human interventions like ploughing, drainage, afforestation, cropping intensity could also simply affect the hydrograph shape.

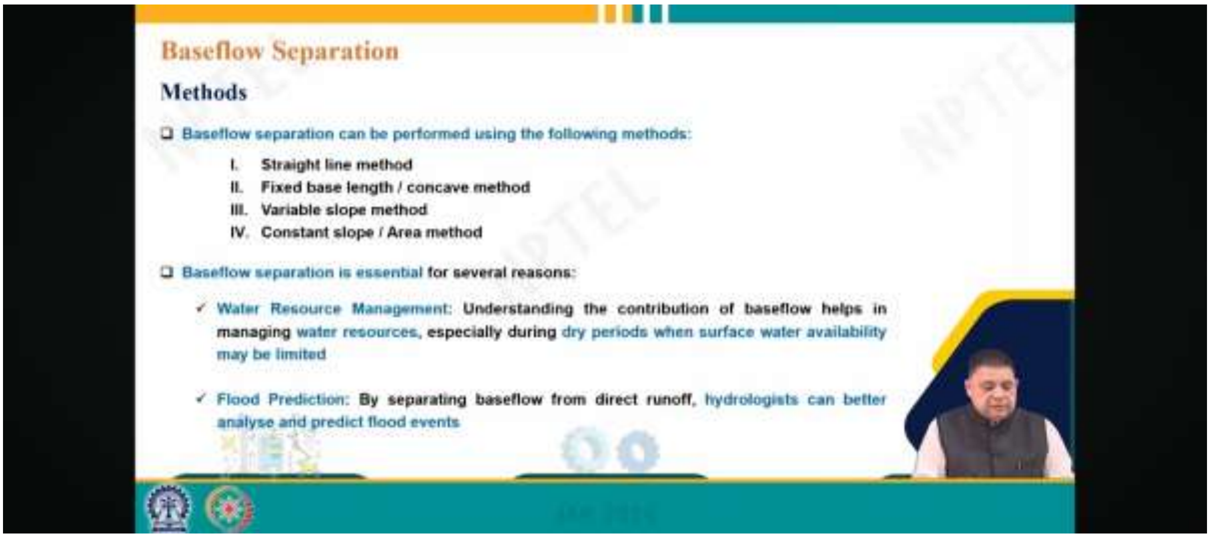
For example, if afforestation is huge then obviously, because there will be more plantation and so that means, more water will be captured in the soil or on the earth surface and because of that the flow will be lower compared to one where there is, for example, a city kind of an urban location. Then we reach base flow separation and base flow separation is a hydrological analysis technique used to distinguish and isolate the base flow component from the total runoff. And if you remember when we discussed the stream flow, we clearly marked that there are two ways, that is, if we talk about stream flow then there are two channels through which water reaches, one is runoff that is overland flow and the other is base flow that is a contribution from the subsurface flow or the groundwater flow. So, there are two components. So, what base flow separation does is that it aims at distinguishing and isolating the base flow component from the total runoff.



So, obviously, if we take out the base flow component from the runoff, then whatever is left is called direct runoff. Base flow represents the portion of the total runoff that is sustained by groundwater contribution, typically originating from precipitation that has infiltrated and been filtered into the soil, subsequently discharged into a river over an extended period. So, we also see that the velocities of subsurface flow or groundwater flow are much slower, but it is a sustained flow because the flow is slow and that is what base flow provides. It offers a steady, continuous flow between precipitation events and is crucial for maintaining stream flow during dry periods. So, obviously, when runoff events occur, then, of course, direct runoff is very important. However, during the dry period, stream flow is primarily sustained by base flow, and that is why base flow has its own significance, and that is why we separate these two and treat them slightly differently.

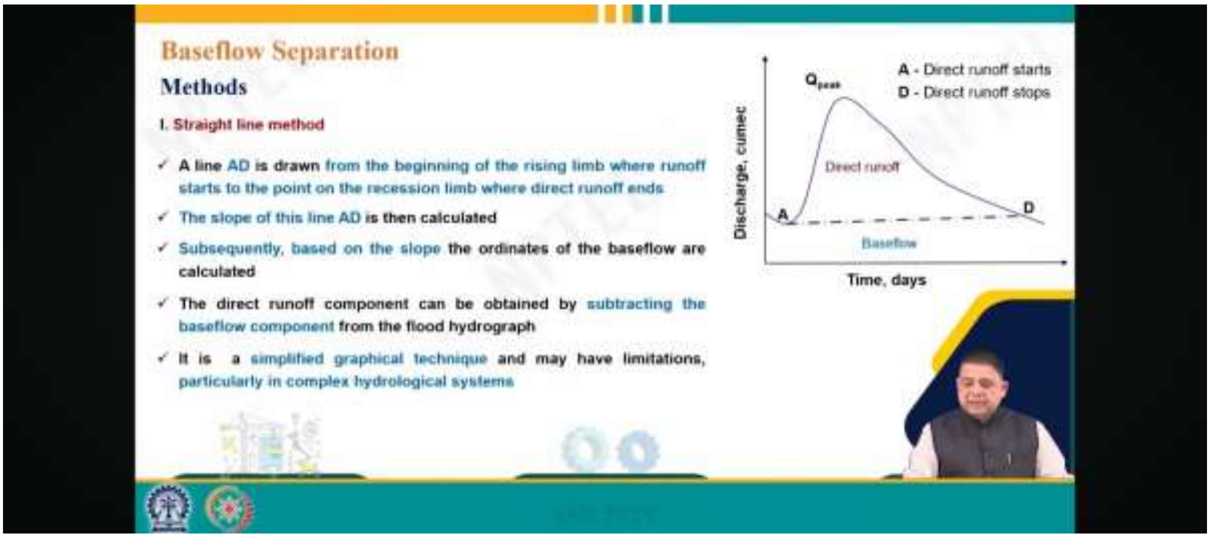
So, if you have a hydrograph and if we identify the base flow there, then obviously, if we identify the base flow and then separate it from the base flow, then whatever remainder is direct runoff. So, this one is a flood hydrograph, and this is called a direct runoff hydrograph. So, this is the difference. The lower one is a direct runoff hydrograph because here the base flow has been eliminated from the flood hydrograph. So, here we have direct runoff as well as flow, but here base flow has been taken.

So, we are left with the direct runoff hydrograph. We will see this in detail. There are several methods of base flow separation, and the important ones are the straight-line method, fixed base length or concave method, variable slope method, and constant slope or area method. Base flow separation is essential, as I already mentioned, during dry periods when surface water availability is limited. It is very significant, and that is why understanding base flow is important from the water resource management perspective during dry periods. And of course, it helps us in finding out because once we know the base flow component, then we know that whenever rainfall occurs, what will be the flood peak, and once we know that, it might also help in predicting and analysing flood events. So, that is why base flow separation is essential.



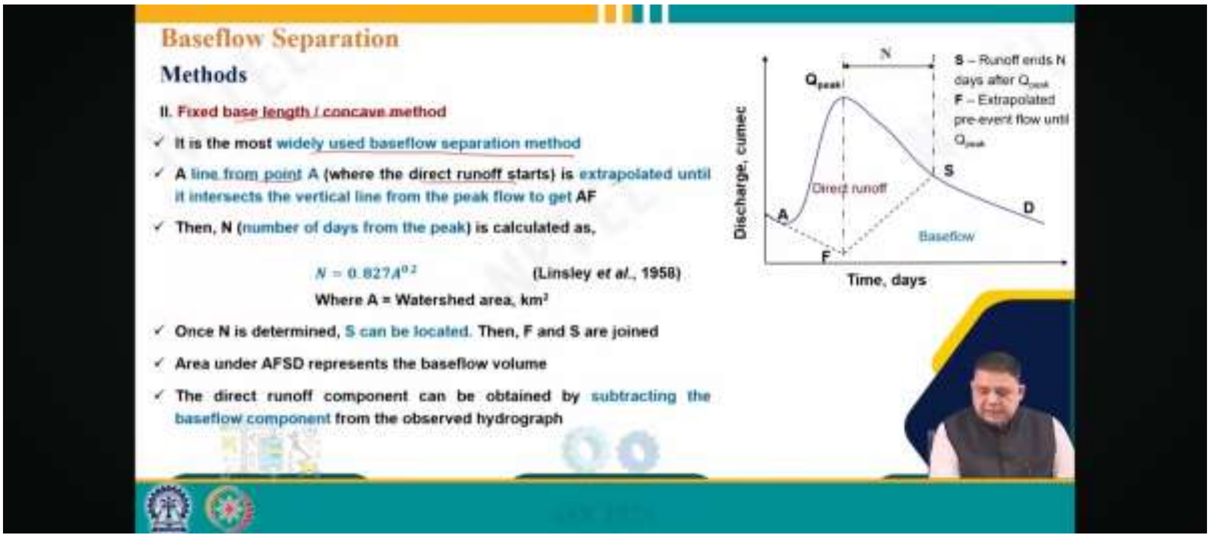
Let us take the methods of base flow separation one by one and let us start with the straight-line method. So, here, this is the flood hydrograph we talked about; now, we are calling earlier we call these points B and E, now we are calling A and D. So, a line AD is drawn from the beginning of the rising limb where runoff starts to a point on the system limb where direct runoff ends. So, that is where so here to hear we identify these two points and we draw a straight-line AD. The slope of this line AD is then calculated, and subsequently based on the slope, the ordinates of the base flow are calculated.

So, obviously, once I know the slope, so any time interval, I can find out what the base flow component is, and the direct runoff component can be obtained by subtracting the base flow component from the flood hydrograph. So, at any hour, I know what the total ordinate value is, and if I know the base flow, then I can separate it out and get the direction of the ordinate. And this procedure, the straight-line procedure, is very simple, so it is a simplified graphical technique and may have limitations, particularly in a complex hydrological system. So, if a system is complex, then this simple way of identifying and separating base flow may not work well. So, we have other methods like fixed base length or concave method, which is the most widely used base layer separation method.



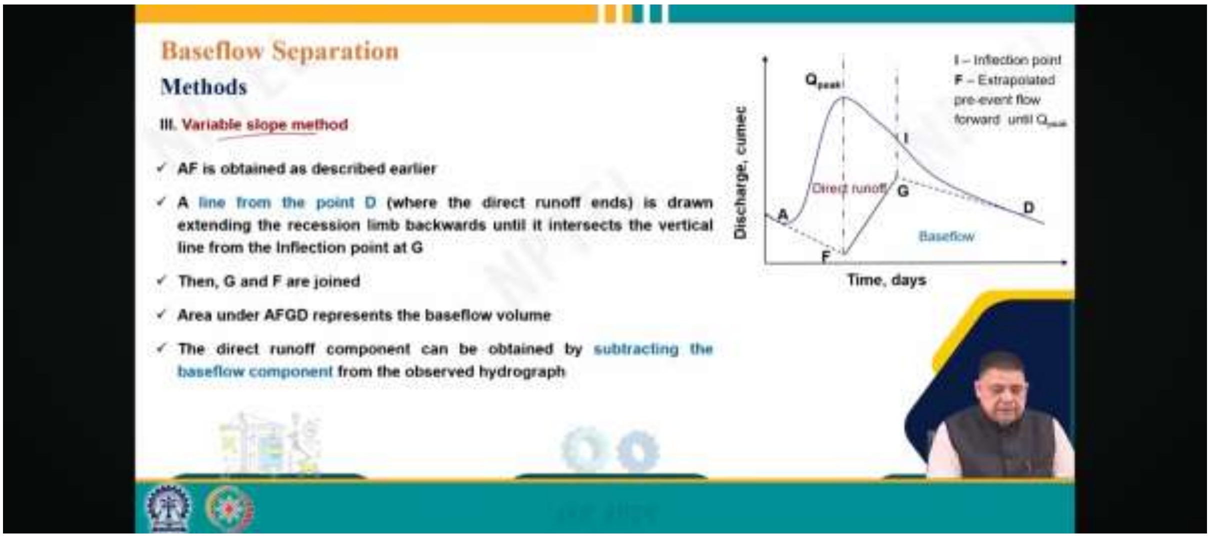
And in this case, a line from point A, where direct runoff starts, is extrapolated until it intersects the vertical line from the peak flow to get AF. So, here's what happens: this is the point where this direct runoff basically starts, and that's why we see a rise in the slope. So, what happens is that the curve that existed prior to the commencement of this particular storm or direct runoff, that line is extended, and it intersects a vertical line drawn from the peak. So, that is how we locate this point F. So, the AF line is drawn, and then we calculate this n within a number of days from the peak using this relationship which was given by Linsley and others in 1958.

So, here n is 0.8278 to the power 0.2 where A is a watershed area in square kilometres. So, knowing the watershed area, we can calculate the value of n, and then that helps in locating this point S. Once n is determined, S can be located. Then, F and S are joined, and the area under AFS represents the base flow volume. So, whatever area of the curve lies between AFS, that is represented here. So, there are 4 points: 1, 2, 3, 4. Whatever area that lies below this line is base flow, and above that is direct runoff.

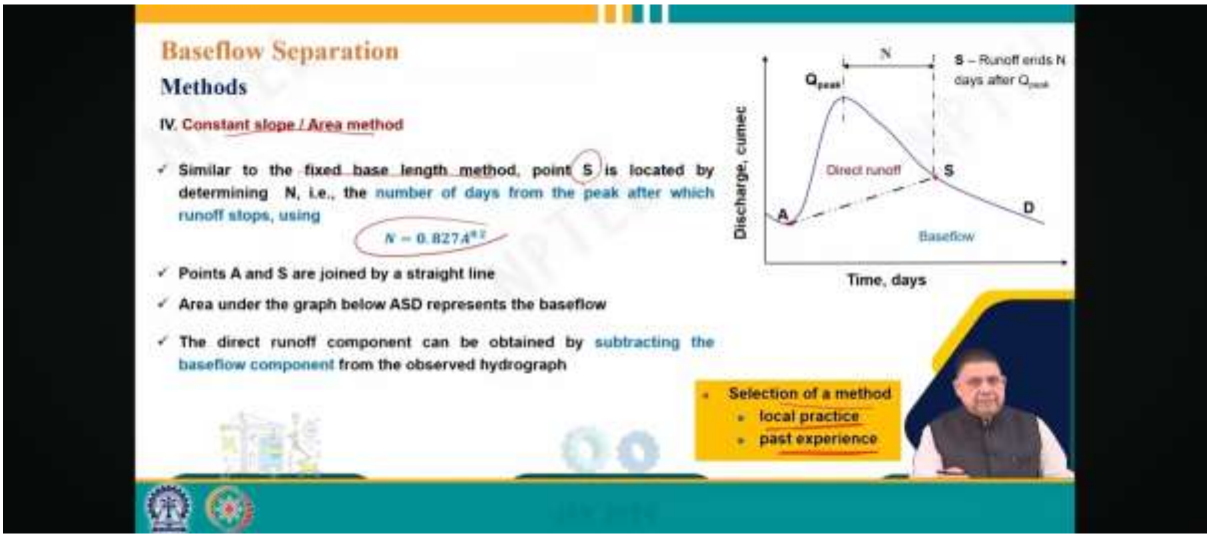


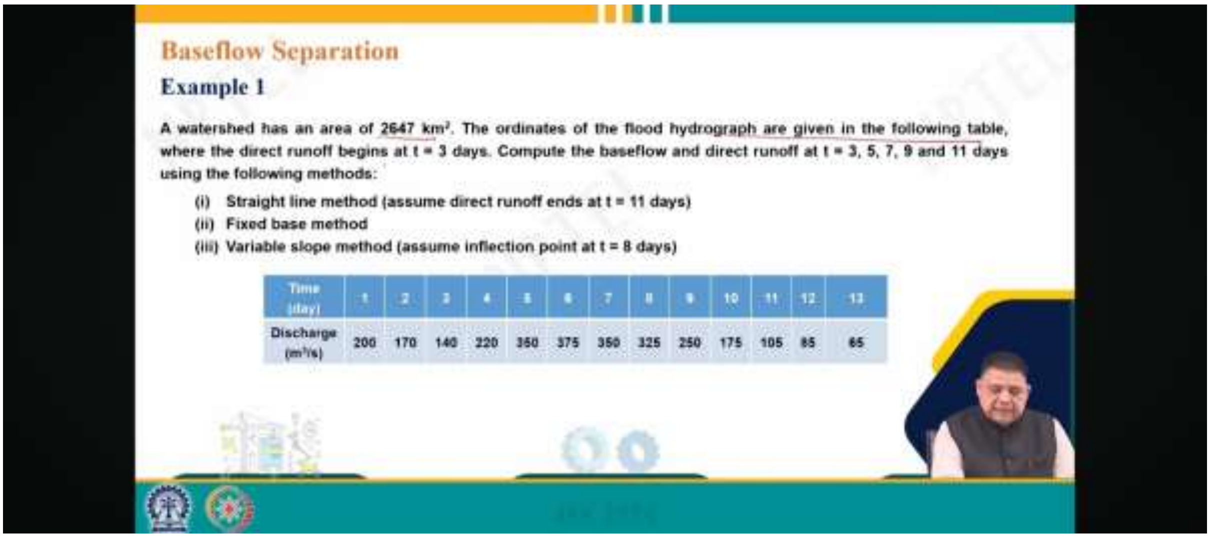
So, I mean it is easily done provided we locate these points, and then the third matter is the variable slope method. In this case, AFS remains as it is, but a line from D, where the direct runoff ends, is drawn, extending the recession limb backwards until it intersects the vertical line from the inflection point at G. So, the curve existing after D, meaning when the natural base flow has started, is extended backward, and then we draw a vertical line passing through point I, which is an inflection point on the recession limb. That's how we get the point G. So, AFGD. These are the 4 points: A, F, G, and D, and they become our representative points. The area under AFGD represents the base flow volume, and of course, if you subtract that, you get the direct runoff component. These are the methods, and the fourth method is the constant slope or area method. It is similar to the fixed base lean method. What we do here is locate point S by calculating N and then we join point A and S.

So, here you can see that it is also a pretty simple method. In the straight-line method, we join A and D. Here, what we do is we locate S and then...

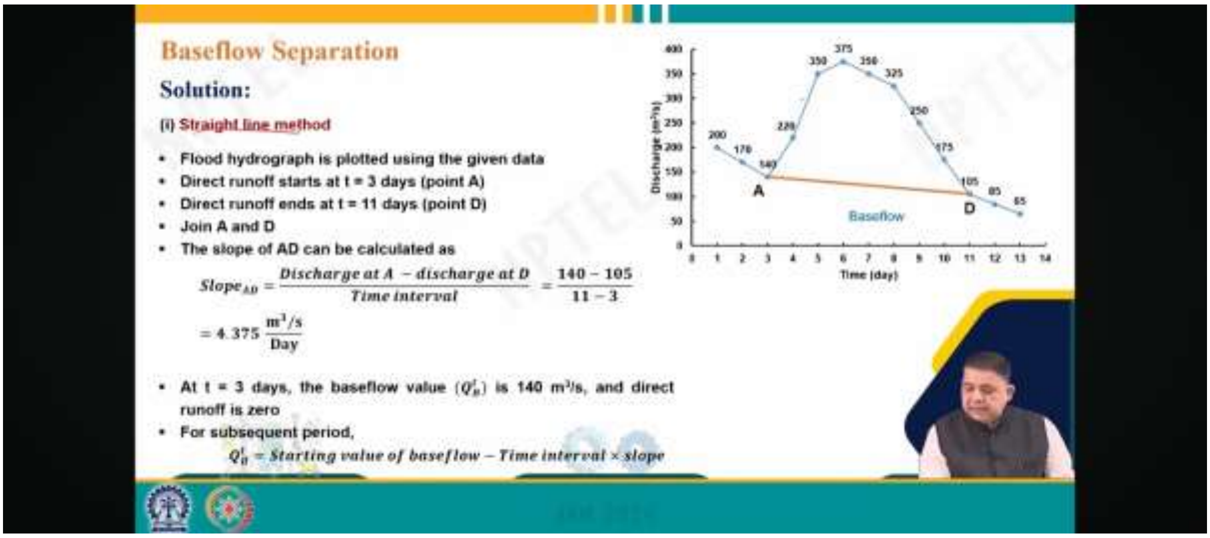


So, now, as you can guess, different methods have different magnitudes of base flows, but there is no hard and fast rule or recommended rule that one should use this particular method. So, the selection of a method depends more on local practice and past experience. What local practice is there or what past experience says for a particular place about the base flow contribution, as you can see that base flow contribution changes from method to method. So, based on that, we choose any one of the 4 methods and we imply that.

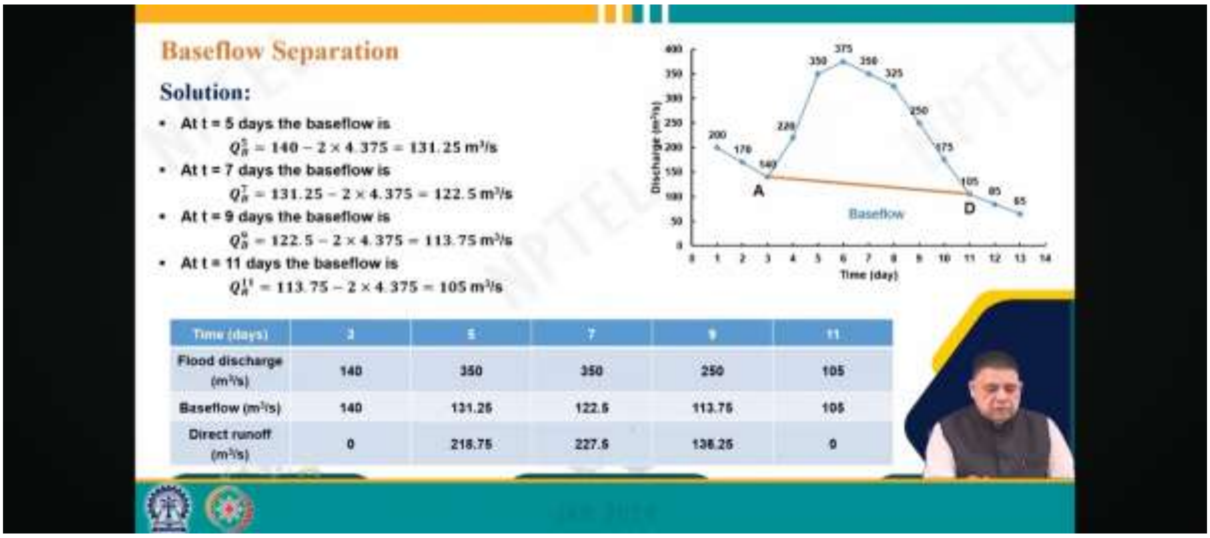




Let us take an example, a watershed in an area of 2, 6, 4, 7 square kilometers. Ordinates of the flood hydrograph are given in the following table where the direct runoff begins at t equal to 3 days. So, here runoff begins. Compute the base flow and direct runoff at t equal to 3, 5, 7, 9, 11 days using the following methods: straight line method (assume direct runoff ends at 11 days). So, this direct runoff starts here and ends here. These points are already located. Fixed base method and variable slope method assuming the inflection point at t equals to it. So, the inflection point here is mentioned in the variable slope method. These are important points which are already mentioned here.



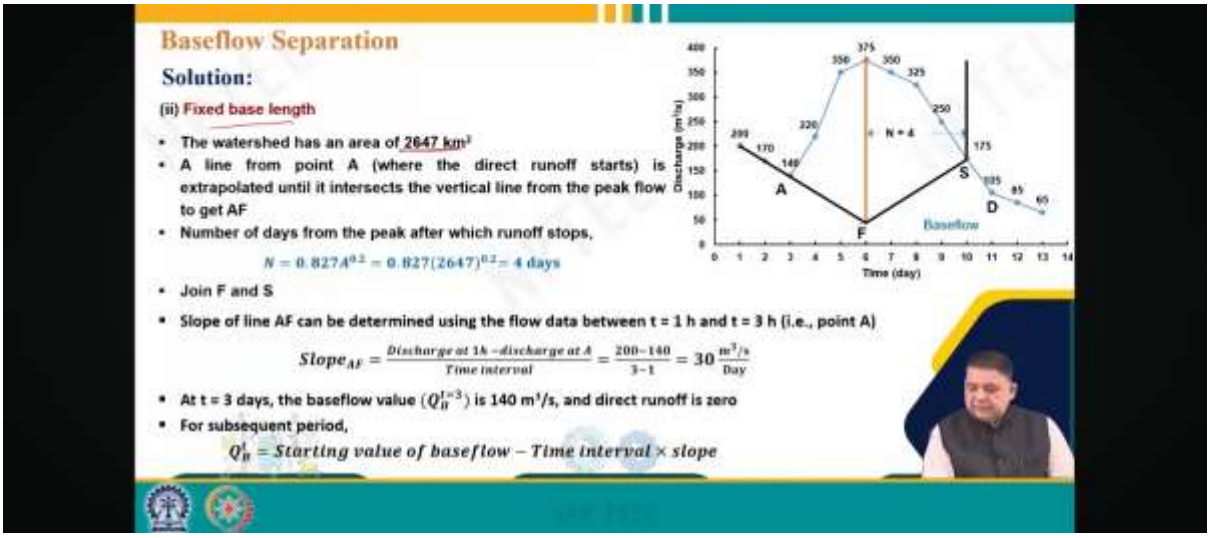
So, we start with the straight-line method. We have to obviously plot the flood hydrograph using the data that is given, and direct runoff starts at day 3. So, this becomes our point A; it ends at 11, so it becomes our point D, and we know the method that we join a line, draw a line joining A and D that gives us base flow. So, obviously in order to we have to find out in order to get the quantify base flow we have to know the slope. So, basically, the slope of the line A D can be found out very easily because at 3 hours we know the magnitude and at 11 hours we know the magnitude.



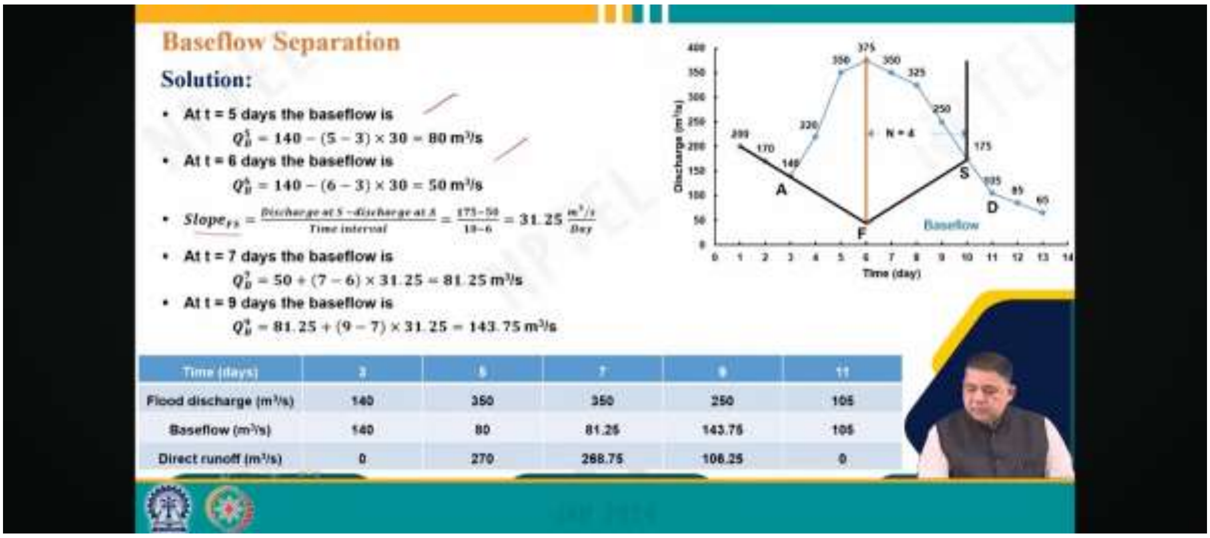
So, 140 minus 105 divided by 11 by 3 that gives us the slope of the line which comes out to be 4.375 cubic meter per second per day. So, at day 3 base flow is 140 because direct runoff starts from here. So, that is whatever is there that is weight flows, and direct runoff is 0. And for subsequent period Q B, that base flow at a time t starting value of base flow minus time interval into slope, and so, we know the slopes at t equal to 5. 140, that is from 3 to 5 we are calculating.

So, we know the slope. So, 140 minus 2 into this is the slope. So, that will give us at day 5, day 7, day 9, and day 11. So, this is how we can get, and all these values the flood values were known, we have found out the magnitude of base flow here.

So, the remainder is direct runoff. Thus, 0.21, 8.1, 72, 127.7 and so on, that is the base flow by this method. Now, we take the fixed base length method. So, watershed area is given which is useful here. Obviously, what we do is draw A f by extending this line between this 200 and 140, extend this line till 0. Till it intersects. So, a vertical line drawn here, you can see the orange colour is drawn from peak.

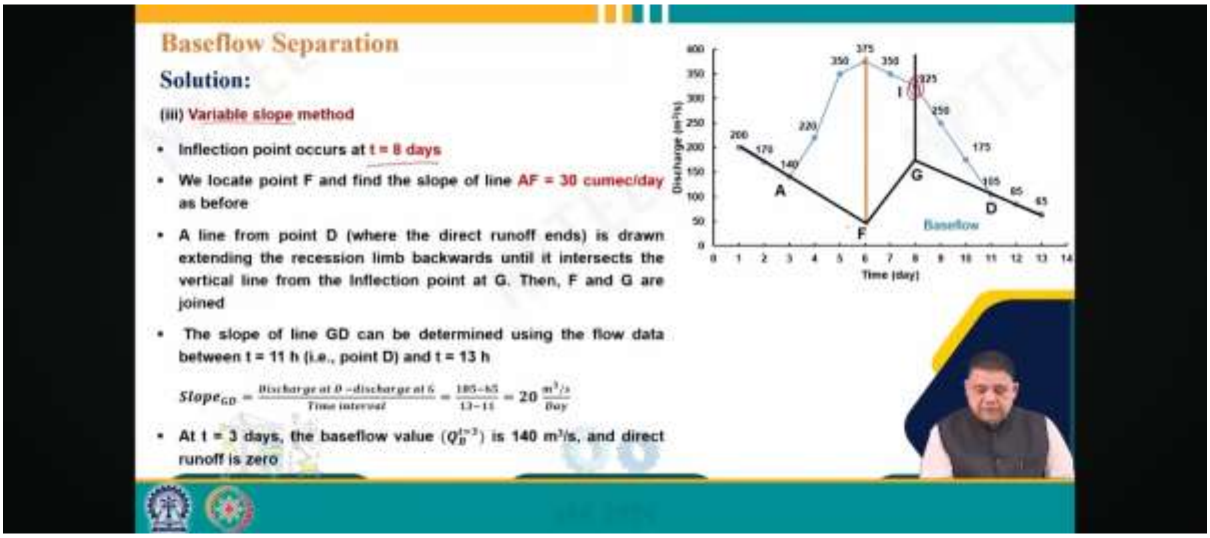


So, A point f is easy to locate then for locating point S, we calculate N by using this relationship; the area is known, this is for 4 days. So, obviously, from peak was at 6 days. So, this point will be located at 10 days, that is what here. So, here this point is located at 10 days and then, obviously we have to find the slopes of A f A f and f s actually.



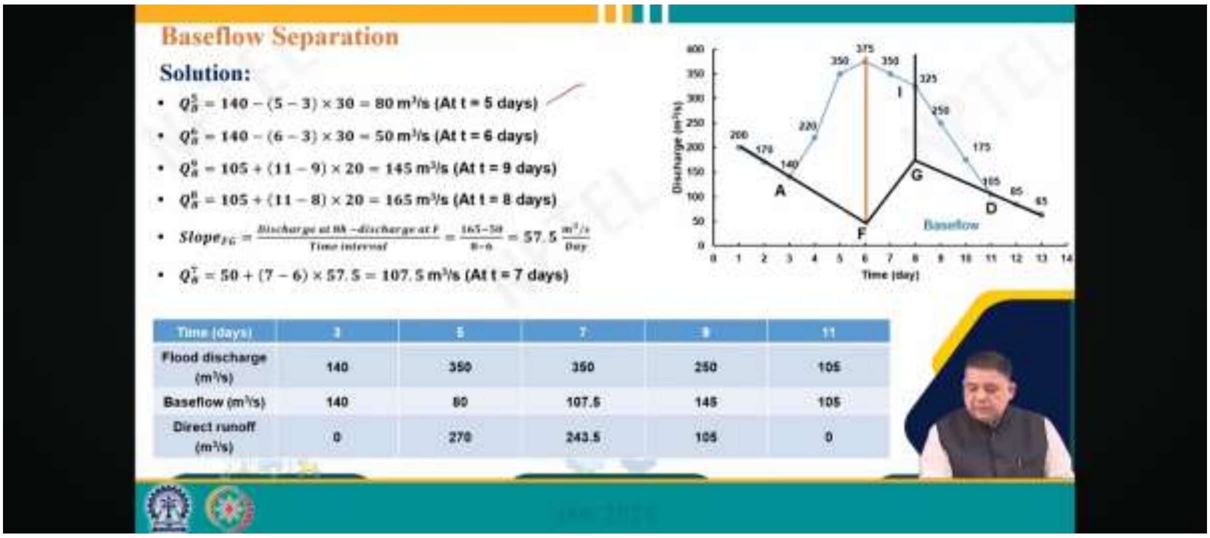
So, the slope of A f is of course, we can find the slope between these two points, that is 2 hours 200 minus 140 2 hours. So, 30 cubic meters per second per day. So, obviously at day 3, the base flow is whatever is there, base flow diagram of 0 and for subsequent periods, we can use the same relationship and we can calculate at D equals to 5 days and D equals to 6 days. And then of course, for finding out the slope between f and S now we know the coordinate at f, now we know the value at S. So, obviously, 175 minus 50 because f 6 hours we have calculated 150 which is f and it is 175.

So, 175 minus 50 by 10 minus 6. So, the slope of this particular line, f s, is 31.25 cubic meters per second per day. So, obviously, then at day 7, this will be 50 plus 1 day into 31.25 that will give us at day 7 for day 9 we can start with 81.2 and then 2 days. So, the slope is this value comes out to be 130 hm 1 143. So, obviously, if we once we can locate these points, we can calculate the slope because the values are known to us and once slopes are known we can find out the magnitude below these this A f S D at any time and that is how we can calculate we know the base flow at different points and the direct runoff by subtracting from flood hydrograph we can get the base slope.



The last method is the variable slope method where we have to use the inflection point which is already given that it is located at 8. So, obviously, we locate point f and A f is drawn as we have already calculated and slope also is known to us then what we do is we draw an extended line beyond the point D that is this line we extend in this direction till it intersects the vertical line drawn from I which is the day 8-point G. So, that is how we have A f G D located and then of course, it we have to find the slopes of the line.

So, line A to f is already known, line G to D can be found out using these 2 coordinates: 105 and 165, and that is 2 hours. So, that comes out to be 20 cubic meters per second. So, using this, we can get the coordinate of this point, and using this, we can get the coordinate of this point, and then we can get the slope of line f to G and then get the coordinates at 7 hours, 8 hours, or whatever. So, here you can see that using the earlier 2, we can get it. At 5 hours, we have to use the slope of A to f, at 6 hours again, we have to use the slope of A to f, at 9 hours, we have to use the slope of G to D, and at 8 hours, we have to use the slope of G to D. Once we know it is 6 hours and 8 hours, that is at f and G, we know what are the coordinates, that is 165 and 50, then we can get the slope of this line f to G and once we know that it is 7 hours, we can calculate like it comes out to be, and slope we have used here, you see the slope of line f to G and it comes out to be 107.



So, now, we know the base flow at different hours of interest and we know the flood hydrograph. So, subtracting, we get the direction of the hydrograph. So, this is how, I mean, we introduced hydrograph and we also saw the factors affecting hydrograph and then we discussed the base flow separation and 4 different methods of base flow separation, this through an example also. It is pretty simple, I think once you see it for yourself, it will be easy to find out because we only have to find the slope of the straight lines in these methods. So, with this,

we close this lecture. Please give your feedback and if you have any questions, please raise so that can be answered on the forum.

Thank you very much.