Advanced Hydrology
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Lecture – 18

Good morning and welcome to today's lecture. In the last two lectures we have looked at the atmospheric water in which we looked at the formation of rainfall, various types of precipitation or forms of rainfall. Then we looked at the representation of rainfall that is mass curve analysis, hyetograph, and maximum depth duration curve. We also looked at the evaporation in the last chapter; empirical methods, analytical methods and some experimental methods for estimating evaporation.

Today we will start the next chapter. which is on surface water. What happens to the rainfall when the rain is falling on a catchment, alright. What we will try to do in this chapter is look at different types of storage components in a catchment, look at the rainfall runoff process, how the rainfall gets converted into runoff. We will look at various definitions involve with a hydrograph, then we will go to some mathematical modeling of the rainfall runoff process.

So, first let us get started with the chapter on surface water. As the rain is falling what happens to it is, it gets stored in different storage components. All right, we have discussed this earlier and these storage components will have different storage capacities and depending upon the storage characteristics and catchment characteristics it will be able to release the water from these storage components.

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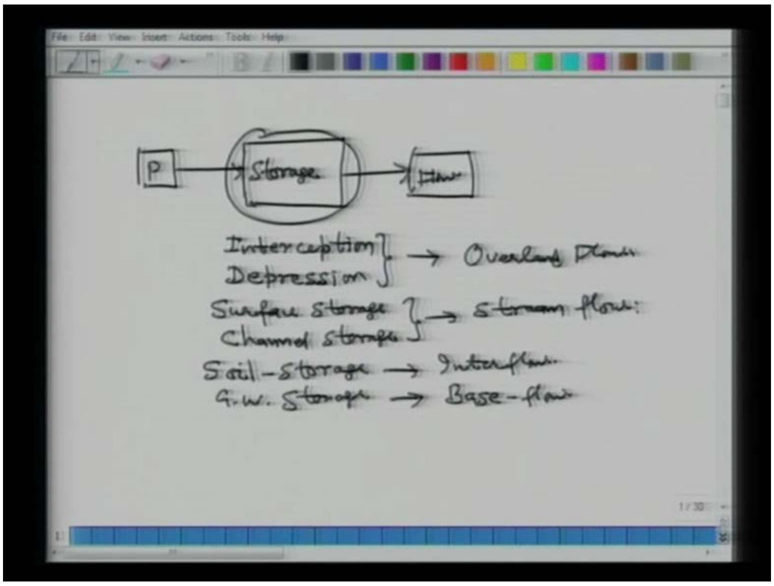

So, if you look at it here, we have the rainfall P falling on the catchment, then the catchment basically consists of lots of storage components all right. And out of these storage components, then we have the output coming out from the catchment is what is called flow, stream flow, runoff, etcetera. In any mathematical model of rainfall of runoff process, basically we try to model these storage characteristics of the catchment all right. It consists of various types of storage components. First one of them is what is called interception, what is interception? Interception is the storage of rain water on the forest cover or the leaves and branches of the trees all right.

This interception storage gets evaporated after sometime and lost into the atmosphere. All right, they will not be any runoff directly from this before the interception storage capability or capacity of the catchment is satisfied alright. So, that is a interception storage. This another type of storage, initially in the catchment which is called depression storage alright. What is depression storage is the water stored in a catchment in the various depressions on the landmarks or lopaddles or small lakes or you know some obsections buildings etcetera.

So, the interception in depression storage has to be satisfied first of all, before any runoff can occur from a catchment alright. So, these are the first two storages. And then what comes out of this is what is called the overland flow. So, let us say there is sufficient supply of water due to rain, what will happen is that the interception and the depression storage capacities of the catchment will get completely satisfied. After that you will have water running down into the ground and then it will start as the overland flow.

Then we have water getting stored into the surface storage. On the surface of the land will have water getting stored and once that capacity of surface storage is satisfied will have the flow coming out of this. Another example could be the channel storage all right, the water that is stored in the rivers and streams and strikes etcetera. What comes out from these storages is what is call stream flow? Stream flow that we observed in the rivers and streams, alright. What is the another type of storage, apart from a these four storages; water goes into the ground alright. And then what happens to the water that goes into the ground, that it can gets stored into what is called the soil storage or soil moisture. Then the water gets stored into the into the soil moisture storage or soil storage it gets transpired or it gets lost into the atmosphere, through the process of evapo-transpiration which we have looked at in the last class.

If there is sufficient supply of water available in the soil storage, it can come out as what is called interflow. I think all of you understand what is interflow all right. It is the movement of water in the unsaturated zone of the ground or subsurface data of the earth all right. When there is sufficient supply of water, what can happen is that water can travel literally and appear as interflowing into the strikes and rivers. Another type of storage is the ground water storage. From the a soil moisture storage what may happen is the water may get deep into the ground water through deep percolation and how does it come out into the surface, in the form of base-flow. So, we see that there are different type of storages in the catchment all right, as the rainfalls all this storage is will get satisfied obvious this get filled up and these storages will have different mechanisms of releasing the water and that is what is involved in the rainfall runoff model.

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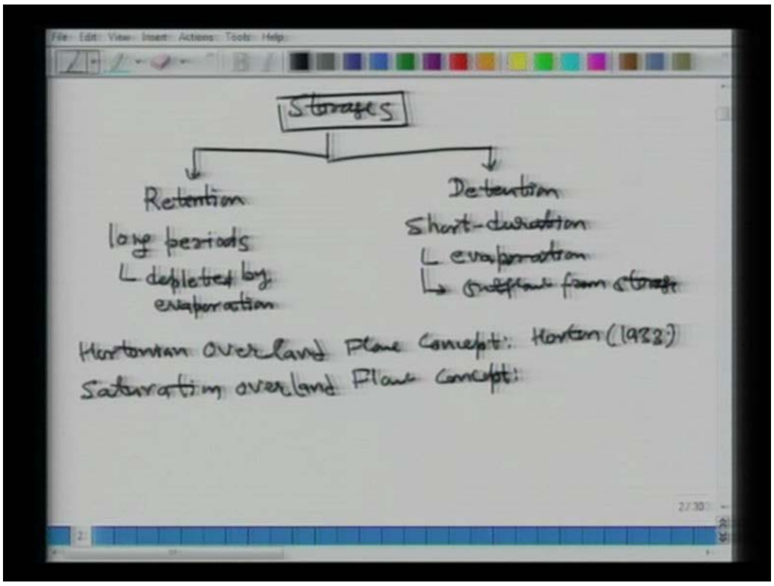

Now we come to the classification of these different types of storages. All this storages which we have looked at can be classified broadly into two parts. One is called the retention storage and other is called the detention storage. What is the difference in retention and detention? As the name suggests, in the retention storage the water gets stored and that particular storage for long periods. So, water is retained for a longer duration and how it is depleted? It is depleted by evaporation. Can anybody think of the example of retention storage. It is the soil moisture storage. For example, water is get retained in the soil moisture for longer duration and then it can get evaporated or transpired evapo-transpiration into the atmosphere.

So, soil moisture storage is an example of a retention storage and also the ground water storage. The other types of storage classification is what we have is detention storage which is for short duration as the name suggests. And how is it depleted. It is depleted by either evaporation or the outflow you can say or flow out of that surface storage.

For example we have blood control structures or detention basin all of you may have heard about them what is a detention basin or in detention storage when there is a lot of water coming in into the catchment due to rainfall what we do is we temporarily store the water in the detention storage or the detention basin all right. And which will have an outflow structure over which after sufficient capacity of the detention storage is satisfied ,we allow the water to overflow over a wear or spill way or something all right. So, that is called the retention storage. Another way to a look at, this is as per as the kind of you know storages in terms of periods of retention or detention. Another way to look at the different types of flows is either Hortonian overland flow concept verus the saturation overland flow concept. These are two different theories we can say which try to model the infiltration or the abstraction from the rainfall all right. This Hortonian concept was proposed by a Horton in 1933.

So, we are going to look at this first. So, let us say we have Hortonian flow. When do we have Hortonian overland flow or Hortonian Flow. He basically proposed that the runoff from the catchment can be calculated by simply subtracting infiltration from rainfall.

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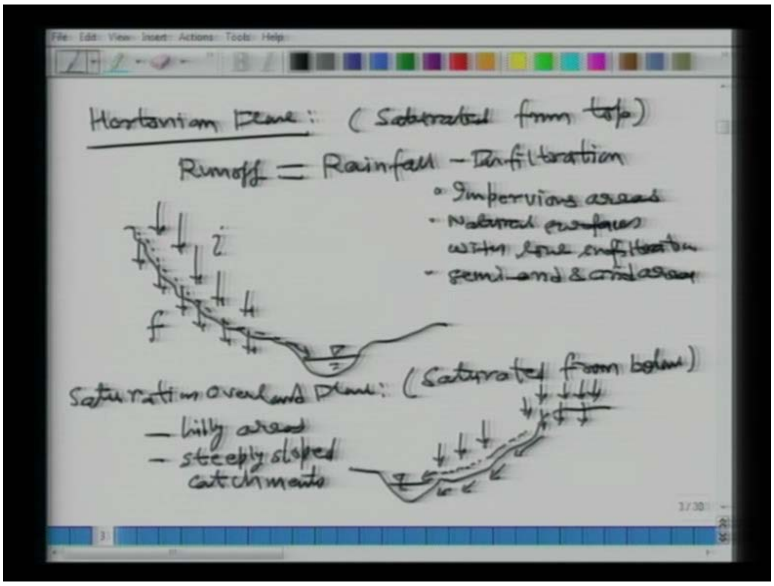

So, it is not accountant for any other types of losses. So, mainly the infiltration losses and what he proposed is that if we want to find out or estimate how much runoff will occur we just take the total rainfall and estimate the infiltration somehow any subtract it. So, that was the first time he proposed and this is called the Hortonian concept of overland flow. The important thing to remember in this Hortonian overland flow concept is that the catchment is saturated from top. What do we mean by that? That is look at this figure .Let us say, you have a catchment in which the rain is falling what we will have is what will be getting ponded all right and then this is your river or some crick.

All right what will happen as the rain is falling is water will infiltrate into the ground. So, let us say your intensity of rainfall is i all right which may be a function of time and the infiltration rate is f all right and we have seen some of these things earlier and what will have is you will have the Hortonian overland flow going directly into the river as the overland flow.

So, when I said that in the Hortonian overland flow we have saturation from the top that is rain is falling on the ground and getting infiltrated into the subsurface zone and which is saturating the subsurface zone from the top all right or water which is infiltrating from the top. So, that is the main important concept in the Hortonian overland flow. As opposed to the saturation overland flow, in which the ground is saturated from below. What do we mean by that. So, we may have a situation like this all right. So, rain may be falling in some hilly areas in the upstream reaches of the catchment all right then what may happen is that this water may get infiltrated into the ground and.

Due to the a stream catchments slopes in the hilly areas. This water may travel inside the ground all right and that will saturate the subsurface zone of the earth in the downstream portion all right and then later on then you may have a rainfall falling in the downstream catchments. The sub subsurface zone is already saturated, but this is saturated from below that is, all ready moisture is there due to rainfall or some other reason through the interflow coming in into the subsurface zone.

So, this type of overland flow then you will have this bonding taking place you, because the subsurface zone is all ready saturated and you will have the overland flow. So, the mechanism of modeling of the overland flow will be quite different for Hortonian overland flow and the saturation overland flow. The Hortonian overland flow is applicable to impervious areas or natural surfaces with low infiltration capacities. These type of conditions will be available in semiarid and arid areas and as you can imagine the saturation overland flow will occur mostly in the hilly areas.

Where the catchment slope is very steep that will encourage the subsurface flow or the interflow. So, that the ground can get saturated early and you can also say steeply sloped catchments. So, these are the basically two concepts of modeling the overland flow one is to the Hortonian and other is to the saturation. In most practical applications or most of the hydrological models commercials software, which we see today the employ Hortonian overland flow velocity.

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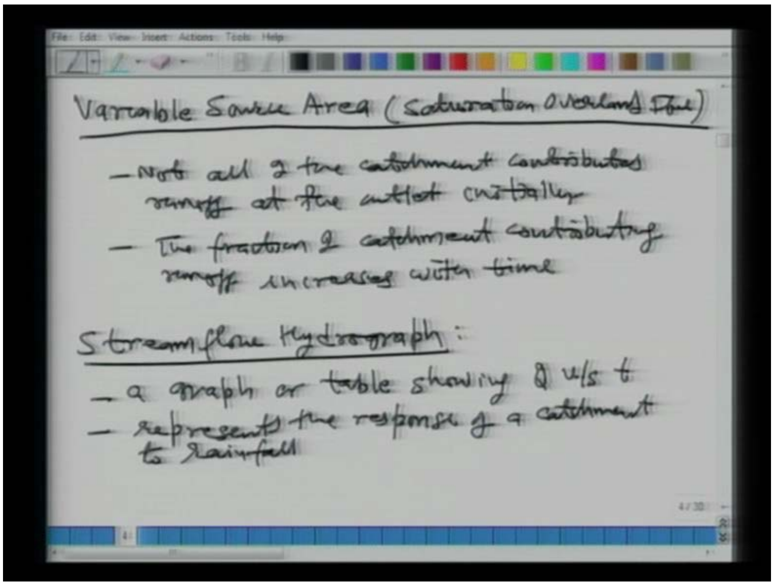

Next we move to a different concept call variable source area and this is applicable for saturation overland flow. As we can see that as the name suggests what is the Variable Source Area? We are observing runoff at the outlet of a catchment due to rainfall and the subsurface zone is saturated from below all right due to some reason rainfall of stream in the catchment. So, at any given point of time the amount of area or the fraction of the area of the catchment that is contributing runoff at the outlet will be different.

All right a during a storm initially, initial first our only small portion of the catchment will be contributing runoff at the outlet: next two hours larger area of the catchment will be contributing runoff because more subsurface zone will get saturated later on and more amount of surface runoff will be coming in all right. So, this is basically what we say is that not all of the water share or catchment contributes runoff at the outlet initially. The fraction of catchment contributing runoff increases with time as we can see all right. So, this what is called the Variables Source Area concept, in which the area that is contributing runoff the outlet is varying with respect to time all right. So, the modeling of this type of a physical phenomena is much more complex and that is under taken in the hill slope hydrology all right which is not part of these course.

So, we will not be focusing too much on this. Next we move to basic concepts of what is called the Stream Flow Hyetograph. So, what will be doing from this point on in this course is, we will be looking at the Hortonian overland flow only. We will not be doing this saturation overland flow in this course all right.

So, what is a stream flow hyetograph I am sure all of have seen what stream hydrograph in your under graduate hydrology course it is simple a graph or you can represent this form of a table of numerical values showing what the flow as a function of time. So, the graph between Q and t is what we call a Stream Flow Hyetograph all right and this stream flow Hyetograph is observed or measured at a particular location in the river; particular location as we know is called the concentration in a river. A Stream Flow Hydrograph gives us lot of information about the catchment all right because it essentially represents the response of a catchment to rainfall or when a catchment is objected to rainfall event how it response all right, how it response means there are various components we have seen and how these various storage components behave as a function of time.

How they store the water, how they release the water and how the contribute runoff at the outlet all right. So, this whole concept is your rainfall runoff process. So, ultimate results is the your Stream Flow Hydrograph and the shape and size and the characteristics of a Stream Flow Hydrograph will tell a lot towards about the characteristics of the catchment before we move to the modeling of a rainfall runoff process.

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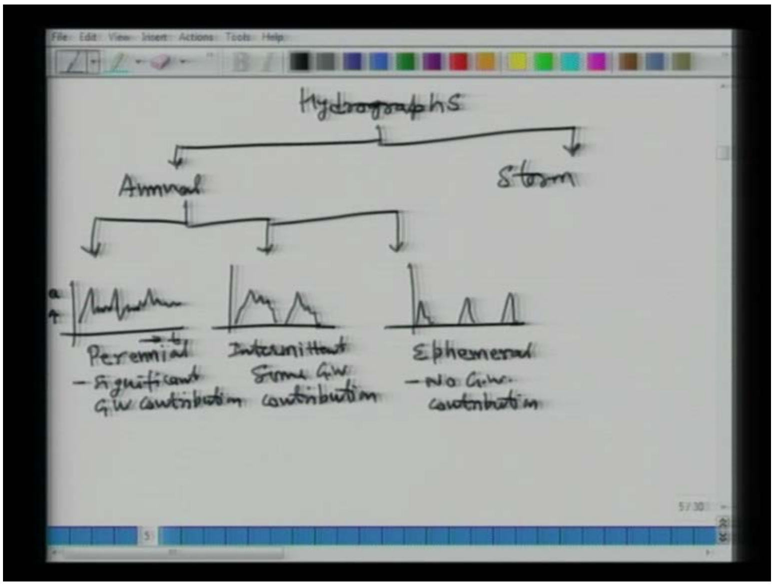

Let us look at the types of Hydrographs. Hydrographs can be classified into two kinds, broadly speaking; first one is we call Annual Hydrograph which you all understand in which the time frame is one whole year. So, its Q versus time in days, let us say a for the whole year, as a post to what is called as Storm Hydrograph. And in a storm hydrograph what we have is for short duration all right. So, we have Q versus t for short duration for which rainfall occurs. Let us say you had you had an intense rainfall storm for the hours.

So, as the result of that force or that rainfall being subjected to the catchment, how the catchment will response in terms of rainfall hydrograph that is called the Storm Hydrograph. So, will come to that later, but first lets us look at the Annual Hydrograph. For the Annual Hydrographs can be divide into three different kinds. First one is called Perennial or a Perennial Hydrograph in which you have a river or a or tree or a stream in which we have water throughout the year. We see that on the x axis we have time and this is your Q of flow in the river all right.

So, you see that the flow never touches 0 all right. It is never 0, there is always some water or always some flow in the river all right. So, when we have this kind of Hydrograph from a river that is called a Perennial Hydrograph and that kind of river is called a Perennial river. As we all know where is this water coming from in the river. It is manly from the base flow. It has significant base flow or ground water contribution in the Perennial rivers or in Perennial Hydrographs.

Then the second one we have is what is called an Intermittent Hydrograph in which you have flow in the catchment or in the river for most of the year, except very few periods when you do not have any flow in the river. All right this type of a hydrograph on an annual bases is called the Intermittent because the rain is occurring intermittently all right and where is this water mainly coming. Then again there is some ground water contribution. There is not a whole lot all right, because sometimes the flow will touch 0 value on the annual scale. All right, the third one is what is called an Ephemeral Hydrograph all right. What is Ephemeral Hydrograph? It is a Hydrograph in which you will have just sparts of flow which are separated by long intervals of no flow all right. So, there are longer intervals of no runoff in the river in a several streams and this basically means, there is hardly or no ground water contribution in the Ephemeral Stream or in the Ephemeral Annual Hydrograph all right.

So, this about the Annual Hydrograph which are of three different types, again to summarize Perennial in which there is significant contribution from ground water, there is Intermittent in which there is some contributions of some ground water in the form of base flow and Ephemeral in which where is no contribution from ground water.

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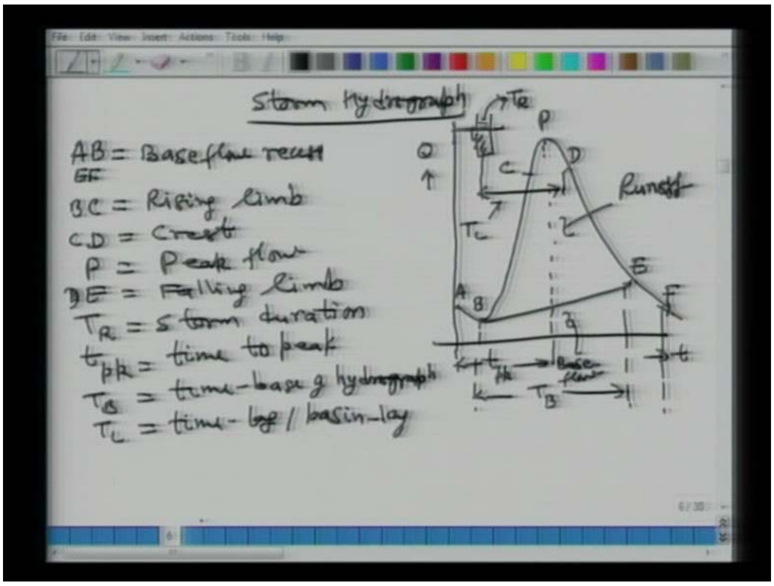

Now, we come to the Storm Hydrograph what we will do is we will define various components of a Storm Hydrograph first, and then we look at these different component more closely. So, as you all know this is time and this your Q. We define various points on the Storm Hydrograph. What we normally do is, we plot the effective rainfall hyetograph on top which produces this Storm Hydrographs all right. So, this your DRH and this time duration this called T R are the duration of the rain fall. And will define some more thing here in the form of find it is T p k from here it is T B. We join the line the beginning of the hydrograph D and the end of the hydrograph E.

So, anything above this line as we all know call runoff and anything bellow is called base flow all right. So, lets us look at different portions of this Hydrographs. A B is the base flow recession and A B actually is coming from the previous Hydrograph all right. This particular hydrograph rising from B all right. So, B is the beginning point you can say A B or may all right it is the base flow recession component and then you have B to see is called the rising limb of the Hydrograph a portion C D and P is there in between the start this called the crest of a Hydrograph and P is the peak flow. D E is called the falling limb of the hydrograph. D R is the storm duration for the hydrograph .T p k is the time to peak and T B is called the time base of the Hydrograph there is one more thing which we have not define here is called the time lag let me say, write it first its call the time lag or base in lag this time.

Lag is nothing but the time between the centroid of the effective rainfall hyetograph and the point of infection on the Hydrograph. So, if I take the and D is let us say the point of inflection of hydrograph. This time is called base in lag all right this of the base and it response of that much time. So, it is a synonymous or equivalent to time of concentration in most of the cases. So, these are the basic elements of a storm hydrograph all right and what we will do next is we will look into some of these components for example the rising limb and so on.

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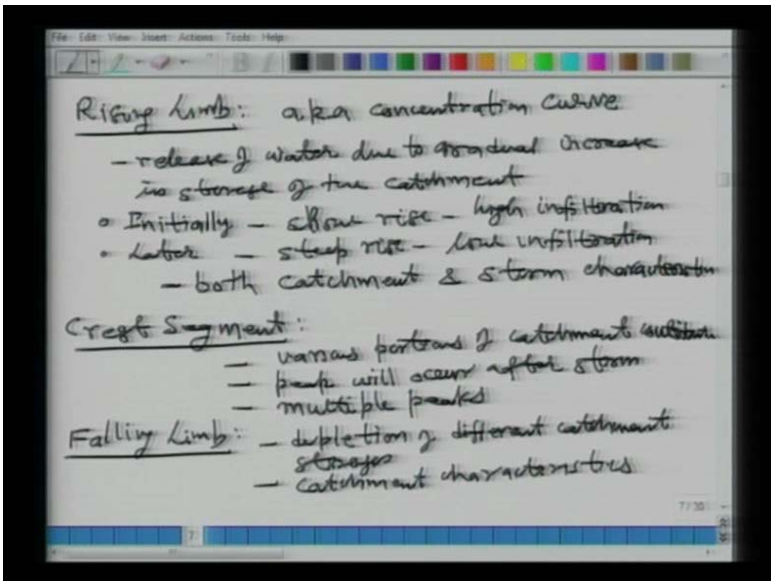

So, if you look at the Rising limb of a Storm Hydrograph it is also known as the concentration curve. What is the concentration curve or the Rising limb. Basically we see that there is initially a small rise in the in the runoff volume in the catchment all right or in a river and then there is become very peak.

So, what is happening when rain is falling is that different components or storage components are getting satisfied or they are getting filled up all right as a result of that the catchment is releasing some water from a storage mainly the subsurface storages all right. So, what we see is the rising limb is basically the release of water due to gradual increase in the storage of the catchment.

So, the rain is falling continuously or there an intense storm catchment is holding some water alright, but it is not able to do it because the capacity are getting satisfied by slowly start to release some water all right. So, as the rain is increasing we are seeing some water at the outlet of the catchment and that rate of that water will keep on increasing slowly with time. Another important point to note for the rising limb is that initially it rises slowly. It is a slow rise. Why is there is slow rise in the beginning of the rising limb, because we have higher infiltration very good all right due to high infiltrations. At the beginning of the storm there will be certain initial condition, the catchment may be either dry or it may be 10 20 30 percent saturated all right.

. So, they will be more infiltration in the beginning and you see if I go back that you see that this portion this a rising very slowly all right then later there is steep rise due to low infiltration in the catchment. So, you have rising limb rising very steeply towards the latter portions because of the little or no infiltration and catchment getting saturated in most of the components. As we can see that the rising limb is a function or its size and shape and steepness will depend upon both the catchment characteristics and storm characteristics. What do we mean by that; the length, the steepness, the size and shape and everything related to the rising limb will depend upon the exercised of the catchment. If the catchment is if you compare two different catchment one is of small area, other is of large area. The small area same rainfall if you apply it will start to rise very quickly.

It will steeper as compare to a larger one all right. Similarly, it will also depend upon the storm characteristics. What you do mean by that. If we apply a higher intensity of rainfall then; obviously, you will have a steeper rising unit all right. So, it depends both on the catchment characteristics and on the storm characteristics. Then the next is, the Crest Segments. As you can understand we are close to the peak of the Hydrograph. At that point of time all the catchment area is contributing runoff at the outlet all right.

So, most of the area is contributing. So, you say various portions of catchment contribute runoff at the outlet. The peak will occur after the storm all right. Note that the peak will not occur before the rainfall has stopped all right. Peak will occur only after rainfall has stopped. We may also have situations of what is called multiple peak crest segments. when can we have the multiple peaks. Let us say you have a rainfall event it is stop for some time and then this another in rainfall event.

So, we have the rising limb rising then it is started to go down, but then it will go back up again all right. So, you have multiple peaks in the catchment. And the third important component of a Storm Hydrograph is called the falling limb where is the water coming from, when we are on the falling limb. Its mainly different storage components it may be surface, it may be subsurface, it may be deep ground water.

So, basically you have depletion of different which is contributing water on the falling limb of a Storm Hydrograph. Will it be a function of storm or the rainfall characteristics that is intensity of rainfall and duration of rainfall etcetera. No, the falling limb will be function of the catchment characteristics only it will depend upon the holding capacity and how it is releasing the water out of this different types of storage then this falling limb the recession. So, the next portion is as we were looking at the falling limb of a Storm Hydrograph and there is a mathematical equation that was proposed by Horton in nineteen thirty three and that what we look at next which is called the recession curve.

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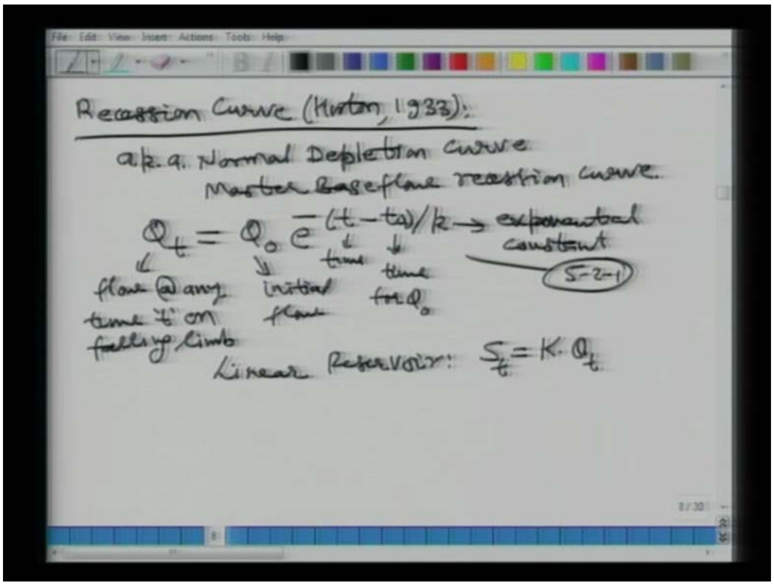

This recession curve is actually also known as in different books you will find different terminology use for the falling limb its call Normal Depletion curve or Master Base flow recession curve. So, they are different use for this recession curve and is same and this is how will model the flow at any time t on the falling limb as Q 0 times e to the power minus t minus t 0 divided by K. And this equation your Q t is flow at any time t on the falling limb. Q 0 is the initial flow at the beginning of the falling limb t is of course, time any time after t 0 and t 0 is the time or do not and when the flow Q not starts or when your time begins on the falling rain and K is called an exponential constant and will name this equation as 5.2.1 as per the convention.

We have been following from the book Ventitures book. This equation as been based on the assumption of catchment behaving as a Linear Reservoir that is storage in the catchment that any time t is some constant times the outflow at that point .What is a linear reservoir we have seen earlier, when the storage and the outflow from the catchment are linearly related with each other.

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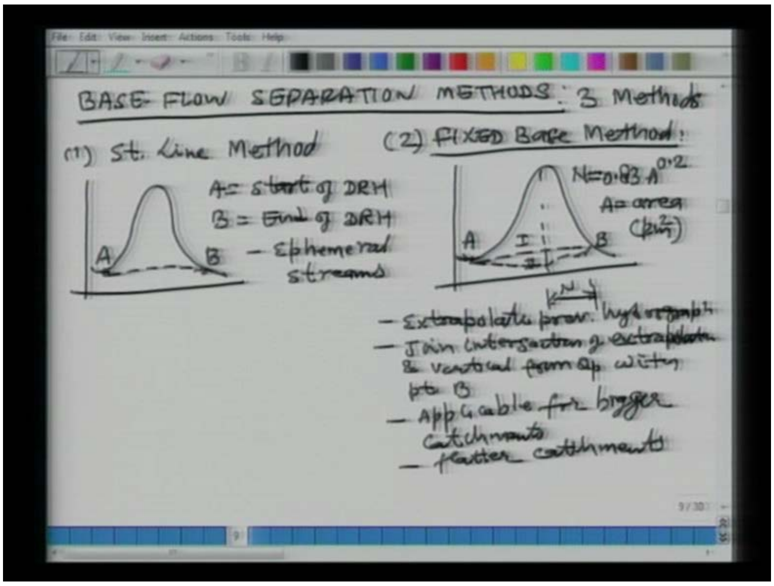

Next we move to Base Flow Separation Methods. I am sure you may have looked at the Base Flow Separation Methods in your under graduate hydrology also, but we will revisit some of these methods. Basically there are three methods we are going to look at which differ in certain assumptions and depending upon those assumptions when they are valid, they will be used in different types of situations in the field. First one is called the Straight Line Method, what we do in the Straight line method is define the beginning of the term hydrograph.

All right let us say that point is A and we estimate the end of the runoff let us call that B all right end of the runoff and after that base flow will be occurring in the river, then we simply join these two points by a straight line and this method is called the Straight Line Method. So, A is the start of your direct runoff hydrograph this is your direct runoff hydrograph B is the end of the DRH and this type of method is applicable to Ephemeral streams when we have hardly any contribution from the base flow all right.

So, you have very little contribution and then you can join the beginning and end point by simple straight line. Second method is called the Fixed Base Method. The problem with the first method, that is straight line method is that we do not know when the D R H will end all right. This is just based on some experience or judgment all right we will try to location point b on your hydrograph all right and depending upon the person there is some subjectivity involve all right. Some people will take b here some people may take it.

You know slightly around in a different position. So, what the Fixed Base Method does is, it gives you an equation to locate that end point b. So, beginning there is no point all right start of the hydrograph is A, and we draw a line at the peak all right. Then we define N let us say this is B which is located N end is after the peak has occurred all right. So, what is N? N is the number of days after the peak.

So, you know when the peak has occurred and the equation for N is given like this its 0.83 A to the power 0.2 where A is the area of the catchment in square kilometer all right. So, what we do is we have located the points A and B all right now what we do is we take the previous hydrograph all right and then we just extrapolated all right and find the point of intersection of this extrapolated hydrograph with the line drawn from vertical and then we join this point with the end point.

So, what we are doing is we extrapolate the previous hydrograph and join intersection of extrapolation or extrapolated line and vertical from take this all right with point B or the end of the hydrograph all right.

So, what we are doing is we are trying find the point of intersection of the vertical drawn from the peak and the extrapolated hydrograph from the previous hydrograph and then we join with point P. This type of method is applicable for bigger catchments, and also latter catchments. Why do we say that, if I apply the first method that is say on this all right and we compare the straight line method and the fixed based method, the straight line method is giving me higher base flow alright as compare to the fixed base method all right.

So, this is your let us say method one and this is your second method .And the second method is giving you less amount of base flow all right that can occur from bigger and latter catchment. So, that is why it is applicable to the bigger and latter catchments.

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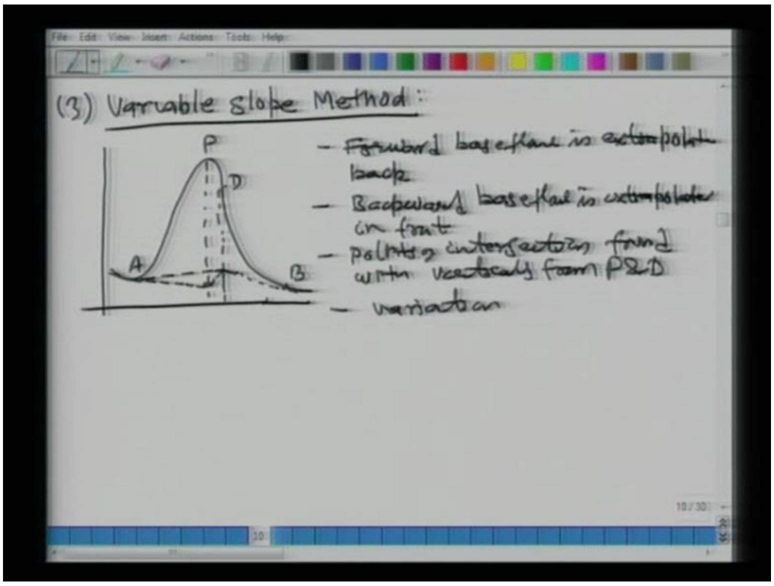

The third method is called the Variable Slope Method. In this what we do is we extrapolate the previous hydrograph get the point of intersection like we did earlier and then we also extrapolate the next hydrograph, get another point of intersection drawn from the point of inflection. So, A and B are your start and end of the direct runoff hydrograph V is your P and D is your point of the inflection.

So, you draw the vertical from P and from point of inflection you extrapolate the previous hydrograph to some point and then get that intersection and join these two intersection which you may have the got. So, basically what we do is we forward base flow is extrapolated back, means from B going back finding the intersection with the vertical from B and the backward or the previous Base Flow is extrapolated in front points of intersectional found with verticals from P and D that is shown in the figure as we have discussed.

And then both of this intersection points are joined by the intersect line. There is another variation in this method in which A point is join by the vertical drawn from the D by A smooth curve like this. So, that two different variation in the first we just join the two point, points of intersections and other which just simply join point A with vertical from the D. As you can see that in this method what we are doing is we are giving more importance to the Base Flow that is occurring just after the P you may have a situation as in certain catchments in which you may have base flow contribution during the storm, just after the peak or around the p all right. The earlier two methods are not allowing us to do that. So, it this method is applicable to moderately size catchments in which there is quicker base flow occurring during the storm. So, as we see there are three different methods and all three will be applicable in different types of situations.

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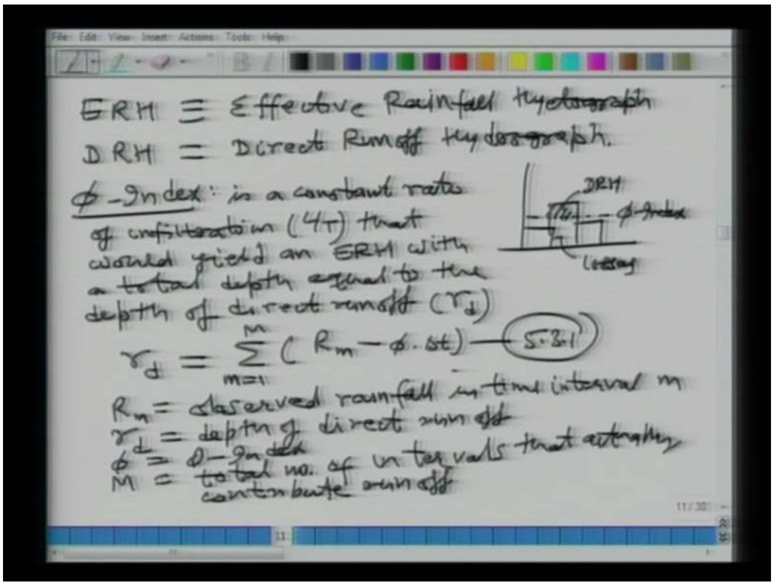

Now we move forward and we will define the concept of what is ERH and I think we all understand this is Effective Rainfall Hyetograph all right and this convert gets converted into what is called a DRH which is Direct Runoff Hydrograph .How do we find the Direct Runoff Hydrograph given an DRH all right and there are various methods we will get started with the very simple concept all right which will have problem in under graduate classes again and this called the phi index .What is phi index? It is nothing but a very simple concept in which we have the rainfall hyetograph and we draw a horizontal line on a such that everything above that line is direct runoff and everything below is abstraction or the lost right. So, if you look want to look at a graphically all right if this is your rainfall hyetograph you just draw a line like this and will let us call a phi index anything above is this is our DRH and anything below that is your losses.

So, how we define this phi index it is a constant rate of infiltration and its units; obviously, would be L by T that would yield and ERH or Effective Rainfall Hyetograph with a total depth of your ERH that is equal to the depth of your Direct Runoff, and which we define as r d. So, that total depth of direct runoff is r d .And this is how we define this relationship your r d or the depth of direct runoff be equal to summation m varying from 1 to capital M of R m minus phi delta t and this is our equation 5.3.1 as for the been following. In this equation it is important to understand some of these variables R m is the observed rainfall, time interval m or the m time interval that is…

And units again r in centimeters in case of whatever r d is the depth of Direct Runoff same units phi is your phi index; of course, and capital m which is I would like to understand very important is the total number of interval that actually contribute runoff. This is very important to understand what is capital M or a in the next class we will take up an example on how to calculate phi index and what is capital M all right. This will not be equal to the total number of rainfall intervals all right, it may be less than that all right. So, it is important to understand that.