Advanced hydrology

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Lecture – 22

Good morning and welcome to this post graduate course on advanced hydrology. We have a looking at the modelling of surface water, in the last class we studied the rainfall run of process and how we can model it. In this chapter we have seen how we can do the modelling of infiltration process initially, so given the infiltration equation the rainfall data we know how to calculate the effective rainfall hyetograph, and once we have the effective rainfall.

The next thing is to calculate what will be the d r h or what will be the run of response. In the last class, we looked at the modelling of the surface flow process and in which we said that the surface flow is composed of 2 components; one is the over land flow, and other one is the channel flow. For overland flow component, we derived an a general expression for the flow depth right from which we can also calculate the velocity of flow.

So, the objective was to find out the flow depth and velocity, and we found a general expression. We could find out the flow depth well the overland flow is laminar as well as turbulent. When the initially when the velocity is a small we can use the laminar flow equations, and then later we can switch to the turbulent flow equations. Similarly, for the channel flow we looked at or we applied the manning is equation in the channel Total Raphson Alternative method. This is what we have done in the last class, what we would like to do today is we would look at the modelling of the rain fall run of process when it is unsteady.

So, whatever we have done is for which steady state conditions you find out what is the flow depth? What is the velocity? when the steady state conditions has been reached however what happens or you know when the rainfall pattern is unsteady in itself then those models will not be applicable.

So what we want to do today is we look at one method right later on in later chapters we would look at some other methods, but we would look at a concept of what is called the time area diagram? Then we would look at an example on that and then we would look at certain gemmological parameters, which are useful in understanding the behaviour of a catchment with respect to the rainfall. How the response of the catchment in terms of the run of who would be there we can get lot of inferences using the gemmological parameters.

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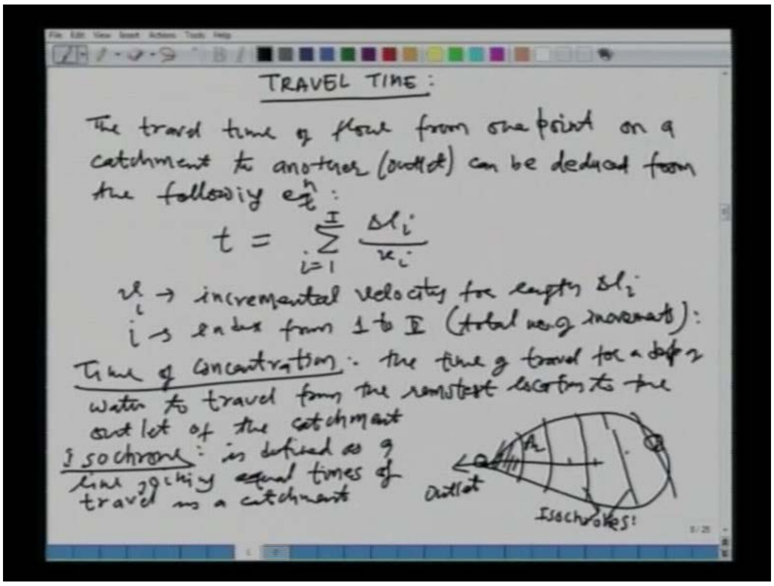

TRAVEL TIME:

The travel time of flow from one point on a catchment to another (outlet) can be deduced from the following eqn:

$$t = \sum_{i=1}^{I} \frac{\Delta l_i}{v_i}$$

v_i → incremental velocity for length Δl_i

i → index from 1 to I (total no. of increments):

Time of concentration: the time of travel for a drop of water to travel from the remotest location to the outlet of the catchment

Isochrone: is defined as a line joining equal times of travel in a catchment

So, we would get start today by looking at the concept of what is called travel time? What do we mean by travel time is that when the rainfalls on the catchment right it goes through lots of processes. Now, we are looking at the rainfall on of process on the surface flow, so it will take some time all right to appear at the outlet. Let us say you have an effective rainfall impulse occurring in the absence reaches of a catchment, how long it is going to take or the water particle to reach the outlet from different portions of the catchment, this is the call this is called the concept of travel time.

So, when we are talking of the unsteady flow modelling or we are trying to calculate the direction of hydrograph we need to be able to find out how the input in a system is going to get translated in time. If for example, let us say there is a rain fall 2 hours ago what will be the impact of the rainfall 2 hours ago on the flow or the run of 2 hours later.

So, these are the kind of thing which we can do using this travel time concept so, let me first define it as for as the travel time definition is concerned. The travel time of flow from one point on a catchment to another and then we are saying another it is normally we outlet we are looking at, but not necessarily it could be between any 2 points also can be deduced from the following equation that is t is equal to summation of your delta l i over v i that i is in that is that re goes from one to that say capital I all right where what is v i? Well v i is the incremental velocity for length delta l i and i is an index from 1 to i that is capital I for total length or total number of representing the total number of increments a so, what we are saying here is basically that there is a the travel time of water from any point in a catchment to the another point or to an outlet will be different.

We can calculate that is we can divide the path of water of the travel of water from one point to the other into different segments of length delta l i once we have done that we can estimate the average flow velocity in that component once we have the lengths and the velocities or the average velocities we can find out the travel time between those 2 segments and then we can some all those are so we can find out the total time in a from what are to travel some point to the other.

So, this is a very simple concept normally when we are dealing with real catchments are there are 2 major components one is the overland flow other is the channel flow in which the average velocity would be quite different or significantly different. Within the overland flow we can divide the catchment into further you know delta l i's maybe 100 feet each or whatever so this is the concept through which we can try to estimate the travel time now related to the travel time. I am sure you all know what is called the time of concentration? Another important term which is called time of concentration. What is time of concentration? It is nothing, but the time of travel for a drop of water or for water we are saying to travel from the remotest location to the outlet. It is very simple in the simple term that is how we define what is called the time of concentration? Outlet of the catchment.

So, if you want to look at this concept let a is your catchment in which there is a major channel. Now there may be a point on the boundary which is the remote as location. So, the time for water to travel from this location and let us say this your outlet that is where we want to measure or find out or estimate the direct run of response so, time taken by water to travel from the remotest location to be outlet is called the time of concentration.

What is time of travel? Well we can find out the time of travel all right from here to here or from here to be outlet or any 2 points. So, we can calculate the time of travel or estimate the time of travel that way also now when we are doing the on steady flow modelling or the rainfall of modelling what we need to do is we need to find out what is called the concept of Isochrones? We need to understand what is an Isochrones? Using this time of concentration concept which is the maximum travel time in a catchment from travelling from the remotest location to the outlet we can develop what is called the Isochrones? as the name suggest what is an Isochrones? An Isochrone is a line joining equal times of travel in a catchment.

So, we should define as Isochrone is defined as a line joining equal times of travel in a catchment. When we are talk about the time of travel of obviously if you are not saying anything it is be respect to the outlet. So, we are trying to find out the time of travel to the outlet so, if you look at this catchment which we are drawn here let say this is our outlet we want to draw a line from where the time of travel is same.

So, let say we are looking at this line so, any drop of water that falls on this line or close to this line will take let us say 1 hour to reach the outlet. So, we say that this is a line or this is an Isochrone corresponding to 1 hour or some interval delta t similarly, we can draw another one which is further up seen in the catchment and that will be 2 hours all right 3 hours 4 hours and so on and then final will be a time of concentration. So, all these lines which we are seen these are actually called Isochrones.

The concept of this isochrones is extremely important why because the area between these 2 lines or this inter Isochronal area is an important concept why because what we do is we assume that this whole area this takes about 1 hour to reach the outlet or whatever the time delta t is the next one A 2 we say is going to take 2 hours or twice of delta t and so on so, with that you see that whatever input that is falling on the catchment we would be able to translate that input in time. So, that we will be able to find out the direct run of hydrograph response how the shape of the hydrograph would be.

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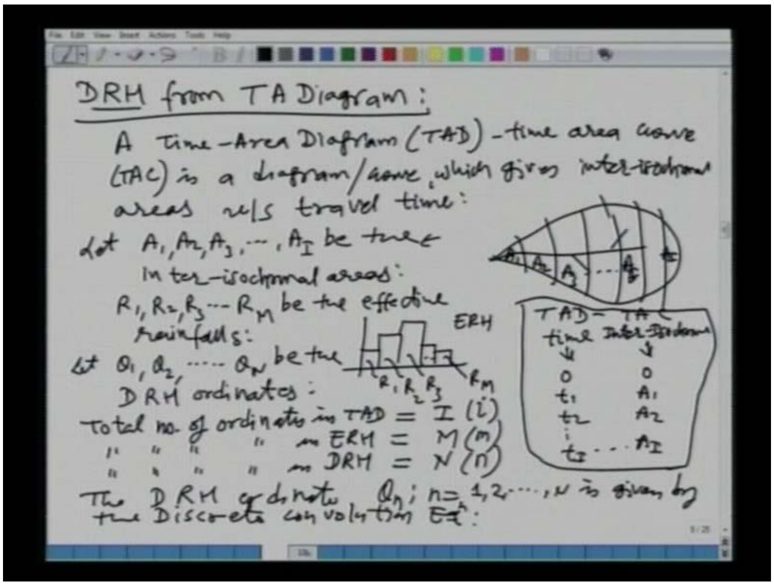

DRH from TA Diagram:

A Time-Area Diagram (TAD) - time area curve (TAC) is a diagram/curve, which gives inter-isochronal areas v/s travel time:

Let $A_1, A_2, A_3, \cdots, A_I$ be the inter-isochronal areas:

$R_1, R_2, R_3 \cdots R_M$ be the effective rainfalls:

Let $Q_1, Q_2, \cdots Q_N$ be the DRH ordinates:

Total no. of ordinates in TAD = I (i)

" " " " in ERH = M (m)

" " " " in DRH = N (n)

The DRH ordinate Q_n; $n = 1, 2, \cdots, N$ is given by the Discrete convolution Eqn:

TAD - TAC

time	Inter-Isochronal
0	0
t_1	A_1
t_2	A_2
t_I	A_I

So, let us move on and then first look at the concept or how we can actually calculate the direct run of hydrograph from what is called a time area diagram? We just looked at the concept of travel time, time of concentration, Isochrones and inter isochronal areas all these things are very important or useful in developing what is called a time area diagram in a catchment which can be use for calculating the DRH response.

So, let us first look at what is the time area diagram? TAD or it is also known as time area curve then we say time area curve different book would follow different terminology. So, let us not get confused about that so, either the time area diagram or the time area curve is a diagram. We could be looking at it graphically or in a tabular form or curve which gives inter Isochronal areas verses travel time. So, it is nothing, but a curve or a in the tabular form it is the data of travel time with respect to or verses your inter I Isochronal area.

So, what it will be able to give is that that much of area in the catchment of that section water takes about 1 hour to travel that much or a two will take 2 hours and 3 hours and so on so we can define area verses time curve which is the time area diagonal. So, let us say that we have this catchment in which this is our stream network let us say that we have divided this into using the isochrone into different isochronal areas let us say this is A1 A2 A3 and so on AI. Well the AI has to be the last one that is capital I and this is let us say a small i so, say let your A1,A2,A3 etcetera all the way have to A capital I subscript is going from small i is going from 1 to capital I be the inter isochronal areas.

So, let me first do that here what is that time area diagram? or your time area curve which is nothing, but your travel time here and inter isochronal areas is here it can be in square metres or square kilometres or hectares whatever so let us say it is 0 it will be 0 then you have t 1 it will be A1 t 2 A2 and so on you have t capital I up to A capital I.

So, this is called your time area diagram. This table or you can plot it that curve and that is what we have defined here? This is your inter isochronal areas while we are doing the modelling for that direct run of hydrograph also let the R1 R2 and R3 etcetera all those at up to R subscript capital M be the effective rain falls that is fall even the catchment. Let say that it looks like this these are the ERH this your ERH. So, what are these things this is your R1 well this different impulses are let me write it here R1 this is your R3 this is your R2 all the way up to the last one is your R capital M and let say your Q1, Q2 all the way up to Q capital N. Be the DRH or the direct run of hydrograph ordinates.

So, what we are saying is that the total number of ordinates in your time area diagram are how much this is I the total number of ordinates in your ERH is how many this is capital M all these numbers are important and they would be different they do not have to be same and then the total number of ordinates in your direct run of hydrograph is let say capital N we would look at a relationship between all these is later in the course, but for right now let say these are your maximum number of ordinates in different physical parameters let us say that this is an index I this is represented by some index small m and this is represented by an index n. So, we are defining the lower case letters as the index and upper case letters is the maximum number of ordinates then the DRH ordinate will be what Q subscript n were n will go from where to where 1, 2 all the way to capital N is given by using this time area concept the discreet convolution equation.

This discreet convolution equation is something which we have not seen yet all right that what we will do is we will just look at it in the discreet form and we will derive this equation in the continues form in the next chapter. So, what I will do is I will just give you this equation and explain each and every term in it and how we actually use this discreet convolution equation to calculate the output from it in term of the DRH bonds.

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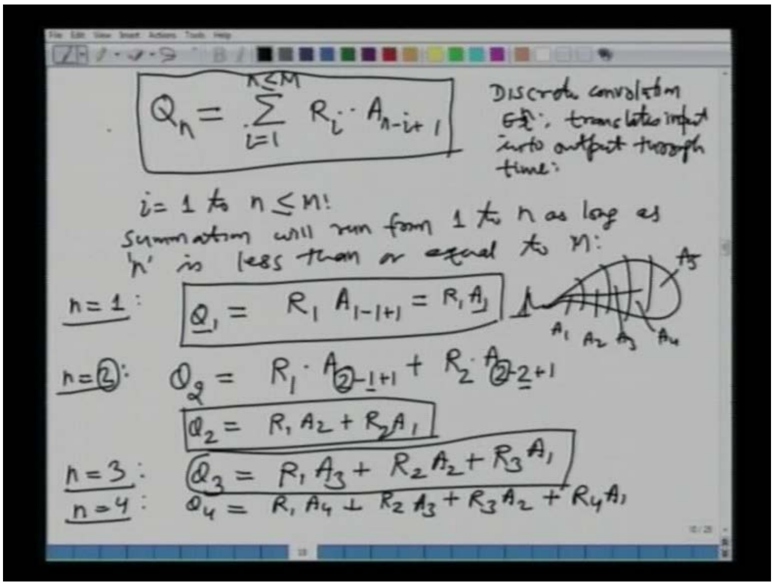

$$\boxed{Q_n = \sum_{i=1}^{n \leq M} R_i \cdot A_{n-i+1}}$$

Discrete convolution Eq: translates input into output through time:

$i = 1$ to $n \leq M$:
summation will run from 1 to n as long as 'n' is less than or equal to M:

$\underline{n=1}$: $\boxed{\underline{Q_1} = R_1 A_{1-1+1} = R_1 \underline{A_1}}$

$\underline{n=\textcircled{2}}$: $Q_2 = R_1 \cdot A_{\textcircled{2}-\underline{1}+1} + R_2 \cdot A_{\textcircled{2}-\underline{2}+1}$

$\boxed{Q_2 = R_1 A_2 + R_2 A_1}$

$\underline{n=3}$: $\boxed{Q_3 = R_1 A_3 + R_2 A_2 + R_3 A_1}$

$\underline{n=4}$: $Q_4 = R_1 A_4 + R_2 A_3 + R_3 A_2 + R_4 A_1$

So, how does it look like this looks like this it will give you the ordinate Q n as summation running from i is equal to 1 to small n as long as it is less than or equal to capital M and this term in the summation is R i times A small n minus i plus 1 so, this is a very important equation which can convolute your input into output or it can translate your input in time and give you the response at the outlet in the form of DRH. this is your discreet convolution equation which translates the input response or input into output through time.

So, let us look at the application of this equation for a any data let us say you have capital M is equal to 4, 5, 6 there may be 2, 4, 5, 6 impulses in your effective rainfall hyetograph. You may have a catchment in which you have done the time area diagram how do we actually calculate this time area diagram we take the topographic map. We estimate the approximate the travel times and then we draw the isochrones using our knowledge of contorting and we can have any delta t any desirable controlling interval. And then let us say we have the capital I or A1, A2, A3 up to capital I then Q is something which we want to find out which is the DRH ordinate using this equation how can we do that let say you want to use this equation for n is equal to 1 now before I actually go to that let me first explain. What is this concept? I going from 1 to n less than equal to capital n this important what we mean by that is the summation will run from 1to small n what is small n small n is the index of DRH ordinate. it is not capital N small n will keep on changing from 1,2,3,4 it will go all the way up to capital N, but small n is the index.

So, for example, you want to find out what will be the DRH ordinate and the end of first hour for that n is equal to one all right if you want to find out the DRH ordinate H let say some Nth ordinate or Nth time step or forth time step so, that value you have to take accordingly now the summation will run from 1 to n as long as n is less than or equal to capital M. This small n should not be more than capital M what is capital M? Capital M is the total number of effective rainfall impulses in the ERH. So, this small n should be less than or equal to that value of maximum number of impulses in ERH that is to say if in opening up this expression or this summation value encounter n values which are more than capital n they will just vanish.

So, they will not existent or you just put them equal to zero all right this will become clear when we take some example later on so, let say that what will be your Q1 for n is equal to 1 if you utilize this equation just think about it what will be Q1 if you look at the summation this summation will run from where to where now we have said that small n is equal to 1 so, the summation will go from 1 to small n which is 1 so, they will be 1 term in the summation.

So, you have R i is going from 1 to 1 so, this is one multiplied by A area which area well small n is one minus i is 1 plus 1 is it clear so, this will be nothing, but R1 A1 is it clear. So, let me draw a diagram here quickly so, this is your let us say these are your areas this is A1 this is A2 this is A3 this is A4 this is A5 and so on now what this equation is telling us physically if you want to think about it what this equation is telling us physically it is saying Q1 or with direct run of hydrograph at the end of first hour let us say 1 hour is the delta t for example, for demonstration.

So, the DRH at the end of first hour is what nothing is, but R1 multiplied by A1 that is the contribution from the catchment during the first hour what is A1? A1 is the entire isochronal area corresponding to 1 hour so, there will be no response at the outlet and the end of first hour from A2, A3, A4 and so on why because the travel time concept we are using at the end of first hour only A1 is contributing.

So, that if you come here the Q1 the contribution is coming from A1 only so, if you look at this diagram the run of response here you see that the response at the end of first hour will be only from A1 that is what this equation is telling us now look at let say n is equal to 2 at the end of second hour the end of second time interval what will happen the contribution will come from where obviously the contribution will come from both areas A1 and A2, but which rainfall would be used. If think about it and then we will use this equation and then will try to deduce what is actually happening and which area is contributing at what time so, small n is equal to 2 in that equation this equation that is so, you are saying Q at the end of second hour will be equal to what how many expressions or how many terms will be there in the summation small i varying from 1 to small n and the value if small n is what 2 so, there will be two terms.

So, I will run from 1 and 2 so, first we will write the expression for i is equal to 1 what would that be well it will be i 1 i is equal to 1 times a small n is what 2 minus 1 plus 1 just simply apply this equation like a computer program plus there will be another term. So, we have R now i is 2 times area which 1 n is constant n is 2 here so, we are not changed n so, this is 2 minus 2 i is 2 plus 1 so i is one here and 2 here, but n is constant n is constant all right so that means your q 2 would be equal to what it will be R1 A2 plus R2 A1 does that make sense now think about it with respect to this diagram here what this equation is telling us is that these are not response at the end of second hour this one Q2 is equal to what is equal to the contribution from area A2 which contribution the rainfall.

Which fell during the first hour the rainfall that fell on the whole catchment during the first hour on A2 will appear at the outlet at the end of second hour similarly, the rainfall R2 that is the rainfall that fell during the second hour that will contribute from A1 at the end of second hour so, you see that this A1 rainfall R2 will appear here similarly, A2 the rainfall that fell during the first hour will appear at the end of second hour so, you can try to think about it and try to make sense that intuitively this equation is making sense which rainfall impulse will appear at the outlet at what time this pure translation or this translation in time is taken care of by this time area diagram.

So, it is a very important tool physically it is important to understand the mechanism otherwise mathematics is very simple let us look at 1 or 2 more cases let us say you have n is equal to three. What will be the answer now you see a pattern now your Q3 will be equal to I am going to write it directly you would have R1 A3 plus R2 A2 plus R3 A1. What is this equation telling? You can apply the same logic the run of at the end of third hour is contributed from all the 3 areas A1, A2, A3, but which rainfall is effective on A1 at the end of third hour it is the rainfall which falls at the during the third hour similarly, the rainfall which falls on A2 during the second hour all right will appear at the end of third hour here similarly, A3 will be multiplied by R1 and so on so, there is a pattern here.

So, n is equal to 4 you can directly which would be Q4 is equal to R1 A4 plus it is going to be R2 A3 plus R3 A2 plus R4 A1 and so on so, you can successively keep on applying this equation which is called a discreet form of contribute equation.

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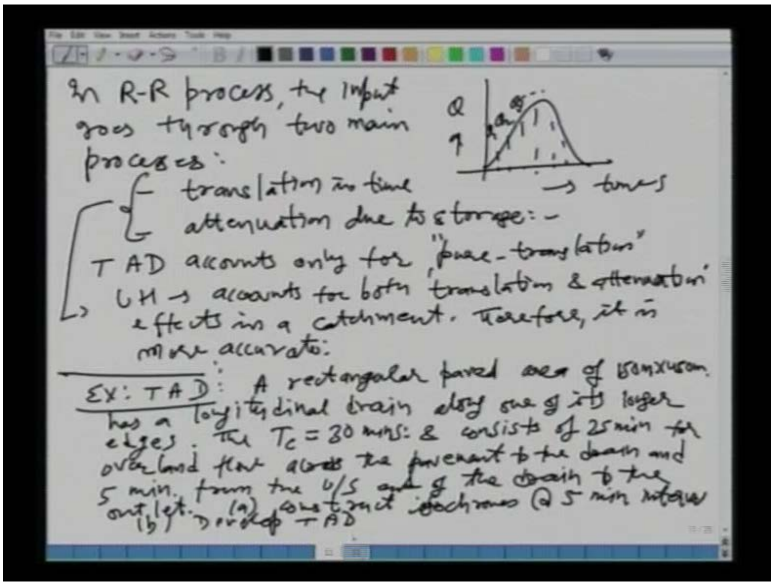

In R-R process, the input goes through two main processes:
- translation in time
- attenuation due to storage:-

TAD accounts only for "pure-translation"

→ UH → accounts for both 'translation & attenuation' effects in a catchment. Therefore, it is more accurate.

EX: TAD: A rectangular paved area of 150m×40m has a longitudinal drain along one of its longer edges. The $T_c = 30$ mins. & consists of 25 min for overland flow across the pavement to the drain and 5 min. from the u/s end of the drain to the outlet. (a) construct isochrones @ 5 min interval (b) Develop TAD

So, you can find out the direct run of hydrograph all right and it would be or look like this we have the different times and then you have Q and these are the different ordinates you have calculated Q1, Q2, Q3 and so on so, you see that the computation of the direct run of hydrograph using the time area diagram it is a very simple process using this discreet are convolution equation. However whenever we have the rain falling on the catchment it is getting converted into run of what is actually going on in the catchment is that the water is going through two hypothetical processes.

We would write these down and then look at the limitation of this time area diagram method so in your rainfall run of process or the physical process the input which is your water goes through two main processes let us say what are those well it is 1 is the translation in time what happens to the effective rainfall it gets translated in time and also it is gets attenuated or you have attenuation due to storage.

So, in the rainfall run of process you have these two components which we needs to model in at any mathematical model all right this time area diagram the method which has looked at account for only translation in time it does not account for the attenuation due to storage in the catchment. So, if you write the limitation of the time area diagram is what that it accounts only for pure translation or translation I should say it does only pure translation can you tell me any method rain fallen of method that is converting effective rain fall into direct run of hydrograph which accounts for both translation in time as well attenuation. If the catchment storages it is unit hydrograph.

I am sure you will have seen this so, you can say that UH accounts for both translation and attenuation effects in a catchment attenuation effects in a catchment therefore, it is more accurate then time area diagram obviously any mathematical model which is able account for all the processes through which the input is going through would be more accurate. Will come to the unit hydrograph in the next chapter what I have like to do next is look at an example of the time area diagram how we can actually develop it and how we can use it so next thing we are going to look at is example on the time area diagram.

In this example I am going to first write it down and then we will see how we can solve it. A rectangular paved area of 150 metres by 450 metres has a longitudinal train along one of H longer edges the time of concentration in this rectangular paved area or the catchment is 13 minute the maximum travel time is 30 minutes and consists of this total 30 minutes consists of 25 minute for overland flow as I said it takes more time in the for water to travel as overland flow and less time during in the channel.

So, it takes 25 minutes for the overland flow across this payment to the drain or towards the drain along the longitudinal edge and 5 minutes from the upstream end of the drain upstream end of the drain to the outlet. So, total 30 minutes 25 minutes in overland flow and 5 minutes in the channel flow or along the drain. What you have to do is a construct? The isochrones at 5 minute interval so we are looking at this example a part we have to construct the isochrones at 5 minute interval and b in the second part we have to develop what is called your time area diagram?

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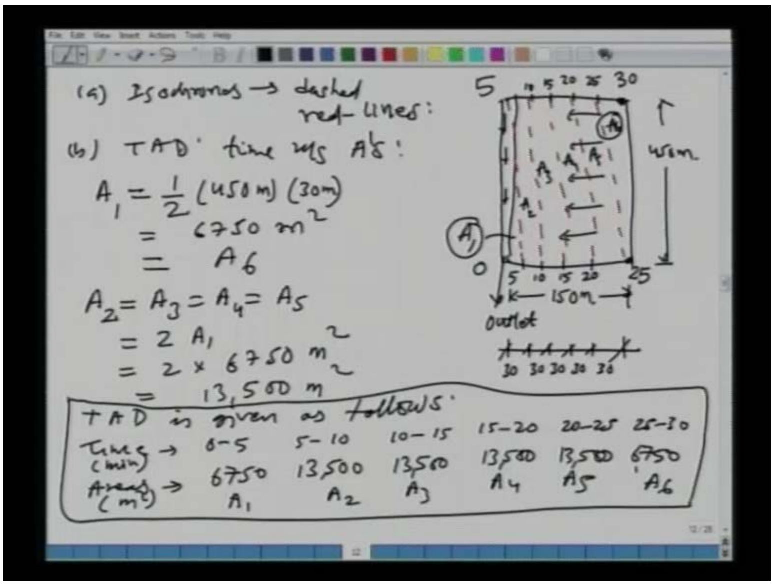

(a) Isochrones → dashed red lines:

(b) TAD: time vs A's:

$$A_1 = \frac{1}{2}(450\,m)(30\,m)$$

$$= 6750\,m^2$$

$$= A_6$$

$$A_2 = A_3 = A_4 = A_5$$

$$= 2\,A_1$$

$$= 2 \times 6750\,m^2$$

$$= 13,500\,m^2$$

TAD is given as follows:

Time (min) →	0–5	5–10	10–15	15–20	20–25	25–30
Areas (m²) →	6750 A_1	13,500 A_2	13,500 A_3	13,500 A_4	13,500 A_5	6750 A_6

So, what will do is let us look at this problem first graphically or arrange al this data so, that we can understand the problem the length of the payment is 450 metres that is given to us all right and this way or the width is how much it is 150 metres.

So, it is a parking lot or something there is a drain along the longitudinal edge let us say this is a drain so, the water actually travels from right to left all right let me just draw this like this so, this is a overland flow all right and then it comes into this drain and then it goes down like this that is the flow pattern. We are looking at now what we have to do is we have to draw the isochrones on this all right what are the isochrones? Isochrones are the lines joining equal times of travel.

So, what we can do is when whenever we have to do contouring what do what do we do on a map you put the bench marks all right or you put certain spot elevations so, what we will do here try to do here or in any kind of problem which is similar to this at important points or at some you know points on this graph you put the travel times which are available to you and the information that is available to me is that the maximum time of travel is 30 minutes and the maximum time of travel in the drain is 5 minutes all right so if you put that information this is the remote as point so, from here it is 30 minute. What about this point here from here how long does it take for and by the way this is your outlet so, the water is taking 30 minutes from here how 25 minutes along the overland flow and 5 minutes along the drain similarly, from here it is taking 25 minutes as the overland flow and then it reaches the outlet what about this point just at the upstream end of the drain this takes 5 minutes.

This edge is the outlet itself so, it takes zero. Now we have these 4 points on this rectangle at which we have mark the travel times how can we find out or how can we draw the isochrones at 5 minute interval well.

We can do linear interpolation so, if use the linear interpolation concept then let us say we can divide it into 1, 2, 3, 5 parts this 1 and 1, 2, 3, 4, 5 parts. Now what will be the time of travel from here so, it is 5 to 30 along this width and we have divided this into 5 parts. So, it has to be then 25 from here it is 20, 15, 10 and this is 5 similarly, this will be 5, 10, 15, 20 and 25 so, what we have done is we have found out the points all right of of travel now what are the isochrones which is the part a in this problem we have to find out the or develop the isochrones. Isochrones are the lines joining equal times of travel now you have two points in the catchment which have equal travel times you have 25 here and you have 25 here you have 20 here and 20 here so, all you need to do is just join these points.

So, let me try and do that you can join 25 with 25, 25 with 20, 15 with 15, 10 with 10 and this is a 5 with 5 so, these are your isochrones all right you can subdivide all these areas let us say this is your A1 this is A2 this is A3, A4, A5 and A6. So, part A is the isochrones by dashed red lines now part b we have to develop the time area diagram what is time area diagram? It is time verses this is inter isochronal areas now all do we find this A1, A2, A3, A4, A5, A6 well we have the width and the length of the catchment or this paired areas we have divided are that into 5 different parts each of them will be 30 metres each so what will be your A1 this area A1 is a triangle.

If you see it is one width is 5 metres the other width is 400 and not 5 metres this is 30 metres and other width is 450 metres so, area of a triangle is half of base into height half of base is let us say 450 metres multiplied by how much is this is let me try to do it here you have derived at into 1, 2, 3, 4, 5 total was 150 so, each of it would be how much 30 you see that so, each step is 30 metres. So, this is 30 metres this would be equal to 6750 square metres what will be A6 this area will also be equal to A6 you see that this A1 and this area A6 are same. Why because you have same base and same height. So, A1 is equal to A6 now similarly, you have A2 is equal to A3 is equal to A4 is equal to A5.

Which are parallelograms of equal size all of them that will be equal to what using with geometry you can see twice of let us say A1 one is a triangle other is other is consisting of twice of that triangle.

So, it will be twice of your 6750 square metres so, which would be 13500 square metres so, your time area diagram then is given as follows. Which is your time is in minutes I should say 0 to 5, 5 to 10, 10 to 15, 15 to 20, 20 to 25 and the maximum is 25 to 30 these are the inter intervals and then your inter isochronal areas in square metres is how much well it is for first 5 minutes which is A1 is 6750 that is A1 then other one the all of the middle areas are equal which 13500 square metres this is 13500, 13500, this is also 13500 and the last one is equal to the first one which is 6750. So, let me write it this is A2, A3, A4 and A5 and the last one is A6 so this is your answer b.

So, you see that we have taken a very simple example of taking a catchment knowing the time of concentration we can do put some certain spot derivations in terms of travel times and then do the contouring this contouring of isochrones can be done either manually on a map or there are sophisticated software available these days are which can do that once we have done that we can measure the inter isochronal areas on the map on a natural in a topography or if you have a you know simple example like this we can use our manual calculations.

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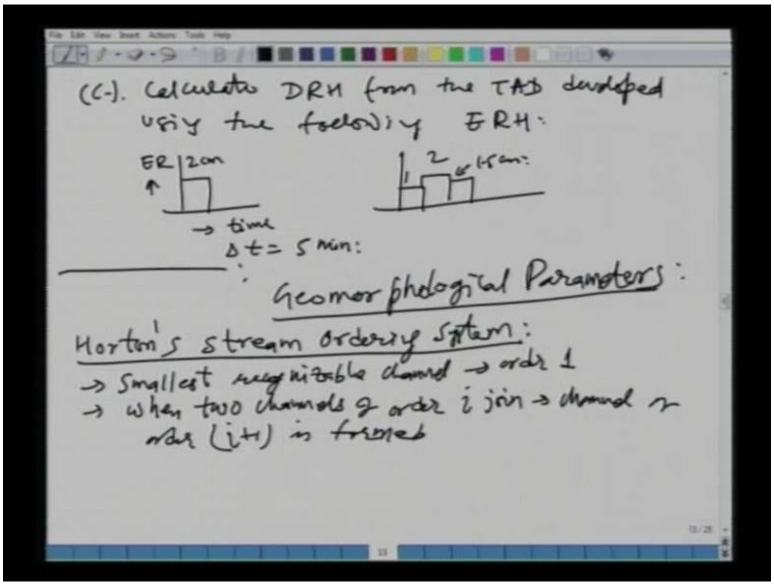

(c). Calculate DRH from the TAD developed using the following ERH:

Δt = 5 min:

Geomorphological Parameters:

Horton's stream ordering system:

→ Smallest recognizable channel → order 1

→ when two channels of order i join → channel of order (i+1) is formed

Now I block to extend this particular example and I will give you a home work type of problem in which you solve part c to calculate to DRH from the time area diagram which we have developed using the following ERH first one is very simple let us say it is 2 centimetre. This is your effective rainfall and this is your time and this is time I am going to say is time interval is 5 minutes so, let me say that for this ERH delta t is 5 minutes so, that there is no problem so, that is part one and the other one let us say this is 1 centimetre this is 2 centimetres and this is 1.5 centimetre.

So, what you do is you try to solve this problem in which there are 2 effective rainfall hyetographs are given to you so, after having look at this example what we would like to do the last thing in this chapter is about certain Geomor Phological parameters so, what we will do is we will look at if you do not have lot of information about the you know rainfall or the gages in the catchment in terms of flow then what we can do is we can take the topographic map of the catchment and then develop certain parameters of characteristics. We can calculate certain parameters using those topographic maps and try to infer certain information about the run of response of the catchment when it is subjected to rainfall.

So, you look at you know few of these Geomor Phological parameters. First one of them is what is called the Hortans stream ordering system. You may have a large catchment in which there may be a main channel or the downstream channels they would be you upstream channels small channels which will be forming you know very very small you know channels in the upstream catchments.

So, what Horton is done is it has he has developed a certain notation or system of numbering or ordering roughs streams. So, that we can calculate many physical or this Geomor Phological parameters or each of these different types of streams. So, what they have said is that the small or the smallest recognisable channel in the catchment is given order one order first order and then the other rule is when two channels of order i join the channel of order i plus 1 is formed. Will try to look at this concept in a graphical manner.

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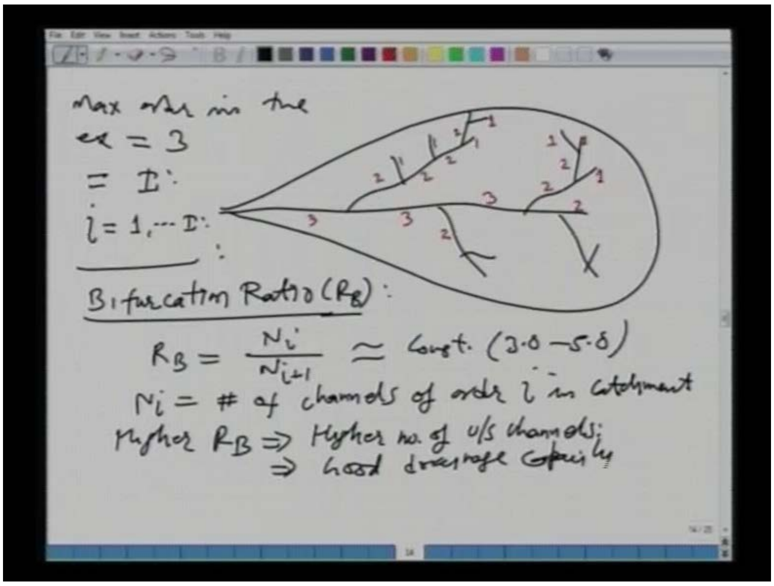

Max order in the ex = 3

= I:

i = 1, ... I:

Bifurcation Ratio (R_B):

$$R_B = \frac{N_i}{N_{i+1}} \simeq \text{Const. } (3.0 - 5.0)$$

N_i = # of channels of order i in catchment

Higher R_B ⇒ Higher no. of u/s channels;

⇒ Good drainage capacity

Let us say this is the catchment we have in which there is a main channel there is some tributary is to that the some further sub tributary is other small streams joining. Then there may be other streams joining them similarly, other places like this so, this is your network of streams. So, upstream you have very channels and then as you go down stream you will have the bigger channels so, how do we order it using the Horton stream ordering number well the smallest recognisable channel is one.

So, let me use a different colour actually let us say this is one this is also one these two will join they will form two all right and then this is the smallest one so this is one. 1 and 2 will join they will form what it will remain 2 and 2 and 2 will join when the two streams of order i or two will join then i plus one will be form otherwise not so, this is 2 and let us say this one also 2 and the 2 plus 2 will be 3 and let us say this is 2 so this 3 and 2 will be 3 here and let me order this one here so this is 1 and 1 join this is 2 this is 1 so, this is 2 this is 1 this is 2 this is1 and this is 2 and then 2 and 3 would join it will form number 3.

So, this may you see that we can keep on ordering this different channels or number numbering these channels using the Horton's concept and then the maximum order in the example which we have drawn is what it is 3 and let us in general it is capital I so, your order index is i it will vary from 1 to capital I so. this is the ordering system as per Horton the next parameter we are going to look at is what is called the Bifurcation Ratio it will be denoted as RB Bifurcation Ratio and this r b is nothing but, n i over n i plus one and people have found out that this is a constant and it ranges between three point zero to five point zero, but let me first define what is n i as it suggest the…

It is the number of channels of what of order I which we have just defined above in the catchment in a catchment so, you see that higher the r b what is the r b? Is the bifurcation ratio higher the r b means what it would mean that there is higher number of what of upstream channels? So, there are more channels in the upstream reaches what would that mean? In terms of the drain h capacity if you have more number of channels the catchment will be able to drain what are the very quickly efficiently right.

So, higher the r b you will have good drain edge capacity of your catchment so, you see that by looking at this bifurcation ratio r b we would be able to say something about the hydraulic efficiency of a catchment or we can compare the 2 catchments.

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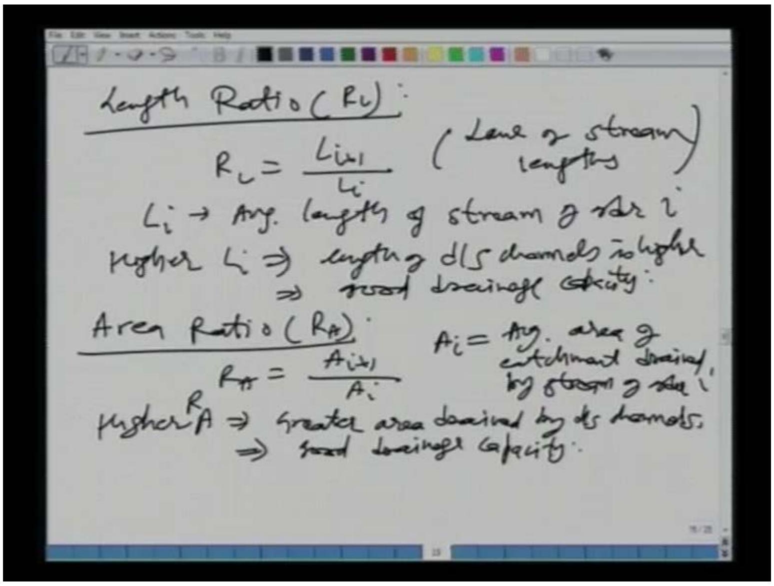

Length Ratio (R_L):

$R_L = \frac{L_{i+1}}{L_i}$ (Law of stream lengths)

L_i → Avg. length of stream of order i

higher L_i ⇒ length of d/s channels is higher

⇒ good drainage capacity.

Area Ratio (R_A):

$R_A = \frac{A_{i+1}}{A_i}$

A_i = Avg. area of catchment drained by stream of order i

higher R_A ⇒ Greater area drained by d/s channels.

⇒ good drainage capacity.

Moving on the next ratio or the next parameter we would look at is called the length ratio r l it is defined as the ratio of l i plus 1 over l i it is also called law of stream lengths where l i is the average length l i is the average length of stream order i similarly, we can argue that higher the l i would mean what means the length of the downstream channels is higher that would also mean you would have good drain edge capacity of the catchment. The next parameter is the area ratio which we would define as r a and r a is given as a i plus one over a i and what is a i well it is the average area of catchment drained by stream of order i a when you compare the 2 catchments one with higher r a or the area ratio that would mean what that would mean? Greater area drained by what the downstream channels? As compare to the earlier one. So, that is also indicative of god drain edge capacity of the channel or the catchment.

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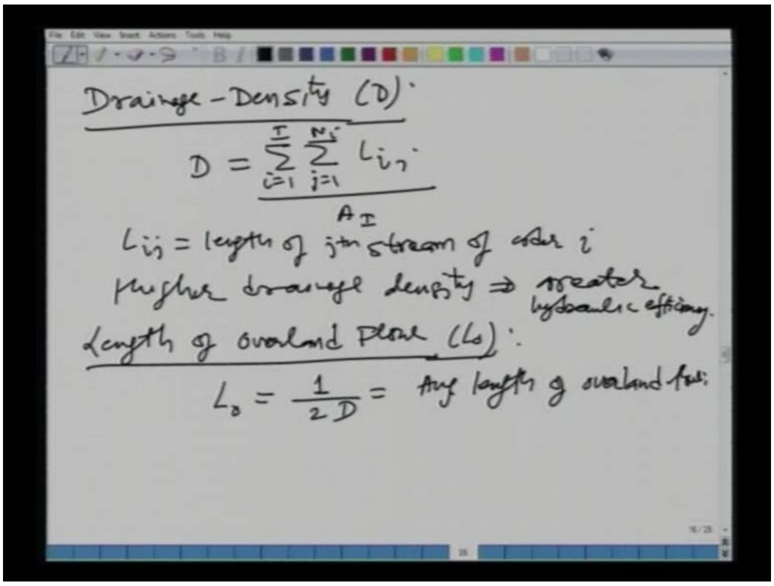

Drainage-Density (D):

$$D = \frac{\sum_{i=1}^{I} \sum_{j=1}^{N_i} L_{ij}}{A_I}$$

L_{ij} = length of jth stream of order i

Higher drainage density ⇒ greater hydraulic efficiency.

Length of overland Flow (L_o):

$$L_o = \frac{1}{2D} = \text{Avg length of overland flow;}$$

Moving on the next thing we are going to look at is what is called the drain edge density as you can see we can estimate or calculate all of these geomorphological parameters using the topographic map. This d is defined as summation of L i j and i need 2 summations L is i running from 1 to capital I all the streams and then j running from 1 to n i and this whole thing divided by AI were L i j is what is the length? Of jth stream of order i so, you see that this drain s density is what it basically represents the ratio of the total length of streams divided by the total area. So, it is the length of the all the channels al the streams per unit area of the catchment. So, this is called the drain h density obviously when you compare to catchments and we can calculate their drain h density.

So, let us you have two catchments one has lower drain edge density as compare to be other. Which one will be more hydraulically efficient obviously the one with higher drain edge density why because the one with the higher drain edge density has higher length of the total number of channels or greater length so, you can say that higher drain edge density means what greater hydraulic efficiency? Or drain edge capacity of the catchment the last one in this we are going look at is called the length of the overland flow this is denoted by Lo and people have found out that this Lo is nothing but, 1 by 2D which is the average length of your overland flow.

So, you see that we have defined a lot of these parameters the bifurcation ratio or the area ratio the length ratio the drain edge density and so on. with that I am (( )) we come to the end of this chapter which is on the surface water so, we have looked at the modelling of the surface water in this chapter in a competency manner the next chapter is on the unit hydrograph which is a more comprehensive or little bit more detailed modelling of the rain fallen of process in which we would look at various types of functions which are needed to develop this unit hydrograph concept so, I would like to stop at this point of time and then will start the next chapter in the next class tomorrow.

Thank you.