Advanced Hydrology
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Lecture - 20

Good morning friends and welcome to the next lecture of this video course on advanced hydrology. In the last class we looked at an example of how to calculate phi index given the rainfall data and the runoff data. Then we also looked at the concept of w index and the runoff coefficient; these are all the methods of accounting for abstractions from precipitation while we are doing some kind of rainfall runoff modelling. Then we moved on and started developing an algorithm for abstractions from precipitation due to infiltration that is and then we said that we will develop this algorithm using the Green-Ampt equations. If defined the problem we looked at what are the data given what do we need, and what are the outputs from this algorithm.

In the process we defined 3 ponding cases. Case 1, case 2, and case 3 in which we said that why will we develop this algorithm for abstraction from precipitation due to infiltration, we march in time domain that is we analyse each time step or each time interval and while we do that we can encounter 3 possible cases. So, all the time intervals will fall either of this in either of these 3 possible cases, and we had said that the case 1 is a ponding throughout, case 2 was no ponding throughout, and the case 3 was when the ponding starts somewhere in between in that particular interval. That is where I think we are stopped and then what we will do today is we will start or we will look at the flowchart or the algorithm how it can be developed.

As I said we will just look at the flowchart, and then the coding can be done or a computer program can be written looking at that flowchart. There is a solved example given in the book in the ventures book on this particular flowchart or this algorithm, I will highly encourage that all of you write your own code, a small little computer program in which the rainfall data would be given, the Green-Ampt infiltration equation parameters will be given, and then what you would have to find out is effective rainfall hyetograph. So, that will be a very important component in a rainfall runoff model.

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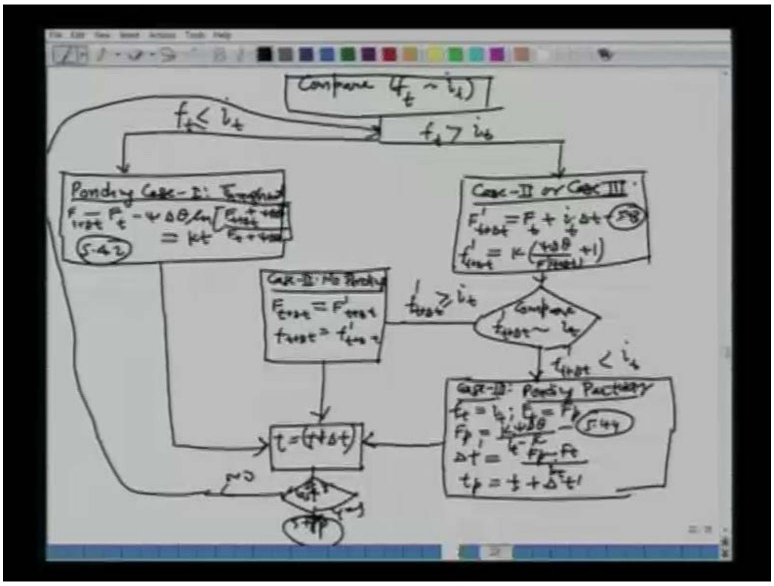

So, let us get started today by looking at how we will find the infiltration by analysing every time stab. So, the first stab would be we will compare infiltration at time t with i or i is the rainfall at time t. So, you have this will involve either of the 2 cases. So, either you have infiltration less than or equal to i t or it is greater than the rainfall intensity. In the first case which case is this, in this case when you have the intensity of rainfall is higher throughout then you would have what is called the ponding case 1 or ponding throughout.

Then what we do is we use the associated equations which would be f at t plus delta t minus f at t minus psi delta theta natural log of your f t plus delta t plus psi delta theta divided by f at t plus psi delta theta you close this bracket it should be equal to on the right hand side you would have equal to k t so this is basically your equation number 5.4.2. So, we do what we do is we analyse the ft with i t and then compare and then see which case it is. So, if that is true this will be case 1 you come here on the other side you would have what is this now the rainfall intensity is less than the infiltration intensity or infiltration rate at time t.

So, this would be either case 2 depending upon the 3 ponding cases we had seen yesterday we consider easily or it will be case 3 alright it could be either of these 2 cases now what we do is in order to distinguish between case 2 and case 3 is we calculate the rate of infiltration at the end of the time interval. We calculate the variables at the end of the time interval and then we compare that with the rainfall intensity the rate of infiltration at the end of the time interval we compare with the rainfall intensity and that will tell us whether it is case 2 or case 3 depending upon where the relative magnitude.

So, what we do is we calculate and we because these are intermediate variables we will denote them as prime. So, let us say you find out f prime at t plus delta t as f h times t which is supposed to be known plus rainfall intensity times delta t and this is equation I am taking 5 .4 . 3 basically from the book and once we know capital f prime you can always find out small f prime from the Green-Ampt equation. So, this would be nothing, but equal to k times psi delta theta over capital f prime of your t plus delta t which we have just found out plus 1 this is the basic equation of Green-Ampt.

So, we have the rate of infiltration at the end of the time interval now we compare this with the rainfall intensity at the end of the time interval which is same as i t because we said that during an interval rainfall intensity is constant. So, the next step then is we compare f prime t plus delta t with i t I am writing i t, but you understand that i t and i t plus delta t are same then if we are f prime t plus delta t is less than i t o we go in this direction and if not then we go in this direction let us say f prime t plus delta t that was less and this is greater than equal to i t now let us look at this case first which case this would be can anybody tell me that when we rate of rainfall is less than the rate of infiltration obviously it is a case of no ponding whether there will be ponding or not there will be no ponding actually in this case so, at the beginning there was no ponding at the end of the time interval there is no ponding so, we have no ponding throughout and that is case 2.

So, this way we are able to distinguish and then we can say that this is your case 2 of no ponding and then we use the appropriate equations and we all will say is that f at the end of the time interval is nothing, but whatever we had calculated f prime and t plus delta t and similarly, your f at t plus delta t is equal to f prime which we had calculated your t plus delta t which we have calculated already so, this is your case 2 and then what is the case 3 this is obviously your case 3 the last 1 in which you have the ponding part ways where the ponding starts somewhere in between so what we are going to do is I'll write the set of equations what we need to do in case 3 is we need to determine the the time exact time when the ponding starts within that time interval delta t. So, let us say the delta t is one hour and you are into the fifth hour. So, during from 4th hour to 5th hour exactly when the ponding starts.

That is what we want to find out and will call that a variable called delta t prime and once we find the delta t prime then we can calculate the infiltration everything before that is your you know whatever rainfall falls after that we use the Green-Ampt equations. So, the corresponding equations then would be your f of t is equal to i t f capital T would be f let us say at p then we calculate f p using the equation we have k psi delta theta over i minus k i at t that is this I am using 5 4 4 you can look at these equations and then once we have that we can find out delta t prime from our ponding time equations and that would come out to be f p minus f t which we have just found divided by i t and then exact time to ponding would be your t at the beginning of that time interval plus your delta t prime which you have just found out so, this way we can find out what is the exact time to ponding for the case 3 in which the ponding starts somewhere in between in that particular time interval.

Now I need to close down this loop so, you have a tree coming up coming down and then all of this algorithm has to convert somewhere So let me see for from the case 1 let me say that I am going to have a box here in which I am going to set t is equal to t plus delta t we have analysed the first or or you know t h times stab or any time stab and then i increment that. So, this is going here the logic will flow from here from case 2 to here and then from case 3 also it will flow there so, once we have analysed the time interval delta t all we do is we increment the time stab that is we start looking at the next time stab and then we apply our test for the condition is your t or the time last 1 if the answer is yes you say you are going to stop if it is no then what you do well you go back to your origin then start analysing the whole thing over and over again.

So, this way you see that the logic would flow that you will start with the first time stab analyse whether it is case 1 or case 2 or case 3 depending upon that you calculate the rate of infiltration and cumulative infiltration at the end of the time interval once we have done that we can find out the incremental infiltration at each time stab once we have that we can subtract the infiltration from the rainfall or the rainfall hyetograph and developed what is called the effective uniform.

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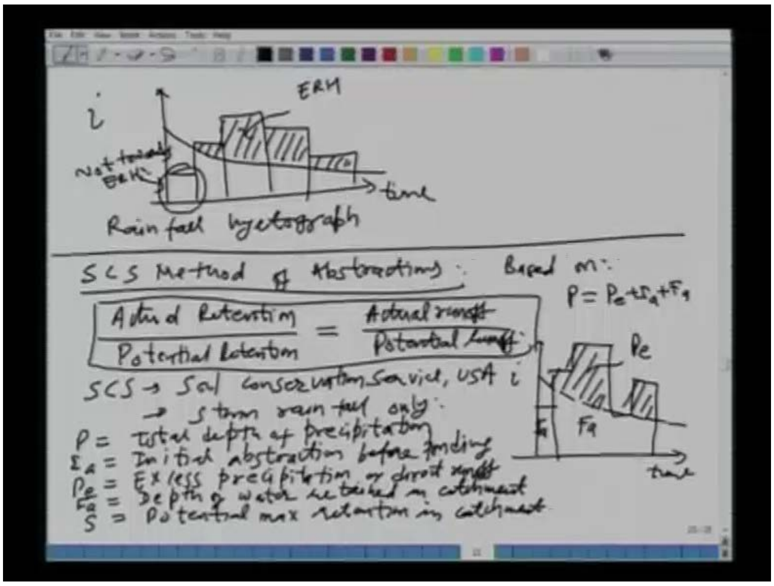

SCS Method of Abstractions: Based on:

$P = P_e + I_a + F_a$

$$\frac{\text{Actual Retention}}{\text{Potential Retention}} = \frac{\text{Actual runoff}}{\text{Potential runoff}}$$

SCS → Soil conservation Service, USA

→ storm rainfall only:

P = total depth of precipitation
I_a = Initial abstraction before ponding
P_e = Excess precipitation or direct runoff
F_a = Depth of water retained in catchment
S = Potential max retention in catchment

So, if I did that let me just try to demonstrate that if this was your let us say this is our rainfall hyetograph data in which this is your time and this is your what I rainfall intensity now as a result of this algorithm which we have developed we have calculated the rate of infiltration or the actual infiltration as a function of time so, let us say it is this something like this. So, everything about that is your ERH.

What does this represent this is your ERH does this contribute anything to ERH no why because this is a which case this is the case of no ponding through out. So, this is not towards the ERH so, you see that we have looked at this algorithm in which we have the rainfall hyetograph and we can convert that into effective rainfall hyetograph by subtracting losses due to infiltration using Green-Ampt equations the algorithm which we have developed does not account for the initial abstractions we had said that earlier however if we have the initial abstractions estimated somehow they can be incorporated before infiltration can be subtracted. So, that way we have done a half of the rainfall runoff modelling as for as calculation of the losses is concerned and calculating the effective rainfall is concerned and then we can go either to the unit hyetograph or any other complicated rainfall runoff model, but we will not start that yet.

So, this is the algorithm and the next topic we will start in this chapter is we will look at some another method which is also very important and very simple to you so, this algorithm of course, is slightly complicated one has to understand the process of infiltration ponding cases analyse everything and then develop this program in practice there are some very simple methods and one of them is what is called the SCS curve number method and that is what we are going to look at next SCS method of abstractions this method is based on a certain concept or assumption we would look at that first what it says is that the actual retention in a catchment divided by potential retention now what we are talking we are talking of the retention of the water storage is linearly related with the actual runoff over potential runoff.

Before I actually go into the details I must mention that this SCS curve number method or the SCS method was developed by what is SCS? SCS is an organisation in the United States it is called Soil Conservation Service. So, what is SCS? It is the Soil Conservation Service. It is an organisation what are resources organisation in USA they have developed this method and this method is applicable for storm rainfall only what do you mean by that? That this is applicable to an isolated storm this is a not meant to be finding the effective rainfall or the direct runoff hyetograph on a continuous bases this is only for the may be the flood events or the isolated storm events it is not for the continues modelling. So, we will look at this concept before we understand this I think we would need to define certain physical variables that are involved in this equation or this method so, let us look at them first so, first let us look at them first graphically and then will come to the equations.

This is the what we are looking at is the let us say rainfall hyetograph and then there some form of this is your losses so, everything above will contribute to the DRH and everything below is what is called the losses however let me first say that this is time and this is your i or losses and let us say that this is your i a; this is your f a ;and what we are seeing on the top is p e; and total p is your p e plus i a plus f a; so, the total rainfall is p it is divided into 3 components where does all the water go all the rainfall that falls on the catchment gets converted into 3 parts or this gets distributed into 3 components alright is the effective rainfall 1 is the initial abstractions and other is the f a ;so, let me just define all these parameters then first p is the total depth of precipitation or rainfall when during a storm event remember in the SCS Method we are talking about a storm event.

So, during the whole storm it may be 3 hours it may be 10 hours it may be 24 hours so, during that whole duration p is the total depth of the rainfall or the precipitation i a; is the initial abstraction. So, you see that this method does account for the initial abstraction before ponding p e; is the excess precipitation or effective rainfall commonly known as or direct runoff what is excess rainfall or effective precipitation or excess precipitation that actually runs off because all the requirements of the storage in the catchment below the ground have been satisfied all of those retention has been satisfied. So, everything else will runoff as effective rainfall f a; is your depth of water retained depth of water retained in the catchment or in the water shade and let us define one more a parameter which is not shown on that figure.

On your right will say capital S is the potential maximum potential or maximum what retention in the catchment. So, what we are saying is that capital s the maximum possible or the potential what retention of the catchment how much water catchment can store this is the maximum however during any given rainfall at any given time it would be less than that that we are defining as f subscript a; f a is the actual retention; now with this terminology let us come back to this equation or the assumption or the concept or the bases of this SCS Method in which what we have said is that the ratio of the actual retention potential retention is equal to the what actual runoff to the potential runoff the ratio of the actual runoff to the potential runoff.

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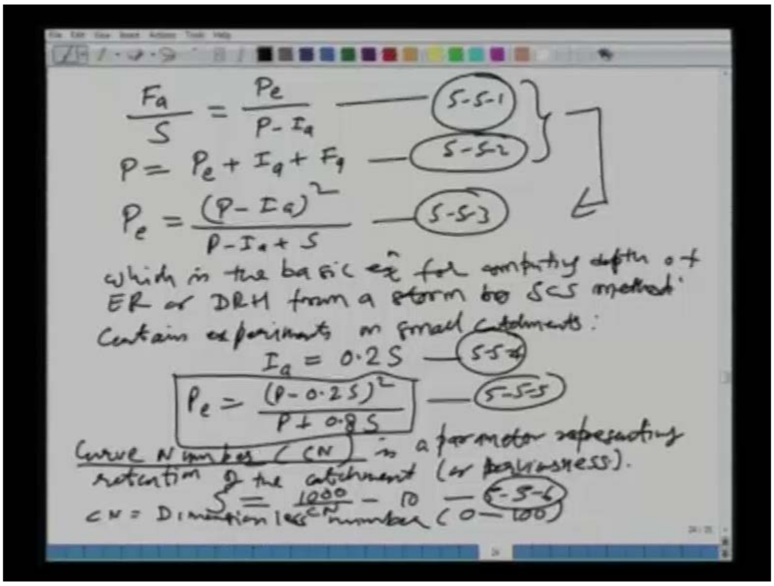

$$\frac{F_a}{S} = \frac{P_e}{P - I_a} \quad \text{—— (5-5-1)}$$

$$P = P_e + I_a + F_a \quad \text{—— (5-5-2)}$$

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \quad \text{—— (5-5-3)}$$

which is the basic eqn for computing depth of ER or DRH from a storm by SCS method.

Certain experiments on small catchments:

$$I_a = 0.2S \quad \text{—— (5-5-4)}$$

$$\boxed{P_e = \frac{(P - 0.2S)^2}{P + 0.8S}} \quad \text{—— (5-5-5)}$$

Curve Number (CN) is a parameter representing retention of the catchment (or [illegible]).

$$S = \frac{1000}{CN} - 10 \quad \text{—— (5-5-6)}$$

CN = Dimensionless number (0 — 100)

So, let us look at these quantities what is the actual retention we have just said is f a. The way we have defined all the parameters divided by the potential retention which is capital S this is equal to we are saying actual runoff over the potential runoff what is the actual runoff? The excess rainfall that will become your actual runoff the off divided by what is the total or the maximum possible runoff well it is the rainfall and what part of the rainfall does not become runoff well it is only the initial abstraction initial abstraction does not contribute anything to be runoff so, this is the equation basically done or the concept on which this method is based.

So, let me number this equation as 5.5.1 the other equation is as we have already written the total p is some of these 3 components that is p e; the excess rainfall plus abstractions plus the actual storage and I call that 552 now what we will do is we combine these 2 equations the mathematical or the algebraic manipulation we will not go through should be easy to see that.

Once we combine these two equations we can find the following relationship which is p e is equal to p minus i; a whole square divided by p minus i; a plus s; and let us number this as 553 which is the basic equation for computing the depth of excess rainfall or ERH will say in short or the DRH the direction of hyetograph from a storm by the SCS Method this is a basic equation now there is one quantity i a; of the initial abstraction so, what SCS has done is it has given certain guideline to estimate i a; in the absence of any other method you are expected to calculate or estimate this initial f section separately depending upon the catchment characteristics in the particular catchment in which you're applying this equation however if there is no information available they have said that based on certain experiments which they conduct in on small catchments.

Again this is not going to be applicable to the large catchments so, for the small catchments the SCS has found that your initial abstraction is about 20 percent of your maximum retention has. So, point 2 as if it is 5 .5 .4 we put this back into 5 .5 .3 and the final equation then would come out to this this is 0 .8 it S in the denominator that is your final equation so, this way we see that if we want to find out the excess rainfall from a storm based on the SCS Method all we need to know on the right hand side of what well of course, we need to know the total precipitation capital p the data that will be known to us there is a parameter called capital S or the maximum possible retention the SCS has try to characterise or quantify this parameter S for a catchment depending upon the catchment conditions it will depend upon what this is basically representing the storage in the catchment so on.

What things the storage will depend well it will depend upon the soil type the land use condition the infiltration and then the storage characteristics and so on. So, what they have done is they have characterised this in another parameter called a curve number that is why this method is also known as SCS curve number method. So, the next we will look at is the curve number concept or c n is a parameter representing retention of the catchment that is S it is another parameter as i said in other words actually it is also quantifying perviousness how pervious the parameter is and the relationship is that S is given as 1000 over the curve number minus 10 and this is let us say 5 5 6 then obviously I think I forgot to number this this is 5 5 5 where this c n is what it is a dimensionless number it does not have any dimensions dimensionless number and its values is ranges between 0 to 100.

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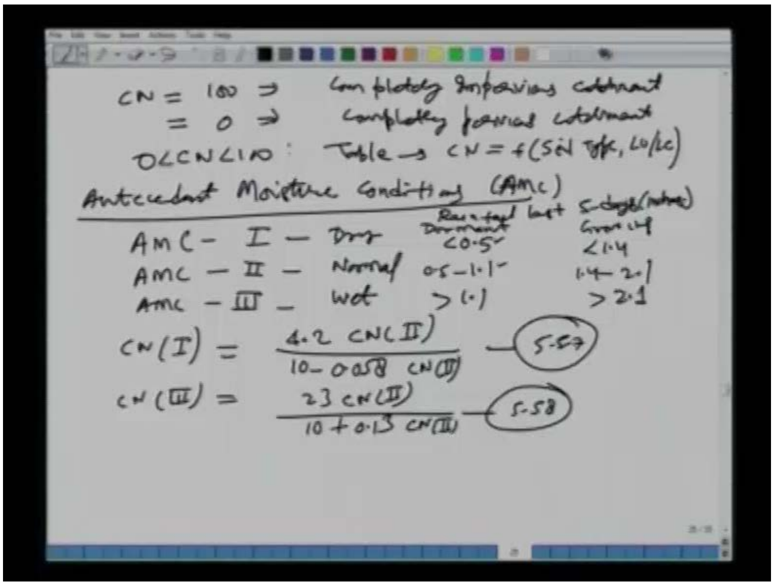

$CN = 100 \Rightarrow$ Completely Impervious catchment

$\quad = 0 \Rightarrow$ Completely pervious catchment

$0 < CN < 100$: Table → $CN = f(\text{Soil type}, LU/LC)$

Antecedent Moisture Conditions (AMC)

		Rainfall last 5 days (inches) Dormant	Growing
AMC – I	Dry	< 0.5"	< 1.4
AMC – II	Normal	0.5 – 1.1"	1.4 – 2.1
AMC – III	Wet	> 1.1	> 2.1

$$CN(I) = \frac{4.2\, CN(II)}{10 - 0.058\, CN(II)} \quad (5.57)$$

$$CN(III) = \frac{23\, CN(II)}{10 + 0.13\, CN(II)} \quad (5.58)$$

Then go with curve number is equal to 100 means completely impervious catchment and if the curve number is 0 means completely pervious which actually does not occur in real life pervious completely pervious catchment and normally the curve number will be between 0 to 100. So, when the curve number is close to 100 we are saying the catchment is completely impervious means what there is hardly any infiltration alright it does not allow the water to infiltrate.

So, what kind of a catchment would that be in which there are lots of buildings there is lots of roads there is lot of parking areas lot of trees so, all of those areas will not allow the water to infiltrate. So, if you have any highly industrialized catchment in that the curve number will be high and accordingly the storage characteristics would be different if you have a rural catchment in which there is lot of grassy areas.

And, you now a vegetal cover that will allow higher amount of infiltration so, that will have the capital S or the storage value or depending upon that curve number is because that is very small. So, this way the curve number is defined and then next thing we look at is what is called the antecedent moisture condition before I actually go to that I must mention that this curve number has been defined or these have been calibrated or given by the soil conservation service depending upon the soil type and the land use pattern the SCS has classified all kinds of soils into 4 kinds class a class b class c and class d so, depending upon whether you have clay soil or the sandy soil or the lome or whatever you first find out whether you know it classified into a or b or c or d once you have done that then you look at the catchment conditions.

Whether it is the residential whether it is rural whether it is you know a paved areas or different kinds within rural and within you know urban areas there are various categories so, depending upon these 2 parameters the curve numbers have been specified and in the book there is a table which is specifies the curve number as a function of these things as I said which is the soil type and the land use land covered conditions in short that is what I am writing so, what you can do is depending upon what type of soil is there what type of valuable conditions are there you just read off from the table you can just pick up the value of the curve number for the catchment again I should. Out that in a large catchment the you can expect lot of heterogeneity that is these this can be more than one type of soil there can be more than one type of land used land cover conditions.

So, that case it is possible to classify your whole catchment into small sub areas then you assign a curve number depending upon the soil type and the land used land cover conditions and then you can compose it or you can find out a weighted average of the curve number. So, actually I did not want to go through you know that step yet, but it is possible to model or characterize a composite or a complex catchment also using the SCS curve number method. So, these are the 2 things and then another important thing when we are doing this rainfall runoff modelling or the calculating the direct runoff hyetograph is the initial conditions let us say you have the same rainfall event or you have a catchment you have 2 different rainfall events of those equal magnitude occurring with the same distribution however the initial conditions were different so, if you use the SCS curve number method it will give you the same curve number because the curve number depends on what.

As of now we are said as the soil type and land used land cover conditions which are going to be same so, it will give the same amount of excess rainfall depending upon different initial conditions so, we have to account for the initial conditions or the what is called the antecedent moisture conditions so, what they have done the SCS people is that they have defined the curve number for what is called the AMC condition 2 which is the normal condition and then they have given certain equations using which we can convert the curve number for different initial conditions so, what they do is the AMC conditions or the antecedent conditions are defined into 3 classes or 3 types AMC 1 AMC 2 and AMC 3. One is let us say our dry, second one is normal, and the third one is the wet, instead of the direct magnitude what they are doing is, they are just classifying the initial conditions into 3 types dry, normal, and wet.

The curve numbers that are given in the table are for normal and then we have equations which will convert the curve number for the drier conditions and the wetter conditions and how we define or how we characterize these 3 different. Well what they do is? they take the antecedent rainfall for last 5 days you look at the rainfall for the last or the previous 5 days the total rainfall the cumulative rainfall depending upon the magnitude of that cumulative rainfall for last 5 days. You say that the current conditions are either dry or normal or wet this rainfall for the last 5 days also they have defined for the dormant season and for the growing season for the benefit of the rural areas or the agricultural areas so, for the dry I will just through these numbers at you it is 0 .5, 0 .5 to 1.1 and then it is more than 1.1 so, in the dormant season.

If the last 5 days rainfall is less than point 5 then you have dry conditions. If it is between this then you have normal and if it is more than 1.1 then it is wet and by the way all these things are in inches, and in the growing season this is less than 1.4 inches, this is 1.4 to 2.1 and this is greater than 2.1. So, we take the last 5 days rainfall data and then we find out what will be the current conditions or antecedent moisture condition and then we look at the equations which can be applied. So, the curve number for the dry condition that is AMC 1 is given as or given by this equation which is 4 .2 c n c for 2 divided by 10 minus 0 .058 of your curve number for 2 as I said the curve number which we will read off from the table is for normal condition that is c n 2 and then if you have the wet conditions.

Then you can convert or find the suitable value of curve number for the wet season as this over 10 plus 0.13 of your curve number for the second conditions this is 5.5.8 so, you can see that these are very simple equations to use you just find out what is the curve number in your catchment using the curve number depending upon AMC one or 2 or 3 depending upon the Soil type and the land used land cover conditions once you have done that you can convert that c n into S and then you can use that S in your basic equation for the SCS method so, you can get the effective rainfall.

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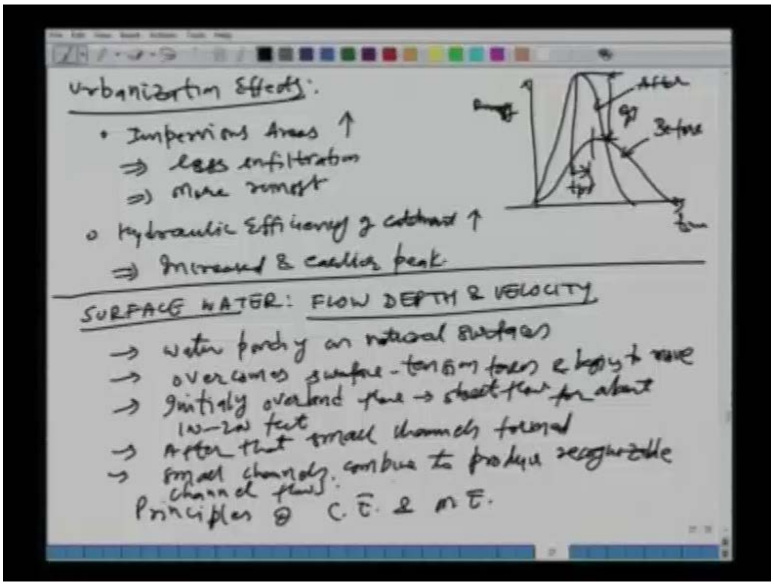

Urbanization Effects:

- Impervious Areas ↑
  - ⇒ less infiltration
  - ⇒ More runoff
- Hydraulic Efficiency of catchment ↑
  - ⇒ Increased & earlier peak

SURFACE WATER: FLOW DEPTH & VELOCITY

→ water ponding on natural surfaces
→ overcomes surface-tension forces & begins to move
→ Initially overland flow → sheet flow for about 10–20 feet
→ After that small channels formed
→ small channels combine to produce recognizable channel flows.

Principles of C.E. & M.E.

Now I think we would move on take a move on here and the next thing we are quickly going to look at this what is called the Urbanization Effects in a catchment what happens when a catchment goes a through the process of Urbanization over a long period of time let us say in 10 or 20 or 30 years a catchment.

You will have you will see that there will be lots of buildings coming up there will be lot of paved areas. So, the runoff from the catchment will tend to increase the infiltrations would decrease and the hyetograph characteristics will or the runoff response from the catchment will keep on changing. So, what we want to just look at very briefly is what will be the impact of the Urbanization on the shape and the magnitude of your runoff hydrograph. So, if you look here let us say that this is your shape of the runoff hydrograph before urbanization or the before conditions. Now during the urbanization process what happens is the impervious areas increase during the industrial due to the industrial activity or the economic development you will have lot of impervious area coming up so, the faction impervious will increase as a result as you know in the SCS method what will happen the curve number will increase.

So, what does that mean that means that there will be less infiltration and there will be more runoff also what we say is the hydraulic efficiency hydraulic efficiency of the catchment increases as a result of urbanization we are saying the hydraulic efficiency of the catchment increases means what due to the lot of paved areas or the urbanization or the buildings coming up you would have good drainage system also because the water will runoff quickly it will get collected into the small channels into the bigger channels and it will reach the outlet of the your catchment very efficiently very quickly so, that drainage system becomes more efficient so, that is what we need when we said the hydraulic efficiency of the catchment increases as a result of Urbanization what else that will result into increased and earlier peaks so, as a result of the urbanization we have seen that there will be less infiltration more runoff the peak will be higher the peak will occur earlier.

So, if this is a my shape before the Urbanization on the same graph before I do that let me say that this is time and this is your runoff that goes without saying so, what you have done is something like this where in this is your after Urbanization this difference you see this much what is this? This is the increase in q p; and then this time difference you see the peak what is this? This is the decrease in the time to p so, you see that as a result of urbanization what happens to the runoff response from a catchment is that you have earlier peak and you have higher peak so, after 10, 20, 30 years you may have noticed that you have a catchment or a you know your surrounding areas in which if the rainfall used to occur at 10 years ago there will be no flooding the drainage system would be able to take care of the water, but because of the inter changing condition or the Urbanization that is no longer valid.

Why because the drainage capacity of your drainage system has remained constant, but the runoff generated the peak discharged which are generated are more for which the system is not designed. So, these concepts are important from the point of view of the drainage design basically. So, we will not spend too much of time on this, but we would move to a very important concept in this chapter in which what we will do is we will look at the modelling of the surface water the overland flow modelling and the channel modelling. Until now we have looked at the modelling of the abstraction or the to the rain from the rainfall how do we get to the effective rainfall. Once we have done that then we want to find out how this effective rainfall gets converted into your direction of hydrograph Or how the surface runoff. And how the channel you know flow is getting modelled?

So, the next thing is your surface water modelling and in which we would look at what is called the flow depth and velocity what will be our objective our objective will be to find out the flow depth and velocity for the overland flow. So, what happens is at the rainfalls on a catchment the infiltration takes place that goes in the remaining water or the excess rainfall starts to runoff the certain amount of holding capacity the water starts to pond but, after some time that water starts to move because of the gravitational forces taking dominance so, the water or the surface water or the overland flow it is also called the sheet flow its starts to move very slowly initially and then the velocity is become higher and then the water will start to move into very small channels or these are called the grills after sometime these channels will combine into bigger channels and then bigger channels will finally, get into the rivers and stream.

So, this is the process of conversion of your effective rainfall to the flowing the rivers so, let us look at it a briefly and then we will go to the mathematical modelling so, you have initially the water ponding on the natural surfaces as the rain is falling then what happens is this ponded water overcomes the surface tension forces or the surface retention forces and begins to move initially this over land flow is moves as a sheet flow very small sheet of water which is flowing slowly for about 100 to 200 feet this sheet flow will not continue for the very long for about 100 to 200 feet after that it will start forming the small channels and after that small channels starts to appear or small channels get formed.

Then later these small channels combine to produce recognisable channels these small channels which we have just said these are very small channels its actually the if you look at it by a naked eye it look like a sheet flow or the overland flow, but water is actually going through a very small channels and when many channels combine many small channels combine then we have what is called actually is, some recognisable channel flow. So, what we are then going to do is we will model this sheet flow or the over land flow or the surface flow process and what will we do again we will go back to our basic principles or theorems which we have learnt in this course number in the beginning of this course I had said we will develop a consistent mechanism for the movement of fluid all kinds of fluids and we are dealing with water in the atmosphere in the ground on the surface everywhere.

So, we will be using your Reynolds transport theorem your continuity equation of in the continuity equation form and in the momentum form will come will write the continuity and momentum will combine the 2 and then finally, will be able to write the expression for what is called the flow depth and velocity for the over land flow so let me say that we will be using the principles of again the continuity equation and the momentum equation to model this whole process.

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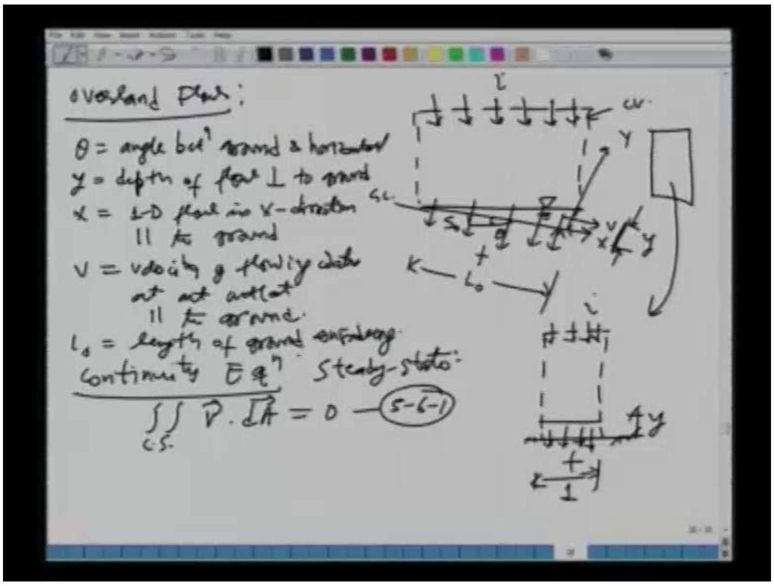

overland Flow:

θ = angle betn ground & horizontal

y = depth of flow ⊥ to ground

x = 1-D flow in x-direction
|| to ground

V = velocity of flowing water
at at outlet
|| to ground.

L_0 = length of ground surface

Continuity Eqn Steady-state:

$$\iint_{c.s.} \vec{V} \cdot d\vec{A} = 0 \quad \text{(5-6-1)}$$

So, let us then look at the overland flow modelling and we want to find out flow depth and velocity of the overland flow. So, what I would like to do is, I will just draw the schematic first and then define various variables will define the control volume. So, this is your direction x this is your ground or this is your ground level this angle is theta this we call as naught.

Perpendicular to the x direction is we say is y this you are looking at the sheet flow or the water is flowing from left to right and what comes out is this, which is your velocity v and this is the depth of flow you let us say y. so, you have a sheet flow or overland flow taking place from left to right and at the outlet we have velocity is v and the depth of flow is y that is what we want to actually find out in this particular case and this dash line which I have drawn is called the control volume this is your let us say c v what is happening is the rain is falling. Let us say I at the rate of I into your control volume infiltration is taking place into the ground perpendicular to the ground which is let us say small f and the length of the overland flow which we are considering let us say is l 0 so, let me then define all these parameters first. So, you have theta as the angle between the ground alright the flow is taking place parallel to the ground keep that in mind.

So, the theta is the angle between the ground and the horizontal you see here the theta the way we have defined is what it is the angle between the ground and the horizontal y is the depth of flow perpendicular to the ground see the way we have defined this y this y is perpendicular to the ground. What is x? Well x is the 1 dimensional a flow or the direction in x direction x is representing a direction in which the flow is 1 dimensional which is parallel to the ground x is the direction of flow which is parallel to the ground c is the velocity of flowing water at the outlet and what is the direction? It is parallel to ground again and what is l naught? L naught is the length of the ground which we are considering. So, you see that we are considering a length l 0. So, if you have a very large catchment you can subdivided into different small catchments or the different flow lengths depending upon the need.

So, you would have certain flow depth and velocity coming out of this portion and then next you have another overland flow if you want to model that then you will have an input coming from upstream and then you want to calculate what is the flow depth and velocity outside of that. So, we are not doing that we are just taking one element of overland flow of length l naught alright now what I would like to do is I will also look at the cross section of this overland flow or this control volume what is happening if you look at it from the right hand side. So, if you did that then we see actually this cross section will come here I do not have the space I'm going to draw it here so, you have this like this if you are looking from the right hand side just perpendicular to the direction of flow so, this is your ground level this is your depth of flow y you have infiltration f going into the ground you have I coming into the or control volume and.

Let us say that this is what this is perpendicular to your first figure so, what we will do is we will take the unit length perpendicular to that so, this is 1 so the width we are taking perpendicular to the board is unity length is l 0 and the width is unity so with that what we will do is we will write the continuity equation so, what we will do in this case is we when we write the continuity equation. We will say that we are going to do that for steady state conditions what does that mean you that means that you have the rate of rainfall intensity is falling at the certain rate infiltration is taking place at a constant rate after a very long time and then you have the surface runoff taking place and sufficient time has elapsed. So, that the flow depth and the velocity are constant so, everything this whole process is a steady state process.

So, when you write the continuity equation for a steady state process again you apply the extensive property intensive property the left hand side is 0 on the right hand side you have 2 terms in the Reynolds transport theorem alright first term is the accumulation because of the steady state nature there is no accumulation there is no increase of mass within the control volume. so, then your continuity equation will be double integral over the cross section or surface cross section beta rho d v plus beta rho v dot b a beta is 1 rho is you know it can cancel out or come out so, all you have is v dot d a is equal to 0 and this we will say is 5.6.1. So, I am going to stop at this point of time. So, all we have done is we have defined the schematic and overall problem of calculating the flow depth and velocity for overland flow and will come back and look at this continuity and momentum equation tomorrow.