Soil and Water Conservation Engineering
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Lecture – 08
Modifications in Universal Soil Loss Equation

Welcome back friends. Welcome to this NPTEL online certification course and title Soil and Water Conservation Engineering. I am Rajendra Singh, professor Agricultural Food Engineering Department, IIT, Kharagpur. We are in lecture 8, week 2 and the topic today is Modifications in Universal Soil Loss Equation. This is the part 1 of the lecture, we will continue this lecture also in next class which is which will be cleared from here.

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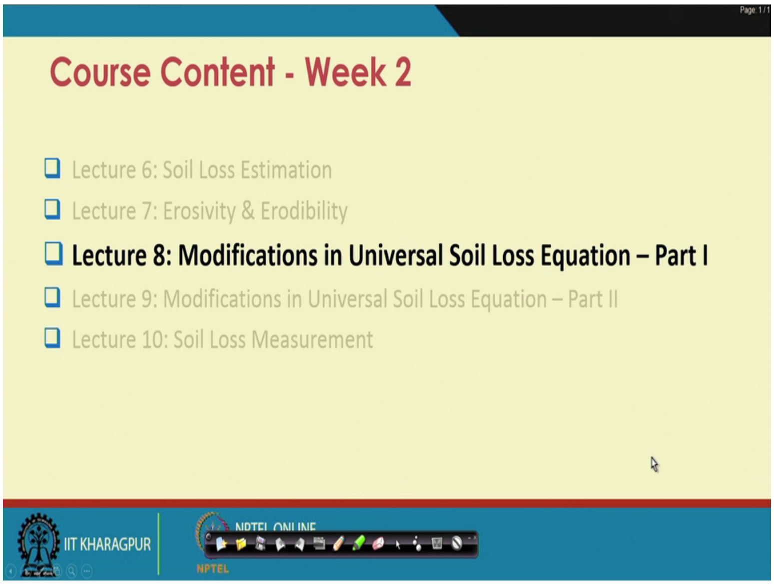

Because, this is a course content of this week, in lecture 6, we covered universal soil loss equation or method for finding out the soil loss. In lecture 7 that is previous lecture, we saw how to estimate two major components of USLE; universal soil loss equation that is rainfall erosivity and soil erodibility.

And today's lecture, we will see modifications in universal soil loss equation and this will be part 1 of the lecture and we will continue with this in next lecture also where will see the part 2 of modifications in universal soil loss equation. And finally, lecture 10 that is the last lecture of this week, we will see soil loss measurement.

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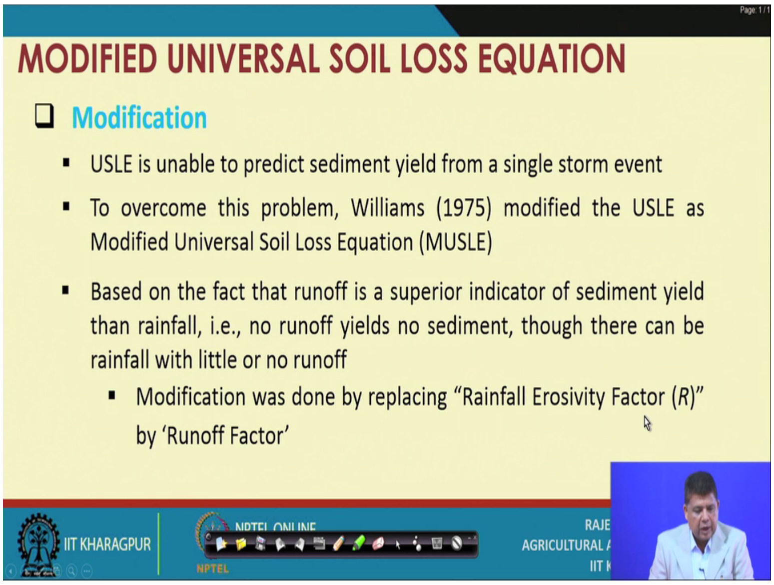

Now, coming to modifications, the modified form of universal soil loss equation, the name also is modified universal soil loss equations. So, that is the modified form of universal soil loss equation; that is modified universal soil loss equation and basically modification why modifications were needed. Because, USLE as we saw is unable to predict sediment yield from a single rainstorm event and we when we define USLE or universal soil loss equation, we say that it gives a long term average estimation of soil loss. And that is why the unity in USLE is for a that is sediment in this metric tons per hectare per year.

So, per yearly basis, we estimate. So, to overcome this problem that we cannot estimated USLE using USLE, we cannot estimate sediment yield from a single event, Williams in 1975 modified USLE and the name is given is modified universal soil loss equation or MUSLE. And this modification is based on the fact that run of is a superior indicator of sediment yield than rainfall, which simply means which is logical because no runoff will yield no sediment, through there can be rainfall with little or no runoff. That simply means that because you remember that once again we go to the basics that there are two major components: detachment and transportation.

Now, detachment is because of primarily because of raindrop impact where is transportation is because of the overland flow or the runoff. So, what it means to say that even if there is a rainfall there, there is a rainfall event, there might be detachment. But, suppose entire rainfall volume is absorbed by soil or that is not allowed to flow because of this file cover on the soil surface then; obviously, there will be no runoff; that means, there will be no transportation; that means, there will be no sediment yield from the given area.

So, that is why based on this very fact Williams propose that runoff is a superior indicator of sediment yield and that is why he modified USLE by replacing rainfall erosivity index or rainfall erosivity factor by a runoff factor. So, that is the major modification. One of the major component that is rainfall erosivity index or rainfall erosivity factor R, in previous class, saw how to estimate that that is replaced in modified universal soil loss equation by a runoff factor.

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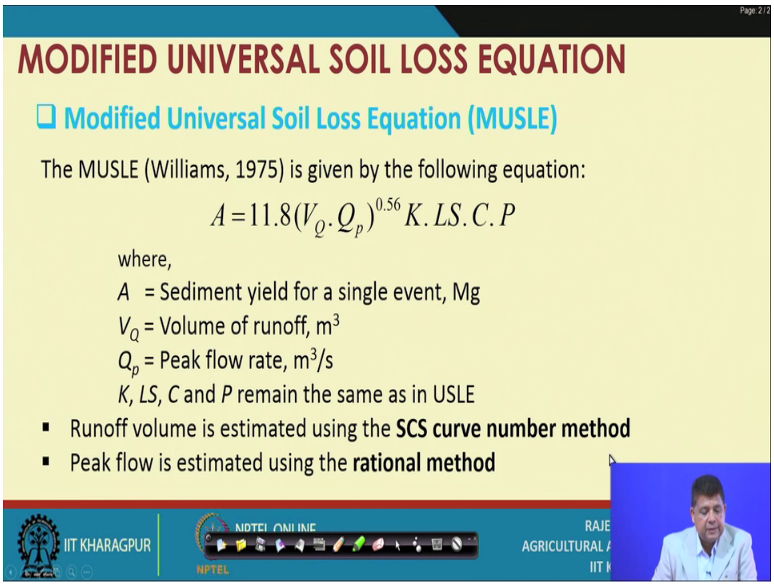

And this is how the modified form of universal soil loss equation looks or MUSLE looks and it is given by this formula that A is equal to 11.8 V Q times QP to the power 0.56 K. LS. C. P. So; that means, you can see the earlier we had RK. LS C.P. where R was the rainfall erosivity index; So, that is mouth been replaced by this term 11.8 VQ times QP to the power 0.56 and that is being called as runoff factor instead of the rainfall erosivity factor rest of the terminology as you can see are same K. LS. C and P that is soil erodibility factors topographic factors crop management factor or conservation practices factor, they remain the same.

And here there are two new terms are coming VQ which is the volume of runoff and QP which is the peak flow rate or peak rate of runoff units are cubic meter and cubic meter per second and for estimating these two components that is volume of runoff and peak flow rate two standard methods are used. So, runoff volume is estimated using the SCS curve number method and peak flow estimated using the rational method. So, I am sure that these two methods, you might have studied in hydrology, but just to take the course forward, we will we will we will repeat this here and if for the benefit of those were not read they will be getting it for the first time.

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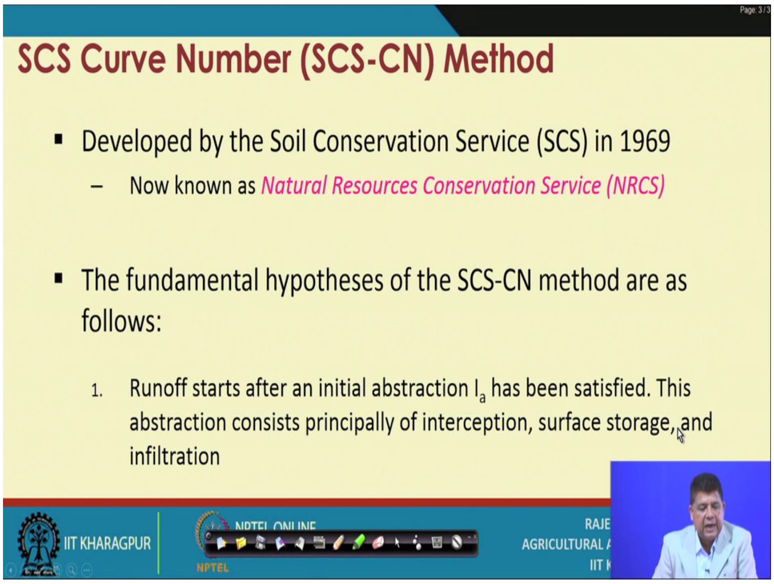

So, we start with SCS curve number method SCS-CN and method and it was basically developed by soil conservation service United States, department of agriculture in 1969 and that is why the first term of this method SCS curve number method. SCS come from the soil conservation service which is USDA organization, but just to let you know that the name soil conservation service.

Now, has been changed to natural resource conservation service NRCS, but still the method is known as SCS curve number SCS-CN method only and this method is based on two fundamental hypothesis. The first one says that runoff is starts after initial abstraction I a, has been satisfied. And this abstraction consists of interception surface storage and infiltration and basically this hypothesis is very true in natural nature also because when we know when from our hydrologic cycle knowledge, we know whether rainfall occurs a part of that gets intercepted either by any kinds of abstract object may be plant canopy maybe there are some bushes on the surface or buildings and roads or whatever.

So, some interception takes place because of the undulating topography on the surface sub part of the water gets stored on the surface and obviously, a part of this gets infiltrated and then remainder of that basically flows is runoff. So; that means, runoff will start only after interception surface storage and infiltration process are completed or the initial abstraction I a which is the combined term to represent all these obstructions has been satisfied that is the first hypothesis.

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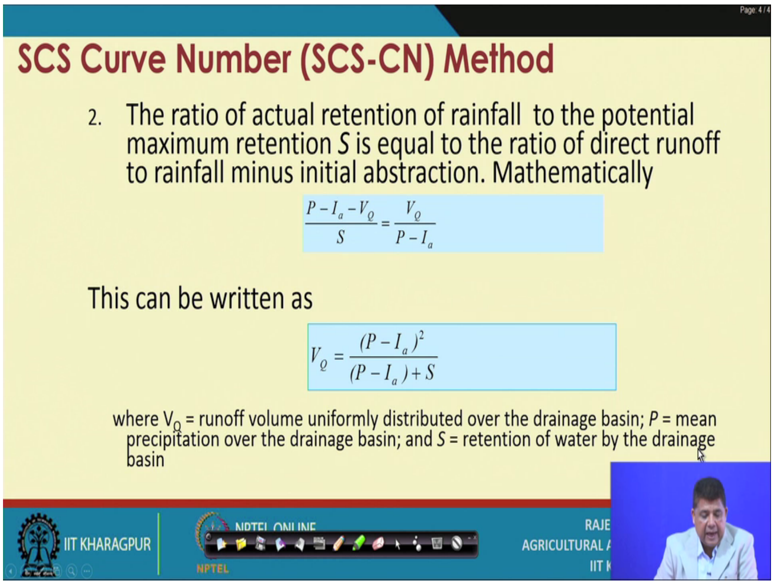

The second hypothesis says that the ratio of a actual retention of rainfall to the potential maximum retention S. S is the terminology representing the potential maximum retention is equal to the ratio of direct runoff to rainfall minus initial abstraction and mathematically this is represented like this P minus I a minus VQ this is initial abstraction this is initial abstraction this is surface runoff.

And obviously, if from the total rainfall if initial abstraction in the runoff is taken away then that represents the actual retention that is the volume of water that is retained in the basin itself. And this is actual retention and the its ratio is division by maximum potential maximum retention that is a left hand side, on the right hand side, we have a direct runoff that is a total flow which is taking place divided by the rainfall minus initial abstraction.

So, mathematically, this is the second hypothesis that this ratio of actual retention to maximum retention is equal to the ratio of direction of to rainfall minus initial abstraction and by some mathematical rearrangements, we can also write this equation in this form that is VQ equals to P minus I a square divided by P minus I a plus S.

And here the terminologies are P represents precipitation I a is initial abstraction and S is potential maximum retention that we have already seen and potential maximum retention by drainage basin and BQ is the runoff volume which we want to determine. And that is why SCS curve number method is used and P is the P mean by specification of the drainage basis SI, these are the terms which are involved in this equation.

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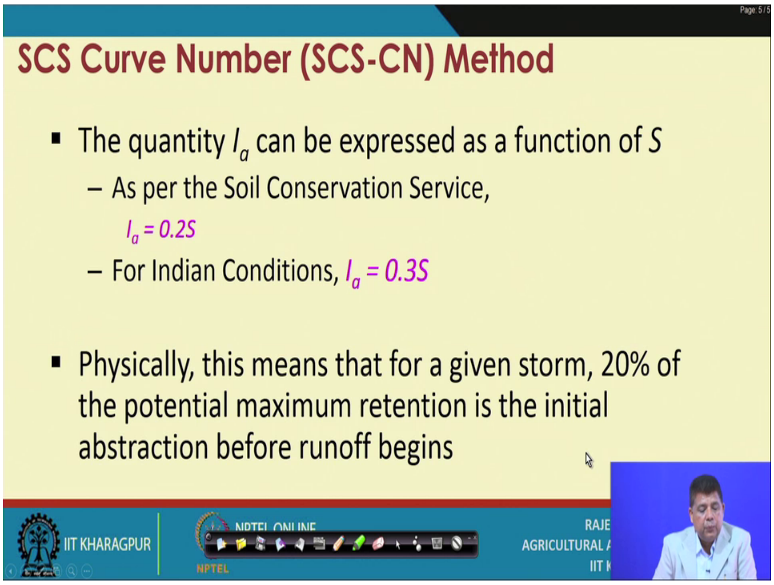

Now, this quantity I a which is initial abstraction that is that can be expressed a function of S that is the hypothesis given by SCS or soil conservation service and they said that I a is equal to 0.2 S, which similarly that for a given storm 20 percent of the potential maximum retention is the initial abstraction before runoff begins. So, initial abstraction is 20 percent of the potential maximum retention that is that is the meaning physical meaning of this expression and for Indian conditions several researchers have reported that.

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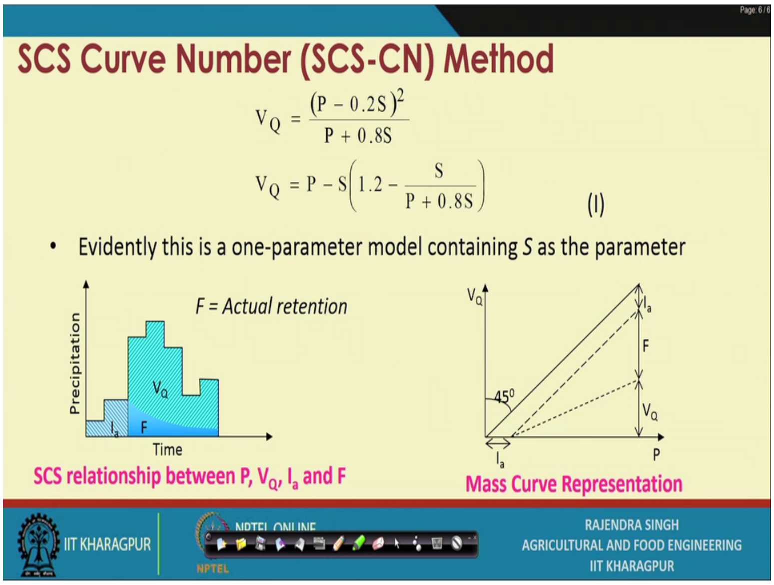

For Indian conditions, the value of I a could be 0.3 S, but still we in India also be used typically we use 0.2 S. And therefore, in our original equation V P minus I a we replace I a by 0.2 S. So, this is the form of equation get that is VQ equals to P minus 0.2 S square and in the in the denominator, we had P minus I a plus S. So, I a is 0.2 S and that is why we are getting P plus 0.8 S and if we again make some kind of rearrangement this is the form of equation we get which we are calling equation number one.

And as you can see here, this is a one parameter model containing S only as a parameter the potential maximum retention is the only parameter in the model because P is the input for which we want to find out the VQ or volume of surface runoff. So, S is the only parameter which needs to be determined and then this Sa relationship can also be expressed graphical in this form that is relationship between P VQ I a and F, these are the 4 terms which are here.

So, if we plot precipitation versus time, then this is what we get basically and here that simply means initial over initial period of time, they will be initial abstraction and then flow will start, but a part of that will be first retained here. So, this is F actually gives the actual retention of a part will be retained and then whatever remainder is there that will flow a surface runoff. And the mass curve of the same can be represented here that P verses VQ if he plot then; obviously, this is a 45 degree line where P equals to VQ. So, from week from P I a F and VQ they are 3 components. So; obviously, the VQ which is the surface runoff volume that is only this component and I a is initial abstraction F is the actual retention of water in the basin.

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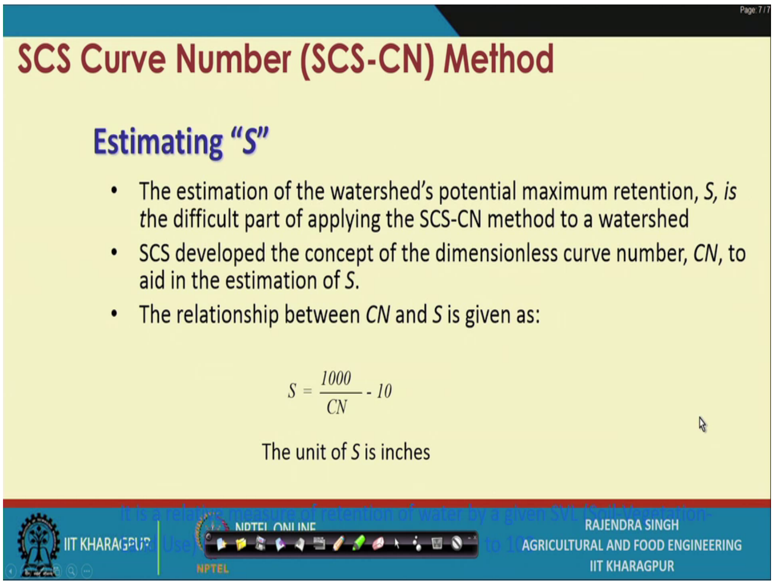

Now the most important thing is estimating S that is the because it is a single parameter model. So; obviously, we our focus will be on estimating S, if you can estimate S properly, then knowing the precipitation we can find out what is the runoff. So, estimation of the watersheds potential maximum retention S is the difficult part of applying SCS-CN method to watershed because it is very difficult really to know potential maximum retention of a given area.

So, basically in order to overcome this problem SCS developed the concept of dimensionless curve number CN to aid to estimation of S. So, basically that is where the curve number the second part of the name CN counts curve number is dimensionless number which can be which can help us in estimating the potential maximum retention.

And then thus they gave a relationship between curve number and S which is given here S is equal 1000 by curve number CN minus 10 here the unit of S is in inches. So, if S to be expressed in inches then this is a relationship which will tell us what is the F curve number is known then using this relationship we can find out the value of us S in inches, if we want S to be in millimeters, then this is the form of equation be used S equal to 25,400 by CN minus 254.

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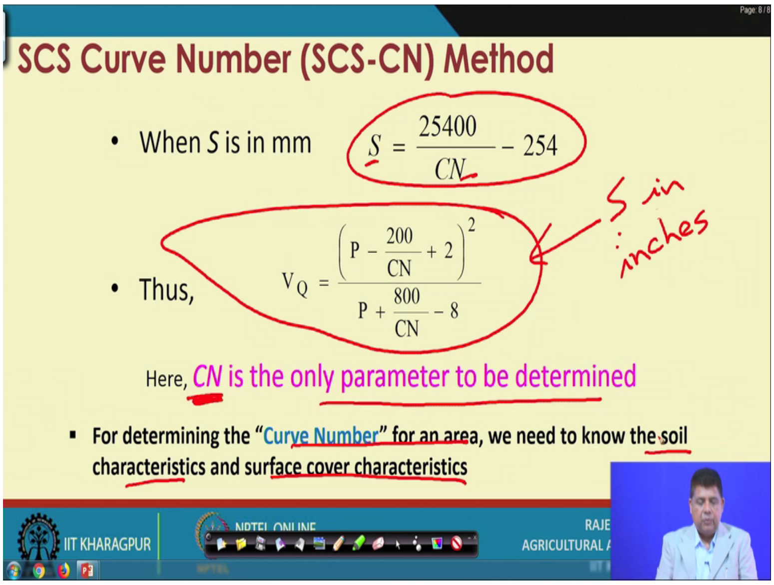

So, this will this you will us S in millimeters and then that simply means that we can replace S in terms of curve number in our original equation, this is the equation. And here you remember we are using the previous form that is S in inches S in inches, we are using here basically that is the equation just now, we saw that is what that is the form we are using here and if we replace S in terms of curve number then this is a form of equation.

So, now the entire equation CN is the only parameter to be determined that is the curve number is only parameter is still single parameter model, but the parameter now is curve number and for determining the curve number of an area, we need to know the soil characteristics and surface cover characteristics.

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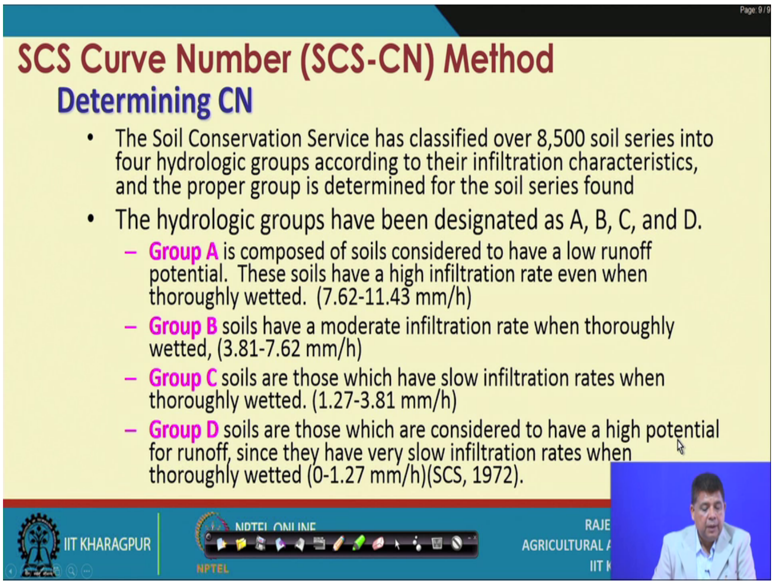

So, if you know the soil characteristic and surface characteristics, then we can find out what is the curve number applicable for that particular area and for determining curve number SCS; what SCS did that they classified around 8500 soils in each into 4 hydrological groups and these groups are designated as a B C and D.

So, soil hydrological group A, B, C and D. So, total all soils all the data that was available all the soils based on their infiltration characteristics SCR classified into 4 categories. So, the categories are group A, group B, group C and group D and of course, it is based on the infiltration characteristics. So, group A is composed of soils considered to have a low runoff potential. So, these soil have a high infiltration rate even when thoroughly wetted.

So that means, the infiltration rate range for such soil is 7.62, 11.43 millimeter per hour. So, if you know that your soil belongs to this the infiltration kept of yours of the soil of your area in this range. So, knowing this you can say that I my soil belongs hydrological soil group A. Similarly, group B soils of a moderate infiltration rate when thoroughly wetted and range is 3.81 2 to 7.62 millimeter per hour from group source sea soils are those that have slow infiltration rate. And the values are 1.27 to 3.81 millimeter per hour and for group D the value lies infiltration rate lies between zero to 1.27 millimeter per hour and this have been by SCS in 1972. So, knowing the infiltration characteristics we can find out in which soil hydrology group A, B or C or D our soil belongs to which soil hydrology soil group our belongs to.

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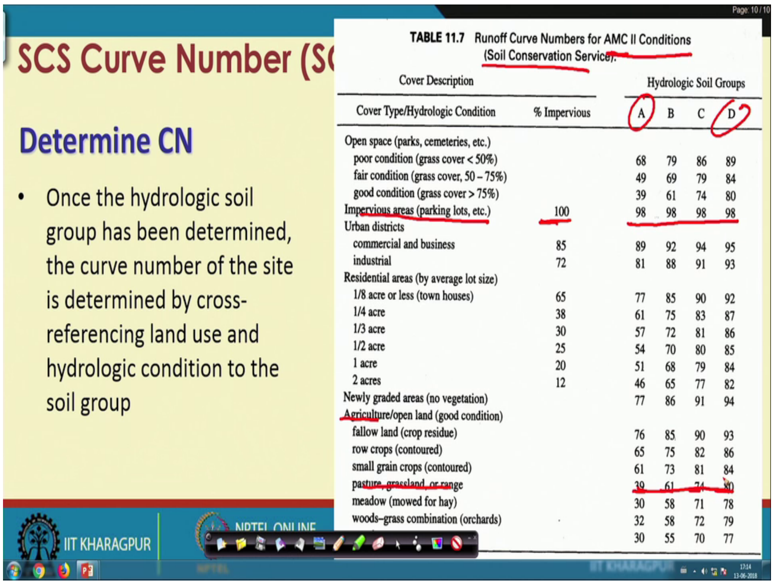

And once that is known then using the cover conditions or cover description and percent imperviousness, we can find out the curve number applicable for a given area or for a given watershed. Now, there is not yet another component which is very important this initial condition and this is the morsel condition 2. So, that standard runoff table which was given by soil conservation service that is for AMC 2 conditions and we will come to what AMC how AMC conditions are defined.

So, from here, if you can see, if we take impervious area which is a parking lot which is 100 percent per impervious, then based on the soil groups irrespective of soil groups. In fact, in this case, the value is 98 which simply means that whatever rainfall occurs it is almost gets translated into runoff, there is no loss in filtration or in abstraction in this case, everything is almost getting translated which is quite obvious because impervious area, but if you come to agricultural area and if you take the example of say pasture or grassland or range land.

Then our values vary from 39, 61, 74 to 80. So, 39 to 80 depending upon whether if soil belongs to group A or group D higher, the value of runoff higher, the value of curve number; that means, the higher the runoff and you see that group D soils are poor in filtration; that means, they will the more runoff will be generated from there and that is why the curve number values high.

So, that is from this, we can also say that higher the curve number more will be the runoff generation for a given area. So, knowing the soil hydrological soil group knowing the cover conditions that is cover type and what is the hydrologic condition of that we can use the standard table provided by SCS; SCS that is soil conservation service for finding out the runoff curve number and these are for AMC 2 conditions is already mentioned.

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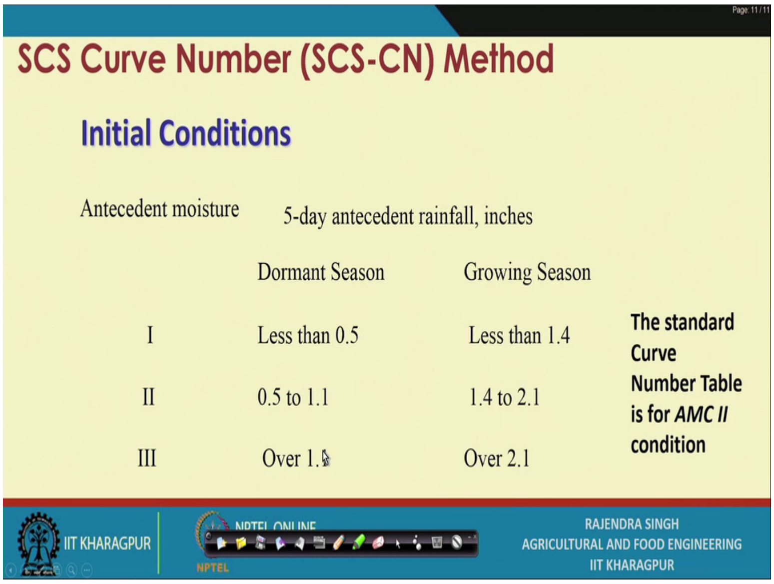

Now, as I already mentioned that there are 3 AMC conditions that are use that is antecedent moisture conditions 1, 2 and 3 and basically this antecedent moisture condition is defined based on 5 day antecedent rainfall in inches that is previous 5 days, what is the total magnitude of rainfall that defines in what conditions, basically, we are and then SCS is also said the values will differ for dormant season; that means, when there is no crop and then growing season when there is a crop.

So, if we take the AMC 2 dormant season the rainfall has to be between 0.5 to 1.1 inches and in growing season, it has to be between 1.4 to 2.1 inches. So obviously, based on this table we can find out which AMC condition, we are working and if you are working in AMC condition 2, then standard table value which you have obtained from the table that is self can be utilized.

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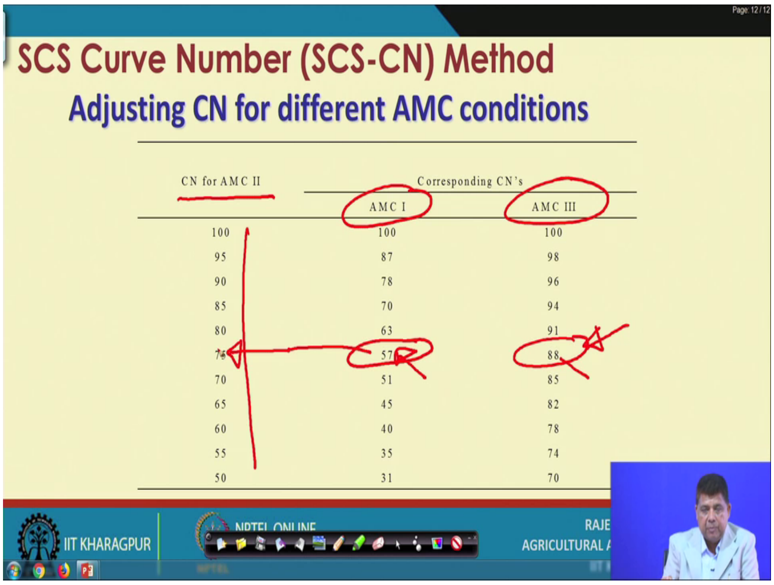

Otherwise, we have to manipulate our value and for that also SCS are provided a table for. So, adjustment table so, these are the curve number value for AMC 2 which we read from the table and based on whether we are working in AMC 1 or AMC 3, then we can find out the corresponding values; so, for example, from our table, we read the value of curve number is 75.

So, if we are working AMC 1, then our value will be 57 and if it is 88, if AMC 3, then 88 so; obviously, AMC 1 lesser rainfall; that means, lesser runoff; that means, the curve number value will be is be lower than AMC 2 condition. Where in AMC 3 rainfall value is magnitude is higher; that means, more runoff could be expected and that is why the value this curve number is high is compared to AMC 2 so; that means, again we see that higher curve number means higher magnitude of runoff.

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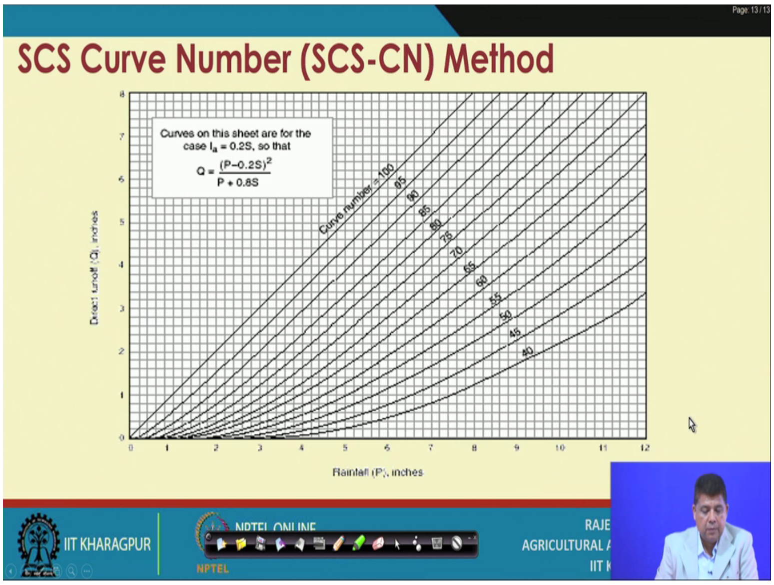

And people have also generated certain kind of nomographs to help estimate curve number easily. So, as you can see that this is a direct runoff value; Q value and this is the rainfall magnitude in inches and these are different curve numbers nomograph of different curve numbers; So, if the total rainfall at a particular place in 5 and if you know that the applicable curve number is 70, then from here roughly, we can say that the direct runoff will be 2 inches. So, height of 5 inches of rain fall if curve number is 70; around 2 inches of runoff can be expected.

So, directly if you knowing your rainfall on if you know the curve number, then you can directly read the expected value of a direct runoff from this curve instead of using I mean same equation is also used for developing the this nomographs.

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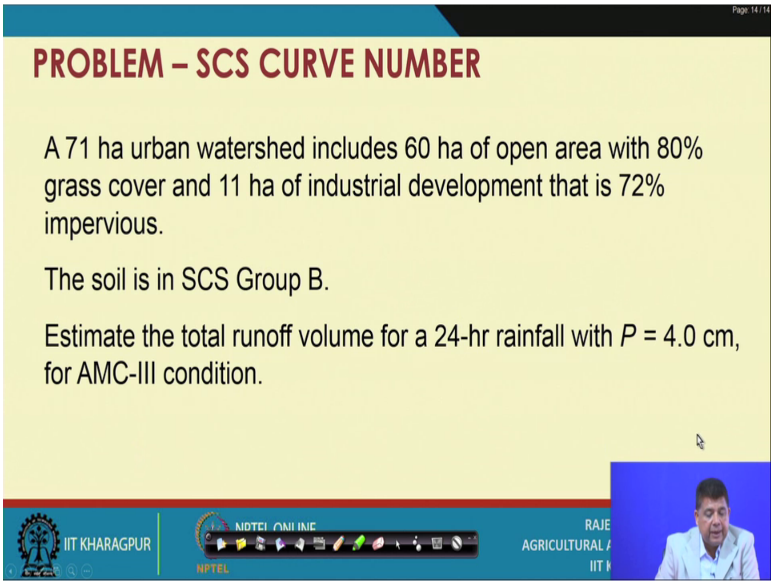

So, the after knowing the entire background, let us take a problem on see how to estimate the direct runoff volume using the SCS curve number So, we have a problem where we have a 71 hectare urban watershed that includes 61; 60 hectares of open area with 80 percent glass cover and 11 hectares of industrial development that is 72 percent impervious that is the conditions are given the soil in the SCS group B, the soil hydrological group is B estimate the total runoff volume for a 24 hour rainfall where P equals to 4 centimeter for AMC-III conditions, we have to obtain rainfall is given and AMC condition is also described.

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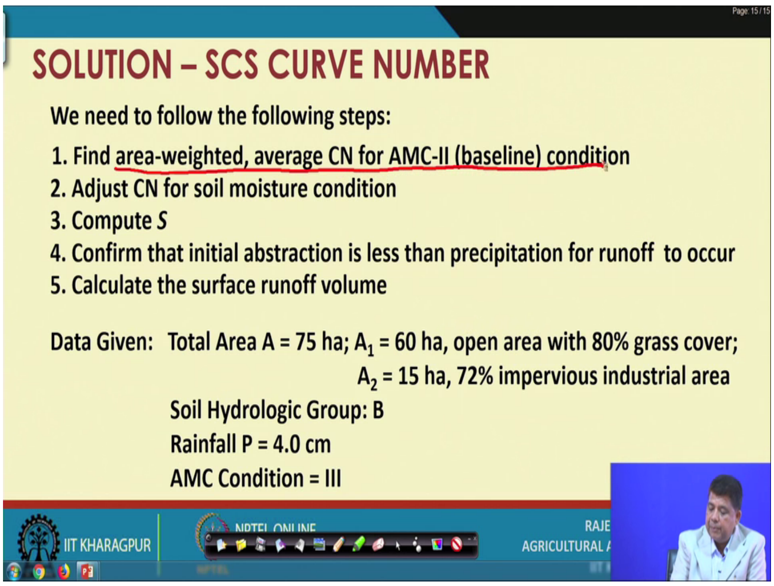

So, we need to follow the fund following steps basically we have to first find out the area weighted average curve number for AMC 2 which is the baseline condition, then we have to adjust curve number for soil moisture condition we are the problem says AMC 3. So, that is why we have adjust.

Then we have to compute the value of S that is potential maximum retention and we have to confirm that initial abstraction which is 0.2 S is less than precipitation for runoff to occur, if it is more than that then; obviously, precipitation if runoff will not occur. And then we have to finally, calculate the surface runoff volume using the SCS curve number equation. So, here data given are the total area is 75 hectares which has two components A 1 and A 2; 60 hectares open area with 80 percent grass cover A 2; 15 hectares with 72 percent of impervious industrial area soil hydrology group is B rainfall is 4 centimeter and AMC condition is 3.

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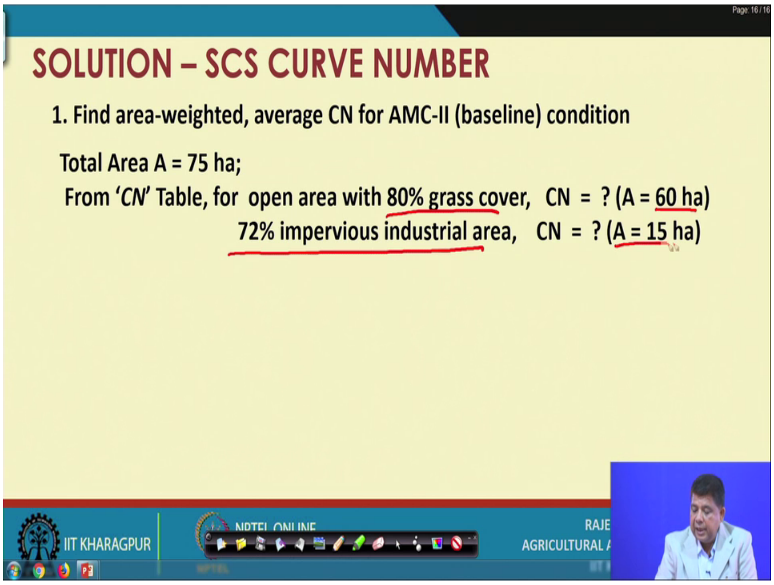

So, first thing will be to calculate the average curve number for AMC 2 baseline condition. So, our total area is 75 hectares. So, we have to reach curve number table for open area with the 80 percent grass cover, what is the curve number area is 60 hectares, 72 percent impervious industrial area, area is 54; 15 hectares. So, if you look at the table and; obviously, we have to be in soil group B.

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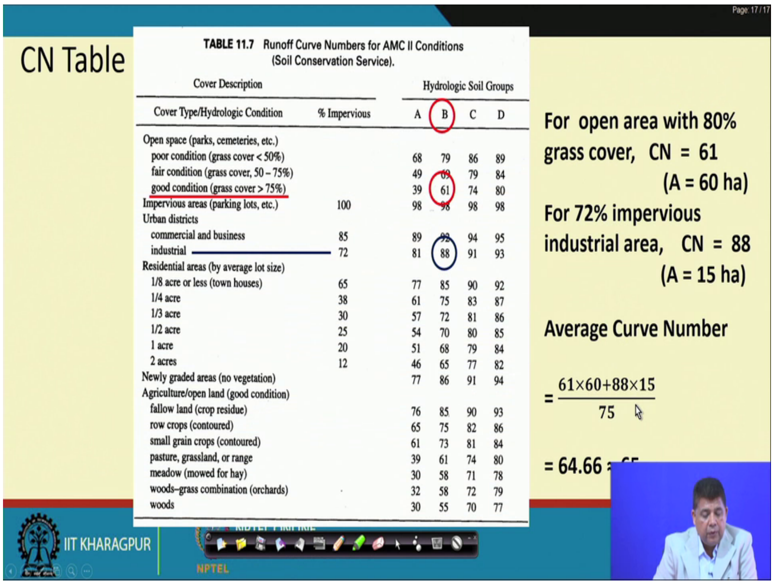

TABLE 11.7 Runoff Curve Numbers for AMC II Conditions (Soil Conservation Service).

Cover Description		Hydrologic Soil Groups			
Cover Type/Hydrologic Condition	% Impervious	A	B	C	D
Open space (parks, cemeteries, etc.)					
poor condition (grass cover < 50%)		68	79	86	89
fair condition (grass cover, 50 – 75%)		49	69	79	84
good condition (grass cover > 75%)		39	61	74	80
Impervious areas (parking lots, etc.)	100	98	98	98	98
Urban districts					
commercial and business	85	89	92	94	95
industrial	72	81	88	91	93
Residential areas (by average lot size)					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Newly graded areas (no vegetation)		77	86	91	94
Agriculture/open land (good condition)					
fallow land (crop residue)		76	85	90	93
row crops (contoured)		65	75	82	86
small grain crops (contoured)		61	73	81	84
pasture, grassland, or range		39	61	74	80
meadow (mowed for hay)		30	58	71	78
woods–grass combination (orchards)		32	58	72	79
woods		30	55	70	77

So, here for open space good condition that is grass cover larger to 75; value is 61 and for industrial where impervious is 72, the value is 88. So, for our area A 1, the value of curve number is 61 from table for A to the value is 88 from table. So, average curve number will be 61 times 60 plus 88 times 15 divided by total area that is 75 that is 64.66 or 65.

So, the applicable weighted curve number for this area given area is 65 that we have obtained from the standard curve number curve number tables and also using the procedure so; obviously, next thing is that we have calculated 65 for AMC 2 condition.

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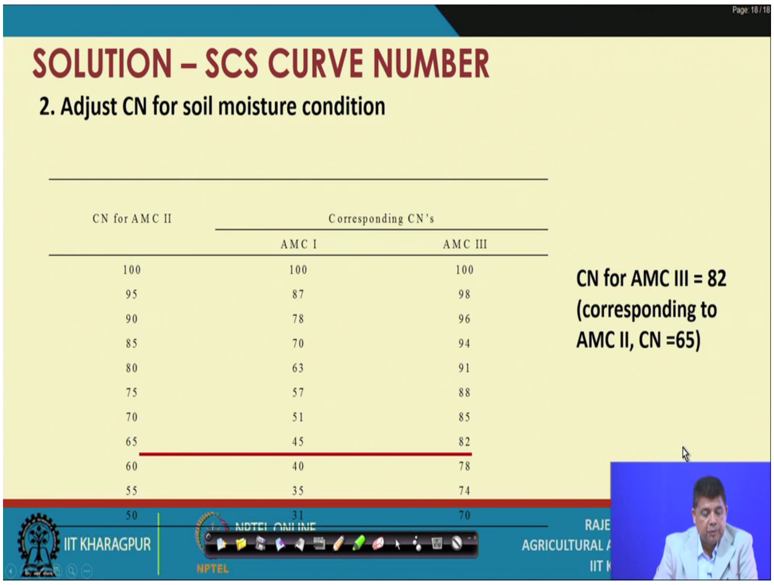

So, now, we have to obtain the corresponding value for AMC 3 and the straight away we can read from table that CN for AMC 3 82 corresponding to MC 2 CN equal to 65. So, there are applicable curve numbers for our problem is 82.

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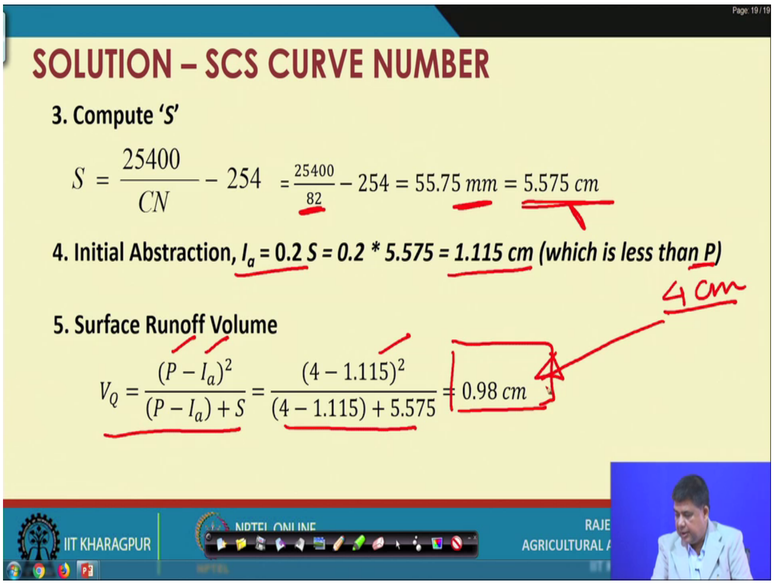

So, once we know the curve number our we can use this equation relationship our specification is given in given in centimeter so; that means, we can use this equation. So, this will give us S value of S here is curve number calculated 82 we are using.

So, the value of S will be in millimeters or we can expressed in centimeter that is 5.575 centimeters and initial abstraction we already know is 0.2 S. So, that will be 1.115 centimeters which is less than VP is 4 centimeters. So, ah; obviously, because initial abstraction less than P; that means, there will be runoff and then finally, we can use this relationship VQ equals to P minus I a square divided by P minus I a plus S.

And this if we put the value of P which is 4 I a, which is estimated value is 1.11 here and S which is estimated is 5.575. So, if you put all these values we get VQ equals to 0.98 centimeters. So, that simply means for the given conditions in given area out of the 4 centimeter of precipitation, we can get the direct surface runoff volume is 0.98 centimeters that is what we get in this problem.

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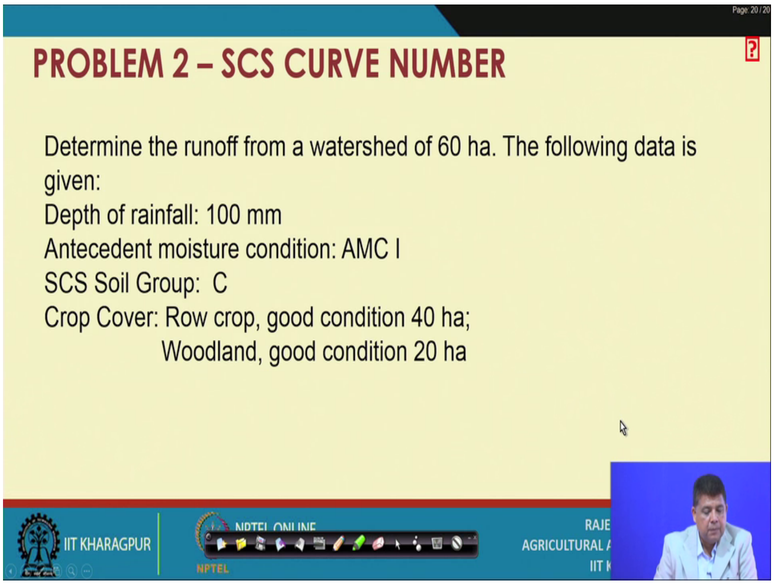

We can also take another problem SCS curve number which say that determine the runoff from a watershed of 60 hectares data given is depth of rainfall 100 mm antecedent moisture condition is AMC 1 soil group is C cover crop cover is row crop good condition, 40 hectares woodland good condition; 20 hectares.

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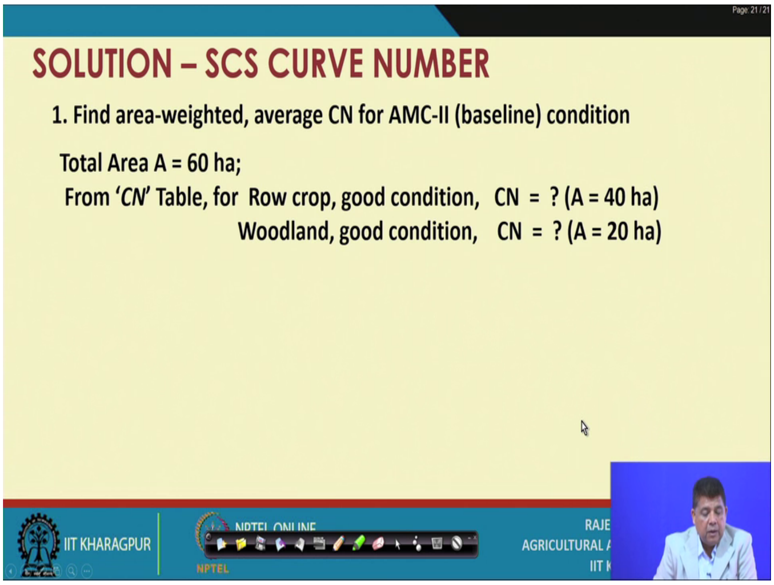

So; obviously, we have to follow the same steps so; that means, we have to find out the weighted area weighted average curve number for baseline condition which is 2 AMC 2 from the table the soil group given in this case is C.

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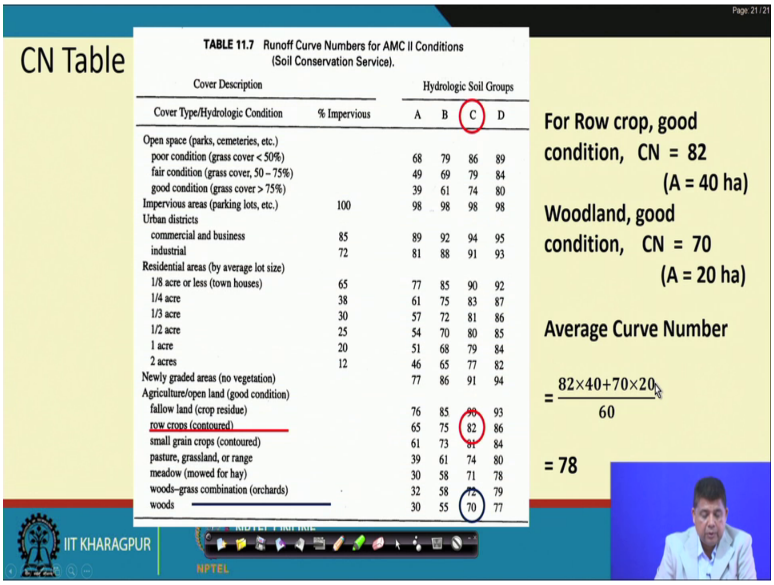

TABLE 11.7 Runoff Curve Numbers for AMC II Conditions (Soil Conservation Service).

Cover Description		Hydrologic Soil Groups			
Cover Type/Hydrologic Condition	% Impervious	A	B	C	D
Open space (parks, cemeteries, etc.)					
poor condition (grass cover < 50%)		68	79	86	89
fair condition (grass cover, 50 – 75%)		49	69	79	84
good condition (grass cover > 75%)		39	61	74	80
Impervious areas (parking lots, etc.)	100	98	98	98	98
Urban districts					
commercial and business	85	89	92	94	95
industrial	72	81	88	91	93
Residential areas (by average lot size)					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Newly graded areas (no vegetation)		77	86	91	94
Agriculture/open land (good condition)					
fallow land (crop residue)		76	85	90	93
row crops (contoured)		65	75	82	86
small grain crops (contoured)		61	73	81	84
pasture, grassland, or range		39	61	74	80
meadow (mowed for hay)		30	58	71	78
woods–grass combination (orchards)		32	58	72	79
woods		30	55	70	77

So, we have to read this column corresponding to hydrological soil group C, then row crop we have good condition 82 and then here would grass combination or woodlands 70, these are the values applicable here. So, for 40 hectares hour value is 82, for 20 hour value is 70. So, 82 times 40 which is here 70 times 20 which is here divided by total area will give us curve number which is for AMC 2 condition that is 78 and now we have to find out the corresponding value for AMC one and here in the table, we see that we have 75 and 80.

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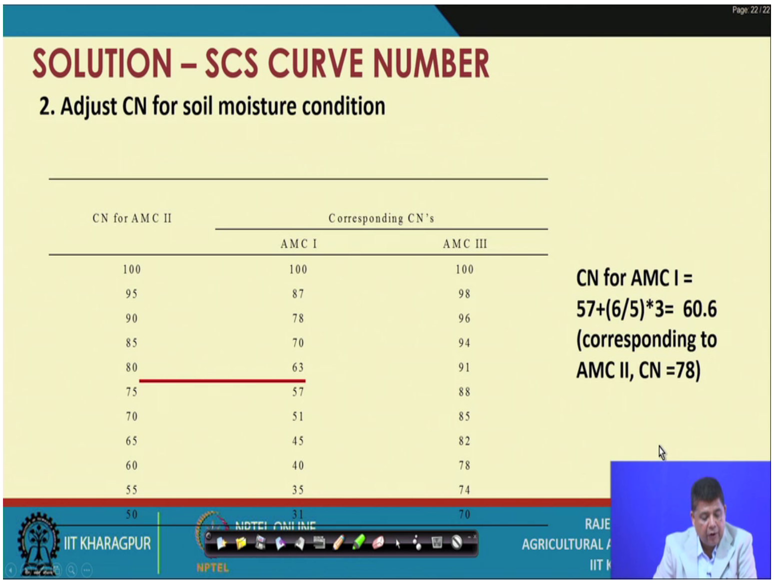

So; obviously, for 78, we have to interpolate that value and that is what we are doing here that is we are saying that 57 corresponding to 75 and then for next 3, we are interpolating in between 75 and 80 where the value ranges from 56. Now 57 to 63 and thus, we get the value is 60.6 that is corresponding to AMC 2 curve number 78 the curve number for AMC 1 is 60.6.

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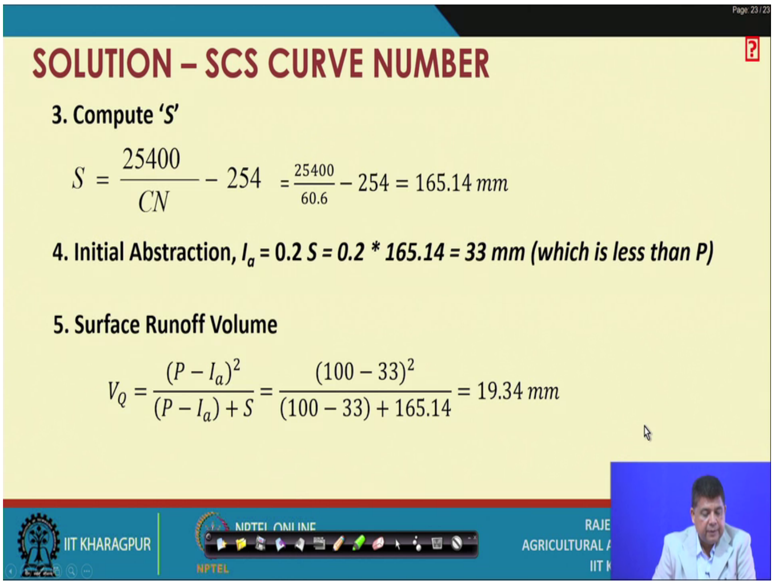

And thus now, we can estimate the value of S by putting curve number 60.6 is 165.14 mm, initial obstruction 0.2 S will be thirty 3 mm which is less than P and then finally, all this estimated value we can put in this situation because value of P is 100 I a, we have estimated 33 and S we have estimated as 165.14. So, the total runoff generated is surface runoff value which is generated is 19.34 mm so; that means, for this is given area and conditions out of 100 mm of rainfall 19.34 mm is getting converted into the into the surface runoff volume ah; so, this brings us to end of this lecture.

So, where we have seen that we have a modified universal soil loss equation where rainfall erosivity index is replaced by runoff factor. And for estimating runoff factor we have to estimate surface runoff volume for which SCS curve number technique is used that we saw in this lecture in next lecture we will take up the other term that is QP that peak rate of runoff for which we use external method. So, we will see how to use a external method to estimate and go further.

Thank you very much.