Course Name: Watershed Hydrology

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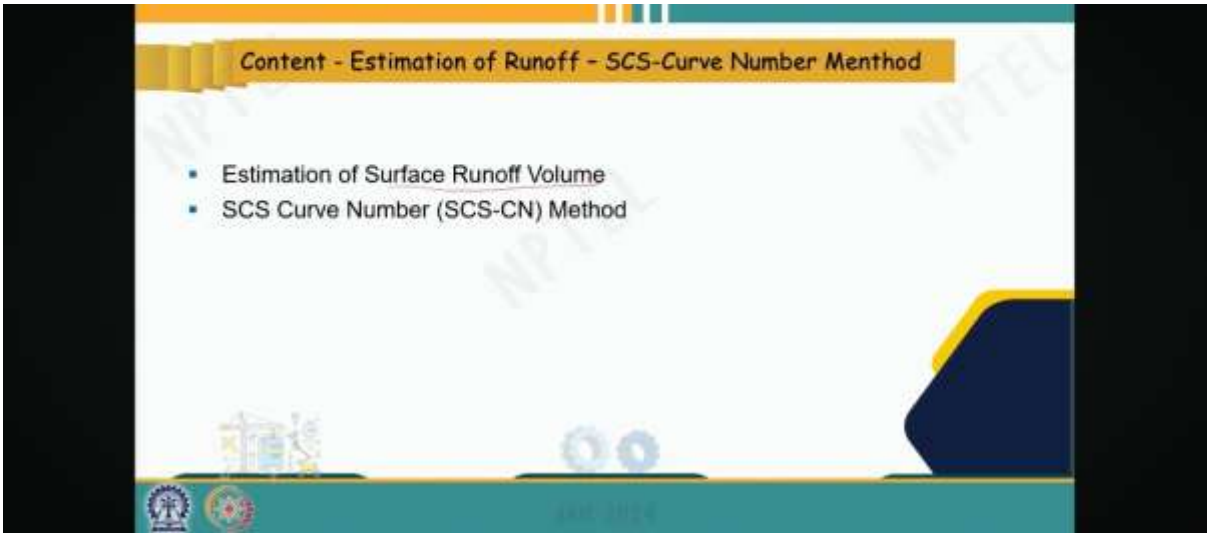
Lecture 19: Estimation of Runoff – SCS-Curve Number Method



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- Estimation of Surface Runoff Volume
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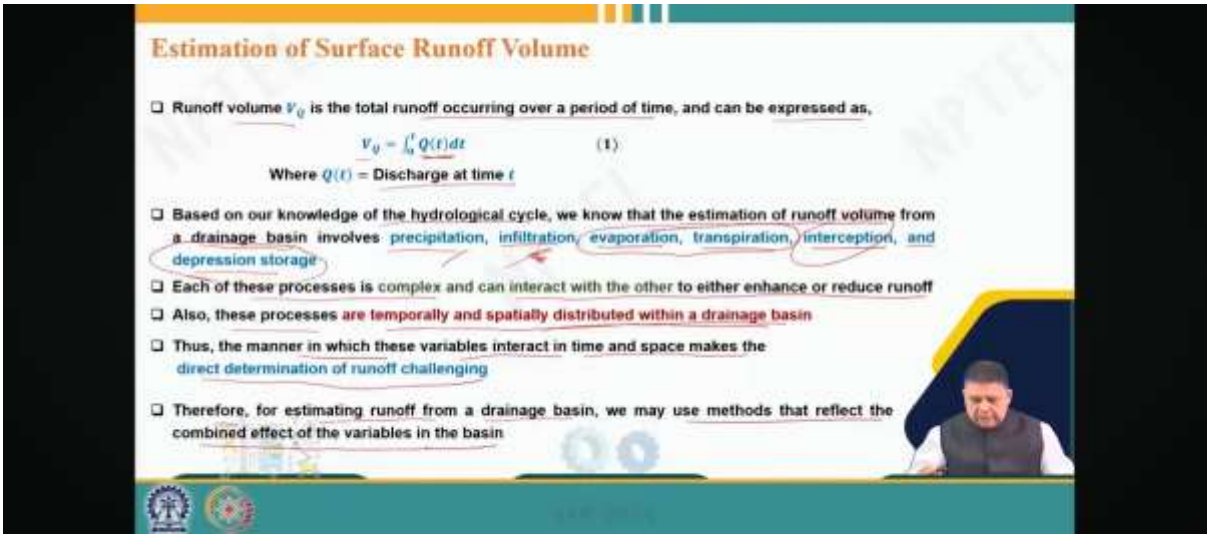
Hello, friends! Welcome back to this online certification course on Water State Hydrodynamic Hydrology. I am Rajendra Singh, a professor in the Department of Agriculture in Food Engineering at the Indian Institute of Technology, Kharagpur. We are in Module 4, this being Lecture 4 and we are still continuing with the estimation of runoff. Today, we will explore another method called the SCS Curve Number method for estimating runoff. The SCS Curve Number method is specifically used for estimating surface runoff volume. Therefore, we will begin by discussing the estimation of surface runoff volume, followed by delving into the SCS Curve Number method in this lecture.



Estimation of Surface Runoff Volume

☐ Runoff volume V_Q is the total runoff occurring over a period of time, and can be expressed as,

$$V_Q = \int_0^t Q(t)dt \qquad (1)$$

Where $Q(t)$ = Discharge at time t

☐ Based on our knowledge of the hydrological cycle, we know that the estimation of runoff volume from a drainage basin involves precipitation, infiltration, evaporation, transpiration, interception, and depression storage

☐ Each of these processes is complex and can interact with the other to either enhance or reduce runoff

☐ Also, these processes are temporally and spatially distributed within a drainage basin

☐ Thus, the manner in which these variables interact in time and space makes the direct determination of runoff challenging

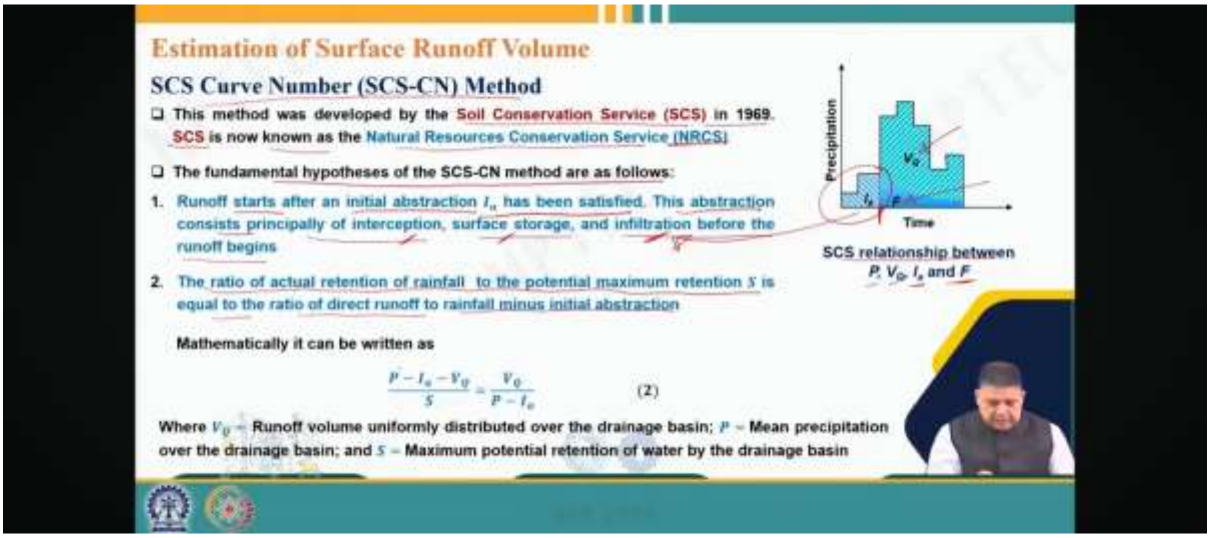
☐ Therefore, for estimating runoff from a drainage basin, we may use methods that reflect the combined effect of the variables in the basin

Turning to the estimation of surface runoff volume, we already understand that volume represents the total runoff occurring over a period of time. In terms of discharge, it is simply the integral of discharge over that period where Q_t represents the discharge at a given time t and V_q denotes the volumetric runoff. We have previously discussed various methods for estimating or measuring discharge.

Knowing how to determine discharge means that if we have the discharge data, we can calculate the total volume over a specific time period by integrating the discharge function. Drawing from our understanding of the hydrological cycle, which we have extensively covered, we recognize that estimating runoff volume from a drainage basin, watershed, or catchment (terms used interchangeably) involves various factors such as precipitation, infiltration, evaporation, transpiration, interception, and depression storage. To recap, when precipitation occurs, a portion is intercepted by the canopy of plants. Then, infiltration occurs as water reaches the surface, followed by runoff once the soil's infiltration capacity is reached. Additionally, during the process of overland flow depression storage also occurs.

And also, we have abstractions called evaporation and transpiration or combined together, evapotranspiration. They also occur. So, that simply means that knowing the precipitation, and considering the hydrological cycle, if we want to find out runoff volume, we need to have a fair idea of infiltration, evaporation, transpiration, interception, and depression storage. That means, all the possible abstractions, actually. And we also have discussed almost all of them. So, we know that all these processes are complex and they can interact with each other to either enhance or reduce runoff. So, obviously, if evaporation is more than evapotranspiration, there will be more total losses, meaning probably the runoff will be less and so on.

Also, these processes are temporarily and especially distributed within a drainage basin. That means, over a drainage basin, all these processes including precipitation or infiltration vary over time and over space. Because, for example, we saw that precipitation always differs over time and over space. Similarly, infiltration depends on the soil characteristics. So, if you take a large basin, then obviously, there will be significant variation in soil characteristics and because of that, infiltration will vary both over time and over space. So, all these processes, similarly, evaporation, or transpiration interception, all these processes are temporarily and especially distributed within a drainage basin. Thus, the manner in which these variables interact in time and space makes the direct determination of runoff very challenging.



Estimation of Surface Runoff Volume

SCS Curve Number (SCS-CN) Method

- ☐ This method was developed by the Soil Conservation Service (SCS) in 1969. SCS is now known as the Natural Resources Conservation Service (NRCS)
- ☐ The fundamental hypotheses of the SCS-CN method are as follows:

1. Runoff starts after an initial abstraction I_a has been satisfied. This abstraction consists principally of interception, surface storage, and infiltration before the runoff begins
2. The ratio of actual retention of rainfall to the potential maximum retention S is equal to the ratio of direct runoff to rainfall minus initial abstraction

Mathematically it can be written as

$$\frac{P - I_a - V_Q}{S} = \frac{V_Q}{P - I_a} \qquad (2)$$

Where V_Q = Runoff volume uniformly distributed over the drainage basin; P = Mean precipitation over the drainage basin; and S = Maximum potential retention of water by the drainage basin

SCS relationship between P, V_Q, I_a and F

So, it is not really easy, of course; we have seen different methods, but it is not really easy. And therefore, for estimating runoff from a drainage basin, we may use methods that reflect the combined effect of these variables in the basin. So, taking the combined effect of these variables on a drainage basin, we may estimate runoff and the SCS curve number method is one such method which takes into account the impact of all those characteristics affecting all these variables, the basin characteristic impacting all the variables. So, this method, the SCS curve number method or SCS CN method, was developed by the Soil Conservation Service in 1969 and already we have seen that now SCS is known as the Natural Resource Conservation Service or NRCS. So, some latest textbooks or latest research papers you might also find NRCS curve number method.

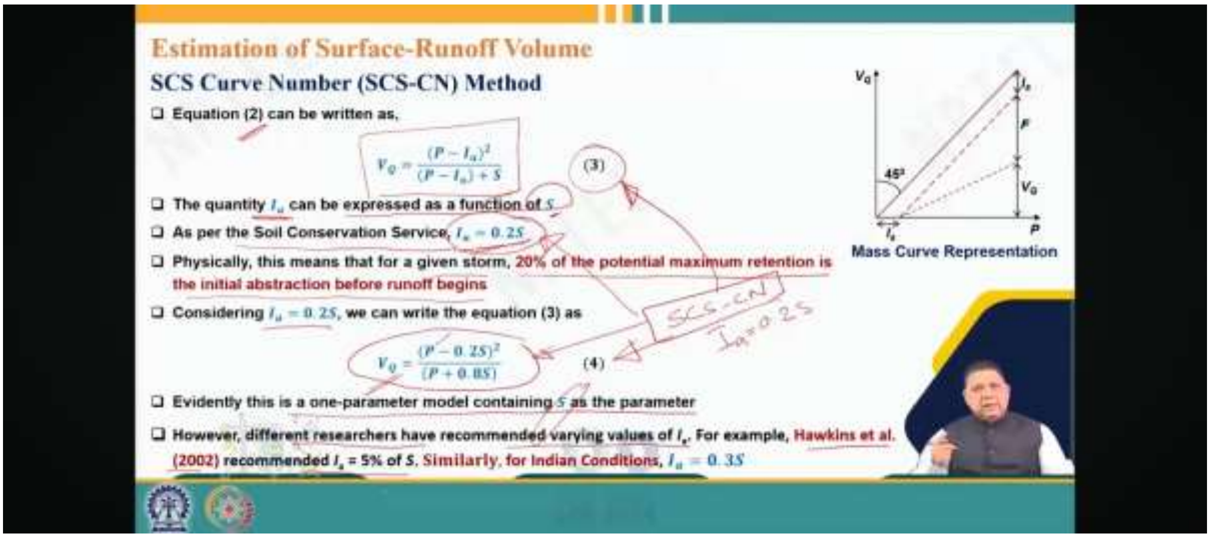
So, it amounts to the same because only the name has changed; SCS, the name has changed to NRCS. So, this method is either known as the SCS curve number or NRCS curve number method. And the fundamental hypothesis of the SCS curve number are as follows; there are two fundamental hypotheses on which this curve number method is based. And the first one is that runoff starts after an initial abstraction (IA) has been satisfied. This abstraction consists principally of interception, surface storage, and infiltration before the runoff begins.

So, we have seen this picture while discussing the phi index or the average infiltration loss from the basin. So, as you can see here, when precipitation starts, there is initial abstraction. This initial abstraction consists of interception, which occurs before infiltration, surface storage, and infiltration because we know that first soil infiltration capacity is satisfied, then only runoff starts. So, before runoff starts during a precipitation process, there will be some infiltration. So, this initial abstraction includes that part of infiltration.

And then we are seeing here that from this point onwards, when initial abstraction is satisfied, we see that the bar chart is divided into two parts: one representing F, which is infiltration after the runoff has started and V_q, which is the runoff actually. So, once this initial abstraction is satisfied, when the runoff process starts, there will be infiltration continuing. Infiltration will be before the runoff started and after the commencement of runoff; both times infiltration will continue. We know that when the soil comes in contact with the soil surface, and the precipitation comes in contact with the soil surface, then the infiltration process begins. So, this is basically what it reflects.

So, this graph shows the relationship between P, V_q, I_A and F. So, P represents precipitation, V_q represents runoff volume, I_A represents initial abstraction and F represents infiltration. So, this is the first fundamental hypothesis: runoff starts after an initial abstraction has been satisfied. And this consists of interception, surface storage, and infiltration before the runoff begins. Then, the second hypothesis states that the ratio of actual retention of rainfall to potential maximum retention is equal to the ratio of direct runoff to rainfall minus initial abstraction.

So, mathematically, this can be expressed as follows: If you take the left-hand side, it says that P - I_A - V_q. So that P - I_A - V_q = F, which represents the actual infiltration that has gone into the soil. And S here represents the maximum potential retention of water by the drainage basin, meaning the total absorbed by the basin. So, the ratio of actual retention (actual infiltration) to maximum potential retention is represented on the left side. And that is equal to the ratio of direct runoff (V_q) to rainfall minus initial abstraction.



Estimation of Surface-Runoff Volume

SCS Curve Number (SCS-CN) Method

- ☐ Equation (2) can be written as,

$$V_Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad (3)$$

- ☐ The quantity I_a can be expressed as a function of S
- ☐ As per the Soil Conservation Service, $I_a = 0.2S$
- ☐ Physically, this means that for a given storm, 20% of the potential maximum retention is the initial abstraction before runoff begins
- ☐ Considering $I_a = 0.2S$, we can write the equation (3) as

$$V_Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad (4)$$

- ☐ Evidently this is a one-parameter model containing S as the parameter
- ☐ However, different researchers have recommended varying values of I_a. For example, Hawkins et al. (2002) recommended I_a = 5% of S. Similarly, for Indian Conditions, $I_a = 0.3S$

So, rainfall minus initial abstraction, that is, of course, rainfall minus initial abstraction, will represent this V_q and F. V_q divided by this will be the same as on the left-hand side. Here, V_q is the runoff volume uniformly distributed over the drainage basin, P is the main precipitation over the drainage basin and S as we have seen is the maximum potential retention of water by the drainage basin. This is the second hypothesis on which the S curve number method is based. Now, if we talk about equation number 2, like we saw this equation here, we can manipulate this equation and write it in this form:

$$V_q = \frac{P-A^2}{P-A+S}$$

We are calling this equation number 3. So, we have simply manipulated that particular equation to represent it in this form.

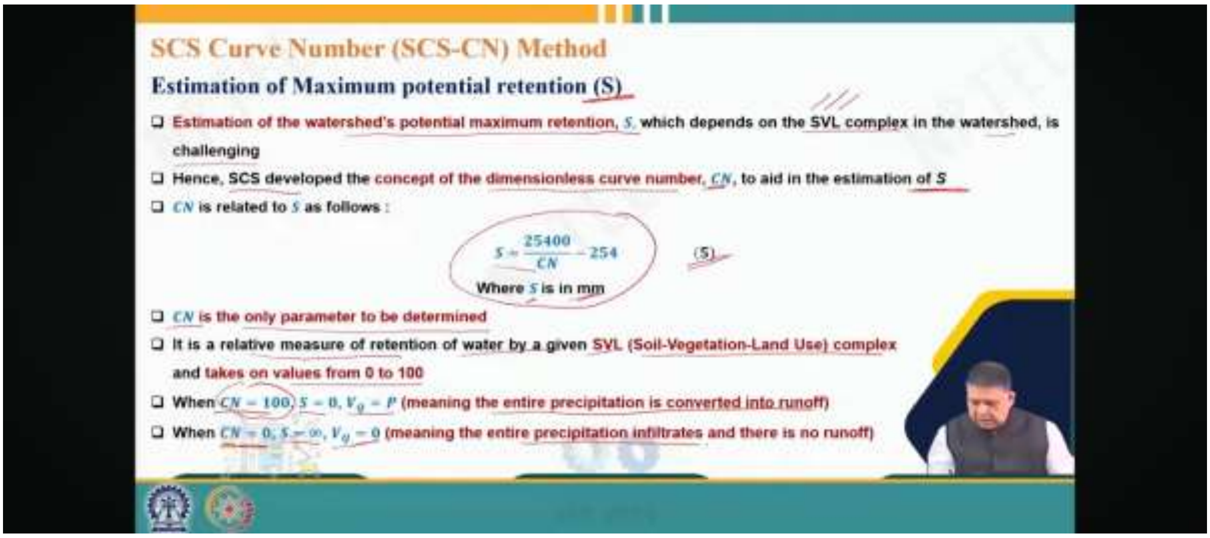
Now, the quantity I_A, which is the initial abstraction, can be expressed as a function of S. This is another assumption that this entire $I_A$can be represented in terms of the maximum potential retention S of the drainage basin. According to the Soil Conservation Service, I_A = 0.2S, which simply means that for a given storm 20 percent of the potential maximum retention is the initial abstraction before runoff begins.

$I_A = 0.2S$. This equation implies that we can substitute I_A with $0.2S$ following the assumption of the S-curve number method. If we replace I_A with $0.2S$ in equation 3, it reduces to the form:

$$V_q = \frac{P-0.2S^2}{P+0.8S}$$

This equation (number 4) represents the S-curve number equation, derived from equation 3 by substituting $I_A = 0.2S$. Essentially, equation 3 and equation 4 are equivalent, with the only difference being the substitution of I_A in equation 4.

Now, looking at this, it's evident that this is a one-parameter model, with S being the parameter. So, if we know the parameter S for a particular drainage basin and the precipitation P, we can determine the runoff volume V_q using this method. Therefore, it's a straightforward method in that regard since it's a single-parameter model. However, various researchers have suggested different values for $\boldsymbol{I_A}$. For instance, Hawkins and others in 2002 recommended a value of I_A = $0.55S$.



SCS Curve Number (SCS-CN) Method

Estimation of Maximum potential retention (S)

- Estimation of the watershed's potential maximum retention, S, which depends on the SVL complex in the watershed, is challenging
- Hence, SCS developed the concept of the dimensionless curve number, CN, to aid in the estimation of S
- CN is related to S as follows :

$$S = \frac{25400}{CN} - 254 \quad (5)$$

Where S is in mm

- CN is the only parameter to be determined
- It is a relative measure of retention of water by a given SVL (Soil-Vegetation-Land Use) complex and takes on values from 0 to 100
- When $CN = 100$, $S = 0$, $V_Q = P$ (meaning the entire precipitation is converted into runoff)
- When $CN = 0$, $S = \infty$, $V_Q = 0$ (meaning the entire precipitation infiltrates and there is no runoff)

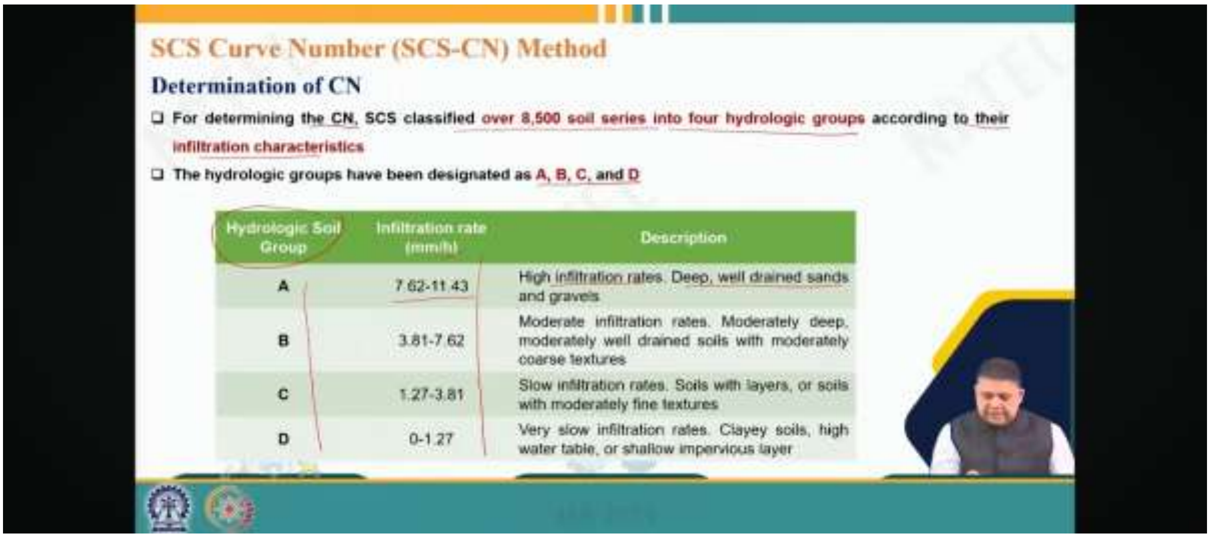
So, I mean this though S recommended I equals to 0.2 S, but this has been a matter of contention among the researchers. Hawkins and his team corrected data from a large number of watersheds and analysed and published a paper where they showed that I_A is just 5 percent of S compared to 20 percent of S, which was assumed by S curve number way back when this method was devised. Similarly, for Indian conditions, different researchers have come up with values like people have used 0.1 to 0.3 S value, typically $I_A = 0.3S$, but this is always a matter of contention. That's why many times we use S or will follow that curve number as a calibration parameter in any model where we use this S S curve number method. Now coming to the estimation of maximum potential retention that is S, which is evidently the only parameter of this model. This estimation of watershed potential maximum retention H, which depends on SVL complex, that is soil vegetation and land use complex in the watershed, is challenging. It's not straightforward; it is a pretty difficult task. And that's why SCS developed the concept of dimensionless curve number CN. That's why the name of the method is SCS curve number. Basically, this curve number is related to S and it helps us determine the value of this parameter, maximum potential retention. The relationship between CN and S is given by this equation, equation number 5:

$$\boldsymbol{S = 25400 \times CN - 254}$$

Here, "S" represents the length in millimeters and "CN" is the variable representing some value that influences the length.

So, if we relate S and CN, we know that the SCS curve number method had only one parameter S, and because now S is being expressed in terms of CN, that simply means CN is the only parameter that needs to be determined in order to apply the SCS curve number method and determine the volume of runoff. So, that is a simple method. Now, this curve number is a relative measure of water retention by a given SVL complex, which stands for soil vegetation land use complex, and takes on values from 0 to 100. Curve number values could theoretically vary from 0 to 100, and when the curve number is 100, then obviously, if you put 100 here, S becomes 0, meaning if S is 0, then the entire runoff volume will become precipitation.

That means the entire precipitation will be converted into runoff, and that could happen only in, say, a paved area or completely saturated area. So, if it is a paved area or completely saturated area, then we can say that the curve number of such an entity will be 100 because there, the entire precipitation will get converted into runoff. On the other extreme, when CN is 0, then S is infinity and V_q is 0, meaning the entire precipitation infiltrates and there is no runoff, which could occur in vegetative humid areas, as we have seen in some cases earlier. But typically, though theoretically the value ranges between 0 and 100, the lower limit is around 30 to 40, somewhere between 30 to 40. And it is earlier mentioned that typically whenever a model uses the SCS curve number method, curve number is always taken as a calibration parameter that we calibrate, and we try to find out the exact value or a relatively better value of curve number that suits a particular drainage basin for a given dataset. And for determining the curve number, SCS classified around 8500 soil series into 4 hydrological soil groups according to their infiltration characteristics and the hydrologic soil groups are designated as ABCD and this is how ah this table looks like, hydrological soil group is given as ABCD and of course, ah it is related to the infiltration rate of the soil. So, you can see that hydrologic soil group has a very high infiltration 7.62 to 11.43 millimeters per hour. So, high infiltration rates indicate deep well-drained sands and gravels that fall under hydrological soil group A.



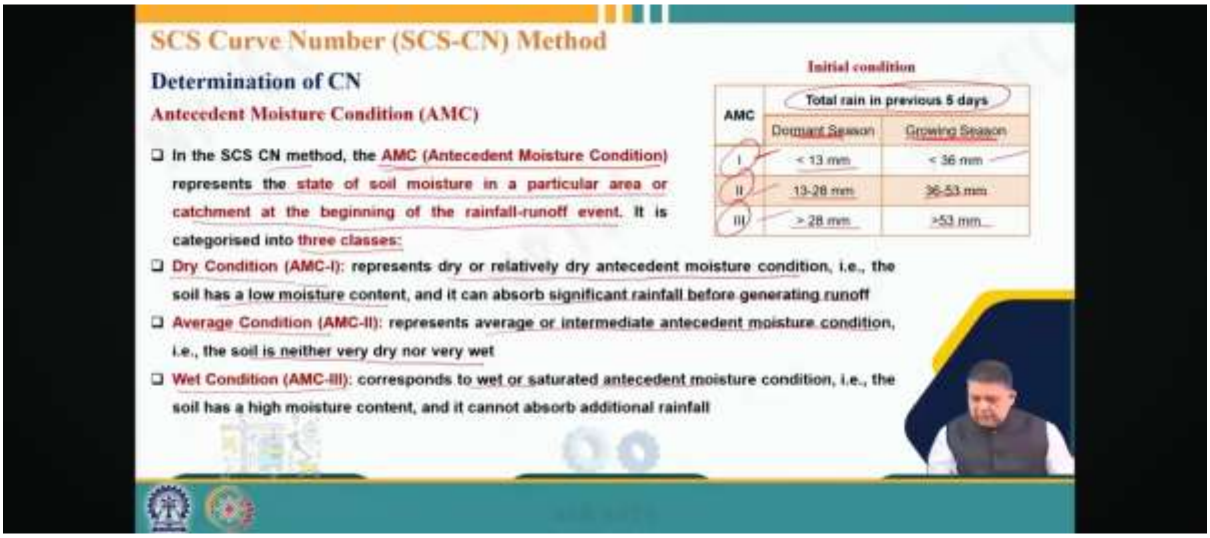
SCS Curve Number (SCS-CN) Method

Determination of CN

- For determining the CN, SCS classified over 8,500 soil series into four hydrologic groups according to their infiltration characteristics
- The hydrologic groups have been designated as A, B, C, and D

Hydrologic Soil Group	Infiltration rate (mm/h)	Description
A	7.62-11.43	High infiltration rates. Deep, well drained sands and gravels
B	3.81-7.62	Moderate infiltration rates. Moderately deep, moderately well drained soils with moderately coarse textures
C	1.27-3.81	Slow infiltration rates. Soils with layers, or soils with moderately fine textures
D	0-1.27	Very slow infiltration rates. Clayey soils, high water table, or shallow impervious layer

Soil group B has infiltration between 3.81 to 7.62 ah millimeters per hour. So, it has a moderate infiltration rate indicating moderately deep, moderately well-drained soils with moderately coarse textures. Hydrological soil group C has a rate of 1.27 to 3.81 millimeters per hour indicating slow infiltration rates in soils with layers or soils with moderately fine textures. And category D has the lowest infiltration rate, which is ah up to 1.27 millimeters per hour, indicating very slow infiltration rates in clay soils with high water tables or shallow impervious layers. So, these are the conditions and these are the infiltration rates. So, if you know the infiltration rate of the soil ah in your basin, you know which hydrological soil group you are dealing with.



SCS Curve Number (SCS-CN) Method

Determination of CN

Antecedent Moisture Condition (AMC)

- In the SCS CN method, the AMC (Antecedent Moisture Condition) represents the state of soil moisture in a particular area or catchment at the beginning of the rainfall-runoff event. It is categorised into three classes:
- Dry Condition (AMC-I): represents dry or relatively dry antecedent moisture condition, i.e., the soil has a low moisture content, and it can absorb significant rainfall before generating runoff
- Average Condition (AMC-II): represents average or intermediate antecedent moisture condition, i.e., the soil is neither very dry nor very wet
- Wet Condition (AMC-III): corresponds to wet or saturated antecedent moisture condition, i.e., the soil has a high moisture content, and it cannot absorb additional rainfall

Initial condition

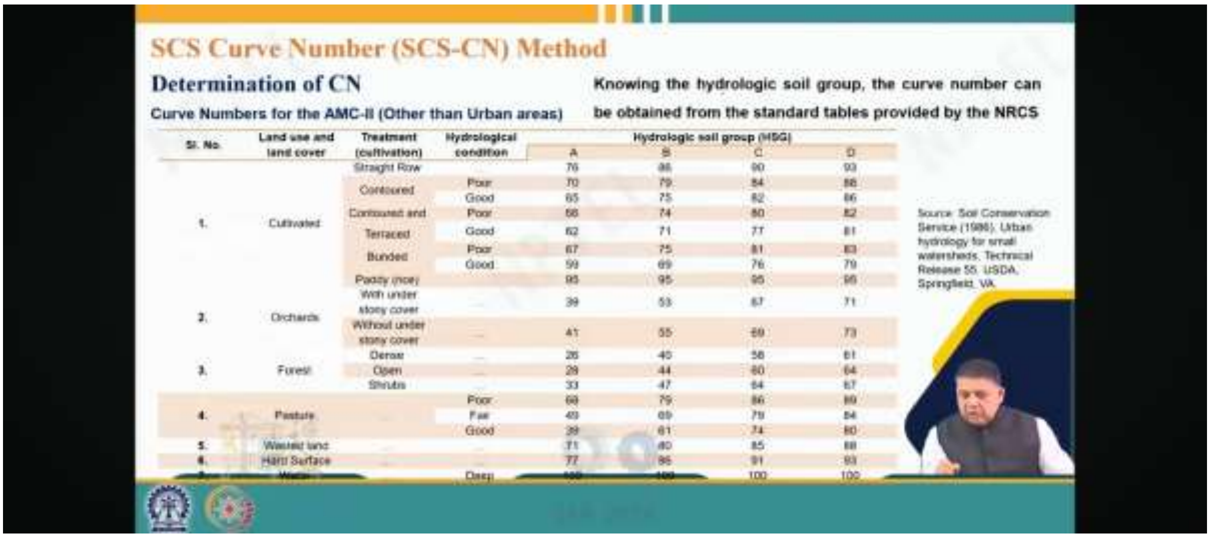
AMC	Total rain in previous 5 days	
	Dormant Season	Growing Season
I	< 13 mm	< 36 mm
II	13-28 mm	36-53 mm
III	> 28 mm	>53 mm

So, that is the first step, and then obviously, in the SCS curve number method, the antecedent moisture content (AMC) condition represents the state of soil moisture in a particular area or catchment at the beginning of the rainfall runoff event. It is basically classified into 3 groups: AMC 1, 2, and 3. This classification is based on the total rainfall recorded in the previous 5 years. That means, any rainfall runoff event starting today considers the rainfall in the previous 5 days. There are two identified seasons: dormant season and growing season. The dormant season indicates no crop, while the growing season signifies cultivated crops.

If during the dormant season the initial rainfall in the previous 5 days is less than 13 mm, then it falls under AMC 1. If it ranges between 13 and 22 mm, it falls under AMC 2 and if it exceeds 28 mm, it's categorized as AMC 3. Similarly, during the growing season, the values range from 36 mm for AMC 1, 36 to 53 mm for AMC 2 and greater than 53 mm for AMC 3.

Dry conditions correspond to AMC 1, indicating low soil moisture content, allowing significant rainfall absorption before runoff generation. AMC 2 represents an average or intermediate condition, where the soil is neither very dry nor wet. AMC 3 indicates extreme wet conditions, corresponding to saturated antecedent moisture condition, where the soil has high moisture content and cannot absorb additional rainfall.

Therefore, understanding the soil and antecedent moisture conditions is crucial for determining the values of the curve number.



SCS Curve Number (SCS-CN) Method

Determination of CN

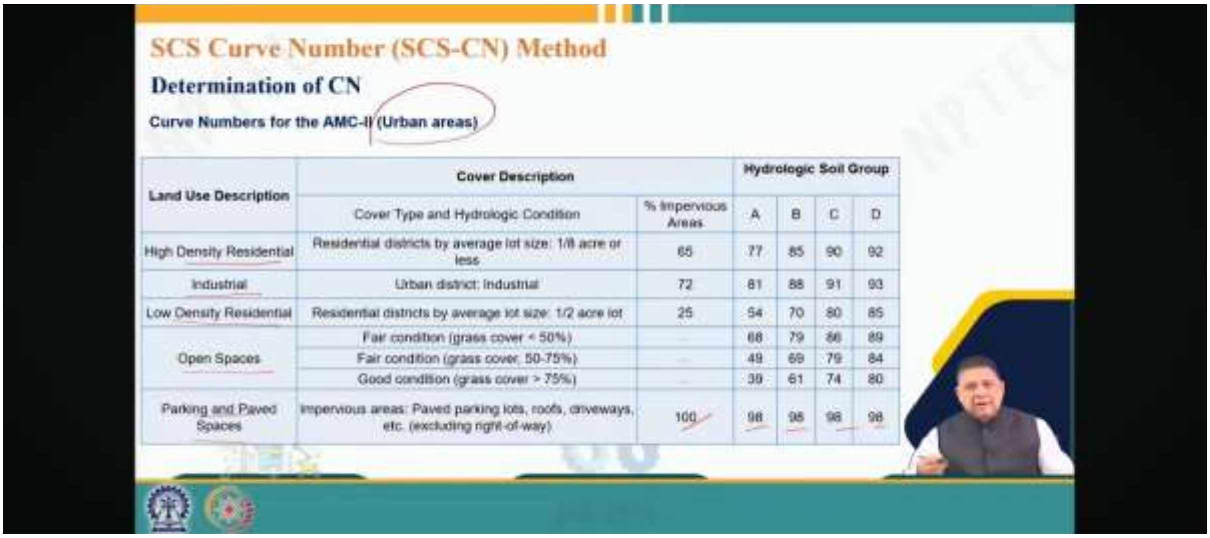
Curve Numbers for the AMC-II (Other than Urban areas)

Knowing the hydrologic soil group, the curve number can be obtained from the standard tables provided by the NRCS

Sl. No.	Land use and land cover	Treatment (cultivation)	Hydrological condition	Hydrologic soil group (HSG) A	B	C	D
1.	Cultivated	Straight Row		76	86	90	93
		Contoured	Poor	70	79	84	88
			Good	65	75	82	86
		Contoured and Terraced	Poor	66	74	80	82
			Good	62	71	77	81
		Bunded	Poor	67	75	81	83
			Good	59	69	76	79
		Paddy (rice)		95	95	95	95
2.	Orchards	With under story cover	—	39	53	67	71
		Without under story cover	—	41	55	69	73
3.	Forest	Dense	—	26	40	58	61
		Open	—	28	44	60	64
		Shrubs	—	33	47	64	67
4.	Pasture		Poor	68	79	86	89
			Fair	49	69	79	84
			Good	39	61	74	80
5.	Wasted land		—	71	80	85	88
6.	Hard Surface		—	77	86	91	93
	Water		Deep	100	100	100	100

Source: Soil Conservation Service (1986). Urban hydrology for small watersheds. Technical Release 55. USDA, Springfield, VA.

So, coming to curve number determination, knowing the hydrological soil group which we have seen as ABCD, the curve number can be obtained from the standard tables provided by NRCS or SCS, basically. And this table is for curve number for AMC 2 other than urban area. So, this is not for urban area, other than urban area; that means, for forest, cultivated land which you can see here land uses are cultivated orchards, forest, pasture, wasteland, hard surfaces all are there other than urban areas.



SCS Curve Number (SCS-CN) Method

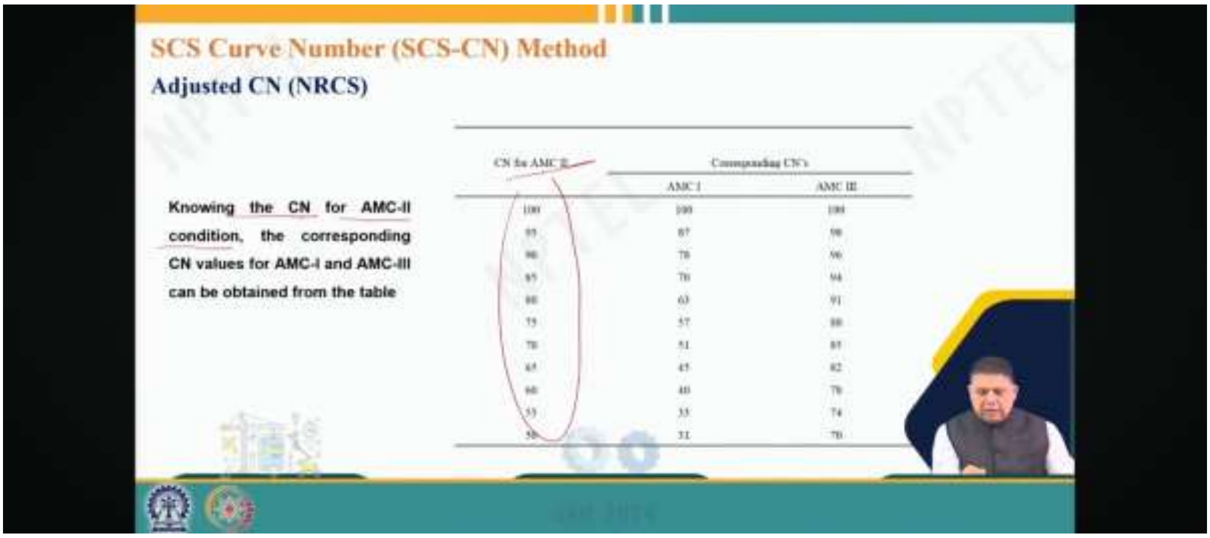
Determination of CN

Curve Numbers for the AMC-II (Urban areas)

Land Use Description	Cover Description		Hydrologic Soil Group			
	Cover Type and Hydrologic Condition	% Impervious Areas	A	B	C	D
High Density Residential	Residential districts by average lot size: 1/8 acre or less	65	77	85	90	92
Industrial	Urban district: Industrial	72	81	88	91	93
Low Density Residential	Residential districts by average lot size: 1/2 acre lot	25	54	70	80	85
Open Spaces	Fair 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
Parking and Paved Spaces	Impervious areas: Paved parking lots, roofs, driveways, etc. (excluding right-of-way)	100	98	98	98	98

So, here you can see that under each category there are some cultivation treatments and the hydrological condition also is being considered and then for different soil groups ABCD, the curve number is listed here. So, for example, if you are in cultivated area and it is contour and terraced land and it has good hydrological condition and we are in soil group A, then the value will be 62; if group B, then 71; group C, then 77; and group D, then 81.

So, values range from 62 to 81. Similarly, if we are in forest which is a dense forest then obviously, the value will be 26 to 61. So, 26 for soil group A, that is very high infiltration, that means, runoff potential will be low and D, the infiltration is low. So, the runoff potential will be very, very high and these tables have been taken from soil conservation service 1986 urban hydrology for a small watershed technical release 55 USDA report number TR 55 that is USDA and that is I said that because all these values come from the curve number values which we always refer from the SCA reports. So, that is why we always calibrate this; this is used as a calibration parameter in any of the models just to find out the relevant value of curve number for the watershed suppose any modelling area, we are doing in a modelling we are doing for any Indian watershed then we obtain the basic value from the SCA table, but we always calibrate that for Indian conditions. So, that we get a reasonably good value for our case and this table is for urban area.



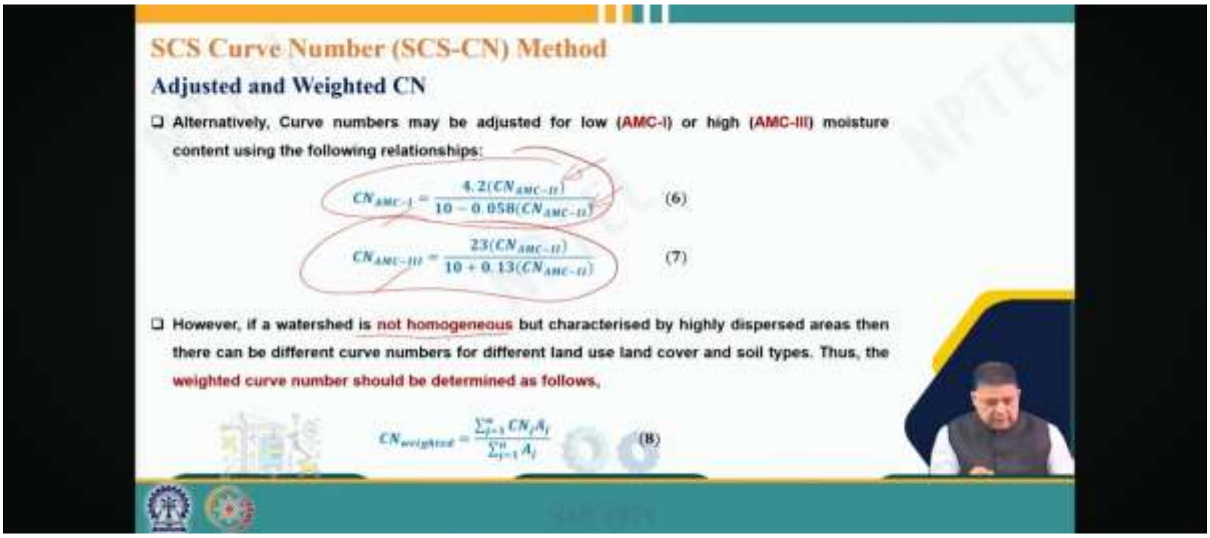
SCS Curve Number (SCS-CN) Method

Adjusted CN (NRCS)

Knowing the CN for AMC-II condition, the corresponding CN values for AMC-I and AMC-III can be obtained from the table

CN for AMC II	Corresponding CN's	
	AMC I	AMC III
100	100	100
95	87	98
90	78	96
85	70	94
80	63	91
75	57	88
70	51	85
65	45	82
60	40	78
55	35	74
50	31	70

So, in this similar table, the land use description will change, that is highly high density residential, industrial, low density residential, open spaces, parking, and paved spaces. So, obviously, parking and paved spaces are 100 percent per-use area. So, you will find that almost the curve number is 98, which means, as we said, that 100 means 100 precipitation gets converted into runoff. But here the value is almost 98. So, that means, 98 percent of your precipitation will get converted into runoff, that is what it means. But industrial, similarly, its values will change from residential to parking or paved areas.



SCS Curve Number (SCS-CN) Method

Adjusted and Weighted CN

- ❑ Alternatively, Curve numbers may be adjusted for low (AMC-I) or high (AMC-III) moisture content using the following relationships:

$$CN_{AMC-I} = \frac{4.2(CN_{AMC-II})}{10 - 0.058(CN_{AMC-II})} \quad (6)$$

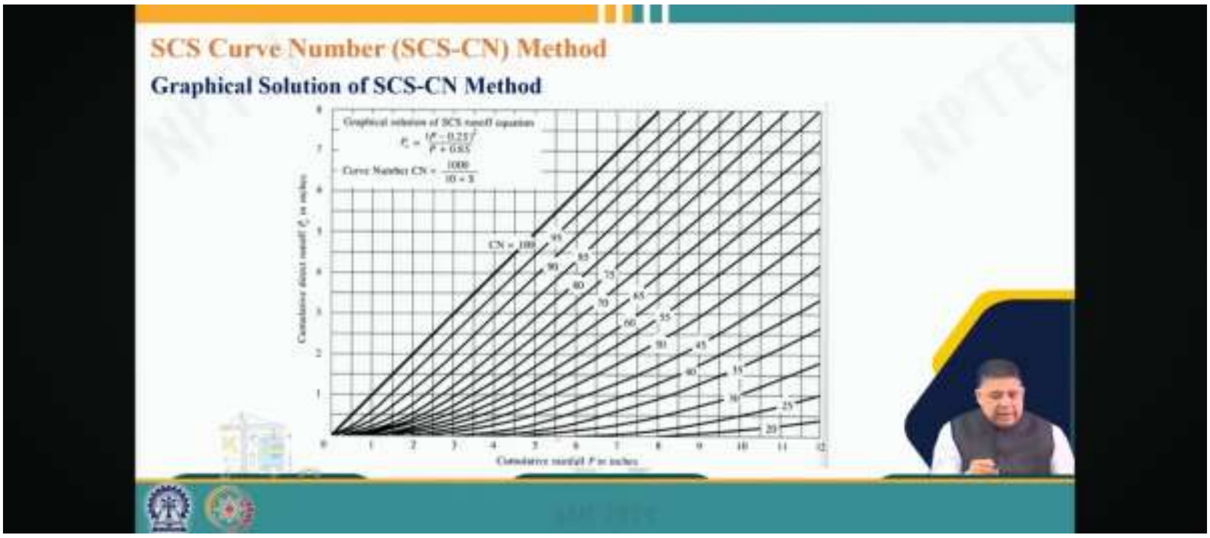
$$CN_{AMC-III} = \frac{23(CN_{AMC-II})}{10 + 0.13(CN_{AMC-II})} \quad (7)$$

- ❑ However, if a watershed is not homogeneous but characterised by highly dispersed areas then there can be different curve numbers for different land use land cover and soil types. Thus, the weighted curve number should be determined as follows,

$$CN_{weighted} = \frac{\sum_{j=1}^{n} CN_j A_j}{\sum_{j=1}^{n} A_j} \quad (8)$$

So, this is for urban areas. Now, once we know the curve number, that is from knowing the hydrological cycle, soil group, and the hydrological conditions we have, what kind of cultivation practices or what kind of paved area we have in the area, we will know the curve number from the previous two tables we just now saw, and those values are given for average conditions, that is for AMC 2 condition. So, the value which you obtain from the previous two tables is for AMC 2 condition. But as we all already saw, that depending upon the previous 5-

day rainfall, the AMC could be 1, 2 or 3; it could be dry, it could be wet, it could be average. So, accordingly, once we know AMC curve number for AMC 2, then obviously, if we are dealing with a situation of AMC 1 or AMC 3, then we have to get the corresponding value. So, if we get 90 and we have AMC 1, then the value that we will use in the model is 78; similarly, if it is AMC 3, then we will use a model value of 96. So, that means, knowing the soil group and land use practices, we will get the curve number from standard tables for AMC 2, and then knowing AMC and this moisture condition, we will decide which AMC group we belong to and then accordingly, we will convert and get the correct value of curve number, that is how it works.



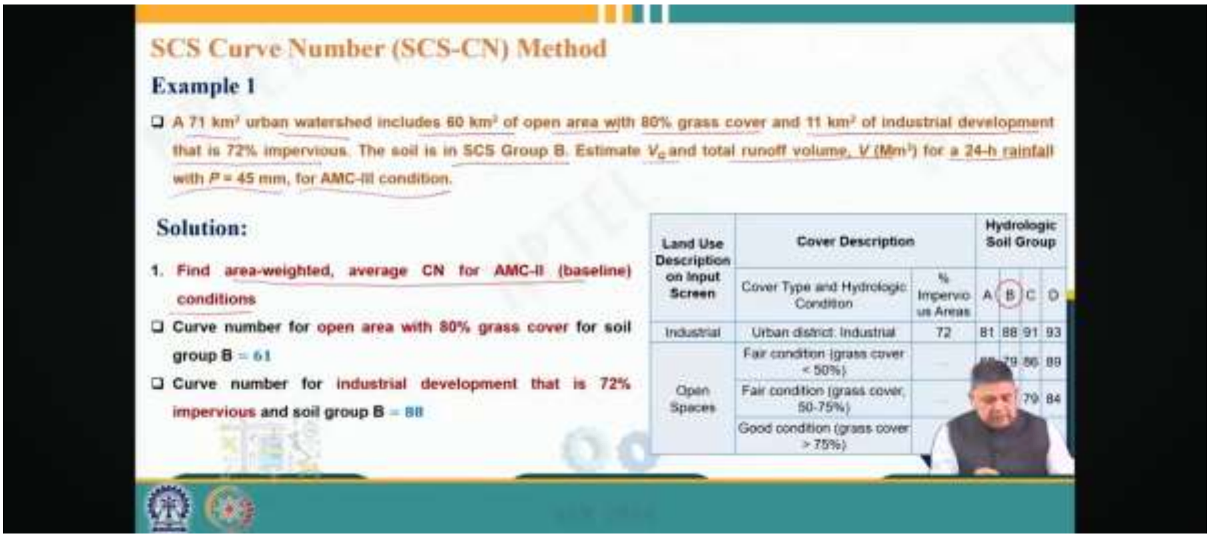
SCS Curve Number (SCS-CN) Method

Graphical Solution of SCS-CN Method

Now, another important thing ah is that ah besides this table, just now we saw there are some situations also available for determining the curve number for AMC and AMC 1 or AMC 3 if provided we have AMC 2 values. So, this relationship as you can see they are in terms of AMC 2. So, knowing AMC c n curve number value for AMC 2, we can also mathematically determine the values of curve number for AMC 1 and AMC 2. And already, as we saw in runoff coefficient case, ah, the watershed may not have a homogeneous, ah, land use or homogeneous characteristics. So, the we may use different curve numbers for different land cover or soil types.

So, that means, as we saw yesterday, that there could be 3 different uses and that means, there are 3 different curve number values will get. So, we have to know the area represented by a particular curve number in order to get the ah weighted curve number that will be applicable in our case. So, this is how we obtain this curve number weighted curve number we can obtain here. So, using this relationship we can do that. So, that simply means that ah the steps are very clear which will be still when we take up the problems, we can be very clear.

And in earlier times when computational facilities were not as good, graphical solutions also developed. In this context, we consider cumulative direct runoff, cumulative rainfall, and their relationship for different curve numbers. So, if you know the rainfall and the applicable curve number, you can derive the value from this graph. This assumes that I = 0.2 S, which is the original SCS curve number procedure.



SCS Curve Number (SCS-CN) Method

Example 1

- A 71 km² urban watershed includes 60 km² of open area with 80% grass cover and 11 km² of industrial development that is 72% impervious. The soil is in SCS Group B. Estimate V_Q and total runoff volume, V (Mm³) for a 24-h rainfall with P = 45 mm, for AMC-III condition.

Solution:

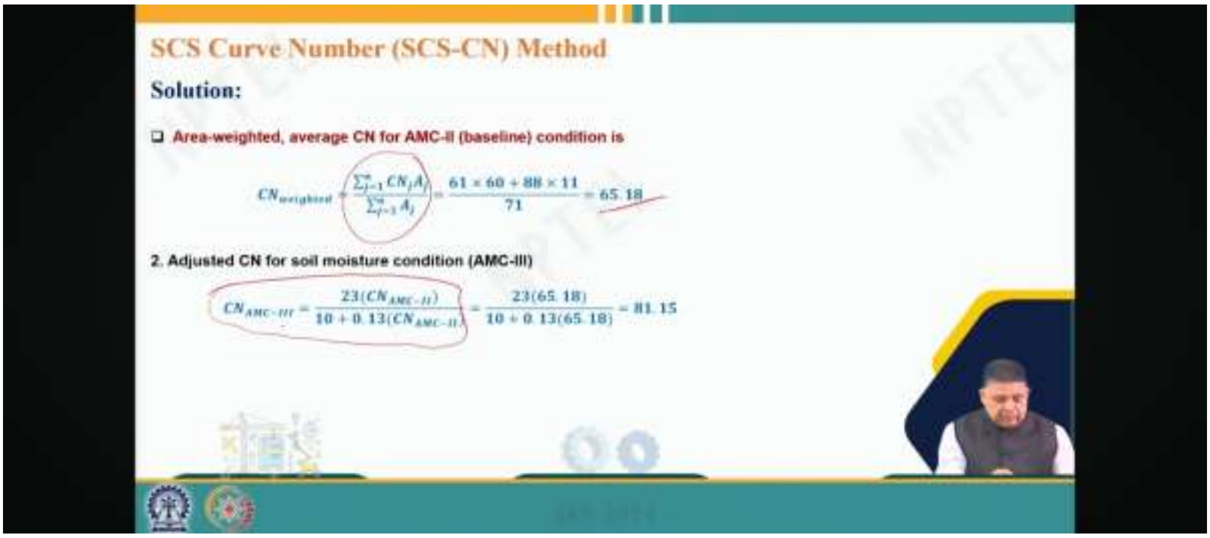
1. Find area-weighted, average CN for AMC-II (baseline) conditions

- Curve number for open area with 80% grass cover for soil group B = 61
- Curve number for industrial development that is 72% impervious and soil group B = 88

Land Use Description on Input Screen	Cover Description		Hydrologic Soil Group			
	Cover Type and Hydrologic Condition	% Impervious Areas	A	B	C	D
Industrial	Urban district: Industrial	72	81	88	91	93
Open Spaces	Fair condition (grass cover < 50%)	--	[illegible]	79	86	89
	Fair condition (grass cover, 50-75%)	--	[illegible]	[illegible]	79	84
	Good condition (grass cover > 75%)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Let's take an example: a 71 square kilometers urban watershed, including 60 square kilometers of open area with 80 percent grass cover and 11 square kilometers of industrial development, which is 72 percent impervious. The soil is in SCS group B. We need to estimate V_q and total runoff volume for a 24-hour rainfall with P equals to 45 mm for MC_3 condition.

Of course, we have to find the area-weighted average curve number forMC_2, which is the baseline condition. We can refer to this table. In the open area with more than 80 percent grass, we are in group 2. So, obviously, the curve number is 61. Given that this area is 60 square kilometers, the basin has a curve number value of 61. Similarly, for industrial development, which is 72 percent impervious.



SCS Curve Number (SCS-CN) Method

Solution:

- Area-weighted, average CN for AMC-II (baseline) condition is

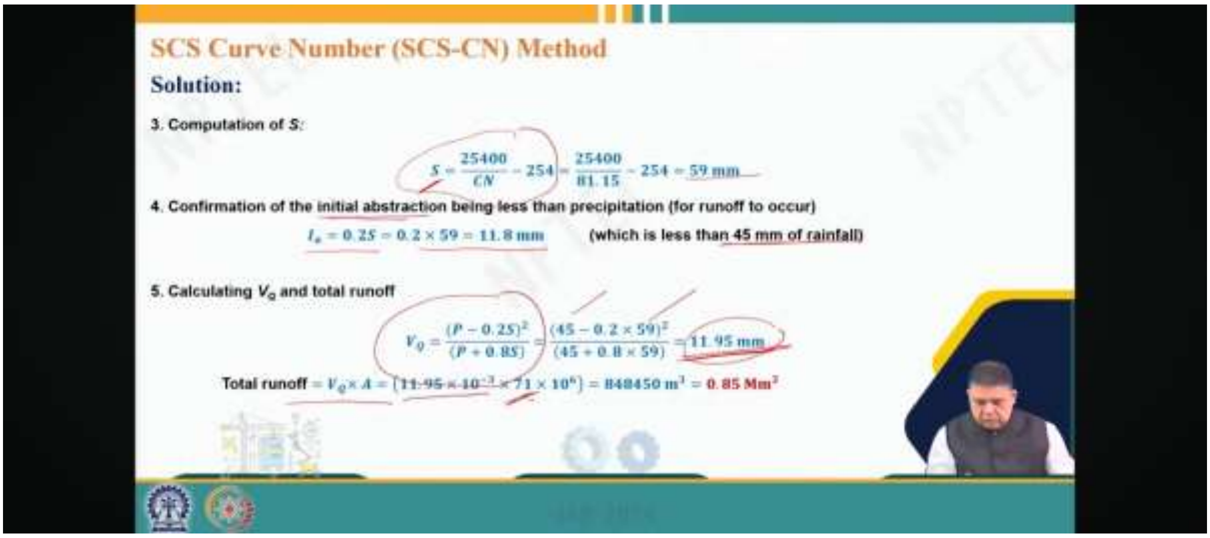
$$CN_{weighted} = \frac{\sum_{j=1}^{n} CN_j A_j}{\sum_{j=1}^{n} A_j} = \frac{61 \times 60 + 88 \times 11}{71} = 65.18$$

2. Adjusted CN for soil moisture condition (AMC-III)

$$CN_{AMC-III} = \frac{23(CN_{AMC-II})}{10 + 0.13(CN_{AMC-II})} = \frac{23(65.18)}{10 + 0.13(65.18)} = 81.15$$

So, interest year still 22 per years the value is 88 and that is for 11 area is 11 square kilometers. So, we know 2 uses 2 curve numbers 2 areas. So, of course, we can find out the weighted curve number using this relationship and that comes out to be 65.

So, 65.18 is AMC_2 condition area, but ah we know that we are dealing with AMC 3. So, that means, we have to use either ah the conversion table or this relationship which relates the curve number for AMC 3 to curve number for AMC_2. So, by putting the curve number for ah AMC 2 condition here we can get the curve number AMC_3 condition 81.15. And ah then of course, S value can be calculated using this standard relationship because we know the curve number.



SCS Curve Number (SCS-CN) Method

Solution:

3. Computation of S:

$$S = \frac{25400}{CN} - 254 = \frac{25400}{81.15} - 254 = 59\ \text{mm}$$

4. Confirmation of the initial abstraction being less than precipitation (for runoff to occur)

$I_a = 0.2S = 0.2 \times 59 = 11.8\ \text{mm}$ (which is less than 45 mm of rainfall)

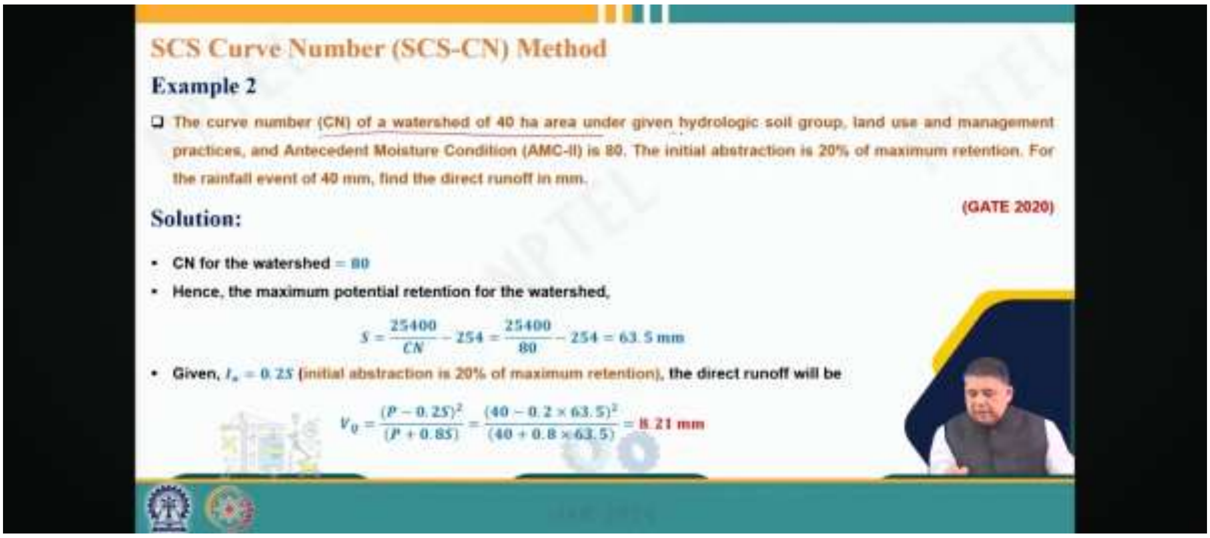
5. Calculating V_Q and total runoff

$$V_Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} = \frac{(45 - 0.2 \times 59)^2}{(45 + 0.8 \times 59)} = 11.95\ \text{mm}$$

Total runoff $= V_Q \times A = (\cancel{11.95 \times 10^{-3}} \times 71 \times 10^6) = 848450\ \text{m}^3 = 0.85\ \text{Mm}^3$

So, the value comes out to be 59.55 ah 59 ah millimeters and of course, ah this I a equal to 0.2 S is 11.8 mm. Since a S value is greater than um I_a is 0.2 S that is initial abstraction that means, there will be ah runoff that is less than rainfall value of 45 mm.

So, there will be ah runoff generated. So, then we can use this relationship ah and put the values of P 45 mm which is known and ah the um the S which we this is known to us and then we get the value of V_q equals to 11.59, but we have to also get the volumetric terms. So, obviously, the 11.95 millimeters we have to multiply with ah the total area also. Of course, this is a unique conversion just to get everything in ah meters and so, we get ah this value of 848450 ah cubic meters or we can say that it is 0.85 million cubic meters. So, the runoff for that volume for the given data set was 0.85 million cubic meters.



SCS Curve Number (SCS-CN) Method

Example 2

❑ The curve number (CN) of a watershed of 40 ha area under given hydrologic soil group, land use and management practices, and Antecedent Moisture Condition (AMC-II) is 80. The initial abstraction is 20% of maximum retention. For the rainfall event of 40 mm, find the direct runoff in mm.

(GATE 2020)

Solution:

- CN for the watershed = 80
- Hence, the maximum potential retention for the watershed,

$$S = \frac{25400}{CN} - 254 = \frac{25400}{80} - 254 = 63.5\ \text{mm}$$

- Given, $I_a = 0.2S$ (initial abstraction is 20% of maximum retention), the direct runoff will be

$$V_Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} = \frac{(40 - 0.2 \times 63.5)^2}{(40 + 0.8 \times 63.5)} = 8.21\ \text{mm}$$

We will quickly take another example: the curve number of a watershed of 40 hectares area under given hydrological soil group, land use and management practices, and antecedent moisture condition 2 is 80. The initial abstraction is 20 percent of maximum retention for the rainfall event of 40 mm. Find the direct runoff in millimeters. This question has been taken from GATE 2020.

So, already we have been given the curve number. So, the maximum potential relationship retention we can obtain using this relationship, which comes out to be 63.5 mm, and we have also been given l_a = 0.2S, that is, initial abstraction 20 percent of maximum retention. So, that means we can use this simplified formula where already l_a is taken as 0.2S. So, putting the value of P and S, already we know P equals to 40 mm and S value already we have calculated as 63.5 mm. Putting these values, we can find out V_q, which comes out to be 8.21 mm. So, this is what we saw in this lecture. ICS curve number method which basically uses the SVL soil vegetation and land use complex of a given basin and of course, we have to use the standard tables and get the curve number from there and then use the procedure we have discussed. So, this is one way of finding out the direct runoff volume from a given basin.

Thank you very much. Please give your feedback and also raise your doubts or questions so that they can be answered on the forum.

Thank you.