Forest Hydrology: Lect. 10

Contents

- The flood hydrograph
- SCS - Curve Number method
- Application of the SCS – CN method at hourly (sub-event) time steps

The flood and its hydrograph

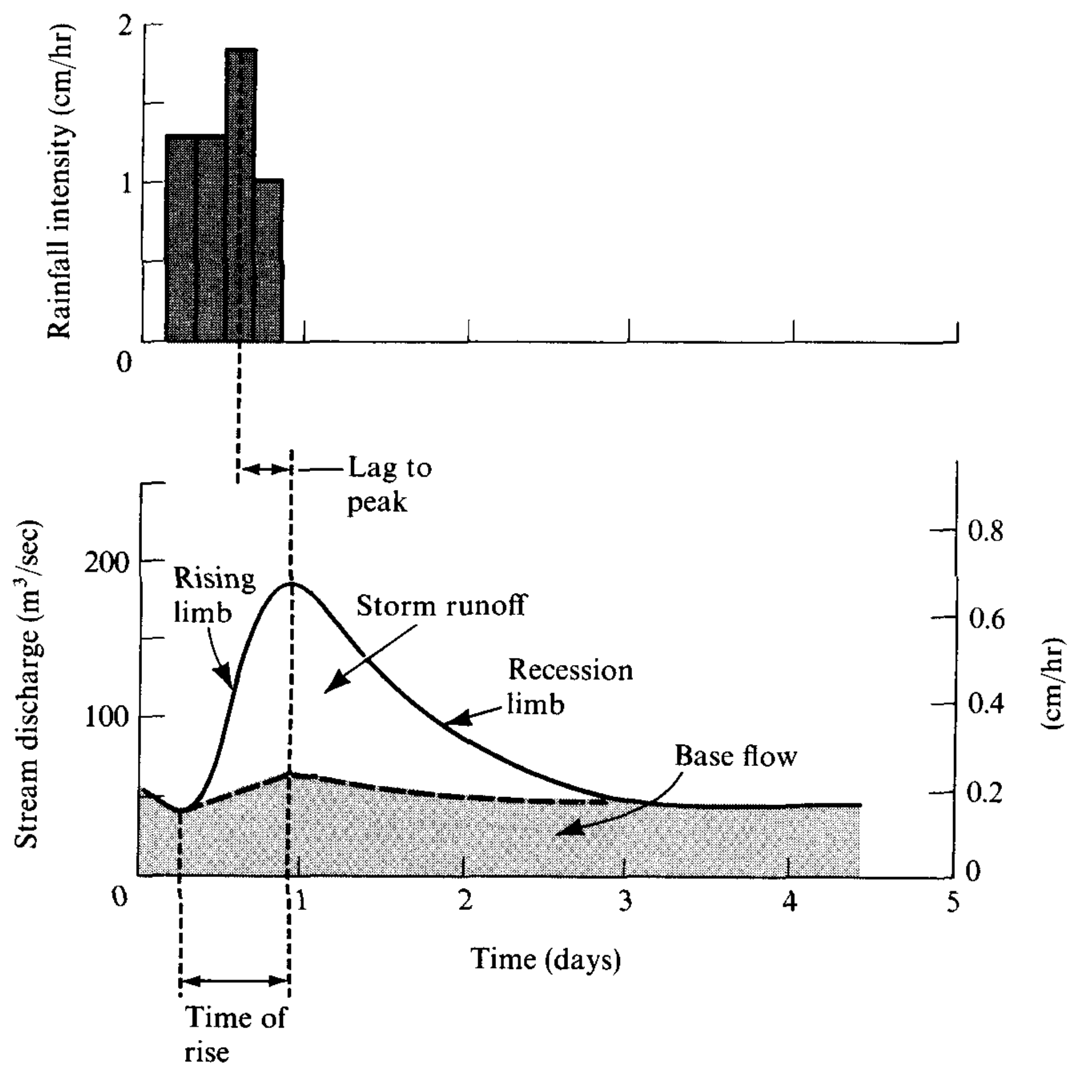
Terminology

Streamflow (runoff) = storm runoff + baseflow

or

quickflow + delayed flow

Flood runoff coefficient= (event runoff)/(event rainfall)



Prediction of watershed runoff (i.e.: computing the flood event runoff coefficient)

What do we want to know? Total volume of storm runoff given the rainfall

- **Soil Conservation Service Method (Curve Number)**
- **Very** widely used in prediction software
- Accounts for effects of soil properties, land cover, and antecedent soil moisture
- Prediction of storm flow depends on total rainfall rather than intensity
- Based on a **very** simple conceptual model, as follows.

Prediction of storm runoff volume ('SCS' method)

All quantities expressed in mm of water

Total precipitation, ***P***, is partitioned into:

• An initial abstraction, I_a , the amount of storage that must be satisfied before any flow can begin. This is poorly defined in terms of process, but is roughly equivalent to interception and infiltration that occurs before runoff.

• Thus, $[P - I_a]$ is the 'excess precipitation' (after the initial abstraction) or the 'potential runoff'.

• Retention, ***F***, the amount of rain falling after the initial abstraction is satisfied, but which does not contribute to the storm flow. This is equivalent to volume of water that is infiltrated.

• Storm runoff R_s

It is assumed that **a watershed can hold a certain maximum amount of precipitation, S_{max}**

$$S_{max} = I_a + F_\infty \qquad (1)$$

where F_∞ is the total amount of water retained as t becomes very large (i.e. in a long, large storm).

It is the cumulative amount of infiltration

It is also assumed that during the storm (and particularly at the end of the storm)

$$\frac{R_s}{[P - I_a]} = \frac{F}{S_{max}} \qquad (2)$$

- The idea is that "the more of the potential storage that has been exhausted (cumulative infiltration, F, converges on S_{max}), the more of the 'excess rainfall', or 'potential runoff', $P-I_a$, will be converted to storm runoff."

- The scaling is assumed to be linear.

- One more relationship that is known by definition (balance):

$$F = P - I_a - R_s \qquad (3)$$

- Combination of these leads to

$$R_s = \frac{[P - I_a]^2}{P - I_a + S_{max}} \qquad (4)$$

- Another generalized approximation made on the basis of measuring storm runoff in small, agricultural watersheds under "normal conditions of antecedent wetness" is that

$$I_a \approx 0.2 S_{max} \qquad (5)$$

The few values actually tabulated in the 'original' report are 0.15-0.2 S_{max}.

- Thus

$$P - I_a = P - 0.2 S_{max} \qquad (6)$$

- Combination of these relations yields

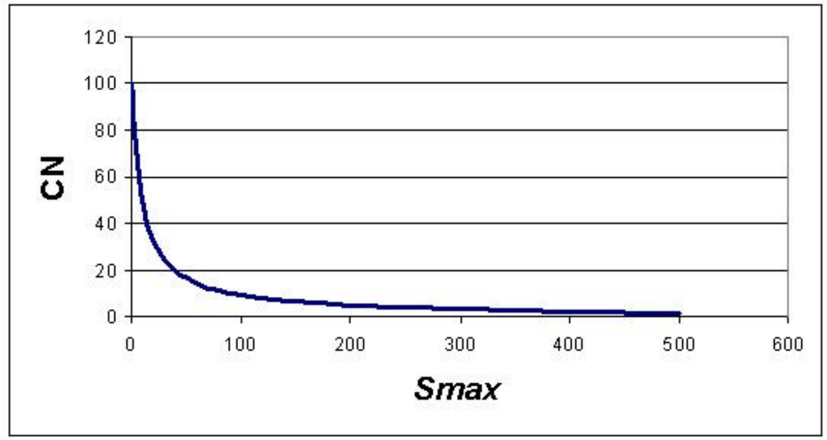
$$R_s = \frac{\left[P - 0.2S_{max}\right]^2}{\left[P + 0.8S_{max}\right]} \qquad (7)$$

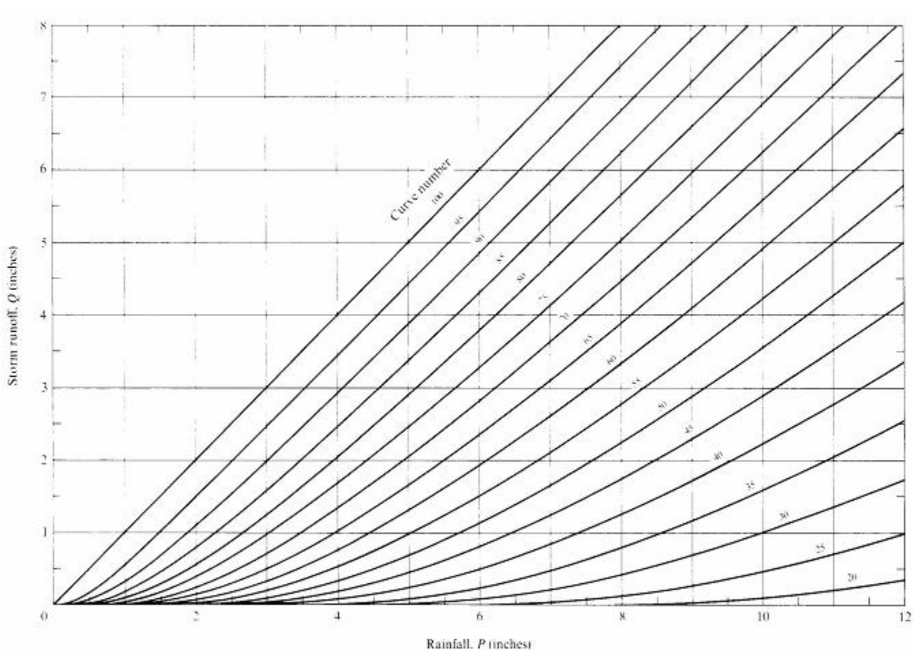
for all $P > I_a$. ELSE $R = 0$.

Thus, the problem of predicting storm runoff depth is reduced to estimating a single value, the maximum retention capacity of the watershed, S_{max}.

The parameter S_{max} (mm) is related to a parameter called the Curve Number, which is an index of "storm-runoff generation capacity", varying from 0 to 100.

$$S_{\max}(mm) = 254.0\left(\frac{100}{CN} - 1\right)$$





Relationship between rainfall and runoff (in depth) for a given event

- The entire rainfall-runoff response for various soil-plant cover complexes is represented by the Curve Number (large oversemplification!).
- A higher curve indicates a large runoff response from a watershed with a fairly uniform soil with a low infiltration capacity.
- A lower curve is the smaller response expected from a watershed with a permeable soil, with a relatively high spatial variability in infiltration capacity.

CNs are evaluated for many watersheds and related to:

- soil type (SCS soil types classified into Soil Hydrologic Groups on the basis of their measured or estimated infiltration behavior)
- vegetation cover and or land use practice
- antecedent soil-moisture content

CLASSIFICATION	TYPE OF SOIL
A (low runoff potential)	Soils with high infiltration capacities, even when thoroughly wetted. Chiefly sands and gravels, deep and well drained.
B	Soils with moderate infiltration rates when thoroughly wetted. Moderately deep to deep, moderately well to well drained, with moderately fine to moderately coarse textures.
C	Soils with slow infiltration rates when thoroughly wetted. Usually have a layer that impedes vertical drainage, or have a moderately fine to fine texture.
D (high runoff potential)	Soils with very slow infiltration rates when thoroughly wetted. Chiefly clays with a high swelling potential; soils with a high permanent water table; soils with a clay layer at or near the surface; shallow soils over nearly impervious materials.

Hydrologic Soil Groups are defined in SCS Soil Survey reports

Classification of hydrologic properties of vegetation covers for estimating curve numbers (US Soil Conservation Service, 1972)

VEGETATIVE COVER	HYDROLOGIC CONDITION
Crop rotation	Poor: Contain a high proportion of row crops, small grains, and fallow.
	Good: Contain a high proportion of alfalfa and grasses.
Native pasture or range	Poor: Heavily grazed or having plant cover on less than 50% of the area.
	Fair: Moderately grazed; 50–75% plant cover.
	Good: Lightly grazed; more than 75% plant cover.
	Permanent Meadow: 100% grass cover.
Woodlands	Poor: Heavily grazed or regularly burned so that litter, small trees, and brush are destroyed.
	Fair: Grazed but not burned; there may be some litter.
	Good: Protected from grazing so that litter and shrubs cover the soil.

Runoff Curve Numbers for hydrologic soil-cover complexes under average antecedent moisture conditions

Table 10-3 Runoff curve numbers for hydrologic soil-cover complexes under average conditions of antecedent moisture. (From U.S. Soil Conservation Service 1972.)

LAND USE OR COVER	TREATMENT OR PRACTICE	HYDROLOGIC CONDITION	HYDROLOGIC SOIL GROUP A	B	C	D
Fallow	Straight row	Poor	77	86	91	94
Row crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Contoured and terraced	Poor	66	74	80	82
	Contoured and terraced	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Contoured and terraced	Poor	61	72	79	82
	Contoured and terraced	Good	59	70	78	81
Close-seeded legumes or rotation meadow	Straight row	Poor	66	77	85	89
	Straight row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Contoured and terraced	Poor	63	73	80	83
	Contoured and terraced	Good	51	67	76	80
Pasture or range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadow (permanent)		Good	30	58	71	78
Woodlands (farm woodlots)		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads			59	74	82	86
Roads, dirt			72	82	87	89
Roads, hard-surface			74	84	90	92

Curve Numbers for urban/suburban land covers (US Soil Conservation Service , 1975)

LAND USE		HYDROLOGIC SOIL GROUP A	B	C	D
Open spaces, lawns, parks, golf courses, cemeteries, etc.					
good condition: grass cover on 75% or more of the area		39	61	74	80
fair condition: grass cover on 50% to 75% of the area		49	69	79	84
Commercial and business area (85% impervious)		89	92	94	95
Industrial districts (72% impervious)		81	88	91	93
Residential*					
Average lot size	Average % Impervious†				
1/8 acre or less	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
Paved parking lots, roofs, driveways, etc.‡		98	98	98	98
Streets and roads					
Paved with curbs and storm sewers‡		98	98	98	98
Gravel		76	85	89	91
Dirt		72	82	87	89

*Curve numbers are computed assuming the runoff from the house and driveway is directed toward the street with a minimum of roof water directed to lawns where additional infiltration could occur.

†The remaining pervious areas (lawn) are considered to be in good pasture condition for these curve numbers.

‡In some warmer climates of the country a curve number of 95 may be used.

Accounting for the Antecedent Moisture Condition

Table 1

AMC category	Rainfall depth in the previous 5 days (mm)	
	Dormant sesaon	Growing season
AMC-I	< 12.7	< 35.6
AMC-II	12.7-27.9	35.6-53.3
AMC-III	> 27.9	>53.3

$$CN(I) = \frac{CN(II)}{2.3 - 0.013CN(II)}$$

$$CN(III) = \frac{CN(II)}{0.43 + 0.0057CN(II)}$$

The previous table permit the computation of a CN which is valid for an average AMC (Antecedent Moisture Condition). It is possible to adapt the method to varying AMC based on the AMC category defined in Table 1, and then computing the corresponding CN values based on the relationships for CN(I) (valid for AMC-I) and CN(III) (valid for AMC-III).

Example

It is required to compute the runoff depth (in mm and in cubic meters) for a 20 km^2 catchment and for a storm event given by the following hyetograph (the hyetograph is the record of rainfall with time for a given storm):
hour 1: 20.0 mm
hour 2: 35.0 mm
hour 3: 15.0 mm
Use the CN method (*curve number*), taking a value of 60 for the CN.

$$S = 254\left(\frac{100}{60} - 1\right) = 169.3mm$$

$$I_a = 0.2S = 33.9mm$$

$$R_S = \frac{(70-33.9)^2}{70+135.4} \cong 6mm$$

$$which \quad means$$

$$6\times10^{-3}\times20\times10^{6} = 120\times10^{3}m^{3}$$

Esercise (2)

The SCS method allows one also to compute the runoff at each time step (i.e., not only at the event time scale).
To this end, the SCS relationship is applied at each time step in terms of cumulative quantities, and then subtracting at each time step the cumulative quantities computed at the previous time step.

Example

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$$I_a = 0.2S = 33.9mm$$

$$R_s = \frac{(70 - 33.9)^2}{70 + 135.4} \cong 6mm$$

$$i.e.$$

$$6 \times 10^{-3} \times 20 \times 10^6 = 120 \times 10^3 m^3$$

Esercise (3)

$$Hour\ 1:$$

$$P = 20mm < I_a \quad (no\ runoff)$$

$$Hour\ 2:$$

$$during\ \ hr1 + ht2\ we\ have\ \ 55\ mm > I_a$$

$$R_s = \frac{(55 - 33.9)^2}{55 + 135.4} \cong 2.3mm$$

$$then\ R_s\left(hr\ 2\right) = 2.3mm$$

$$Hour\ 3:$$

$$during\ \ hr1 + hr2 + hr3\ we\ have\ \ 70\ mm > I_a$$

$$R_s = \frac{(70 - 33.9)^2}{70 + 135.4} \cong 6.0mm$$

$$then\quad R_s\left(ora\ 3\right) = (6.0 - 2.3)mm = 3.7mm$$

Application

Examining the hydrologic consequences of an extreme storm event in Este (31.05.1995)

catchment: 70 ha
Rainfall depth: 199.8 mm
(in two events: 1°: 58.2 mm;
2°: 141.6 mm)
CN(II) catchment: 72
CN(I): 58
CN(III): 86
for 1° event: condition AMC I; for 2° event AMC III

1° event

$$S = 254\left(\frac{100}{58} - 1\right) = 183.9 mm$$

$$if \quad c = 0.2$$

$$\Rightarrow P_e = \frac{(58.2 - 0.2 \cdot 183.9)^2}{58.2 + 0.8 \cdot 183.9} = 2.2 mm$$

$$runoff\ coeff. = \frac{2.2}{58.2} = 0.04$$

2° event

$$S = 254\left(\frac{100}{86} - 1\right) = 41.3 mm$$

$$if \quad c = 0.2$$

$$\Rightarrow P_e = \frac{(141.6 - 0.2 \cdot 41.3)^2}{141.6 + 0.8 \cdot 41.3} = 101.8 mm$$

$$runoff\ coeff. = \frac{101.8}{141.6} = 0.72$$

Esercise (4)

Four raingauges measures rainfall during one storm event.
The measured rainfall depths and the Thiessen factors (for a given catchmet) for each raigauge are as follows:

Raingauge 1: 35 mm Thiessen weight=0.2
Raingauge 2: 45 mm Thiessen weight=0.2
Raingauge 3: 85 mm Thiessen weight=0.2
Raingauge 4: 10 mm Thiessen weight=0.4

The catchment is characterised by a CN=75, Ia = 0.2 S, and it is 50 km^2 wide.
Compute the runoff depth, in mm and in m^3.