Estimating Depth of Daily Rainfall Infiltrating the Soil Using the USDA-NRCS Curve Number Approach

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Abstract. *Estimating rainfall infiltrating into the soil (rainfall less runoff), is a key input to the checkbook method of irrigation scheduling. The checkbook method is a common tool for managing root zone soil moisture to maintain desired plant health and to conserve water.*

However, estimating infiltrated rainfall is fraught with uncertainty. It is strongly influenced by: rainfall (intensity, duration, amount), soils (texture, structure, bulk density, surface-sealing), land slope/ topography, antecedent soil water content, and plant cover (type, spatial extent, surface residue/mulch).

The USDA-NRCS curve number approach has been used for decades within hydrologic, soils, and water resources communities to estimate infiltrated rainfall. Required inputs include: daily rainfall depth, antecedent soil moisture, and selection of an appropriate curve number reflective of soil texture, land slope, and plant cover. Curve number values directly relate to depth of water intercepted by vegetation canopy and the soil surface before runoff occurs.

The curve number approach provides a reasonable balance between simplicity and accuracy to estimate depth of daily rainfall infiltrating soils. It is a significant improvement over use of a simple multiplier applied to measured rainfall or an algorithm based on a single factor such as rainfall intensity.

Keywords. Rainfall runoff, effective precipitation, irrigation scheduling, urban landscape water budgets, weather based irrigation controllers.

Background

When estimating rainfall infiltrating soils, it is common to first predict the expected runoff from measured rain. Surface runoff from rainfall is more easily observed and measured than the fraction of rainfall being infiltrated. Hence runoff algorithms can be readily supported by direct measurements in the field. Infiltrated runoff becomes the unmeasured remainder, and is calculated as measured rainfall minus runoff.

However, estimation of runoff from rainfall is fraught with uncertainty. Runoff during rainfall events is strongly influenced by multiple factors, including: soil texture, soil structure, sealing and crusting of the soil surface, vegetative cover, land slope, local land forming (tillage, furrowing, and ridging), antecedent soil moisture, and rainfall (intensity and duration/depth). Additional factors affecting effective precipitation are included in Table 2-42 of USDA-SCS Part 623 National Engineering Handbook, Chapter 2, Irrigation water Requirements.

The USDA-NRCS curve number approach utilizes characterizations of soil texture by the hydrologic soil groups described in Table 1.

Table 1. Hydrologic Soil Groups - from USDA-NRCS Part 630, National Engineering Handbook, Chapter 7, Hydrologic Soil Groups.

A	K_{sat} is generally greater than 1.42 iph. Water is transmitted freely through the soil. Typically have less than 10% clay and more than 90% sand or gravel, with more than 40 inches of soil above an impermeable layer or water table.
B coarse	K_{sat} is always generally between 0.57 iph and 1.42 iph. Water transmission is unimpeded through the soil. Typically have between 10%-20% clay and 50%-90% percent sand, with more than 40 inches of soil above an impermeable layer or water table. Loamy sand or sandy loam texture.
C medium	K_{sat} is generally between 0.06 iph and 0.57 iph. Water transmission is somewhat restricted through the soil. Typically between 20%-40% clay and less than 50% sand, with more than 40 inches of soil above an impermeable layer or water table. Loam, sandy clay loam, clay loam, and silty clay loam textures.
D fine	K_{sat} is generally less than 0.06 iph. Water movement is restricted or very restricted through the soil. Typically have greater than 40% clay and less than 50 percent sand, with more than 40 inches of soil above an impermeable layer or water table.

Procedures

Required data for using the USDA-NRCS curve number approach for estimating rainfall runoff are:

- daily precipitation depth.
- selection of appropriate CN (curve number) based on general soil, vegetation types, and land slope.
- AWC (antecedent soil water condition) - measured directly or computed from a daily soil water balance.

Table 2. Terms and Definitions.

P	Depth of rainfall during the event (inches).
CN	Curve number. Represents the relative imperviousness of the soil-vegetation complex and ranges from 0 for infinite perviousness and total infiltration to 100 for complete imperviousness and total runoff. Incorporates various factors effecting runoff, including land slope.

$S = 10*(100/CN - 1)$	Maximum depth of water that can be retained as infiltration and canopy interception during a single rainfall event (inches).
$0.2*S$	Rainfall intercepted by the vegetation canopy and soil surface before runoff occurs (inches).
$RO = (P - 0.2*S)^2 / (P + 0.8*S)$	Depth of surface runoff during the rain event (inches). RO = 0 when P<= 0.2*S and RO is always <= P
$P_{inf} = P - RO$	Depth of infiltrated rainfall (inches).
AWCI	Antecedent soil water condition for dry conditions, when watershed conditions are dry enough for satisfactory plowing or cultivation to take place.
AWCII	Antecedent soil water condition for average conditions.
AWCIII	Antecedent soil water condition for wet conditions, when watershed is practically saturated from antecedent rains.

If appropriate CN values are unknown, they can be approximated using the following algorithms. For AWCII (average soil water conditions), the CN values for fine soil textures can be calculated from observed values of 0.2*S, which is the depth of rainfall intercepted by the vegetation canopy and soil surface before runoff occurs. Once 0.2*S is determined, CN can be calculated as:

$$CN_{fine} = 100 / (0.2*S / 0.2 / 10 + 1)$$

For AWCII, the CN values for coarse and medium soil textures can be obtained from:

$$CN_{medium} = [(CN_{fine} - 47.2) / 0.5283] * 0.66 + 34$$

$$CN_{coarse} = [(CN_{fine} - 47.2) / 0.5283]$$

The CN values for AWCI and AWCIII, can be estimated from the corresponding CN for AWCII:

$$CN_{AWCI} = CN_{AWCII} / (2.281 - 0.01281 * CN_{AWCII})$$

$$CN_{AWCIII} = CN_{AWCII} / (0.427 + 0.00573 * CN_{AWCII})$$

When the actual AWC falls between AWCII and AWCIII, additional accuracy can be obtained by proportionally interpolating the CN values based on the value of AWC in relation to AWCII and AWCIII. This method can similarly be applied when AWC lies between AWCI and AWCII. This procedure was utilized by Allen and Robison, 2007.

Results

Tables 2a, 2b, and 2c include calculations of P_{inf} (rainfall infiltrated) for coarse, medium, and fine soil textures for a daily P (depth of measured rain) of 1.00 inches. Table 2a is for AWCI or dry antecedent soil water conditions, Table 2b is for AWCII or average antecedent soil water conditions, Table 2a is for AWCIII or wet antecedent soil water conditions.

Table 2a. Typical Values for Dry Antecedent Moisture Conditions

AWCI	Curve Number (CN)			P_{inf} for P=1.00 inches		
	Soil Texture			Soil Texture		
	Coarse	Medium	Fine	Coarse	Medium	Fine
Lawns, parks, golf courses, etc.	41	56	64	1.00	1.00	1.00
Bare urban soil - no vegetation	73	82	87	0.98	0.89	0.77
Suggested for urban landscape with 0 to 3% slope	62	73	78	1.00	0.98	0.94
Suggested for urban landscape with >3% to 6% slope	71	80	83	0.99	0.92	0.86
Suggested for urban landscape with >6% to 12% slope	77	84	87	0.95	0.84	0.77
Suggested for urban landscape with>13% slope	81	87	89	0.91	0.78	0.71

Table 2b. Typical Values for Average Antecedent Moisture Conditions

AWCII	Curve Number (CN)			P_{inf} for P=1.00 inches		
	Soil Texture			Soil Texture		
	Coarse	Medium	Fine	Coarse	Medium	Fine
Lawns, parks, golf courses, etc.	61	74	80	1.00	0.98	0.92
Bare urban soil - no vegetation	86	91	94	0.80	0.64	0.50
Suggested for urban landscape with 0 to 3% slope	79	86	89	0.93	0.80	0.72
Suggested for urban landscape with >3% to 6% slope	85	90	92	0.83	0.68	0.60
Suggested for urban landscape with >6% to 12% slope	89	92	94	0.73	0.58	0.50
Suggested for urban landscape with>13% slope	90	94	95	0.66	0.51	0.44

Table 2c. Typical Values for Wet Antecedent Moisture Conditions

AWCIII	Curve Number (CN)			P_{inf} for P=1.00 inches		
	Soil Texture			Soil Texture		
	Coarse	Medium	Fine	Coarse	Medium	Fine
Lawns, parks, golf courses, etc.	79	87	90	0.94	0.78	0.67
Bare urban soil - no vegetation	94	96	97	0.52	0.37	0.27
Suggested for urban landscape with 0 to 3% slope	90	94	95	0.68	0.52	0.44
Suggested for urban landscape with >3% to 6% slope	93	95	96	0.56	0.41	0.34
Suggested for urban landscape with >6% to 12% slope	95	97	97	0.45	0.32	0.27
Suggested for urban landscape with>13% slope	96	97	98	0.39	0.28	0.23

The values in Tables 2a, 2b, and 2c reflect significant differences of infiltrated rainfall due to varying soil textures, antecedent soil water conditions, and land slopes.

Conclusions

The curve number approach provides a reasonable balance between simplicity and accuracy to estimate the depth of daily rainfall that infiltrates the soil. Besides the measured rainfall depth, it incorporates additional key factors, including soil texture, vegetation/groundcover, land slope, and antecedent soil moisture conditions.

The use of the USDA-NRCS curve number approach would be expected to improve the accuracy of the checkbook method for irrigation scheduling, provide for improved landscape health, and promote conservation of water resources. It can readily be incorporated into landscape water budgets developed by developers or municipalities. Weather based irrigation controllers that utilized measured or estimated rainfall would similarly improve in their performance following significant rainfall events if adapted to incorporate the curve number approach for estimating effective rainfall.

References

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