NO-TILL AND CURVE NUMBERS – A CLOSER LOOK

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Abstract. Since its inception in the 1950s, worldwide adoption and use of the Curve Number (CN) methodology for estimating runoff has highlighted some inconsistencies, limitations and problems. Analysis of curve numbers derived from 34 years of rainfall-runoff data, gathered from a 2.7 ha Georgia Piedmont catchment managed under no-till, showed that the average CN (57) that led to mean runoff estimate matching the mean measured runoff was 16 less than the average of the range of CN values (73) given in standard handbook tables for the catchment. The derived median value of the initial abstraction ratio (λ) was 0.04, compared to 0.2, the standard value. Many researchers recommend 0.05 for λ. Use of standard CN coefficients and values for fields managed in no-till, and possibly other conservation tillage systems, would likely lead to overestimation of runoff.

INTRODUCTION

Empirical analysis of large amounts of rainfall and runoff data from small catchments and hill-slope plots led to the development of the CN methodology in the 1950s by hydrologists at the then USDA Soil Conservation Service for estimating direct runoff from a rainfall event with a minimal data set (Hawkins *et al*., 2009). The derived equations in SI units have the form:

$$Q = (P- Ia)^2 / (P- Ia + S) \quad \text{for } P>Ia;\ Q=0 \text{ for } P\leq Ia; \quad (1)$$
$$CN = 25400 / [254+S] \quad (2)$$

And algebraic manipulations produce the following equations as well as a few others;

$$S = 5[P + 2Q – (4Q^2 + 5PQ)^{0.5}] \quad (3)$$
$$CN0 = 100/(1 + P/2) \quad (4)$$

where Q is runoff (mm), P is rainfall (mm), Ia is the initial abstraction (mm) and equals to λS, with the abstraction ratio λ set at 0.2, S is the potential maximum retention (mm), and CN0 is the CN at which runoff starts for a given P.

A set of tools to solve for Q were among the original packages developed that included:

a) Standard tables of CN values based on land use, conservation practice, the hydrologic condition of soil cover, hydrologic soil group, and antecedent moisture conditions (AMC- now called antecedent runoff condition ARC); and
b) Graphical charts to obtain Q from known P and CN values. The use of the charts diminished with advances in electronic computational aids.

Hawkins et al. (2009) have summarized the origin, development, role, application and current status of the CN method. This simple empirical model continues to be used across the world and is a vital component of many popular hydrologic models. Years of use and adaptation has led to critical review of the methodology. Some inconsistencies, limitations and problems have been identified. For example, many researchers have found that an initial abstraction ratio λ of 0.05, instead of the original value of 0.2, gives more accurate estimations of Q (Hawkins *et al*., 2009). There have also been calls for development of locally defined CN values to address concerns with regional and seasonal variations. Hawkins et al. (2009) cite studies by several researchers and task forces working to improve the method by incorporating knowledge developed since the original formulation.

Conservation tillage cropping stands out among the many technological innovations in agriculture that have been developed since the 1950s. Accumulation of surface organic matter with conservation tillage systems has positive effect on infiltration, water availability, and nutrient cycling leading to increased yields (CTIC, 2001; Endale *et al*., 2000, 2002 a and b, 2008, 2010; FAO, 2008; Schnepf and Cox, 2006). In the USA, 41% of the cropland is in conservation tillage while 57% of that is in no-till (CTIC, 2009). How accurately the CN method estimates runoff from conservation tillage fields is not well known. We hypothesize that because conservation tillage generally enhances infiltration, the CN method would overestimate runoff in conservation tillage systems. Alternatively, CN numbers for conservation tillage cropping systems would be less than the equivalent values given in standard handbook tables.

Our objective in this study was to derive and analyze CN values from rainfall-runoff data gathered from 1976 to 2009 on a 2.7 ha catchment (P1) at the USDA-ARS near Watkinsville, GA, in the Georgia Piedmont. During this period, P1 has continuously been under no-till management.

METHODS AND MATERIALS

Experimental site, cropping and hydrology. The research catchment P1 was established during the spring and summer of 1972 on 2.7 ha at the USDA-ARS J. Phil Campbell Senior, Natural Resource Conservation Center, near Watkinsville, GA. Slopes range from 2 to 7%. A gravely Cecil sandy loam (clayey, kaolinitic thermic Typic Kanhapludults) is the dominant soil type. A gravelly Pacolet sandy loam occurs on a smaller area on 5 to 7 percent slopes, and a Starr sandy loam occupies the lower portion of the catchment on 2 to 4 percent slopes. After 3 conventionally-tilled soybean crops, management converted to conservation cropping systems consisting of double-crop conservation tillage (no-till) rotations which have been maintained since. During the no-till phase, summer crops included soybean (12 yr), sorghum (15 yr), cotton (5 yr), and corn (2 yr). Cover crops included barley (6 yr), wheat (8 yr), clover (11 yr) and rye (9 yr).

From 1972 to 1998, rainfall was gauged with a chart-based Fergusson-type weighing and recording rain gauge while runoff was measured with a 0.762 m (2.5 ft) stainless steel H-flume fitted with a chart-based Friez-type Fw-1 water-level recorder. Charts were manually processed to quantify and archive rainfall and runoff amounts. Beginning in 1998, the rainfall-runoff monitoring system was upgraded and automated using a tipping bucket rain gauge and submersible pressure transducer wired into a data logger. The data logger was programmed to convert the transducer flow depth values into runoff rates using the standard flume calibration curve. In March 2006 the transducer-based water flow sensing was changed to a water flow sensor based on a Shaft Encoder because of occasional instability of the transducer. Rainfall and runoff data were compiled for CN analysis beginning in 1976, one year into conservation tillage management. From a review of the rainfall-runoff graphs, 126 events were identified for analysis. All runoff data except those that could not be quantified or could not be matched with the corresponding rainfall due to instrument, recording, processing, or some other error were included in the analysis. Rainfall and runoff pairs were tabulated for CN derivation with runoff expressed as depth.

Derivation of curve numbers. Two approaches were used to derive CN values from the compiled rainfall-runoff data pair:

1. Using the standard equations <u>assuming the standard abstraction ratio λ of 0.2</u>.
   Knowing P and Q, CN is derived from Eq. 3 and 2 for each tabulated P-Q pair.
2. Using measured values of the initial abstraction Ia, which is taken as the rainfall amount up to the start of runoff.
   Knowing P, Q and Ia, CN is derived from Eq. 1 and 2 for each tabulated P-Q pair. Note that this approach makes λ variable - (λ = Ia/S). Therefore curve numbers derived this way do not have equivalence with standard tabulated CNs, which were derived on assumption of λ of 0.2.

RESULTS AND DISCUSSIONS

As previously reported (Endale *et al*., 2000), no-till management of P1 continues to significantly limit runoff (Table 1) compared to when the catchment was managed under conventional tillage. Despite a mean percent runoff of 6.5, partitioning of the rainfall into runoff was <1% in 50% of the events. Few large runoff events have skewed the mean. There was a 5% probability of exceeding a 35% Q/P ratio, and a 20% probability of exceeding a 10% ratio.

Table 1. Descriptive statistics for CN analysis.

Variable †	Mean	SE	Median	Min	Max
P	55.3	2.7	46.9	10.4	166.7
Ia	27.7	1.8	24.0	0.1	91.0
Q	4.8	0.8	0.3	0.0	52.2
Q/P	6.5	1.0	0.6	0.0	46.0
$CN_{\lambda v}$	36.3	2.8	30.6	0.1	94.3
Q_{CN50}	2.4	0.5	0.0	0.0	36.3
Q_{CN55}	3.8	0.7	0.1	0.0	47.0
Q_{CN60}	5.6	0.9	0.9	0.0	58.4
Q_{CN65}	8.1	1.2	2.4	0.0	70.3
Q_{CN70}	11.2	1.4	4.7	0.0	82.8
Q_{CN75}	15.0	1.7	7.8	0.0	95.7
Q_{CN80}	19.8	1.9	12.0	0.0	109.0

† P, rainfall (mm); Ia, initial abstraction (mm); Q, runoff (mm); Q/P, ratio (%);$CN_{\lambda v,}$ curve number with variable λ, QCN50, etc., runoff estimated with indicated CN and λ of 0.2. A total of 126 Q-P pairs were used in the analysis. SE stands for standard error of the mean.

The CNs calculated with the standard methods (Eq. 1 and 2, 3; <u>λ</u> 0.2) fit the "Standard Behavior" model of Hawkins et al. (2009) (Fig. 1) who found such behavior from analyses of large numbers of P-Q data sets from around the world. The values are characterized by declining CN with increasing rainfall but asymptotically approaching a constant CN at higher rainfall. Hawkins et al. (2009) recommend this asymptotic CN as the CN of choice for the particular watershed for antecedent runoff condition II (average conditions). For P1 this value is 50.4 (Fig. 1; $r^2 = 0.388$; p-value <0.0001 for model and parameters). Hawkins et al. (2009) have identified two other CN behaviors: complacent and violent.

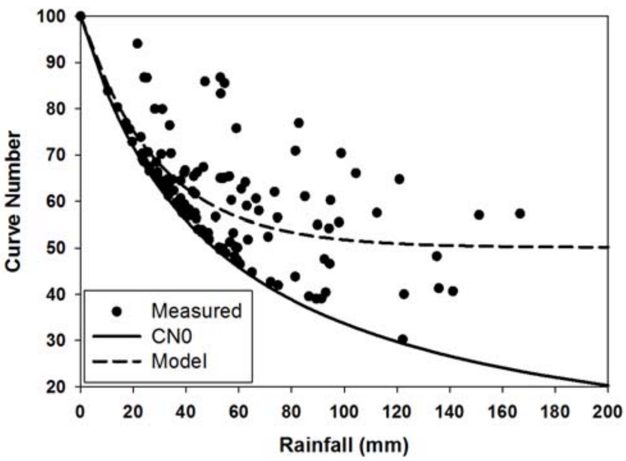

Figure 1. Standard CN behavior for values estimated from 126 P-Q pairs spanning 34 years at P1. The model shows CN approaching 50.4 asymptotically.

The CNs from the standard handbook tables for the conditions at P1 (row crops, straight row, good hydraulic condition, hydrologic soil groups A and B) range from 65 to 80. The mean of this range (73) is 16 units greater than the CN (57) that produced a mean Q estimate that matched the measured mean Q (Table 1). Using a CN of 65 for the 126 events overestimated the mean measured Q by 69%, while a CN of 80 overestimated the mean measured Q by 4.2 times (Table 1). These findings imply that runoff is likely overestimated in models that relay on the standard curve number method to estimate runoff in no-till systems. Runoff is likely to be overestimated. This might be true for other conservation tillage systems as well, which generally also increase infiltration implying reduced runoff.

A major thrust in recent times towards improving the CN method is the idea of replacing the λ value of 0.2 with 0.05 (Hawkins *et al*., 2009). The mean λ value found in this study using the 2nd CN analysis approach was 0.15. However, the median was 0.04 (Table 1). Hawkins et al. (2009), and others, have pointed out that in the original selection of λ, 0.2 was in fact the slope of the median line for a regression of the initial abstraction Ia against the maximum storage potential S. So the data here support the call to change λ to 0.05.

The curve numbers calculated with the 2nd approach (variable λ) had a mean and median of 36.3 and 30.6, respectively (Table 1). These values do not, however, have equivalence with the standard CN values since those are based on constant λ value of 0.2. The call for reducing λ from 0.2 to 0.05 also implies that a new set of curve numbers have to be established mirroring those in the current standard handbook tables.

CONCLUSIONS

Long-term (34-yr) continuous row crop management of a small Georgia Piedmont catchment under no-till resulted in low mean runoff that was matched with an estimate based on CN of 57. This CN is 16 units smaller than the mean of the average for the 65 to 80 CN range from standard handbook tables for the catchment. Using a CN of 65 for the 126 events overestimated the mean measured Q by 69%, while a CN of 80 overestimated the mean measured Q by 4.2 times. The initial abstraction ratio λ had a median value of 0.04 in contrast to the standard value of 0.2, supporting recent calls for changing this standard value to 0.05. Approximately 41% of the 112 million ha of cropland in the USA is in conservation tillage, and 57% of the conservation tillage is no-till. In land development planning, along with TMDL and other water quality-related investigations, use of the established CN method is likely to lead to overestimation of runoff from no-till fields. Long-term data such are those in this study are essential for improving accuracy of predictive models that might have been developed from limited data that do not take into account the possible variability in weather and management.

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REFERENCES

CTIC. 2001. Better soil better yields. A guide for improving soil organic matter and infiltration with continuous no-till. Conservation Technology Information Center, Purdue University, West Lafayette, IN.

CTIC. 2009. 2004 National crop residue management survey. Conservation Technology Information Center, West Lafayette, IN.

Endale, D.M., H.H. Schomberg, and J.L. Steiner. 2000. Long term sediment yield and mitigation in a small Southern Piedmont watershed. *Intern. J. Sediment Research* 15(1):60-68.

Endale, D.M., M.L. Cabrera, J.L. Steiner, D.E. Radcliffe, W.K. Vencill, H.H. Schomberg, and L. Lohr. 2002a. Impact of conservation tillage and nutrient management on soil water and yield of cotton fertilized with poultry litter or ammonium nitrate in the Georgia Piedmont. *Soil & Tillage Research* 66:55-86.

Endale, D.M., D.E. Radcliffe, J.L. Steiner, and M.L. Cabrera. 2002b. Drainage characteristics of a Southern Piedmont soil following six years of conventionally tilled or no-till cropping system. *Transactions of the ASAE* 45(5):1423-1432.

Endale, D.M., H.H. Schomberg, D.S. Fisher, and M.B. Jenkins. 2008. No-till corn productivity in a southeastern United States Ultisol amended with poultry litter. *Agronomy J.* 100:1401-1408

Endale, D.M., H.H. Schomberg, M.B. Jenkins, D.H. Franklin, and D.S. Fisher. 2010. Management implication of conservation tillage and poultry litter use for Southern Piedmont USA cropping systems. *Nut. Cycl. Agroecosyst.* 88:299-313.

FAO. 2008. Conservation agriculture. Food and Agricultural Organization of the United Nations. Rome.

Hawkins, R.H. T.J. Ward, D.E. Woodward, and J.A. Van Mullem (eds.). 2009. Curve number hydrology. State of the practice. American Society of Civil Engineers, Reston VA.

Schnepf, M., and C. Cox (eds.). 2006. Environmental benefits of conservation tillage on cropland. The status of our knowledge. Soil and Water Conservation Society, Ankeny, IA.