CURVE NUMBERS FROM A LONG-TERM NO-TILL CROP FIELD IN THE GEORGIA PIEDMONT

Dinku M. Endale*, Harry H. Schomberg, Dwight S. Fisher and Michael B. Jenkins[1]
USDA-ARS J. Phil Campbell Sr. Natural Resource Conservation Center,
1420 Experiment Station Road, Watkinsville, GA 30677
* Dinku.Endale@ars.usda.gov

ABSTRACT

Since its inception in the 1950s, acceptance, use and adaptation of the Curve Number (CN) method for estimating direct runoff from a rainfall event has increased worldwide. Some inconsistencies, limitations and problems have been identified as a result. There have been calls for development of locally defined CN values to address concerns with regional and seasonal variations. Researchers at the USDA-ARS near Watkinsville, GA, derived CN values from 33 years of rainfall-runoff data gathered from a 6.7 ac instrumented catchment (P1) managed under no-till. Summer crops included soybean, sorghum, millet, cotton and corn, with barley, wheat, crimson clover and rye as cover crops. Derived mean and median CN values were 36 and 31, respectively, compared to 60 to 70 expected from standard tables for the conditions at P1, implying that there was less runoff than would have been expected from standard CN-based estimates. Such low CN values suggest that, under long-term no-till management, hydrologic performance of P1 has become similar to those of pastures or meadows in good hydrologic condition which have low runoff potential. In half of the 126 storm events evaluated, <1% of the rainfall was portioned to runoff. On average, only 6.5% of the rainfall was partitioned to runoff. The derived median value of the initial abstraction ratio (λ) was 0.04, compared to the standard value of 0.2, which is very close to 0.05, a value proposed by researchers to improve the CN method. Such long-term data from field operations are essential for improving models.

INTRODUCTION

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

The derived equation is:

$$Q = (P - Ia)^2 / (P - Ia + S) \qquad \text{for } P>Ia;\ Q=0 \text{ for } P\leq Ia; \tag{1}$$

$$CN = 1000 / [10+S] \tag{2}$$

Where Q is runoff (in.), P is rainfall (in.), Ia is the initial abstraction (in.) and equals λS. The ratio λ is set at 0.2, and S is the potential maximum retention (in.).

---

[1]Agricultural Engineer, Ecologist, Range Scientist, and Microbiologist, respectively.

To solve for Q, one would need to know P and S in Eq. 1. To obtain S from Eq.2 requires selection of CN values from available standard tables based on land use, conservation practice, hydrologic condition of soil cover, hydrologic soil group, and antecedent moisture conditions (AMC- now called antecedent runoff condition ARC). Graphical charts are also available to obtain Q from known P and CN values.

Years of use and adaptation has led to critical review of the CN methodology. Garen and Moore (2005) vigorously argued that, while the CN method was appropriate for flood hydrograph engineering applications, its use in many nonpoint source water quality models was problematic. Hawkins et al. (2009) have summarized the origin, development, role, application and current status of the CN method, and cite studies by several researchers and task forces working to improve the method by incorporating knowledge developed since the original formulation. Some inconsistencies, limitations and problems have been identified. For example, research data across regions suggests that for the initial abstraction ratio λ, the original value of 0.2 is high and that a much smaller values of 0.05 appears to be more accurate. The CN method shows variance with infiltration-based analysis of runoff and the role of prior rain is not clear. Sometimes, additional data have shown the equation to be at variance with patterns of observed rainfall-runoff data. The equation is also more sensitive to CN than rainfall depth. In addition, there might have been bias in the original development of the equation from working with larger storms, since the model appears not to work well for small storm events, which make up the majority of storm events. The soil hydrologic classes can be expanded to include data bases that have been developed since the original formulation. Local and regional measurement and analysis of rainfall and its characteristics are common. However, ground truth data for CN are lacking. Concerns with regional and seasonal variation in CN have led to calls for the development of locally defined CN.

To derive CN values from measured data, one approach would be to solve Eq. 1 for S knowing P and Q (Hjelmfelt et al., 1982), or knowing P, Q and Ia, in which Ia equals the amount of rainfall prior to the start of runoff. With S determined, Eq. 2 can be used to solve for CN. Our objective in this study was to derive and analyze CN values from rainfall-runoff data gathered from 1976 to 2009 on a 6.7 ac catchment (P1) at the USDA-ARS in Watkinsville, GA, in the Georgia Piedmont. During this period P1 has continuously been under no-till management. A summary of the cropping history is given in Table 1, and Figure 1 shows the soil and topographic layout.

MATERIALS AND METHODS

Experimental Site

The research catchment P1 was established during the spring and summer of 1972 on 6.7 ac at the USDA-ARS J. Phil Campbell Senior, Natural Resource Conservation Center, in Watkinsville, GA. Slopes range from 2 to 7 percent. The catchment consists of three soil types: a gravely Cecil sandy loam (clayey, kaolinitic thermic Typic Kanhapludults) where 2 to 6 percent slopes dominate; a similar soil but with thinner solum, 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.

Table 1. Summary of cropping history at P1.

		Spring-Summer		Fall-Winter	
Year	Tillage	Crop	Years	Crop	Years
1972-1974	Conventional	Soybean	3	Fallow	2
				Barley	1
1975-2009	No-till	Soybean	12	Barley	6
		Grain Sorghum	12	Wheat	8
		Forage sorghum	3	Clover	11
		Cotton	5	Rye	9
		Corn	2		
		Pearl millet	1		
Total years	Conventional		3		3
	No-till		35		34

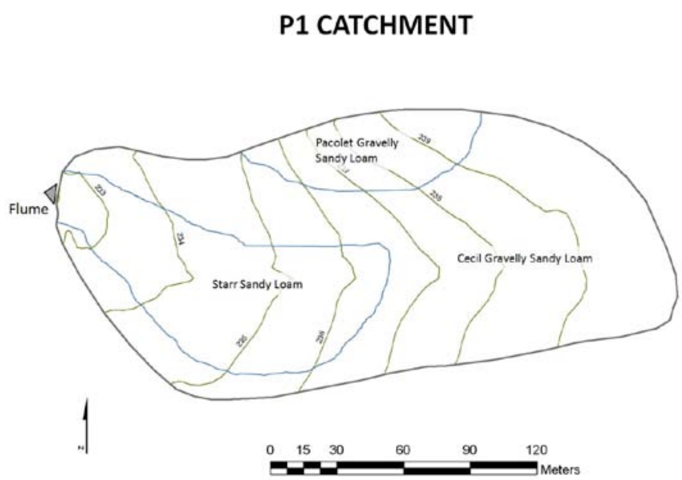

Figure 1. P1 Catchment showing soil distribution and elevation contours.

Research was started at P1 in 1972 to evaluate sediment and herbicide transport in runoff from a Piedmont watershed. The study was conducted cooperatively between the USDA-Agricultural Research Service and the US Environmental Protection Agency (Smith et al., 1978). As shown in Table 1, 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 (Langdale and Leonard, 1983; Endale et al., 2000). A gully formed during the conventional tillage phase on the lower part of the catchment which was renovated by establishing a 36-ft wide (0.79 ac) fescue (*Festuca arundinacea* Schreb.) grassed waterway in October 1974 (Langdale et al., 1979). The grassed waterway was converted back to the crop rotation during the summer of 1997 due to negligible soil losses from the catchment arising over the long history of conservation tillage.

Hydrology data

From 1972 to 1998, rainfall was gauged with a chart-based Fergusson-type weighing and recording rain gauge while flow was measured with a 2.5 ft stainless steel H-flume based on USDA specifications (Brakensiek et al., 1979) 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.

Endale et al. (2000) have summarized 26-years (1972-1998) of runoff and sediment data from P1 that show impacts of the contrasting cropping systems on long-term runoff and sediment losses and residue production. The major conclusions after 26 years were:

- Double cropped conservation cropping system following conventional tillage cropping immediately reduced runoff and soil erosion.
- Conservation cropping was essential to successfully combat accelerated erosive effects of high-energy storms following conventional tillage.
- Residue of 4.6 ton ac^{-1} yr^{-1} was produced over 20 years under conservation cropping systems. The residue modified the surface soil properties and allowed more infiltration and therefore less runoff. Residue production did not exceed 0.9 ton ac^{-1} yr^{-1} under the conventional tillage system.

Curve Number Investigations

Rainfall and runoff data were compiled for CN analysis beginning in 1976, one year into conservation tillage management. The 1976-1990 data were already available in a spreadsheet after the charts had been digitized. The 1991-1998 data were digitized by current staff from intact charts. From 1999 on the data were obtained from the data logger of the automated system. From a review of the rainfall-runoff graphs, 126 events were identified for analyses. Runoff varied from as little as 2.5 ft^3 to as large as 47993 ft^3. 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. The initial step was to chronologically tabulate by columns the selected events and enter details such as rainfall amount, start and end rain times, runoff start, peak and end times, and runoff amount in cubic feet. Runoff expressed as depth was then tabulated by dividing volumetric runoff by the catchment area. For each event the total rainfall amount until runoff began was then determined representing the initial abstraction (Ia; Eq. 1). At that point, Q, P and Ia of Eq. 1 were known leaving S as the only unknown. The equation was solved for S and the results tabulated. Curve Numbers were then calculated using Eq. 2, and finally descriptive statistics were determined and corresponding graphs developed.

RESULTS AND DISCUSSIONS

Descriptive statistics for the parameters are given in Table 2. As expected, the standard deviations for all parameters were high indicating large variability. Values in Table 2 indicate a highly skewed distribution for runoff, percent runoff, the retention parameter S and the initial abstraction ratio λ. As previously reported (Endale et al., 2000), no-till management of P1 continues to significantly limit runoff compared to the period when the catchment was managed under conventional tillage.

Table 2. Descriptive statistics for parameters in Curve Number analyses.

Statistics	Rainfall P in.	Runoff Q in.	Q/P %	Initial abstraction Ia in.	Retention S in.	Initial abstraction ratio λ; (Ia/S)	Curve Number CN
Mean	2.18	0.19	6.45	1.09	378.11	0.15	36.32
Standard Error	0.11	0.03	0.98	0.07	107.95	0.02	2.76
Median	1.85	0.01	0.55	0.95	22.71	0.04	30.58
Standard Deviation	1.21	0.37	11.00	0.78	1211.75	0.23	30.97
Minimum	0.41	0.00	0.01	0.00	0.60	0.00	0.11
Maximum	6.56	2.06	46.02	3.58	9387.26	0.97	94.31
n (sample #)	126	126	126	126	126	126	126
Confidence Level(95.0%)	0.21	0.07	1.94	0.14	213.65	0.04	5.46

Despite a mean percent runoff of 6.5, partitioning of the rainfall into runoff was <1% in 50% of the events. Few of the large runoff events skewed the mean. There was a 5% probability of exceeding a 35% Q/P ratio, and a 20% probability of exceeding a 10% ratio. The runoff partitioning on an annual rainfall basis was much smaller. Piedmont landscapes are prone to serious runoff problems when disturbed by tillage and left without proper cover. In a 1940-1959 study of conventionally tilled continuous cotton on plots nearby, Hendrickson et al. (1963) found that about 21% of the 49.2 in. yr^{-1} rainfall was partitioned into runoff. Endale et al. (2000) reported that runoff at P1 during the initial 2.5 years of conventional tillage practice averaged 7.1 in. yr^{-1} compared to 0.9 in. yr^{-1} during 24 subsequent years of conservation tillage-based management. Endale et al. (2006) also reported that in an adjacent 19-ac field, the percent annual rainfall partitioned into annual runoff from 1940 to 1984 had a median of 5.1 and mean of 6.7. This field has been in pasture for the latter 40 of the 45 years.

The calculated mean and median CN values at P1 were < 40, which support the observed low runoff generating potential of no-till management at P1. In contrast, the CN values from standard Tables (NRCS National Engineering Handbook, Section 4, Hydrology) for conditions at P1 would be in the 60 to 70 range at antecedent rainfall condition II. That is: for hydrologic soil group A (least runoff-prone; sand, loamy sand, sandy loam); row crops on straight row and with good hydrologic condition; and small grains on straight row and good hydrologic condition. The effect of the grass waterway was to reduce the table-obtained CN values by approximately 3. According to the standard CN tables, CN values in the 30 to 40 range are assigned to pastures or meadows in good hydrologic condition. Hence P1 is responding as such under long-term no-till management. Nevertheless, there was a 30% probability of exceeding a CN value of 60. A plot of CN versus Q/P (not shown) indicates that CN values were > 60 for Q/P ≥ 15% approximately. Below a Q/P value of 15% the CN values are scattered in a band with an upper bound line at CN = 80, and a lower bound line from CN=0 to CN = 60 at Q/P of

15% though a few values were outside of these bounds.

There was agricultural drought in 13 of the 33 years whereby, in addition to reduced rainfall during crop growing season, annual rainfall was 29.4 to 46.0 in. compared to the long-term average of 49.2 in. These years usually occurred in clusters: 1985-1988 (34.5-39.6 in.); 1999-2002 (36.1-46.0 in.); and 2006-2008 (29.4-40.9 in.). Generally the mean number of annual runoff events was somewhat lower during these relatively 'dry' years than during the other 'normal-wet' years. However, the correlation for a regression of the number of the yearly runoff events against the annual rainfall was low (r^2 0.19), but the slope (0.005) was significant while the intercept (-2.93) was not. As previously indicated, some but not many runoff events had not been considered because we could not accurately quantify the runoff due to measurement errors.

A major thrust in recent times towards improving the CN method is the idea of replacing the initial abstraction ratio (λ) value of 0.2 with 0.05 (Hawkins et al., 2009). It is interesting that the mean λ value found in this study was 0.15, however, the median was 0.04. 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. Our data support changing λ to 0.05.

CONCLUSIONS

Long-term (33-yr) continuous row crop management of a small Georgia Piedmont catchment under no-till resulted in low mean and median CN values (30-40). Runoff partitioning was <1% of rainfall in 50% of the storms. The CN values from standard tables for the conditions at the catchment are approximately double those found in our study. Curve Numbers exceeded a value of 60 for $Q/P \geq 15\%$. Below a Q/P value of 15% the CN values are scattered in a band that has an approximate upper bound line at CN = 80, and a lower bound line from CN=0 to CN = 60 and a Q/P of 15% with a few values falling outside these bounds on either side. 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. Agricultural drought, where annual rainfall was approximately 3 to 20 in. below long-term average, slightly reduced runoff events but the correlation of annual rainfall with the annual number of runoff events was weak.

Approximately 41% of approximately 277 million acres of cropland in the US is in conservation tillage, and 57% of the conservation tillage is no-till. In land development planning, and 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 variables.

Acknowledgements

We appreciate the competent technical support of Stephen Norris, Robin Woodroof, Michael Thornton, Jeff Scarbrough, Tony Dillard, Eric Elsner, Clara Parker, Ronald Phillips, Dwight Seman, and all others before us who have contributed to the P1 legacy.

Disclaimer

The use of trade, firm, or corporation names is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the United States Department of Agriculture or the Agricultural Research Service of any product or service to the exclusion of others that may be suitable.

REFERENCES

Brakensiek D.L., H.B. Osborn, and W.J. Rawls. 1979. Field manual for research in agricultural hydrology. Agricultural Handbook No. 224. USDA, Washington, DC.

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

Endale, D.M., D.S. Fisher, and J.L. Steiner. 2006. Hydrology of a zero-order Southern Piedmont watershed through 45 years of changing agricultural land use: 1. Monthly and seasonal rainfall-runoff relationships. J. Hydrol. 316:1-12.

Garen, D.C., and D.S. Moore. 2005. Curve number hydrology in water quality modeling: Uses, abuses, and future directions. J. Am. Water Res. Assoc. 41(2): 377-388.

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

Hendricksen, B.H., A.P. Barnett, and O.W. Beale. 1963. Conservation methods for soils of the Southern Piedmont. Agriculture Information Bulletin No. 269. USDA, Washington, DC.

Hjelmfelt, Jr, A.T., L.A. Kramer, and R.E. Burwell. 1982. Curve numbers as random variables. p. 365-370. *In* V. Singh (ed.) Rainfall-Runoff Relationships, Water Resources Publications, Highlands Ranch, CO.

Langdale, G.W., A.P. Barnett, R.A. Leonard, and W.G. Fleming. 1979. Reduction of soil erosion by no-till systems in Southern Piedmont. Trans. ASAE 22: 82-86.

Langdale, G.W. and R.A. Leonard. 1983. Nutrient and sediment losses associated with conventional and reduced tillage agricultural practices. p 457-467. *In* R. Lowrance et al. (ed.) Nutrient cycling in agricultural ecosystems. Univ. of Ga. College of Agric. Exp. Stations, Spec. Pub. 23. Athens, GA.

Smith, C.N., R.A. Leonard, G.W. Langdale, and G.W. Bailey. 1978. Transport of agricultural chemicals from upland Piedmont Watersheds. EPA-600/3-78-056. U.S. Environmental Protection Agency, ORD-ERL, Athens, GA, and USDA-ARS Southern Piedmont Conservation Research Center, Watkinsville, GA.